Appendix H. Coastal Flooding

1. Introduction

Coastal regions of the U.S. are particularly susceptible to the risks of sea level rise and storm surge. As the climate warms, sea levels rise due to the combination of thermal expansion of water volume, melting of glaciers and other ice sheets, and other factors. Higher seas can inundate land and structures, erode beaches, and degrade coastal ecosystems. Higher sea levels also lead to more damaging storm surges, which can cause devastating episodic flooding. The coastal regions of the U.S. that are vulnerable to these climate hazards are critical to the U.S. economy. Although they comprise less than 20 percent of the total U.S. land area, they account for 42 percent of population and employment, and 48 percent of GDP.[1]

The Fourth National Climate Assessment (2018) found that the risks of coastal flooding and erosion can exacerbate preexisting social inequities in low-lying areas of the coastal zone.[2] Concerns for socially vulnerable populations in the coastal zone stem from two related circumstances: 1) in some areas of the coast, disadvantaged communities are disproportionately located in areas that are most vulnerable to damaging flooding; and 2) although adaptation to coastal risks has been shown to be cost-effective in

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[1] Kildow, JT, Colgan CS, Johnston P, Scorse JD, and Farnum MG. 2016. State of the U.S. Ocean and Coastal Economies: 2016 Update. National Ocean Economics Program, Monterey, CA, 31 pp. https://www.midatlanticocean.org/wp-content/uploads/2016/03/NOEP_National_Report_2016.pdf

[2] 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

many instances, the need for financing of adaptative measures and the use of benefit-cost tests for larger adaptation projects implies that properties with lower market value are less likely to be prioritized for protection.

This analysis uses well-established literature and methodologies to map important climate hazards to changes in global mean temperature; assess exposure of low-lying properties to flooding or inundation; connect these physical vulnerabilities to measures of social vulnerability; and estimate potential impacts to socially vulnerable populations.

Section 2 of this appendix describes the motivation and background for investigating these factors, and Section 3 provides more detail on the relevant coastal climate hazards. Sections 4 and 5 lay out the methods employed to perform the coastal risk analysis and the mapping of coastal risks to socially vulnerable populations. Sections 6 and 7 provide the results of the coastal risk analysis and the implications for disproportionate impacts on socially vulnerable populations, respectively. Sections 8 and 9 summarize conclusions from the findings and describe important limitations.

2. Socially Vulnerable Populations in Coastal Areas

Sea level rise threatens to disrupt the lives of individuals vulnerable to coastal inundation by making these areas potentially uninhabitable. At the same time, coastal areas provide amenities that make them attractive, increasing population (an increase of approximately 40% from 1970 to 2020) and population density in these areas.[3] Migration toward the coasts has also led to increases in the populations exposed to coastal hazards, documented by increases in populations residing within the 100-year return period coastal flood hazard area.[4] Census data from 2010 indicates that populations in socially vulnerable groups make up a higher share of the coastal county population than in inland counties – this is especially true for individuals who identify as Asian, Black and African American, Pacific Islander, and Hispanic/ Latino[5] – though overall population counts by county do not necessarily align with populations in near coastal and low elevation areas that are most vulnerable to coastal flooding. These migratory trends toward coastal areas are expected to continue into the future.[6] Population migration toward the coasts, when coupled with existing and expected trends in coastal hazards from climate change, make coastal hazard risk management and adaptation decision-making increasingly complex, including for socially vulnerable populations.[7]

Trends in coastal property value in the coastal zone, which are an important factor in assessing the potential for future property damages as well as the cost-effectiveness of expensive measures to mitigate these damages, are more difficult to summarize. The general understanding is that, with higher population pressure and density in coastal areas, property values would be expected to be greater than

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[3] NOAA. 2013. National Coastal Population Report: Population Trends from 1970 to 2020. March 2013. Available at: https://aambpublicoceanservice.blob.core.windows.net/oceanserviceprod/facts/coastal-population-report.pdf

[4] Crowell M, Coulton K, Johnson C, Westcott J, Bellomo D, Edelman S, and Hirsch E. 2010. An Estimate of the U.S. Population Living in 100-year Coastal Flood Hazard Areas. *Journal of Coastal Research*, 26(2): 201-211.

[5] NOAA 2013, see Figures 7 and 8 in particular.

[6] National Ocean Service, NOAA. 2012. Spatial Trends in Coastal Socioeconomics. Demographic Trends Database 1970-2010; Woods and Poole Economics, Inc. Projections Database 1970-2040. Available from: http://coastalsocioeconomics.noaa.gov.

[7] Kopp RE, Gilmore EA, Little CM, Lorenzo-Trueba J, Ramenzoni V C, & Sweet WV. 2019. Usable science for managing the risks of sea-level rise. *Earth's Future*, 7. https://doi.org/10.1029/2018EF001145

in other areas. In reality, property values in the coastal zone are affected by a complex set of factors that include site-specific amenity values and ecosystem services (which are desirable and increase property values), a growing realization of coastal hazards that can damage properties and ecosystem services (and therefore can decrease property values); and perceptions of the effectiveness of hazard protective measures such as seawalls.[8] Some analysts argue that efforts to insure properties against coastal hazards, and that aim to keep the National Flood Insurance Program solvent by moving away from subsidized premiums, could harm low- and middle-income populations through premium rate increases.[9] The complexities of balancing amenity and risk in the coastal zone have motivated an emerging literature on "climate gentrification," a process which leads to displacement of low-income populations as wealthier residents seek higher ground and safety from coastal hazards;[10] new conceptual models of housing location decisions that suggest low-income and minority populations will be pushed into higher hazard areas of the coastal zone.[11]

In many areas, the implementation of protective measures such as seawalls, beach nourishment (i.e., replenishing sand to rebuild beach profile), and the elevation of properties can be cost-effective. Coastal protection projects may need to be justified using economic tests, such as benefit-cost analysis – and a consequence of these tests is that more valuable homes and properties take priority for protection over those with less value. As a result, many properties owned or inhabited by socially-vulnerable individuals might not qualify for protection under a strict cost-benefit analysis for protection decisions.[12] While local protection decisions may consider non-economic factors such as social vulnerability, many decisions supported in adaptive measures by the U.S. Army Corps of Engineers require benefit-cost analyses to support, and in many cases justify, coastal infrastructure and beach nourishment projects.[13]

The high property values that are most likely to meet benefit-cost criteria for protective infrastructure are often correlated with wealth, meaning gaps in wealth are likely to play a role in economically viable protection decisions. While racial and ethnic gaps in income are concerning (e.g., median incomes about twice as high for those who identify as White or Asian than those who identify as Black/African American or Hispanic/Latino), wealth gaps are significantly higher. For example, median net worth for White households nationally is about 13 times higher than for Black and African American households.[14] As a result, these populations are even more likely to be excluded from protection and face the risk of abandonment or retreat. At the same time, discriminatory actions and laws throughout the U.S. have

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[8] Jin D, Hoagland P, Au DK, Qiu J. 2015. Shoreline change, seawalls, and coastal property values. *Ocean Coast Manag*. 114:185–193. https://doi.org/10.1016/j. ocecoaman.2015.06.025.

[9] Shively D. 2017. Flood risk management in the USA: implications of the national flood insurance program changes for social justice. *Reg. Environ. Chang*. 17:1663–1672. https://doi.org/10.1007/s10113-017-1127-3

[10] Anguelovski I, Connolly JJT, Pearsall H, Shokry G, Checker M, Maantay J, Gould K, Lewis T, Maroko A, and Roberts JT. 2019. Why green "climate gentrification" threatens poor and vulnerable populations. *PNAS* 116(52): 26139–26143. https://www.pnas.org/cgi/doi/10.1073/pnas.1920490117

[11] Bakkensen L and Ma L. 2020. Sorting over flood risk and implications for policy reform. *Journal of Environmental Economics and Management*, 104:102362. https://doi.org/10.1016/j.jeem.2020.102362

[12] Martinich J, Neumann J, Ludwig L, and Jantarasami L. 2013. Risks of sea level rise to disadvantaged communities in the United States. *Mitigation and Adaptation Strategies for Global Change* (2013) 18:169–185, DOI 10.1007/s11027-011-9356-0

[13] See, for example, http://www.csc.noaa.gov/beachnourishment/html/human/socio/part2.htm for information on benefit-cost analyses conducted for beach nourishment projects.

[14] Pew Research Center (PRC). 2016. On Views of race and inequality, Blacks and Whites are worlds apart. Accessed Feb 2021 [https://www.pewresearch.org/social-trends/2016/06/27/1-demographic-trends-and-economic-well-being/#fn-21791-8]

prevented Black and African Americans from public swimming areas, which has been linked to reduced participation in beach activities and beach locations among African Americans today.[15]

Retreat, or abandonment of coastal properties, can take different forms, including owner-initiated retreat because of rising repair costs or safety concerns, government buyout or resettlement programs, or even the result of a growing inability to provide essential services to the community at risk. While retreat or abandonment are certainly not desirable outcomes, for places that are especially vulnerable to permanent inundation from sea level rise or chronic inundation from frequent storms, maintaining a home or business may not be viable or desirable. As activity focused on "managed retreat" strategies, involving buy-outs of threatened properties, becomes more frequent, recent literature provides evidence that these programs could either reduce or promote existing social inequities.[16] For example, North Carolina property acquisitions under these programs have been found to correlate with low home values, household incomes, and population density and high racial diversity.[17]

Although at times retreat has been viewed as a last option, it has gained traction recently as the threats of climate change are realized in coastal communities.[18] However, communities and cultures are not easily transported and retained. Those who have a strong connection to their community have more at stake than those who rely less on those factors. Socially vulnerable individuals often rely on their communities more than those who are less socially vulnerable. For example, connectedness to school and/or community can decrease depression, suicidal ideation, and social anxiety among socially vulnerable adolescents.[19] Native populations often have particularly strong connections to place, and may depend on specific ecosystems or environmental characteristics for their livelihoods, making relocating extremely difficult.[20]

Previous studies have investigated the intersection between social vulnerability with coastal flood hazards. Jepson and Colburn (2013) evaluate vulnerability of coastal communities in the context of local fishing industries.[21] Using Principal Component Analysis, selected communities were assessed based on three vulnerability categories: social vulnerability, gentrification, and fishing engagement and reliance. Variables included in the sub-indices for each vulnerability category were selected based on community engagement or existing literature. While this level of detail and specific community engagement is outside the scope of the analysis, this work provides effective methods for qualitatively summarizing

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[15] Kahrl A. 2018. *Free the Beaches: The story of Ned Coll and Battle for America's Most Exclusive Shoreline*. Yale University Press, March 20, 2018, 376 pages. ISBN-10 0300215142; Phoenix C, Bell SL, Hollenbeck J. 2020. Segregation and the Sea: Toward a Critical Understanding of Race and Coastal Blue Space in Greater Miami. *Journal of Sport and Social Issues*, https://doi.org/10.1177/0193723520950536

[16] Siders AR. 2018. Social justice implications of US managed retreat buyout programs. *Clim. Change* 152, 239–257. https://doi.org/10.1007/s10584-018-2272-5.

[17] Siders AR, Keenan JM. 2020. Variables shaping coastal adaptation decisions to armor, nourish, and retreat in North Carolina. *Ocean and Coastal Management*. 183:105023. https://doi.org/10.1016/j.ocecoaman.2019.105023

[18] Carey J. 2018. Managed retreat increasingly seen as necessary in response to climate change's fury. *PNAS*, 117(24):13182-13185 https://doi.org/10.1073/pnas.2008198117

[19] Foster C, Foster E, Horwitz A, Thomas A, Opperman K, Gipson P, Burnside A, Stone DM and Kinga CA. 2018. Connectedness to family, school, peers, and community in socially vulnerable adolescents, *Child Youth Serv Rev*. 81: 321–331, doi: 10.1016/j.childyouth.2017.08.011

[20] Jantarasami LC, Novak R, Delgado R, Marino E, McNeeley S, Narducci C, Raymond-Yakoubian J, Singletary L, and Powys Whyte K., 2018. Tribes and Indigenous Peoples. 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. 572–603. doi: 10.7930/NCA4.2018.CH15

[21] Jepson M and Colburn LL. 2013. Development of social indicators of fishing community vulnerability and resilience in the U.S. Southeast and Northeast regions. NOAA tech. memo. NMFS-F/SPO; 129, https://repository.library.noaa.gov/view/noaa/4438

across quantitative indices. Martinich et al. (2013) identified coastal counties anticipated to have large damages due to sea level rise and existing social vulnerability through spatial overlays of the two analyses.[22] The coastal damage estimates were based on modeling with an older version of the National Coastal Properties Model, and county-level social vulnerability scores were developed with a Social Vulnerability Index (SoVI) from a Principal Component Analysis. The authors found that areas of high social vulnerability are much more likely to be abandoned than protected in response to sea level rise. For example, in the Gulf region, over 99 percent of the most socially vulnerability people live in areas unlikely to be protected from inundation, while only 8 percent of the least socially vulnerable reside in those areas unlikely to be protected.

Additional information exists on specific effects of the coastal risks of sea level rise and storm surge on the four categories of socially vulnerable populations analyzed here:

- **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.[23,24] Low income individuals are also more likely to be adversely affected as they have fewer financial resources to protect against and support recovery from these hazards.[25]
- **Minority:** Racial and ethnic wealth gaps, which are larger than income gaps and have stronger correlations with property value than income, leave many of these groups more likely to be excluded from protection decisions that consider economic factors.[26]
- **No High School Diploma**: There few quantitative modeling studies in the literature on the link between one's education and the risk of impacts from SLR and storm surge. Individuals with lower levels of educational attainment may be less equipped to anticipate and respond to these hazards.
- **Over 65**: Coastal communities are often a preferred retirement destination for older adults, despite the growing risks of SLR and storm surge – for example, from 1970 to 2010, the percent increase for populations 65 and over in coastal watershed counties increased much faster than the overall increase in the nation – with increases as large as 290% in South Carolina, 228% in Florida, 202% in Texas, and 170% in Washington State coastal areas.[27] The unique physical and psychosocial challenges of the population age 65 and over may affect their ability to prepare, cope with, and recover from hazardous events.[28]

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[22] Martinich J, Neumann J, Ludwig L, and Jantarasami L. 2013. Risks of sea level rise to disadvantaged communities in the United States. *Mitig. Adapt. Strateg. Glob Change* 18:169–185, DOI 10.1007/s11027-011-9356-0

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

[24] Bhattachan A, Jurjonas MD, Moody AC,. Mooris PR, Sanchez GM, Smart LS, Taillie PJ, Emanuel RE, Seekamp EL. 2018. Sea level rise impacts on rural coastal social-ecological systems and the implications for decision making. *Environmental Science and Policy,* 90. https://doi.org/10.1016/j.envsci.2018.10.006

[25] Howell J, Elliott JR. 2019. Damages done: the longitudinal impacts of natural hazards on wealth inequality in the United States. *Soc. Probl*. 66:448–467. https://doi.org/ 10.1093/socpro/spy016..

[26] Martinich J, Neumann J, Ludwig L, and Jantarasami L. 2013. Risks of sea level rise to disadvantaged communities in the United States. *Mitig. Adapt. Strateg. Glob Change* 18:169–185, DOI 10.1007/s11027-011-9356-0

[27] NOAA 2013 – see Table 10.

[28] Bukvic A, Gohlke J, Borate A, Suggs J. 2018. Aging in Flood-Prone Coastal Areas: Discerning the Health and Well-Being Risk for Older Residents. *Int J Environ Res Public Health*, 15(12). doi: 10.3390/ijerph15122900

Social Vulnerability Measures

Figure 2 presents the distribution of individuals in each of these groups across the six coastal regions of the contiguous U.S.: Northeast, Southeast-Atlantic, Southeast-Gulf, Southern Great Plains, Southwest, and Northwest. All follow the NCA Regional boundaries with the exception of the Southeast, which is split into Southeast-Atlantic and Southeast-Gulf to account for characteristically different SLR and storm surge impacts.[29] The populations shown include the demographic characteristics of any Census block group with SLR or storm surge hazards up to 150 cm of global mean SLR.

The total population of all six coastal regions is about 114 million, which represents about 36% of the population in the contiguous U.S. (CONUS). The Southern Great Plains and both Southeast regions have the largest share of low-Income populations while the Northwest and Northeast have the lowest share. Minority populations are highest in the Southern Great Plains and Southwest and lowest in the Northwest and Southeast-Gulf. The Southwest and Southern Great Plains have the highest shares of people over 25 without a high school diploma or equivalent. The Southeast-Gulf and Southeast-Atlantic are the two regions with the highest share of people over 65, and the Southern Great Plains has the lowest.

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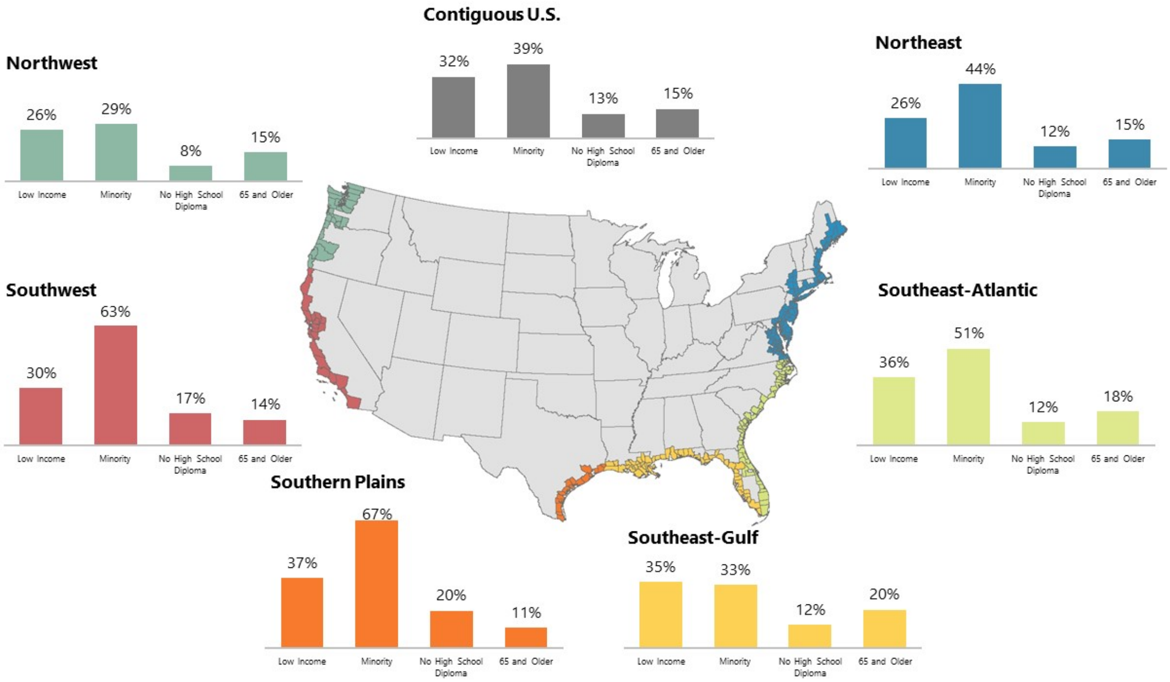
[29] Neumann JE, Emanuel K, Ravela S, Ludwig L, Kirshen P, Bosma K and Martinich J. 2015. Joint effects of storm surge and sea-level rise on US Coasts: New economic estimates of impacts, adaptation, and benefits of mitigation policy. *Climatic Change* 129(1–2):337–349. Available: https://doi.org/10.1007/s10584-014-1304-z.

Figure 2. Distribution of Socially Vulnerable Populations in Coastal Counties of the Contiguous U.S.



3. Hazards and Responses in Coastal Areas

Hazards

Sea level inundation occurs at rates of millimeters per year, a rate which generally provides ample time for a response. However, individuals and communities with tidal waters encroaching on their properties are left with a difficult choice. If the sea is not held back in some way, with sea walls or other forms of nature-based protection, these individuals will likely need to be uprooted from their homes. Since it is costly to relocate structures, both the land and the structures on the land are typically lost to permanent inundation. That choice is especially difficult for those with lower incomes and time budgets, or strong connectedness to the community and location.

Storm surge poses a different kind of hazard to vulnerable populations. In contrast to permanent inundation, storm surge events are difficult to predict in advance, and threaten to cause high levels of damage to property and infrastructure (e.g., roads and underground pipes and cables), as well as create health risks including death. One of the best strategies for keeping people safe from extreme storm surge events is an effective evacuation plan, which depends on individuals making rational decisions for themselves and their families during stressful events. Individuals at risk of storm surge impacts live in elevations below or at the sea level and the storm surge height, although local factors such as hydraulic conductivity, topography, and ground cover can alter the flood zone from surge waters. The velocity and wave height for storm surges can also be an amplifying factor for storm surge impacts on both human health and property, but those aspects of storm surge can be more difficult to quantify and model reliably.

Response to Coastal Hazards and the Implications

The increased risk of exposure to coastal flooding from storm surge and sea level rise raises a number of important issues that should be considered at the state, regional, and local levels. In general, coastal communities have three options for addressing the risk of inundation: 1) protect property and structures, 2) accommodate a receding shoreline, or 3) retreat. Each of these options differs in its magnitude and type of economic costs, as well as the impacts and options to the individuals and communities experiencing these impacts.

Repairing damage from surge flooding tends to be more expensive for higher-valued homes, which is why many estimates of damage have adopted depth-damage functions to estimate flood damage repair costs. Depth-damage functions relate flood depth to the percent damage of the structure value. As a result, there are economic and financial incentives to protect higher-valued homes from storm surge damage, which often excludes households with lower wealth and income. Economic incentives for protecting against permanent inundation are similar in nature and cost, although total damages are often significantly higher since it results in a complete loss of both the structure and property without protection. Also, those who are at risk of storm surge damage can choose to remain in their home following repairs, while that is not an option for those at risk of permanent inundation.

4. Methods for Analysis of Impacts

Current scientific research shows that climate change will accelerate the rate of sea level rise along much of the U.S. coastline. Discerning the impact of sea level rise on coastal development and ecosystems requires an understanding of how much sea levels might rise, how these changes will manifest on the physical landscape, societal responses to these risks, and the economic implications of these responses.

As noted in prior literature, the impacts of sea level rise will vary by location and depend on a range of biophysical characteristics and socioeconomic factors, including societal response. The primary impacts of sea level rise are physical changes to the environment. These changes, in turn, affect human uses of the coast such as tourism, settlement, shipping, industry, commercial and recreational fishing, agriculture, and wildlife viewing. The most serious physical impacts of sea level rise on coastal lowlands are (1) inundation and displacement of lowlands; (2) increased vulnerability to coastal storm damage and flooding; (3) coastal erosion; and (4) salinization of surface water and groundwater. The approach provides comprehensive estimates of the areal extent and economic implications of the first two of these effects.

Impacts to coastal properties from sea level rise and storm surge are particularly site-specific. Local characteristics, such as elevation and proximity to tidally influenced waterbodies, can greatly affect damage assessments and, in particular, adaptation decisions and effectiveness. It is often the case that damages from coastal flooding vary on small spatial scales. For this reason, deterministic models of the impacts of coastal flooding on properties, such as the U.S. National Coastal Property Model (NCPM; see Neumann et al. 2015), simulate impacts at near site-level spatial scales.[30] The NCPM is a well-

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[30] Neumann JE, Emanuel K, Ravela S, Ludwig L, Kirshen P, Bosma K and Martinich J. 2015. Joint effects of storm surge and sea-level rise on US Coasts: New economic estimates of impacts, adaptation, and benefits of mitigation policy. *Climatic Change* 129(1–2):337–349. Available: https://doi.org/10.1007/s10584-014-1304-z.

established model, developed over multiple iterations over two decades, that was designed for national-scale analysis of coastal flooding in the CONUS (Neumann et al 2015; Lorie et al. 2020).[31] The model determines inundated areas at the 150m grid resolution for each coastal county along a sea level rise trajectory for two types of coastal flood hazards—permanent inundation from sea level rise and storm surge—and estimates property losses and expected damage. Inundation is modeled using a modified bathtub approach that ensures a hydraulic connection as sea levels rise. The model assumes complete loss of structure value once the mean high or higher water level reaches the property, and loss of land value equivalent to a representative inland parcel, thereby implicitly assuming inland transfer of the amenity value of proximity to the coast over time.

Sea level rise will increase the severity of coastal flooding by raising the baseline water level over which storms and other high-water level events create a surge. Historical tide gauge measurements (NOAA 2018) were used in this analysis, which allows direct estimation of storm surge for all counties. Using these tide gages, the maximum daily water level was extracted from each record, and the resulting set of maximum gauge heights were de-trended from each time series. From the de-trended data, a distribution of storm surge heights was calculated by fitting a generalized extreme value distribution to the annual maximum time series from each gauge. This provided an estimate of the surge heights associated with return intervals ranging from 2 years to 500 years. Tide gauges with less than 10 years of data were excluded. Stations were matched to counties using proximity and topography. Storm surge probabilities may change in the future as a result of climate change, though important uncertainties still exist in projecting such effects decades into the future. Therefore, this analysis used historical tide gauge information because these provide greater coverage across coastal counties.

It is important to note that the NCPM includes an initiation period that effectively determines existing protection. In order to compare across various adaptation scenarios, it is important for the model to start from a common and stable state. Effectively, this means that the NCPM must use a potentially aggressive, economically optimal adaptation build simulation for existing protection, a likely overestimate of existing protection for all simulations, even one without adaptation. As a result, estimates from the NCPM are likely an underestimate of climate change damages.

To assess the risks of sea level rise and storm surge, a “No Adaptation” scenario was developed where no protective measures are implemented to avoid the impacts of sea level rise and storm surge. As a result, properties incur damages at an increasing rate. This scenario assumes that property owners abandon properties that are inundated by sea level rise and that they incur damages from storm surge flooding. If the damages incurred by storm surge exceed the value of the property, the analysis assumes that the property owner abandons the property.

The NCPM also simulates the rollout of property protection from both permanent inundation and storm surge using a set of decision rules that are governed by least-cost principles. Within the model, properties can be protected by hard structures like sea walls, which protect from sea level inundation and storm surge up to the 100-year surge height; elevation of structures, which protects from storm surge only; and beach nourishment, which is similar to hard structures but is only effective up to a certain flood depth. Hard structures and nourishment protect not only the properties but are also built

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[31] Lorie M, Neumann J, Sarofim M, Jones R, Horton R, Kopp RE, Fant C, Wobus C, Martinich J, O'Grady M. 2020. Modeling Coastal Flood Risk and Adaptation Choices under Future Climate Conditions, *Climate Risk Management*, Vol 29, 100233. https://doi.org/10.1016/j.crm.2020.100233

to protect properties further inland. The decision rules within the NCPM compare the cost of different adaptation options within each cell to the expected reduction in damages that would result from those adaption options. This model assumes that armoring and elevation will be implemented for the 100-year flood. The cost-benefit test compares an estimate of discounted avoided damages over the next 30 years with the cost of each adaptation option. This decision rule is based on an estimate of expected annual damages and expected annual benefits of adaptation. The expected annual benefit is the avoided damages given the assumption that adaptation will prevent damages for events up to and including the current 100-year flood. The decision relies on the following:

- **Cost of adaptation**: varies across cells and adaptation type. For abandonment, cost is equal to property value. For armoring and elevation, cost includes capital and present value of maintenance.
- **Expected annual damages over 30 years** (discounted at 3 percent): The calculation is based on current annual damage, not the projected annual damage.
- **Expected annual damages with adaptation in place**: Damages for events larger than the 100-year event).
- **Expected annual benefits of adaptation:** The difference between the expected annual damages without protection and the expected annual damages with protection.

For each adaptation decision, the NCPM looks ahead 30 years, using current expected annual damage as the approximation. The NCPM discounts future expected annual damage to model adaptation decision-making, which has for Federal government sponsored analyses been the 3 percent (real) rate required by Office of Management and Budget's Circular A-4,[32] to obtain a present value of expected damages over 30 years. Expected damages are estimated with and without adaptation for the 100-year event in order to estimate a present value of expected benefits of adaptation. In its simplest form, the decision rule implements the lowest cost adaptation option if benefits for that option exceeds the cost of protection. This represents a traditional benefit-cost test for optimal risk reduction investment, emulating the protection decision often used by the U.S. Army Corps of Engineers or for flood mitigation assistance to municipal governments (through the Federal Emergency Management Agency, or FEMA). The costs of protection are estimated by site-specific characteristics, such as if the property is situated in the back bay or ocean-facing, which requires additional costs for sea walls to protect from wave action. The model chooses the protection type that is the cheapest for that grid cell.

It is important to note that many adaptation response decisions of this type in the coastal zone are not made with strict cost-benefit decision rules, particularly at the local level. 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. However, the analytical framework of the NCPM provides a simple, benefit-cost decision framework that can be consistently applied for regional and national-scale analysis.

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[32] Office of Management and Budget. 2003. Executive Office of the President. https://obamawhitehouse.archives.gov/omb/circulars_a004_a-4/

5. Methods for Assessing Social Vulnerability Dimensions

This study further investigates if socially vulnerable communities are disproportionately more likely to live in areas where the highest percentage of property is projected to be inundated due to sea level rise, or excluded from adaptation under a benefit-cost decision framework. An important step in this approach is determining the areas that are projected to have the highest impacts. The analysis first delineates the coastal boundary and then determines which areas are projected to be at risk of permanent inundation from sea level rise, or at risk of elevated storm surge.[33] The analysis then identifies populations living in Census block groups within these areas; populations living outside this area are not considered in the following analysis.

For each Census block group, the analysis considers two types of impacts:

1. **Permanent inundation risk:** the portion of property at risk of permanent inundation from SLR. To determine this area, the analysis uses the “No Adaptation” scenario from the NCPM and assesses physical vulnerability – effectively answering the question of whether a property is in the way of advancing seas and storm surge, absent new protective measures.
2. **Exclusion from protection:** the portion of property area excluded from protection because of a failed benefit-cost test using the framework described above. Importantly, the results of this analysis are not meant to be a prediction of where future protective adaptation measures will be implemented. Instead, the approach highlights areas that might be excluded from adaptation measures if a benefit-cost decision framework were used to determine eligibility for protection.

To explore the risks of permanent inundation and exclusion from protection on socially vulnerable populations, the approach follows the five steps outlined in Figure 3 and described in further detail below.

Step 1: Estimate the area at risk of permanent inundation that is projected to be excluded from protection. The method starts by mapping six global sea level rise scenarios to local sea level rise across the U.S. coastline (Sweet et al. 2017).[34] Local sea level rise takes into account local factors such as vertical land movement and effects of climate on ocean currents. The method also maps the storm surge height portfolio estimated at tide gauges (NOAA 2018) to individual counties.[35] These characterizations of coastal hazards are inputs to the NCPM, which simulates inundation and least-cost protection in 302 coastal counties at the 150 m square grid from 2000 (the base year) to 2100. Using the annual model output, the approach uses 11-year windows centered on arrival years of sea level points (25 cm to 150 cm at 25 cm increments), and average across each of the six projections that reach those levels. For more on the sea level rise projection methods, see Appendix C.

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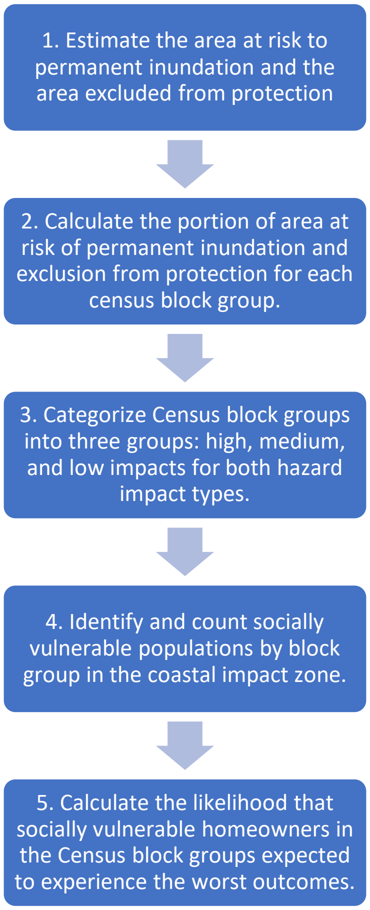
[33] The area at risk of storm surge is defined broadly – it is the area potentially flooded by a 500-year event, with 150 cm of global mean sea level rise (i.e., the 500-year floodplain after 150 meters GMSL).

[34] Sweet WV, Kopp RE, Weaver CP, Obeysekera J, Horton RM, Thieler ER, and Zervas C. 2017. Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083.

[35] NOAA (National Oceanic and Atmospheric Administration). 2018. NOAA Tides and Currents - Water Levels. Available at https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels. Accessed June 2018

Figure 3. Five steps for Assessing Impacts on Socially Vulnerable Coastal Risk-Exposed Populations.



1. Estimate the area at risk to permanent inundation and the area excluded from protection
2. Calculate the portion of area at risk of permanent inundation and exclusion from protection for each census block group.
3. Categorize Census block groups into three groups: high, medium, and low impacts for both hazard impact types.
4. Identify and count socially vulnerable populations by block group in the coastal impact zone.
5. Calculate the likelihood that socially vulnerable homeowners in the Census block groups expected to experience the worst outcomes.

Step 2: Calculate the portion of area at risk of permanent inundation and exclusion from protection for each Census block group. Using the areas at risk of permanent inundation or areas excluded from protection generated in step 1, the approach aggregates these to the Census block group level (generating proportions of each block group) where data exists describing demographic details of the population that resides there.

Step 3: Categorize block groups into three groups: high, medium, and low impacts for both hazard impact types. Output from Step 2 is used to categorize Census block groups into three evenly sized groups. The high impact group comprises block groups with the worst impact, while the low-impact group includes geographies with less impact. The focus of the analysis is on the composition of populations found in the high-impact group. However, since there are areas that are part of the coastal domain that do not have any impacts, particularly at lower levels of global mean sea level rise, the highest one-third of all areas that have any impact at that level are used for that hazard type.

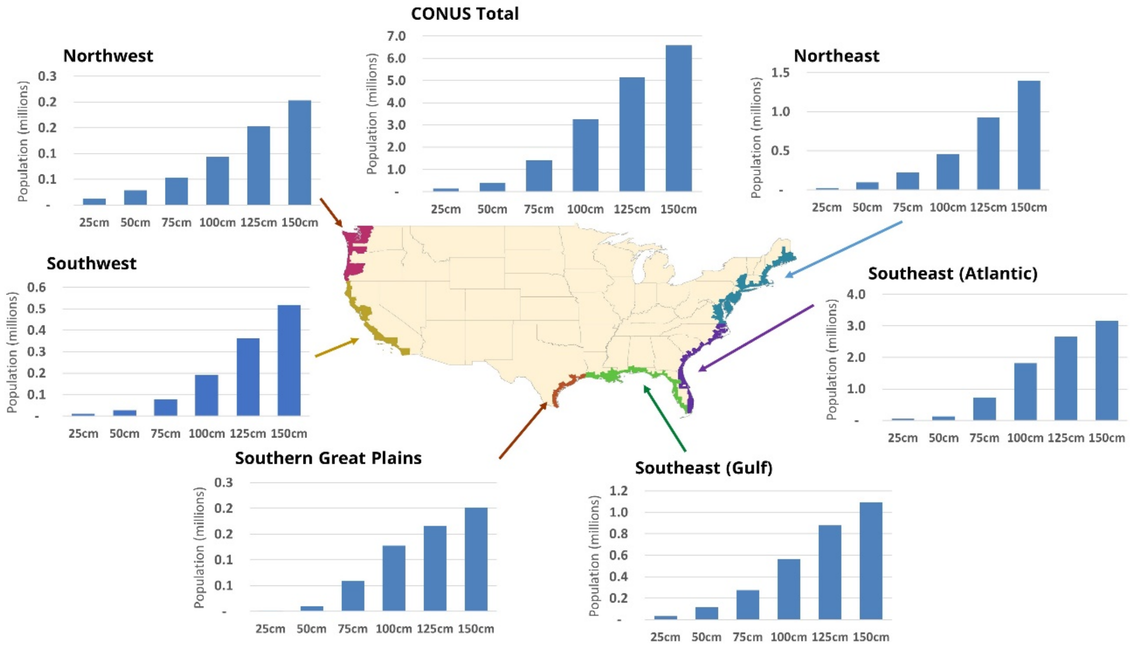
Step 4: Identify and count socially vulnerable populations by Census block groups. The approach does not observe exactly which individuals are both impacted and socially vulnerable. Instead, the method relies on data from the American Community Survey (2014-2018) at the block group level to count the number of individuals in socially vulnerable groups relative to non-socially vulnerable groups. In the absence of projections describing how detailed demographics will shift over the century, it is assumed that the relative distribution of socially vulnerable to non-socially vulnerable populations is fixed at 2014-2018 levels. The four determinants of social vulnerability included in this analysis are: Low Income, Minority, no high school diploma, and 65 or older.

Step 5: Calculate the likelihood that socially vulnerable homeowners in the Census block groups are projected to experience the worst outcomes. These likelihoods are expressed relative to the non-socially vulnerable population and are calculated at the national and regional level. The likelihood measures are separately calculated for each social vulnerability metric. These likelihood metrics can be interpreted as the degree to which the worst outcomes of increasing levels of coastal flooding affect socially vulnerable groups relative to non-socially vulnerable groups.

6. Impact Results

This section describes the impacts from SLR and storm surge. Figure 4 shows the projected areas at risk of inundation (if no adaptation is implemented) at 25 cm increments through 150 cm of global sea level rise (relative to the global mean at the year 2000). The charts in Figure 4 show both the projected areas at risk for the CONUS and coastal regions, as well as the corresponding populations currently living in these areas. CONUS-wide, it is estimated that over 400,000 people are at risk of displacement with 50 cm of rise; 3.2 million are at risk with 100 cm of rise; and 6.6 million are at risk with 150 cm of rise. Figure 4 also shows impacts for six coastal regions, which are shown in the central map and include the Northeast, Southeast-Atlantic, Southeast-Gulf, Southern Great Plains, Southwest, and Northwest. Of the six regions, the Southeast-Atlantic is most at risk, with over 1.8 million people living in areas at risk of inundation with 100 cm of global mean sea level rise. The Southeast-Gulf has the next-highest level of risk (approximately 560,000), followed by the Northeast (approximately 450,000).

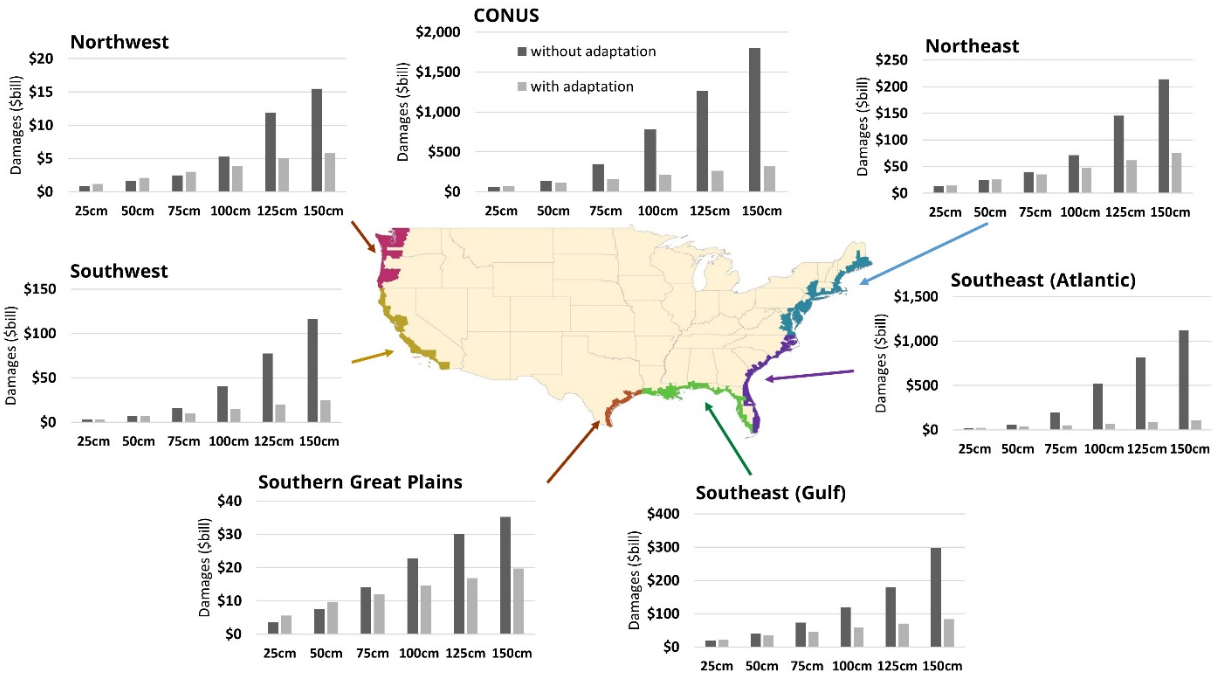
Figure 4. Projected Populations at Risk of Inundation Due to Sea Level Rise



Note: The map identifies the regions analyzed but does not depict the specific areas projected to be inundated by sea level rise.

Figure 5 shows the cumulative damages associated with the projected impacts of six levels of global mean sea rise. Cumulative damages are provided as an index of the relative severity of damages across regions, sea level rise scenarios, and no adaptation versus with adaptation response scenarios – annual estimates for adaptation scenarios can be misleading, as they reflect early investments in protection that reduce impacts later in the century. The figure shows that as seas rise, damages under a no adaptation scenario increase, but not linearly. Projected damages for all regions are estimated at $59 billion at 25 cm of rise, slightly more than double at 50 cm of rise ($137 billion), and 5.6 times higher at 100 cm of rise ($779 billion) compared to damages at 50 cm. However, under a simulated cost-effective adaptation scenario, annual estimated damages are reduced slightly at 50 cm ($118 billion, 86% of the estimate without adaptation damages), but significantly lower at higher levels of global mean sea level rise—27% and 18% for 100cm and 150cm, respectively—as protection implemented earlier in the simulation yields higher benefits.

Figure 5. Cumulative Damages ($billions, undiscounted $2015) with and without Adaptation



Note: The map identifies the regions analyzed but does not depict the specific areas projected to be inundated by sea level rise.

Coastal regions in CONUS are impacted differently for various reasons—in particular, the relationship between property locations, the topology, and variations in the rates of regional sea level rise. Also, projected damages are extensively dependent on the progression of impacts over time. For example, if a property is simulated to be abandoned in a particular year, damage for the abandonment occurs in that year, but that property is no longer subject to damages from storm surge for the remainder of the century.

In the Gulf, storm surge damage has a greater influence than in the other regions at higher levels of rise (>50cm), accounting for about two thirds of the total cost without adaptation. Also, the model initiation plays a role in estimating the resulting damages. This initiation likely overestimates the amount of protection currently in place, especially in the Gulf where more sea walls are estimated to exist in the model initiation than in any other region, which is double initial protection in the South Atlantic region. These costs are not included in the total and effectively protect properties further inland with or without adaptation. As a result, damages and adaptation costs in the Gulf are likely underestimated, and to a higher degree than other regions.

Damages are lowest in the Pacific, where much of the coastal property is not exposed to these hazards because of higher relative elevations and coastal cliffs. Also, regional sea level rise in the Pacific Northwest is lower compared to other regions because of glacial shrinkage and isostatic rebound (Sweet et al. 2017b). The majority of the damages along the West coast are projected to occur in southern

California and the San Francisco Bay area. Three counties (Orange, Los Angeles, and San Diego) make up about two thirds of the total projected damages without adaptation.

How communities at risk of sea level rise and storm surge impacts might respond is the key feature of the NCPM and is a distinguishing factor in the analysis of social vulnerability relative to others in the literature. In effect, areas at risk of sea level rise and storm surge, but with low levels of social vulnerability, should be able to effectively respond by fortifying shores or nourishing beaches, while more socially vulnerable populations would be more likely to have fewer resources within their communities to respond in this manner.

Two metrics are developed to investigate the possibility of disproportionate impacts on socially vulnerable populations. The first estimates the number of people inhabiting properties inundated by sea level rise without the implementation of protection, such or beach nourishment. This approach uses population estimates at each Census block group. The second is based on a calculation of the portion of upland property that would not be protected under a simulated cost-effective adaptation scenario (therefore implying a need to retreat/abandon homes), over the total upland property at risk of retreat due to either permanent inundation or storm surge without adaptation.

7. Impacts on Socially Vulnerable Populations

Figure 6 shows the estimated likelihood that individuals in the four socially vulnerable populations analyzed currently live in areas where the highest percentage of land is projected to be inundated due to SLR. Results are presented for the six global mean sea rise levels analyzed. At the national level, lower income households have an estimated 10-19% greater risk of living in areas with permanent inundation at all the levels of global sea level rise analyzed. Minorities are about equally likely to reside in high-impact areas as non-minorities with 25 cm and 50 cm of global sea level rise, but by 75 cm this group is projected to have a 30% greater likelihood of living in high-impact areas. With 125 cm of global sea level rise, minorities are projected to have 61% greater risk of living in areas projected to be inundated. White, non-Hispanic/Latino populations are more likely to experience impacts at lower levels of inundation, but as sea levels rise, there is a more equal distribution of high impact areas between white, non-Hispanic/Latino and minority populations. At 25 cm of global mean sea level rise, adults without a high school diploma or equivalent are 16% more likely to be impacted by permanent inundation than those with higher levels of education attainment, which remains relatively steady across levels of global mean sea level rise. At all levels, people 65 or older are not projected to experience disproportionate impacts relative to those in younger age groups.

Figure 7 shows the risk to specific racial groups of living in areas projected to be inundated due to 50 cm and 100 cm of global sea level rise. With 50 cm of global sea level rise, individuals who identify as American Indian or Alaska Native[36] have an estimated 48% higher risk of living in areas projected to be inundated, and with 100 cm of global sea level rise, individuals who identify as Hispanic or Latino are projected to be 47% more at risk of living in areas projected to be inundated. Impacts to individuals in all racial and ethnic groups are determined based on self-identification in the American Community Survey

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[36] Based on groupings in the American Community Survey, this analysis groups together individuals who identify as American Indian or Alaska Native. As Alaska Native individuals are not common in the Southeast compared to other races and ethnicities, 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.

data, and therefore, with respect to American Indian individuals, may not correspond to specific Tribal lands or reservations. However, a closer examination of the results reveals that the areas projected to be inundated with 50 cm of global sea level rise overlap with American Indian reservations in Northern California, Washington State, and the Gulf Coast of Louisiana.

Figure 6. Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas where the Highest Percentage of Land is Projected to be Permanently Inundated due to SLR, Relative to Those in Reference Populations

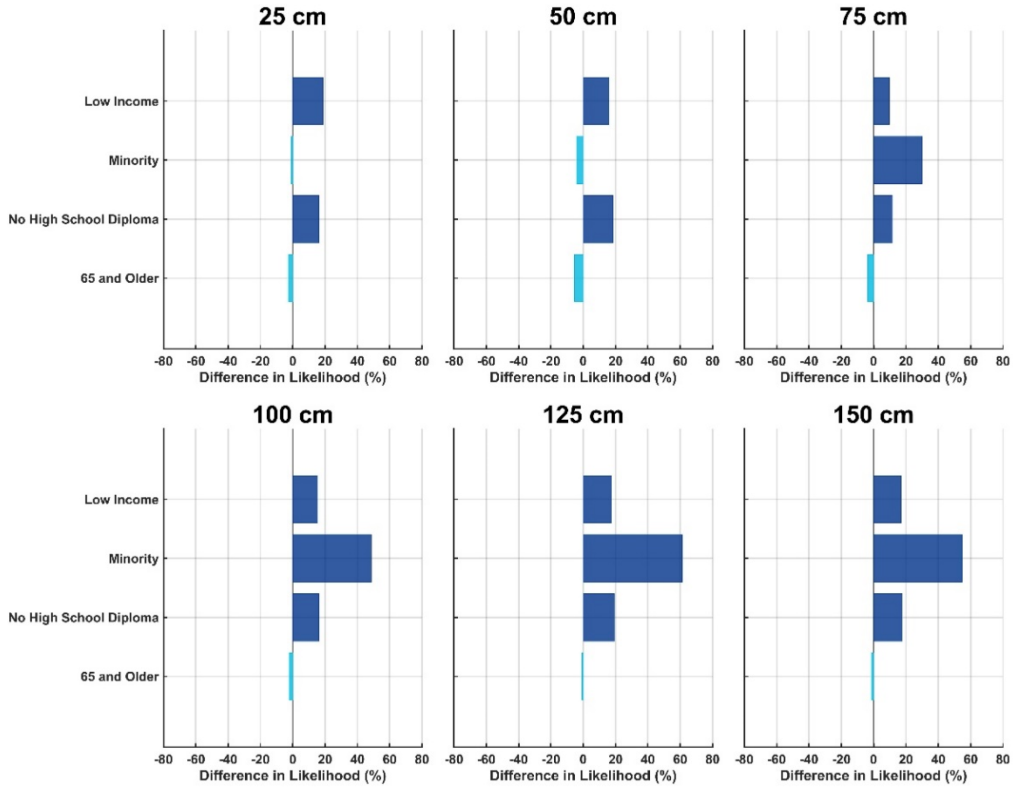


Figure 7. Likelihood that Those in Individual Racial and Ethnic Groups Currently Live in Areas where the Highest Percentage of Land is Projected to be Permanently Inundated due to SLR, Relative to Those in Reference Populations

50 cm

100 cm

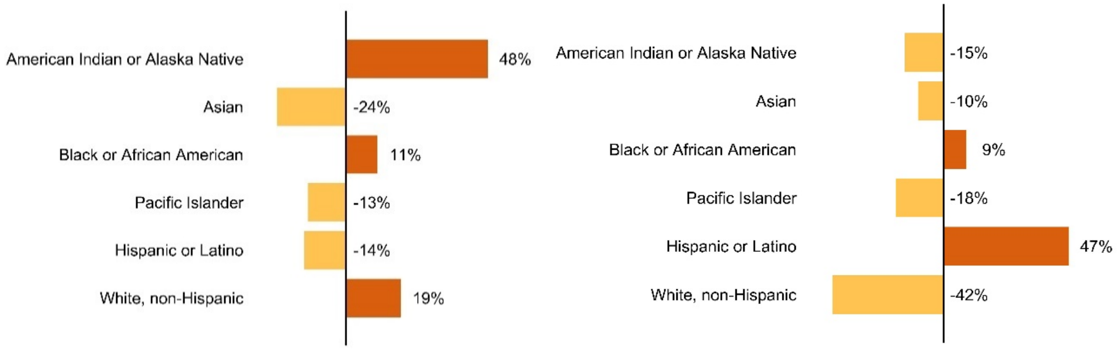


Figure 8 shows the disproportionality for the four social vulnerability categories across the six global mean sea rise levels for the simulated exclusion from cost-effective coastal adaptation. At 25 and 50 cm, the vulnerable groups are about as likely to be excluded from protection than their non-vulnerable counterparts. Most of these groups are also less likely to experience adverse impacts, as indicated in part from Figure 4. At elevations 75 cm and above, there are disproportionate impacts for the low-income and minority groups, which generally increase at higher levels of global sea level rise. Since the simulated decision to protect assets in the NCPM is driven by home values, it is not surprising that low-income populations are less likely to be protected, since property value and income are usually related. Low-income populations are projected to be 9-15% more likely to be excluded from protection across the arrival points of global mean sea level rise of 75 cm and greater. Although minority populations are less likely to be at risk of permanent inundation at lower levels of global mean sea level rise than the same populations at higher amounts of SLR, they are projected to be the most likely to be excluded from protection at 75 cm and above, reaching over 20% more likely than the white, non-Hispanic/Latino population at 125 cm and 150 cm.

Figure 9 presents the difference in relative risk to specific racial and ethnic groups of living in areas projected to be excluded from adaptation. Individuals who identify as American Indian or Alaska Native have a 7% higher risk with 50 cm of global sea level rise and a 23% higher risk with 100 cm.

Figure 8. Likelihood that Those in Socially Vulnerable Groups Currently Live in Areas where the Highest Percentage of At-Risk Property is Projected to be Excluded from Adaptation, Relative to Those in Reference Populations

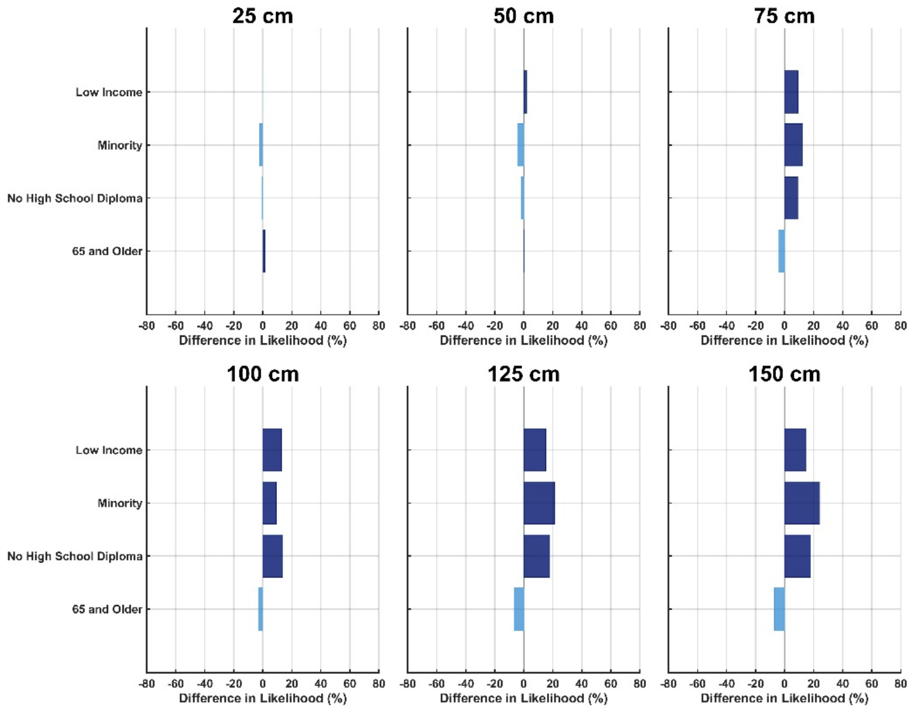


Figure 9. Likelihood that Those in Individual Racial and Ethnic Groups Currently Live in Areas where the Highest Percentage of At-Risk Property is Projected to be Excluded from Adaptation, Relative to Those in Reference Populations

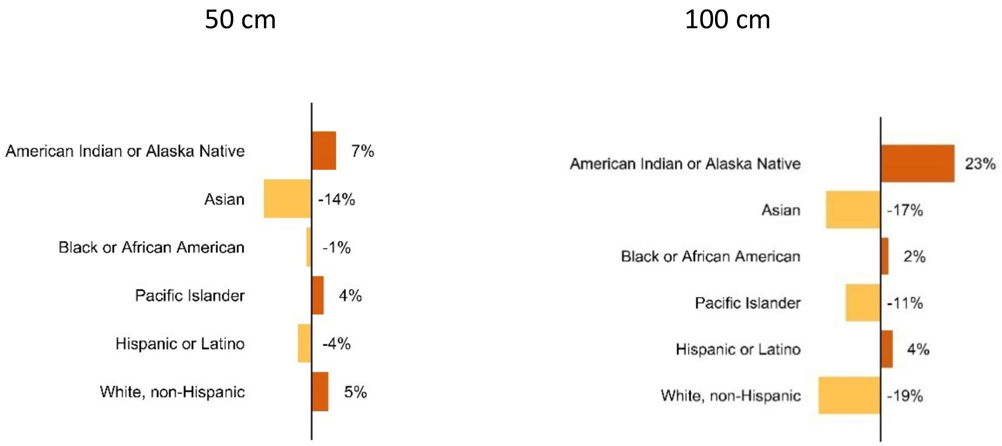


Figure 10 shows the projected difference in risk to low income populations of living in areas projected to be inundated at 50 cm, 100 cm, and 150 cm of global mean sea level rise for each of the six regions. At 50 cm, low income individuals are most likely to be at risk of permanent inundation in the Southeast-Atlantic, Southern Great Plains, and Southeast-Gulf. At 100 cm and 150 cm, low income populations are even more likely to be at risk in the Southern Great Plains, reaching 24% more likely at 150 cm of sea level rise.

Figure 10. Likelihood that Low-Income Populations Live in High-Impact Areas Relative to Those with Higher Income

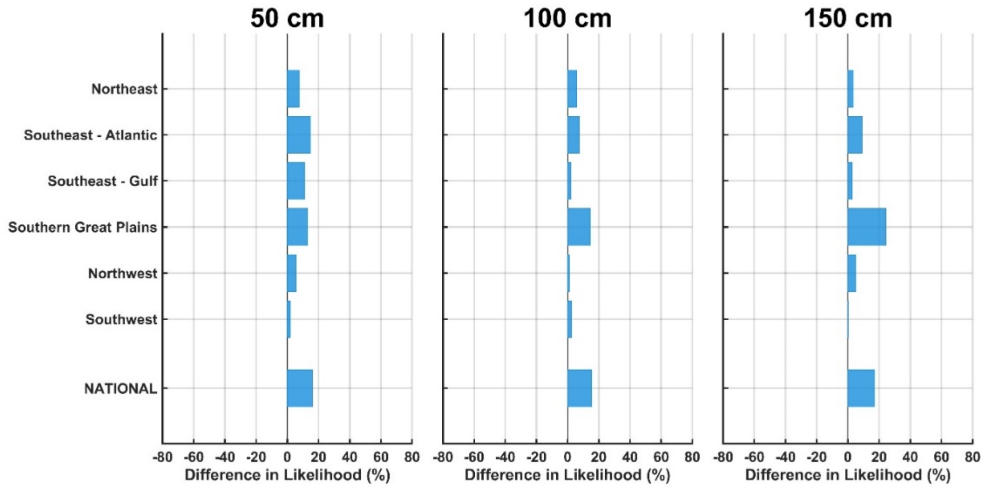


Figure 11 shows the estimated difference in risk to low income populations of living in areas projected to be excluded from protection. People who reside in low-income households are projected to be more likely to be excluded from protection in all regions at 50 cm, 100 cm, and 150 cm of global mean sea level rise. The effect is highest in the Southwest at 50 cm (25% more likely) and the Southeast Atlantic at 100 cm and 150 cm (23% more likely).

Figure 11. Likelihood that Low Income Populations Currently Live in Areas Projected to be Excluded from Adaptation Relative to the Reference Population

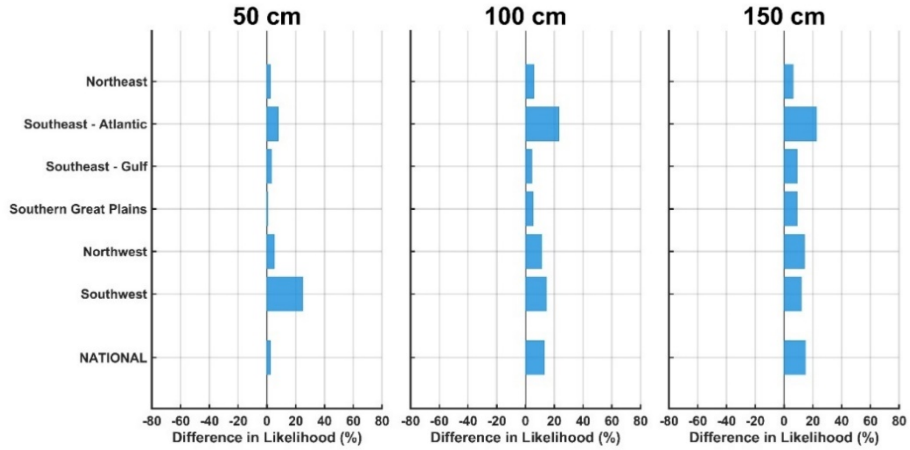


Figure 12 shows the projected difference in risk to minority populations of living in areas projected to be inundated. At 50 cm, the Southeast-Atlantic shows that minority populations are projected to be 18% less likely to inhabit high risk areas, while the Southeast-Gulf shows the opposite, where minority populations are 21% more likely to reside in high risk areas. At higher sea levels, most regions show increased likelihood except the Northeast and Northwest, which have a fairly equal distribution of high impacts between the socially vulnerable and non-vulnerable population. The Southeast-Atlantic shows that minority populations are projected to be much more likely to reside in high risk areas at 100 and 150 cm, reaching 51% and 68%, respectively. At these levels, large areas of Miami-Dade County are estimated to be at risk, which is primarily driving these disproportionate impacts.

Figure 12. Likelihood That Minority Populations Currently Live in Areas Projected to be Inundated by SLR Relative to the Reference Population

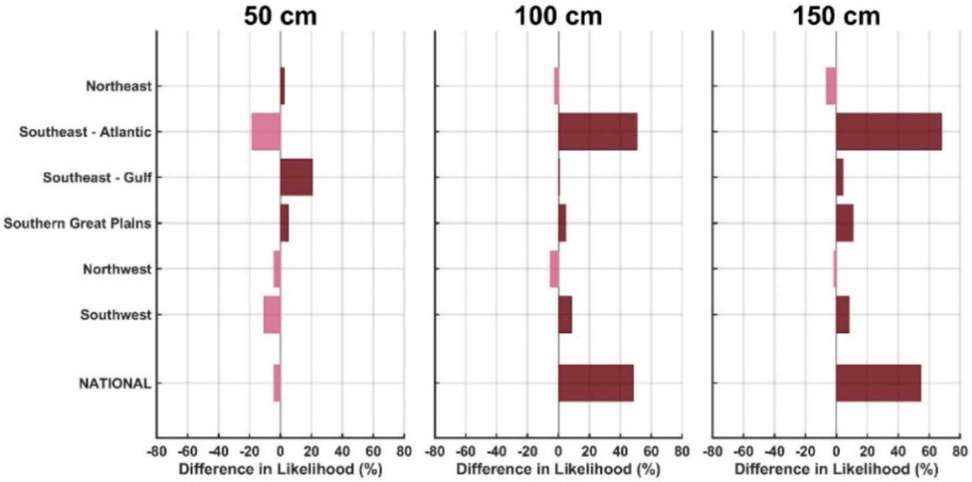


Figure 13 shows the projected likelihood that minorities live in areas projected to be excluded from adaptation (relative to white, non-Hispanic individuals). At 50 cm, results indicate that minority populations in the Southwest are 19% less likely to be excluded from protection, which nears zero percent by 150 cm. Minority populations who live in the Southeast-Atlantic are more likely to be excluded from protection by 9% at 50 cm, which grows to a 23% increased likelihood at 100 cm and 33% at 150 cm. Since this region has the highest overall impacts (see Figure 2 and Figure 3) and has the highest disproportionality values for minority populations and permanent inundation (Figure 8 these disproportionate impacts are substantial. Minority populations in the Southeast-Atlantic, who are also the most at risk and have the highest overall impacts are the least likely to receive protection given the simulated cost-effective protection scenario.

Figure 13. Likelihood that Minority Populations Currently Live in Areas Projected to be Excluded from Adaptation Relative to the Reference Population

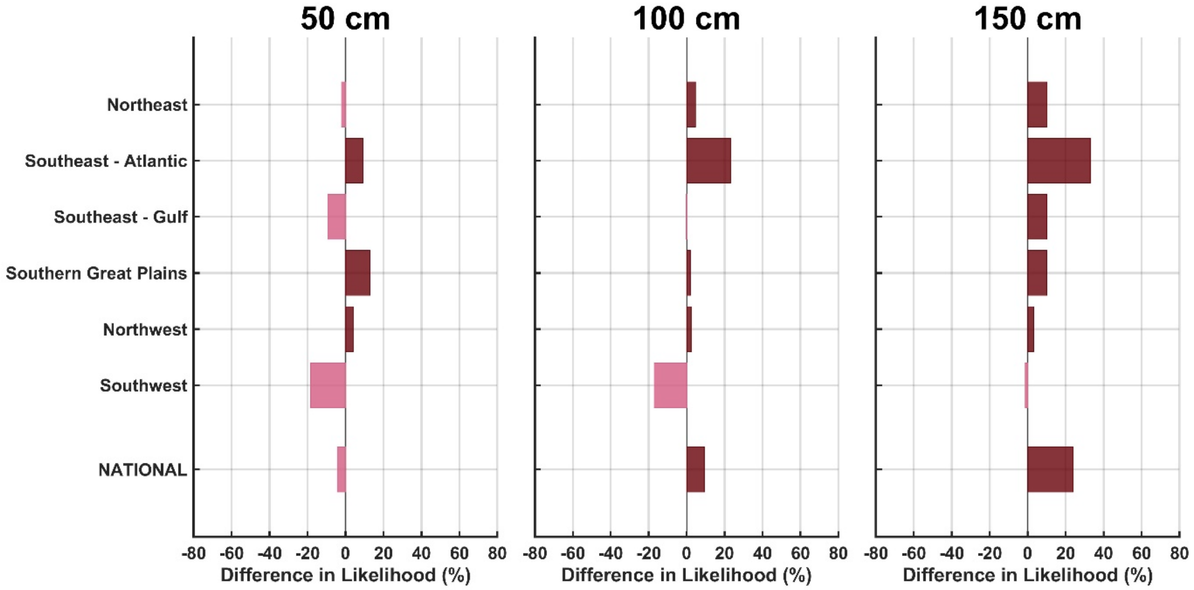
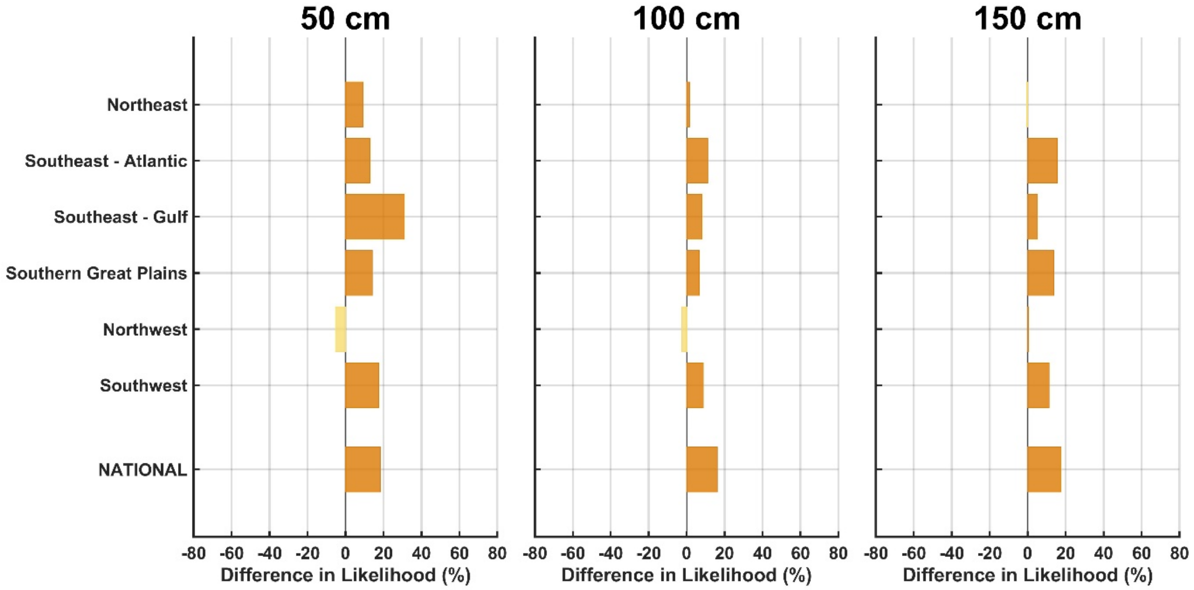


Figure 14 shows the projected difference in risk to those without a high school diploma or equivalent of living in areas projected to be subject to permanent inundation. Most regions show that these populations are more likely to be at risk from permanent inundation except in the Northwest, which also has the lowest proportion of adults without a high school diploma. The Southeast-Gulf indicates a disparity of high impacts from permanent inundation that reaches 31% at 50cm, but decreases to 5% by 150cm. Results for the Southern Great Plains, which has the highest proportion of adults without a high school diploma, show that these populations are over 13% more likely to be at risk for all six levels except 100 cm, which is 7%.

Figure 14. Likelihood that Populations with no High School Diploma Currently Live in Areas Projected to be Inundated by SLR Relative to the Reference Population



Adults without a high school diploma or equivalent are both more likely to live in properties at risk of permanent inundation in most regions, and less likely to be protected under a simulated cost-effective adaptation scenario (Figure 15). This is true for most regions, although by only a small margin for some. In the Southern Great Plains, where the highest proportion of people who fall into this social vulnerability demographic reside, these populations are between 13% and 20% less likely to be protected at levels between 50 cm and 150 cm. Individuals without a high school diploma in the Southeast-Atlantic experience the greatest disproportionality of risk; they are 28% and 29% more likely of experiencing the worst effects at 100 cm and 150 cm respectively.

Figure 15. Likelihood that Populations with no High School Diploma Currently Live in Areas Projected to be Excluded from Adaptation Relative to the Reference Population

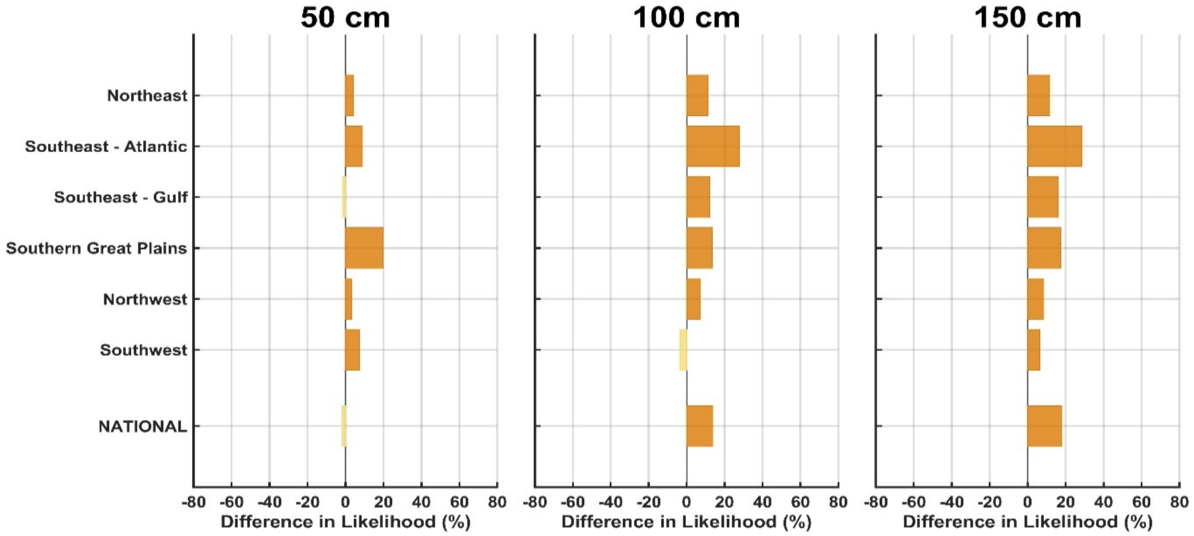


Figure 16 shows the projected difference in risk to people 65 or older of living in areas projected to be inundated. At the CONUS scale, people 65 and older are marginally less likely to live in areas at risk of permanent inundation, but that is the not the case for all coastal regions. At 50 cm, people 65 and older in the Southeast-Gulf are 17% less likely to live in high-risk areas, but in the Southwest, people 65 and older are 15% more likely. However, the vast majority of the regions indicate a difference in likelihood, either positive or negative, of less than 10% at sea level rise changes of 100 cm and above.

Figure 16. Likelihood that Adults 65 and Older Currently Live in Areas Projected to be Inundated by SLR Relative to the Reference Population

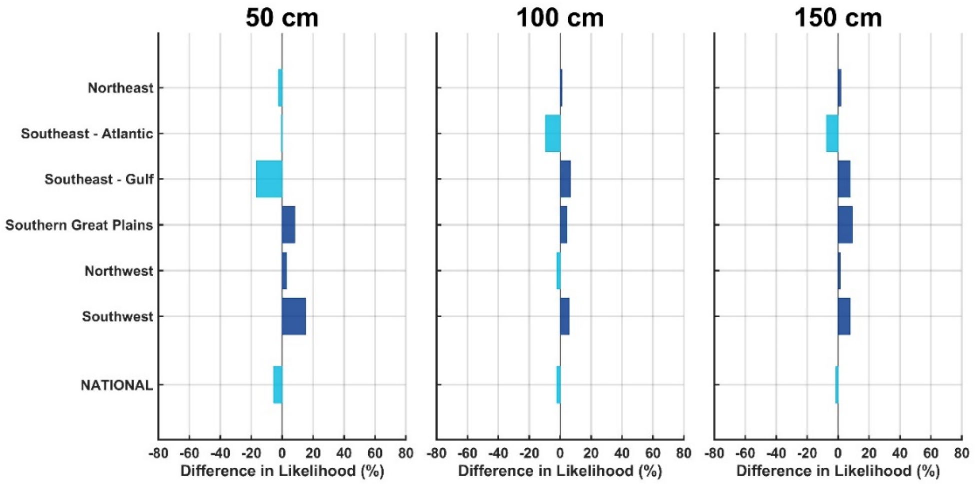
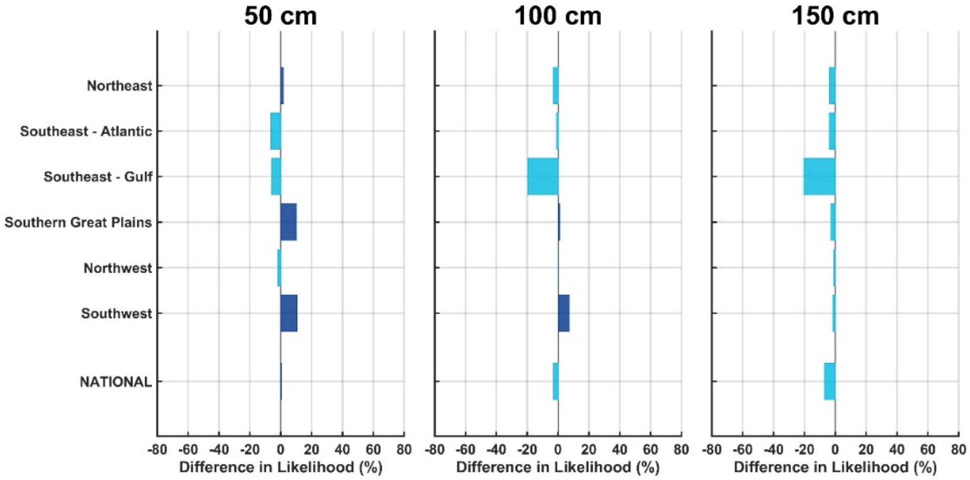


Figure 17 shows the projected difference in likelihood of living in areas projected to be excluded from adaptation. The results indicate that people 65 or older are likely to be protected for most sea level rise scenarios across regions, although only marginally in most cases. The exceptions are the Southern Great Plains and Southwest at 50 cm, where people 65 and older are more likely to be excluded from protection by 10%.

Figure 17. Likelihood that People Over 65 Currently Live in Areas Projected to be Excluded of Protection Relative to the Reference Population



8. Main Findings

- At a national level, low income households and adults without a high school diploma or equivalent are consistently more likely to live in areas at risk of permanent inundation by nearly 20% for all levels of global main sea rise.
- Most regions also show that low income households and adults without a high school diploma or equivalent are more likely to be excluded from protection. Although in some regions the difference in likelihood is relatively small, the Southeast-Atlantic region shows larger differences in likelihood of risk, with a 30% higher risk for adults without a high school diploma and .
- Individuals who identify as Black and African American, Asian, Native American, and Hispanic/Latino (minority populations) are about equally likely to be at high risk of permanent inundation at 25 and 50 cm, but are approximately 30% more likely to be at risk at 75 cm of rise and 61% more likely at 125 cm.
- Minority populations in the Southeast-Atlantic are projected to be much more likely to reside in high risk areas at 100 and 150 cm – the disproportionate increase in risk relative to white, non-Hispanic individuals is 51% and 68%, respectively. These groups in the Southeast-Atlantic region are also least likely to benefit from protection if cost-effective adaptation criteria are used to allocate adaptation resources, and the differential in relative risk grows with higher global SLR scenarios, from 9% at 50 cm, to 23% increased likelihood at 100 cm and 33% at 150 cm.

9. Limitations

The following lists major limitations in this analysis. See Neumann et al. (2015) and Lorie et al. (2020) for additional descriptions of limitations of the NCPM.

- Increasing degrees of sea level rise and storm surge risks over time are likely to trigger changes in the demographics of the population at risk. For example, the owners of properties that are repeatedly damaged by storm surge may choose to sell. Those who have more limited access to information or the necessary social connections to understand the risks of purchasing near-coast property may move into these areas once the property values drop, changing the demographics of the properties at risk, especially at higher levels of rise. Such demographic changes are not accounted for in the modeling approach used in this analysis.
- Although the NCPM evaluates impacts at grid cells that are 150 m square, the property characteristics in the NCPM are at the Census block group level and not at the parcel level. Because of this, the methodology approximates the population impacted by taking the portion of upland property area that is impacted and multiplying that by population for the block group. As such, the analysis does not consider different lot sizes within the block group, vacant lots, or vacation houses with seasonal occupation.
- Similarly, the distribution of demographics within the Census block group are not considered because that information is not available. However, there are likely differences in demographics between, for example, beach-front property-owners and property-owners a few streets away from the beach. These are not captured in this analysis.
- The NCPM estimates the locations of existing protection in the model initiation period by simulating a cost-effective adaptation scenario based in part on property value. While this provides a necessary starting point for comparisons across protection strategy scenarios, it is likely an overestimate of existing protection, which results in a conservative estimate of damages throughout the century.
- As described, the NCPM uses a modified bathtub approach for simulating sea level rise inundation and storm surge flood zones and depth. While this was the only feasible approach at the national scale, local dynamic flood modeling techniques may show different inundation and storm surge flood patterns and depths. Also, changes in topography, ground cover, and hydrology over time will likely alter flood and inundation patterns, especially later in the century. These details are not captured in the NCPM modeling featured in this section of the report.

10. Data Sources

DATA TYPE	DESCRIPTION	DATA DOCUMENTATION AND AVAILABILITY
Sea level rise and tide gauge levels	Sea level rise projections and tide gauge levels used to develop storm surge heights and probabilities	National Oceanographic and Atmospheric Administration. (2017). Global and regional sea level rise scenarios for the United States. NOAA Center for Operational Oceanographic Products and Services, Technical Report NOS CO-OPS 083.
Population and developed land projections	Median Variant Projection of the United Nation's (UN) 2015 *World Population Prospects* dataset used to project future U.S. population for 2015-2100.	United Nations, 2015: World Population Prospects: The 2015 Revision. United Nations, Department of Economic and Social Affairs, Population Division. Data available at: https://population.un.org/wpp/
	U.S. national and county-level population figures from 2000-2015	U.S. Census Bureau, cited 2017: Population Estimates Program. Available online at https://www.census.gov/programs-surveys/popest.html
	County-scale population and developed land projections from the Integrated Climate and Land-Use Scenarios model (version 2)	https://www.epa.gov/iclus EPA, 2017: Updates to the Demographic and Spatial Allocation Models to Produce Integrated Climate and Land Use Scenarios (ICLUS) (Version 2). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-16/366F. Available online at https://cfpub.epa.gov/ncea/iclus/recordisplay.cfm?deid=322479
Domestic economic growth	Projection of future gross domestic product from the Emissions Predictions and Policy Analysis (EPPA, v6) model. The projection of GDP growth through 2040 was taken from the 2016 Annual Energy Outlook reference case, combined with EPPA-6 baseline assumptions for other regions and time periods	Chen, Y.-H. H., et al. The MIT EPPA6 Model: Economic Growth, Energy Use, and Food Consumption. MIT Joint Program on the Science and Policy of Global Change, Report 278, Cambridge, MA (2015). Available online at http://globalchange.mit.edu/research/publications/2892 U.S. Energy Information Administration, 2016: Annual Energy Outlook. Available online at https://www.eia.gov/outlooks/aeo
Price deflator	Dollar years are adjusted to $2015 using the U.S. Bureau of Economic Affairs' Implicit Price Deflators for Gross Domestic Product, Table 1.1.9.	U.S. Bureau of Economic Affairs' Implicit Price Deflators for Gross Domestic Product, Table 1.1.9. See "National Income and Product Accounts Tables" at https://bea.gov/national/index.htm
Infrastructure Inventory Data	Property value for each 150m X 150m coastal county grid cell is derived from compiled tax assessment values for land and structure, and address residential, commercial, industrial, institutional, and most categories of public land (excluding military installations).	Updates from Neumann et al. (2010) available by county at CIRA2.0 sectoral impact data repository. Available at: https://www.indecon.com/projects/benefits-of-global-action-on-climate-change/