When Rising Seas Hit Home

Hard Choices Ahead for Hundreds of US Coastal Communities

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July 2017

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The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

More information about UCS and the Climate and Energy Program is available on the UCS website: *www.ucsusa.org*

This report is available online (in PDF format) at *www.ucsusa.org/RisingSeasHitHome*

Designed by: Tyler Kemp-Benedict
Cover photo: Ron Sher
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[DEDICATION]

We dedicate this report to the late Margaret Davidson. As a NOAA administrator for more than two decades, her vision and passion helped to make possible the coastal tools, data, and expertise that our work relies on. Perhaps even more than her brilliant professional legacy, her generous, humorous humanity touched and inspired us deeply, and will long remind us how to do this work well.

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[ACKNOWLEDGMENTS]

This report was made possible by the generous support of the Barr Foundation, the Energy Foundation, the Common Sense Fund, and members of the Union of Concerned Scientists.

The project team would like to acknowledge the essential assistance received in the development of this report.

For her insight, advice, and support throughout this project, we extend our gratitude to Brenda Ekwurzel, director of climate science and senior scientist with the UCS Climate and Energy Program.

For invaluable technical guidance and input during the analytical process, we are indebted to several advisers from the National Oceanic and Atmospheric Administration: Doug Marcy and Billy Brooks (NOAA Office for Coastal Management); Matt Pendleton (The Baldwin Group for NOAA's Office for Coastal Management); and Billy Sweet (NOAA CO-OPS), who provided DEM data and essential methodological input. Paul Kirshen and Ellen Douglas (University of Massachusetts, Boston) also provided valuable guidance and reviews. Jeremy Martinich, Lindsay Ludwig, and Stefani Penn (EPA) provided US Census tract-level SoVI data, and Susan Cutter (University of South Carolina) provided key advice about the development and use of SoVI.

We are grateful to the following individuals for their thoughtful comments on review drafts of this report: Doug Marcy, Matt Pendleton, Ben Strauss (Climate Central), Paul Kirshen, Ellen Douglas, and Julie Wormser (Boston Harbor Now).

The following people provided indispensable perspective on the location-specific information included in this report: Garrow Alberson (City of Brunswick, GA); Mart Black (Terrebonne Parish, LA); Lisa Craig (City of Annapolis, MD); Donald and Theresa Dardar (Terrebonne Parish, LA); Katie DeHart (member of Isle de Jean Charles Band of Biloxi-Chitimacha-Choctaw Indian Tribe, Terrebonne Parish, LA); Rhonda Haag (Monroe County, FL); Jerry Hardison (Hyde County, NC); Hernan Lopez (Bergen County, NJ); Dan Mundy, Sr. (Jamaica Bay Ecowatchers, Broad Channel, NY); Tim Osborn (NOAA Office of Coast Survey, Lafayette, LA) Matt Pendleton (NOAA Coastal Services Center, Charleston, SC); Kristina Peterson (Lowlander Center, Gray, LA); Christopher Ridings (Borough of West Wildwood, NJ); Louisette Leonard Scott (City of Mandeville, LA); Roderick Scott (L&R Resources, Mandeville, LA); Michael Shannon (Galveston County, TX); Carmalita Sylve (member of the Grand Bayou Indian Tribe, Plaquemines Parish, LA); and Paul Wolff (former city council member, Tybee Island, GA).

Lastly, we thank Susanne Moser of Susanne Moser Research & Consulting for her inspiration. At a meeting in 2016, Susi implored assembled experts: "If you want to do anything useful for coastal communities, tell them how much time they have to act." With this report, we have tried to do just that.

The opinions expressed herein do not necessarily reflect those of the organizations that funded the work or the individuals who reviewed it. The Union of Concerned Scientists bears sole responsibility for the report's content.

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Climate change often seems a distant threat. It is difficult to picture how it will affect and alter our lives.

We can imagine hurricanes and neighborhoods underwater, as after levees failed in New Orleans, Louisiana, during Hurricane Katrina. But many important consequences of climate change are more subtle and slower moving than disasters.

One such consequence is sea level rise. Unlike the catastrophic flooding that can accompany hurricanes, sea level rise impacts can take time to manifest.

The final result, late this century and beyond, may be neighborhoods underwater. But in the decades before that happens, sea level rise steadily encroaches on land. It causes "sunny day" tidal flooding that reaches far beyond the areas where people living in exposed coastal cities and towns have seen such flooding. These communities can cope with the water at first. But there comes a threshold of sea level rise–induced flooding that makes normal routines impossible and drives hard choices.

Americans in some communities already know what it feels like for the slow creep of sea level rise to intrude in some way on their daily lives, flooding their neighborhood or place of work, rerouting their commute, driving down the value of their home. In the decades ahead, though, many more of us will experience these changes.

In the following analysis, the Union of Concerned Scientists (UCS) defines a threshold for sea level rise–induced flooding that can disrupt people's routines, livelihoods, homes, and communities. UCS defines flooding that occurs 26 times per year (on average, once every other week) or more as "chronic inundation." UCS deems as "chronically inundated" any coastal community that experiences this frequency of flooding over 10 percent or more of its land area, excluding wetlands and areas protected by federal wlevees.

There comes a threshold of sea level rise-induced flooding that makes normal routines impossible and drives hard choices.

To understand how US coastal communities will be affected by chronic inundation due to sea level rise, UCS explored these main questions:[1]

- Which East, Gulf, and West Coast communities will become chronically inundated this century and when? Or, put differently, how much time do communities have to respond to this threat?
- How will the size of chronically inundated areas grow over time?
- How does the pace of sea level rise affect the number of chronically inundated communities and the time they have to respond?

1 *For a detailed methodology, see:* www.ucsusa.org/RisingSeasHitHome.

[caption to come]

Photo: David Harp

William L. Thompson

[photo 1: general flooding – Caption to come]

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- How many of these chronically inundated locations are large population centers and/or home to socioeconomically vulnerable communities?
- How can decisionmakers from household to federal levels best prepare in the time that they have?

UCS found that, in the absence of preventative measures, Americans can expect the following:

- Within 20 years, by 2035, nearly 170 coastal US communities[2]—roughly twice as many as today—will reach or exceed the threshold for chronic inundation, given moderate sea level rise. Seventy percent of these will be in Louisiana and Maryland, where land subsidence is contributing to rapid rates of sea level rise. More than half of these 170 communities are currently home to socioeconomically vulnerable neighborhoods.
- Within 45 years, by 2060, more than 270 coastal US communities—including many that seldom or never experience tidal flooding today—will be chronically inundated, given moderate sea level rise.
- By the end of the century, given moderate sea level rise, nearly 490 communities—including 40 percent of all East and Gulf Coast oceanfront communities—will be chronically inundated.
- Given more rapid sea level rise, nearly 670 coastal US communities will face chronic inundation by the end of the century. This number includes nearly 60 percent of East and Gulf Coast oceanfront communities as well as a small but growing number of West Coast communities.
- Given that same rapid rate of sea level rise, more than 50 heavily populated metropolitan areas—including

2 *In this analysis, "community" refers to a US Census Bureau–designated county subdivision. These are typically distinguishable cities and towns both large and small, such as Boston, Manhattan, Kiawah Island, and Key West.*

Oakland, California; Miami and St. Petersburg, Florida; and four of the five boroughs of New York City—will face chronic inundation by the end of the century.

- By 2100, given this same rapid rate of sea level rise, chronic flooding will engulf at least half the total land area of nearly 40 percent of affected communities, including Cambridge, Massachusetts; Alameda, California; and Miami Beach and Fort Lauderdale, Florida.
- Many communities that never reach the 10 percent threshold of chronic inundation this century are nevertheless expected to see chronic flooding of important areas.
- There is still time to prevent such widespread chronic inundation. Curtailing future warming and, thereby, the acceleration of sea level rise could benefit communities in each coastal region. By reducing global warming emissions, we may slow the pace of sea level rise, which could spare hundreds of communities chronic inundation.
- For hundreds of other communities, chronic inundation is avoidable only through significant adaptation measures, including coastal retreat.

Measures to accommodate or keep water out of communities may forestall the inundation projected by this analysis, but often at great cost and for a limited time. Hundreds of communities along the coasts, from Maine to Washington State, will be forced to make difficult choices about whether and how much to invest in flooded areas versus when to retreat from them. Residents in affected areas will be forced to make difficult choices about what they can tolerate and where to live when they can tolerate no more. Many such communities are home to low-income residents who have few of the resources they would need in order to move or to adapt.

For hundreds of other cities and towns, increased flooding is inevitable, and adaptation is now essential.

Large-scale reductions in global warming emissions, similar to those planned under the international climate deal known as the Paris Agreement, may slow the rate at which sea level rise is accelerating and save many communities from chronic inundation. For hundreds of other cities and towns, however, increased flooding is inevitable, and adaptation is now essential.

By making sound decisions soon, communities can prepare for chronic inundation in the time they have and avoid serious losses—not only of homes, schools, businesses, and other infrastructure, but also of regional history, sense of place, local culture, and people's ways of life.

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Introduction

How many times each year would you be able to tolerate flooding that overwhelmed your neighborhood?

If saltwater regularly soaked your basement or first floor, kept you from getting to work, or damaged your car, how often would it have to happen before you began to look for a new place to call home? How long before you could no longer insure or sell your home?

Gloria Tello is a stylist who does hair and makeup for weddings. She rents space with other aestheticians in an office building in the City of Coral Gables, Miami-Dade County,

meunierd/Shutterstock

Tidal flooding continues to disrupt normal life for many people in South Florida, as in September, 2015, in Miami Beach. Here, city workers enlist pumps to cope with flooded streets. In some frequently flooded Florida neighborhoods, there is growing unease about how long they should remain in their homes.

Florida, and she had planned to open her own studio there, capitalizing on nearby bridal shops. But since learning about the risk of heavy flooding over the next decades in the neighborhood, Tello is reconsidering.

"These are things you have to think about now, before you invest your life savings into a business," she says.

In South Beach, a few miles east, increasing floods are hurting shops and stores, Tello knows. As a college student working in a nightclub on the beach, she had to miss work several times because her car could not navigate the water rushing through the streets. She says some businesses have piled up sandbags at their doors. "The water actually goes into their stores," she notes. "I don't know how small business owners can cope with it."

Recurrent tidal flooding is one of the most obvious signs of sea level rise, which in turn is one of the most tangible consequences of global warming. As global temperature increases, driven largely by emissions from burning fossil fuels and other human activities, the increase causes ocean water to expand and ice sheets to shrink, both resulting in sea level rise.

Americans living on the East, Gulf, and West Coasts will feel the effects of sea level rise decades before coastal land is permanently underwater (Kulp and Strauss 2017). The shorter-term consequences are more extensive, more frequent, and, eventually, chronic inundation, which will dramatically alter the landscape and the livability of many coastal communities.[3]

This UCS analysis identifies hundreds of US communities that face this chronic and disruptive inundation, which may render affected areas—currently neighborhoods, commercial districts, and industrial zones—unusable. The analysis also identifies the "response time" remaining before such flooding arrives and how to use this time wisely.

> ***Chronic inundation will dramatically alter the landscape and the livability of many coastal communities.***

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3 *"Chronic inundation" refers to tidal flooding that affects 10 percent or more of a community's area at least 26 times per year (on average, twice per month).*

[CHAPTER 2]

Identifying When and Where Rising Seas Hit Home

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What Do We Mean by *Chronic Inundation?*

The tides rise and fall twice daily along the East and West Coasts and once daily along the Gulf Coast, inundating and then exposing an area known as the intertidal zone. But not all tides are created equal. Twice a month (during new and full moons), the Earth, sun, and moon align, which amplifies the range of the tides. The combined gravitational pull of the sun and moon during these times exerts a greater force on Earth's oceans, creating what are sometimes referred to as spring tides—high tides that are higher than normal and low tides that are lower. Several times a year, during a new or full moon when the moon is closest to Earth, the range of the tides is even greater, producing "king tides." Unlike daily tides, these types of extreme tides can reach beyond intertidal zones.

If you live in a coastal community, you know that the intertidal zone is underwater once or twice daily. You might enjoy building a sand castle in the intertidal zone, but you would not build your house in it, or a road or other infrastructure. But what if high tide began reaching into a neighborhood dozens of times a year, creating a chronic inundation zone. Would you build your house there?

With rising sea levels riding atop normal variations in tide height, high tide is now capable of flooding typically dry land, and on an increasingly frequent basis.[4] And as sea levels rise further, the daily high tide line will continue to move into new areas, shifting the intertidal zone farther inland. Many decades before a community is underwater during high tide, its land area may flood often enough to cause disruption and losses for the community so significant that it would be considered chronically inundated.

- This analysis defines a limited-use or chronic inundation zone as any area where tidal flooding occurs 26 times per year (on average, twice a month—although flooding events tend to cluster, not to occur at neat intervals).[5]
- UCS considers a community to be chronically inundated when 10 percent or more of its usable, nonwetland area floods at or more than that twice-monthly average frequency.

This chronic inundation threshold is based on previously published frequency thresholds (e.g., Sweet and Park 2014), consultation with technical experts at universities and federal agencies, and perspective gained from local experts in communities currently experiencing a range of flooding frequencies.[6] However, it is important to keep in mind that there is no "magic number" for the frequency or extent of flooding that will drive a community to make hard choices.

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4 *Sea level rise will also increase the reach of storm surge, the potentially destructive rise in water level that occurs during hurricanes and other coastal storms such as Nor'easters. This analysis does not evaluate changes in storm surge extent due to sea level rise.*

5 *This analysis uses historical tide gauge data to identify the water level threshold exceeded 26 times per year at each of 93 tide gauges along the US coastline. With two high tides per day, tide gauges along the East and West Coasts could potentially record two exceedances of the threshold daily though today flooding typically occurs with the higher of the two tides. In contrast, water levels along the Gulf Coast, where there is typically just one high tide per day, have just one opportunity to exceed the threshold each day.*

6 *See our complete methods here:* www.ucsusa.org/RisingSeasHitHome.

Marcus Baker/Alamy Stock Photo

Some of the businesses that help make city waterfronts vibrant, as in Annapolis, Maryland, and Boston, Massachusetts, shown here, are finding that periodic flooding of even limited areas can be costly and disruptive.

I assumed "a population of 5,700.7" in edited text for paragraph below was a typo, and removed the ".7"

For example, communities range from urban centers such as the borough of Queens, New York, with a population of 2.2 million, to rural and remote towns such as District 7 within St. Mary Parish, Louisiana, which includes part of Morgan City and has a population of 5,700. If 10 percent of Queens floods, it would cause greater disruption than 10 percent of a coastal Louisiana Parish flooding. The chronic inundation zone may be small in area but still drive major investments or retreat, as in Annapolis, on Maryland's Western Shore, where the frequently flooded area is its economically important waterfront. In contrast, the chronic inundation zone may be large, as in small villages on Maryland's Eastern Shore, but elicit little local response. Because the US coasts are home to a vast range of unique communities, the tolerance for flooding among coastal cities and towns will vary widely.

Many decades before a community is underwater during high tide, its land area may flood often enough to cause significant disruption and losses for the community.

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7 *In this analysis, "communities" are defined by the boundaries of county subdivisions as recognized by the US Census Bureau (US Census Bureau 2012).*

How Sea Level Rise Drives Chronic Inundation

FIRST, GLOBAL WARMING CONTRIBUTES TO SEA LEVEL RISE…

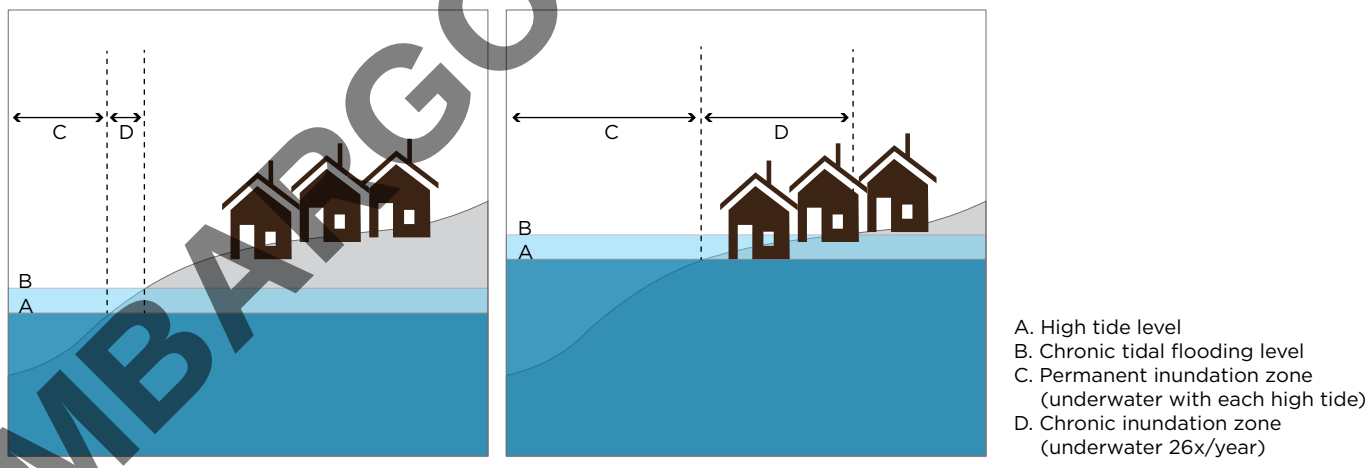
As human-caused emissions of heat-trapping gases, primarily from the burning of fossil fuels, cause the atmosphere to warm, glaciers and ice sheets shrink and the water runs into the oceans. In addition, seawater expands as it absorbs increasing heat from the air. On a globally averaged basis, sea level has risen about eight inches since 1880 (Church and White 2011). However, sea level rise rates vary from place to place, and the East and Gulf Coasts of the United States have experienced some of the fastest rates (NOAA 2013). Seas are rising faster on these coasts for several reasons, including subsidence (the sinking of land, especially acute in Louisiana) in some places and ocean currents, which are changing along the East Coast in response to factors like North Atlantic warming (Ezer et al. 2013; Milliken, Anderson, and Rodriguez 2008). Continued warming is expected to speed the loss of glaciers and ice sheets and, as a result, accelerate the pace of sea level rise in the coming decades to levels not seen in 100,000 years (DeConto and Pollard 2016; Levermann et al. 2013; Dutton and Lambeck 2012).

…THEN RISING SEAS EXPAND THE CHRONIC INUNDATION ZONE.

As sea level rises, adding vertical height and lateral reach to high tide, local flooding occurs more often, and flooding covers even more land for longer stretches of time when extreme tides occur (Figure 1). Eventually, flood conditions arise even during normal tides (Ezer and Atkinson 2014). The rise in sea level during the twentieth century has been associated with more frequent coastal flooding in the United States; tidal flooding events have increased fourfold in some East Coast cities since 1970 (Moftakhari et al. 2015; Ezer and Atkinson 2014; Sweet et al. 2014). Higher sea levels can also prevent rainwater from efficiently draining out to sea when heavy downpours occur, thus making typical rain-induced flooding worse. Far from simple nuisances, these flooding events have created impassable roads; drenched residential, industrial, and commercial areas; and damaged facilities, vehicles, and other machinery (Spanger-Siegfried, Fitzpatrick, and Dahl 2014).

The accelerating pace of sea level rise has accompanied continuing residential, commercial, and industrial development along the coasts. Coastal flooding events are therefore projected to become not only more frequent—increasing tenfold in many locations—but also more disruptive and costly (Figure 2; Dahl, Fitzpatrick, and Spanger-Siegfried 2017; Moftakhari et al. 2017; Moftakhari et al. 2015; Sweet and Park 2014).

FIGURE 1. How Sea Level Rise Causes Chronic Inundation



When higher sea levels are added on top of the normal variations in tide height, the more extreme high tides can reach onto normally dry land. As sea level rises further, this occasional flooding can become chronic, as less extreme tides begin to cause flooding as well. The left panel shows current high tide and the extended reach of extreme tides, which defines a chronic inundation, or limited-use zone. The right panel shows how sea level rise later in the century has expanded the reach of not just extreme tides but also more typical tides such that some land is permanently inundated and a greater portion of the community is chronically flooded.

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In caption below, I assumed it was not intentional to delete "community" after "an East Coast".

FIGURE 2. Expanding the Chronic Inundation Zone

Today **In 30 Years** **In 45 Years**

As sea level rise extends the zone of chronic inundation deeper into communities, chronic flooding may affect commercial, industrial, and residential areas, along with key infrastructure. The left panel shows the current zone of chronic inundation (light blue) in an East Coast community. The center panel shows the chronic inundation zone in 2045, when a densely developed neighborhood can expect to have to deal with twice monthly saltwater inundation. The right panel shows the chronic inundation zone in 2060, when much of the town's coastal area floods with regularity—a sobering challenge for local and state governments.

SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, NCES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

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How Much Sea Level Rise and How Fast?

UCS analyzed the exposure of coastal communities in the continental United States to chronic inundation using three different scenarios developed for the 2014 National Climate Assessment (NCA) and localized for this analysis (Figure 3, p. 11; Walsh et al. 2014; Parris et al. 2012):

- **Highest:** Assumes rising carbon emissions and rapid ice sheet loss over the course of the twenty-first century, leading to a global average rise of 6.6 ft (2.0 meters) above 1992 levels by 2100. This scenario is especially useful when making decisions with a low tolerance for risk, such as siting a new school. This scenario is consistent with recent studies showing that ice sheet loss is accelerating and that future dynamics and instability could contribute significantly to sea level rise this century (DeConto and Pollard 2016; Trusel et al. 2015; Chen, Wilson, and Tapley 2013; Rignot et al. 2011). This UCS analysis refers to projections made based on this scenario as "the high scenario."

  While it was referred to as the "highest" scenario when put forth for the 2014 NCA, scenarios for the upcoming 2018 NCA report include an "extreme" scenario—projecting eight ft (2.4 m) of rise by 2100—to reflect growing scientific understanding of the potential contribution of ice sheet loss (Sweet et al. 2017).

- **Intermediate-High:** Assumes a moderate rate of ice sheet melt that increases over time and projects an ultimate rise of four ft (1.2 m) above 1992 levels, globally, by the end of this century. This scenario assumes that heat-trapping emissions continue to grow through the middle of this century then decline slowly thereafter. This UCS analysis refers to projections made based on this scenario as "the intermediate scenario."

Tidal flooding events have increased fourfold in some East Coast cities since 1970.

BOX 1.

What about Wetlands and Levees?

Wetlands are areas that are permanently or periodically covered by water. They include areas along the coasts, such as salt marshes and mangrove swamps, and can also encompass inland areas such as freshwater marshes and swamps (EPA 2017). Wetlands protect coastal communities from storm surge and erosion while providing habitats for many plant and animal species.

This analysis found that wetland areas are some of the first to be exposed to chronic inundation. Because these are not developable areas, the analysis excluded wetlands from the calculation of chronic inundation zones.

Most vegetated coastal wetlands have historically shown the ability to migrate: provided they have the space and time, they respond to changes in water levels by moving vertically and horizontally (Enwright, Griffith, and Osland 2016). However, modern land-use changes and the relatively rapid pace of present-day sea level rise are challenging wetlands' ability to migrate, with wetlands in the Mississippi Delta region particularly affected (Blum and Roberts 2009; Day et al. 2007). Recent studies have shown that some wetland areas may be able to keep pace with sea level rise (Jankowski, Törnqvist, and Fernandes 2017; Kirwan et al. 2016; Lentz et al. 2016); however, this analysis does not attempt to model how wetlands would respond to sea level rise.

Levees can provide enough protection to transform highly flood-prone areas into livable areas suitable for a variety of uses. Across the United States, there are vast swaths of land protected by levees—the New Orleans region being one of the best known (USACE 2017). As seen quite starkly in New Orleans, levees can fail. Indeed, they may provide a false sense of security and encourage development of land that is increasingly at risk of flooding (GAO 2016). This analysis also excludes areas protected by federal levees from chronic inundation calculations.[8]

- **Intermediate-Low:** Assumes that sea level rise is driven primarily by ocean warming with very little contribution from ice loss. This scenario assumes that global heat-trapping emissions decline drastically; it assumes that twenty-first-century warming is limited to between 2.7 and 3.6°F (1.5 and 2°C). It is associated with a 1.6 ft (0.5 m) rise in sea level by 2100. Because the total twenty-first-century warming in the low scenario is in line with the Paris Agreement's goal of holding warming to less than 3.6°F (2°C) above preindustrial temperature levels, we use this scenario as a proxy for sea level rise under the Paris Agreement. This UCS analysis refers to projections made based on this scenario as "the low scenario."

Scientists have not assigned probabilities to these particular sea level rise scenarios. Rather, UCS encourages decision-makers to rely on the scenario that best reflects their tolerance for risk. Decisions made with a higher tolerance for risk, such as where to locate a high school soccer field, might draw on the intermediate sea level rise scenario. Decisions made with a low tolerance for risk, such as where to locate a hospital or other long-lived piece of critical infrastructure and what specifications should be used in its construction, might draw instead on the high sea level rise scenario (Parris et al. 2012). The low sea level rise scenario, by contrast, is less a future decision-makers should plan for than a future they should work toward by supporting and promoting emissions reductions.

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The low scenario assumes that heat-trapping emissions decline drastically, and is used as a proxy for expected sea level rise under the Paris Agreement.

8 *The accuracy of the projected inundation zone within leveed areas is only as good as the underlying data, and any errors concerning the elevation of levees could result in areas that would actually be protected showing up as inundated in this analysis. To mitigate this effect, we exclude federal leveed areas when calculating the percentage of each community that will fall within chronic inundation zones. Therefore, any stated percentage of usable land in a community that is inundated excludes areas currently protected by federal levees. Areas protected by locally maintained levees, of which there are many in Louisiana, were largely well reflected in the underlying data and remained in the area calculations. This analysis also does not include the possibility of levee failure, although the combination of sea level rise and extreme weather events can place strains on existing levees.*

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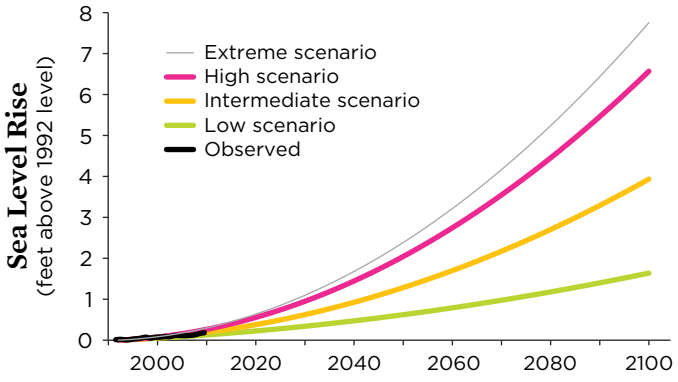
FIGURE 3. Projected Twenty-First-Century Sea Level Rise



How much sea level rises this century depends on our past and future emissions of heat-trapping gases as well as how Earth responds to those emissions. We based projections for sea level rise on the Intermediate-Low, Intermediate-High, and Highest scenarios from the Third National Climate Assessment; we refer to our projections as the low, intermediate, and high scenarios respectively (Parris et al. 2012). The latest suite of scenarios developed for the upcoming Fourth National Climate Assessment includes an "Extreme" scenario that reflects a growing consensus around the possibility of major Antarctic melting this century (Sweet et al. 2017; DeConto and Pollard 2016). We did not analyze the extreme scenario.

Sea Level Rise and Chronic Inundation Meet Social Inequities

Fouche Sheppard is a well-known resident of Charleston, South Carolina, a Gullah poet and storyteller, and a longtime advocate for youth and seniors. She also worked as an administrative assistant at a medical office—until she was fired. The reason: her supervisor was upset she could not come to work. The reason she could not come to work: flooding.

Sheppard says the streets that would have taken her downtown were blocked by what people in Charleston call "nuisance flooding," caused by rain at high tide or even under sunny skies at the highest tides.

"I said to my supervisor, 'You're firing me because you're lucky enough to live in one part of town and I live in another?'" Sheppard recounts. "I'm worried that if this keeps up, it's going to affect a lot of people just trying to get by," she says. "How many people are going to lose their jobs when they can't get to work because their car has been destroyed by flooding?"

Low-income communities face significant social and economic challenges that put them at a disadvantage when faced with natural disasters and other stressors (Deas et al. 2017). The slow-onset stress caused by chronic inundation is yet another such challenge. Many Americans of color—African Americans, Latinos, Native Americans, and others—live in low-income communities. Centuries of structural racism and disenfranchisement have left these communities lacking the resources and services that help cities and towns prepare for impending disasters and recover when disaster strikes (Melillo, Richmond, and Yohe 2014; Friend and Moench 2013; Fothergill and Peek 2004).

For example, Annapolis is a middle-class community that is investing in flood mitigation measures and adaptation plans as sea levels rise. The city's leadership has met regularly to discuss flood preparedness for many years and has petitioned for and received grants for its efforts. Annapolis is also aided by the presence of the US Naval Academy, which funds seawall repair and other preventative construction. By contrast, nearly 60 miles away across the Chesapeake Bay, the city of Cambridge, Maryland, has not yet developed a master plan to assist its predominantly African American residents, or the quarter of its population who live below poverty levels, in responding to sea level rise. The city did secure a grant to begin planning the repair of its crumbling seawalls—but only in 2017.

Climate change is known to pose risks to low-income communities, communities of color, and other traditionally underserved communities—risks more severe than those faced by wealthier, often whiter communities, especially in urban settings (Deas et al. 2017; Graham, Debucquoy, and Anguelovski 2016). This analysis shows that many communities that face chronic inundation may do so without the resources or capacity to respond.

To identify communities with fewer resources for planning and adaptation, UCS used the Social Vulnerability Index, or SoVI (Cutter, Boruff, and Shirley 2003), one of several published and widely used quantifiers of socioeconomic vunerability. This index is based on 29 economic and demographic variables obtained through the US Census at the tract level. These variables include income; poverty; percentages of black or African American, Hispanic, and Native American residents; education level; and age. This analysis uses SoVI to identify communities that are socioeconomically vulnerable

> *"How many people are going to lose their jobs when they can't get to work because their car has been destroyed by flooding?"*
>
> — Fouche Sheppard, advocate, Charleston, South Carolina

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Coco Robicheaux/Alamy Stock Photo

Long-standing inequities leave some communities, however resourceful, with less to invest and fewer options for responding to flooding. In Isle de Jean Charles, LA, 2008, a man salvages furniture in the wake of a major storm.

today and also identifies areas that will be exposed to chronic inundation 20 or fewer years from now.[9] Sometimes these areas overlap, flagging more acute risk. Sometimes the tract with high socioeconomic vulnerability is inland and out of reach of chronic inundation. Even when not exposed to chronic inundation, however, underserved areas may be at risk of coastal gentrification, as is reported in some communities in Southeast Florida (Ariza 2017).

By using SoVI to identify vulnerable localities, this analysis brings attention to the fact that these communities will need more resources and more capacity in order to prepare for the impacts of sea level rise. Fair solutions will be those that include considerations of socioeconomic vulnerability and are implemented equitably across communities (ICJN 002).

Low-income communities face significant social and economic challenges that put them at a disadvantage when faced with natural disasters and other stressors.

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9 *Because demographics change over time and future geographic patterns of socioeconomic vulnerability are uncertain, this analysis limits consideration of the exposure of socioeconomically vulnerable communities to this near-term timeframe.*

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Chronic Inundation Today

Some communities are already grappling with flooding that is frequent and disruptive enough to affect ordinary patterns of daily life. Along the Texas Coast, tidal flooding frequently inundates neighborhoods and overtops the road connecting the Bolivar Peninsula to the mainland, which turns the peninsula into an island. Emergency responders there report finding roads impassable due to floodwaters. And peninsula residents and small business owners, such as Lee Chambers, owner of the Blue Water Bait Shop in the town of Crystal Beach, report frequent shop closures and a loss of customers when high tides flood streets and parking lots. Elsewhere, in parts of Jamaica Bay, New York; Norfolk, Virginia; and Miami, Florida; tidal flooding has changed the behavior of residents, who now share flood advisories and park their cars on streets beyond the reach of high tide.

> *"There are a few days when we are actually an island. The engineers threw down some concrete barriers alongside the road to keep the water out. The water has knocked them sideways. It's a false sense of hope."*
>
> — Matt Summers, firefighter, Bolivar, Texas

Today's Chronically Inundated Places: Where Sinking Land Meets Rising Seas

This analysis classifies about 90 communities as chronically inundated today. Nearly 80 percent of these communities are located in Louisiana and along Maryland's Eastern Shore—regions that are well-documented sea level rise hotspots due to land subsidence, low land elevations, and, in Maryland's case, regional currents (NOAA 2017; Ezer et al. 2013; Milliken, Anderson, and Rodriguez 2008).

Locals and experts in these and the additional states confirm the level of chronic inundation this analysis identified in most cases (see methodology at *www.ucsusa.org/RisingSeasHitHome*). However, recent investments in protective measures such as bulkheads or pump systems can make a substantial difference to community-level flood severity, as seen, for example, in West Wildwood, New Jersey. Upgrades to bulkheads made there in 2016 substantially reduced the extent and frequency of flooding the community experiences (Ridings 2017; Miller 2016).

Additionally, today's chronically inundated communities tend to be rural, often isolated places, with small populations and large open spaces that are often agricultural, recreation, or conservation areas. Such places attract little attention when they flood compared to bigger cities, but in these places, chronic inundation has arrived. And residents are responding.

Realities and Responses of Chronically Inundated Communities

In Louisiana, many communities within coastal parishes (58 in total, plus New Orleans, for two-thirds of the 91 chronically inundated communities nationwide, today) exceed our flooding threshold. "Down here, people are actively dealing with

climate change without calling it climate change," says Tim Osborn, the central Gulf Coast regional manager for the National Oceanic and Atmospheric Administration (NOAA).

Many of these parishes include leveed areas, which were excluded from our flooding threshold calculations. The non-leveed areas on Louisiana's rapidly changing coast, however, can experience frequent and disruptive flooding. Often aided by winds from the south, high tide in Terrebonne Parish now sends water seeping into yards in Pointe-Aux-Chenes and causes residents to navigate their neighborhood by boat rather than risk driving on flooded roads (Dardar 2017). Terrebonne is one of several parishes that have been contending with and adapting to these conditions for several decades. Windell Curole, general manager of the South Lafourche Levee District in the Lafourche Parish bayou, an hour and a half from New Orleans, says his district relies on levees as high as 18 ft in places to stay dry (Curole 2017): "We are building the levee as high as we can afford right now. How far into the future? I don't know. Can't guarantee that we won't have to raise it some more, or that it will get too expensive to raise and that we'll finally have to move out."

The combination of flooding and land loss is driving people from their homes.

In one of today's chronically inundated Louisiana communities, the combination of flooding and land loss is driving people from their homes. The bayou community of Isle de Jean Charles

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baldeagleblluff/Creative Commons (Flickr)

Holland Island, in the Chesapeake Bay, is an early victim of rising seas and sinking land. Pictured here in 2009, the last remaining house on Holland Island collapsed in 2010.

already faces such frequent, disruptive flooding that its residents, most of whom belong to the Biloxi-Chitimacha-Choctaw Native American band, have asked for and received government assistance to relocate; they are among the first Americans to receive federal climate resettlement assistance (Isle de Jean Charles n.d.; Maldonado et al. 2013). The broader county subdivision that encompasses Isle de Jean Charles, which includes the towns of Montegut and Bayou Barre, experiences flooding of 10 to 15 percent of its land every other week on average.

Along Maryland's Eastern Shore, as in Louisiana, the gradual onset of chronic inundation is already prompting changes to daily life—some of them transformative. On Smith Island, about 15 percent of the land area is already chronically inundated. Farmers along the coast of Somerset County, where Smith Island is located, are experiencing land loss due to erosion and decreases in productivity as salinity levels in the water table rise (Erwin et al. 2010; Maryland DNR 2008). Roads are flooding more frequently as sea level rise enables high tide to reach further inland (MDNR 2008).

While the tolerance for flooding may be high in locations such as Smith Island, tipping points exist here, too. The island has lost about one-third of its land area since 1850 and more than one-third of its population since 2010. It has seen so many young people leave the island that the primary school now has just nine students total in kindergarten through seventh grade (TownCharts 2017; Wheeler 2015; Erwin et al. 2010). There are two major shoreline protection projects underway to shield the island's remaining population of just 180, including a $2.4 million shoreline stabilization project at Rhodes Point (Holland 2016a; Holland 2016b).

Less than 20 miles northeast of Smith Island, the small rural community of Dames Quarter on Deal Island, Maryland, is also dealing with chronic inundation. With about 15 percent of its land flooding on average twice monthly, Deal Islanders, who number fewer than 200, have been working with researchers from the University of Maryland to reduce their exposure to sea level rise and enhance their community's resilience to frequent flooding (DIPP 2017).

A Wide Range in What Communities Will Tolerate

The negative effects of chronic inundation, and how much flooding people can tolerate, vary widely today. They will also vary in the future depending largely on how a community currently uses the land in question and how disruptive it will be to change that usage.

In some of today's chronically inundated communities, substantially more than 10 percent of their land area can and does flood regularly, though often with minor consequences compared to more populous locations. For example, several communities in Hyde County, North Carolina, experience chronic inundation of more than 40 percent of their land. Despite roughly 80 percent of the county's land consisting of preserved open space crisscrossed by an extensive drainage network, communities such as Englehard are challenged by tidal flooding that threatens their croplands and aquifers and inundates roads for weeks at a time (Hardison 2017; Hyde County 2008). With assistance from the Federal Emergency Management Agency (FEMA), the county is investing in elevating several properties that floods have damaged multiple times (Hyde County 2016).

In other communities, regular flooding of far less than 10 percent of their land area would drive major changes. For example, frequent tidal flooding in Annapolis significantly disrupts business and tourism in the city's vibrant waterfront district. Less than 10 percent of Annapolis's area floods frequently today, but the area that does flood is highly important to the city. Even though our analysis does not identify Annapolis as a chronically inundated community today, the city has already begun to invest in addressing the growing costs and negative effects of flooding (City of Annapolis 2011). Likewise, less than 10 percent of Miami Beach falls within the chronic inundation zone today, yet frequent flooding there has damaged local businesses and prompted a roughly $400 million investment in flood mitigation measures (Weiss 2016).

> *"Down here, people are actively dealing with climate change without calling it climate change."*
>
> — Tim Osborn, NOAA manager, central Gulf Coast

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Chronic Inundation to Come: When and Where?

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While most of the following results are presented in terms of the names, numbers, and percentages of chronically inundated cities and towns, the real costs and losses ahead are less quantifiable and more human.[10]

Under any sea level rise scenario, this inundation is expected to worsen. And a point will be reached when residents of many neighborhoods will have to think about living elsewhere as their lawns and yards and first floors become unusable, as their businesses remain shuttered and inaccessible, as land where generations of people have lived and died is overwhelmed by seawater.

What is the measure of loss for a city becoming chronically inundated? For locals, it could feel incalculable. How much would they be willing, or able, to invest to delay these losses? Most people wish to remain in the communities they love and to stay in the place they call home. What feasible, affordable options will be open to them? By first understanding when they can expect chronic inundation, such communities can begin to chart a way forward.

When chronic inundation claims cities and towns, the real costs are less quantifiable and more human.

The Next Communities to Face Chronic Inundation

In the intermediate and high scenarios, UCS finds that the following inundation would occur within the next 20 years, by 2035:

- Nearly 170 communities will face chronic inundation, compared to 90 today, in the intermediate scenario. In about 20 communities, mostly in Louisiana, the chronic inundation zone would encompass more than three-quarters of currently usable land.
- Roughly 180 communities will face chronic inundation in the high scenario, including more than 10 percent of the nation's oceanfront communities.
- In both scenarios, more than half of the affected communities are home to one or more socioeconomically vulnerable neighborhoods.

UCS analysis found about 90 US communities that already grapple with disruptive flooding today. (See chapter 3, p. 13.) The majority of these communities—the tip of the iceberg of chronic inundation—have two things in common: low land elevation and high rates of land subsidence. Within just the next 20 years, however, an additional 80 to 90 communities that do not necessarily share those characteristics will join their ranks.

The number of communities experiencing chronic inundation within 20 years nearly doubles to 170 or 180 in the intermediate and high scenarios, respectively (Figure 4, p. 18).

10 For the complete results, see the data tables available here: www.ucsusa.org/RisingSeasHitHome.

As Sea Level Rises, the Number of Communities Facing Chronic Inundation Grows

		Low Scenario		Intermediate Scenario				High Scenario						
% inundation	Present	2060	2100	2035	2060	2080	2100	2030	2045	2060	2070	2080	2090	2100
10–25%	44	63	112	64	103	133	195	75	109	132	165	208	226	240
25–50%	31	53	61	49	71	76	102	55	78	89	89	110	123	155
50–75%	12	42	58	37	50	74	59	30	44	71	69	71	81	76
>75%	4	25	59	17	48	82	133	18	34	68	104	134	170	197
Total	91	183	290	167	272	365	489	178	265	360	427	523	600	668

While this analysis uses the 10 percent threshold as a minimum for defining when a community becomes chronically inundated, the extent of the chronic inundation zone is much larger in many communities, particularly in the latter half of the century. The number of communities that will experience frequent, disruptive flooding of half or more of their land area more than doubles within 20 years if sea levels rise at a midrange pace.

In the intermediate scenario, the 70 or so communities that will be newly exposed to chronic inundation by 2035 are clustered in several regions: the Jersey Shore, the mainland side of North Carolina's Pamlico Sound, and, as today, southern Louisiana and the Eastern Shore of Maryland. Each of these regions is home to some communities already trying to cope with disruptive flooding, but midrange levels of projected sea level rise over the next 20 years will expand the reach of such flooding.

In New Jersey, two decades of sea level rise will bring chronic disruptive inundation to Seaside Park and 14 more towns along the Jersey Shore that today rarely feel the effects of tidal flooding. In North Carolina, the number of chronically inundated communities more than doubles in the intermediate scenario—from just six today to 13 by 2035—with small towns such as Columbia, Englehard, and Lowland in the Pamlico Sound region increasingly flooded. Similarly, while South Carolina's Lowcountry is no stranger to coastal flooding, the chronic inundation zone is projected to reach the famed golf courses of Kiawah Island and islands within the Gullah/Geechee Cultural Heritage Corridor, home to the Gullah people, within the next 20 years (US Climate Resilience Toolkit 2017; Bartelme 2016).

Only four of today's chronically inundated communities experience flooding of 75 percent or more of their land twice monthly (averaged over a year). Nearly 20 communities would experience such flooding by 2035, in both the intermediate and high scenarios (see the table). And about a third of chronically inundated communities in the 2030s would see half or more of their land become limited-use zones. In some of these places, the land in question is largely undeveloped. In other places, such as Moonachie, New Jersey, where chronic inundation with the high scenario is projected to cover about 55 percent of the town, seawater would make its way into densely populated neighborhoods and industrial zones.

Using SoVI as a measure of present-day socioeconomic vulnerability, UCS finds that more than half (55 percent) of the communities facing chronic inundation within the next 20 years are also home to one or more socioeconomically vulnerable neighborhoods or "tracts."[11] This is similar to the proportion of today's chronically inundated communities that contain socioeconomically vulnerable neighborhoods. The causes of socioeconomic vulnerability vary from region to region and community to community. The Eastern Shore of Maryland is home to a large elderly population on fixed incomes and a large African American population, two groups that have traditionally had fewer resources to cope with environmental disasters and change (Deas et al. 2017; Lane et al. 2013; Martinich et al. 2012; Mearns and Norton 2010). The towns within Terrebonne and St. Mary's parishes in Louisiana that face increasing chronic inundation are home to large African American and Native American populations. Here, education levels, which are correlated to natural disaster preparedness, are below the regional average for the Gulf Coast (Al-rousan, Rubenstein, and Wallace 2014). And in south Florida, low incomes and other demographic risks combine to create vulnerable pockets in the Florida Keys.

continued on page 20

11 *This analysis captures communities with census tracts with high SoVI scores anywhere within the chronically inundated community. Because gentrification can threaten socioeconomically vulnerable neighborhoods located inland, SoVI tracts need not be located directly on the coast or within chronically inundated zones.*

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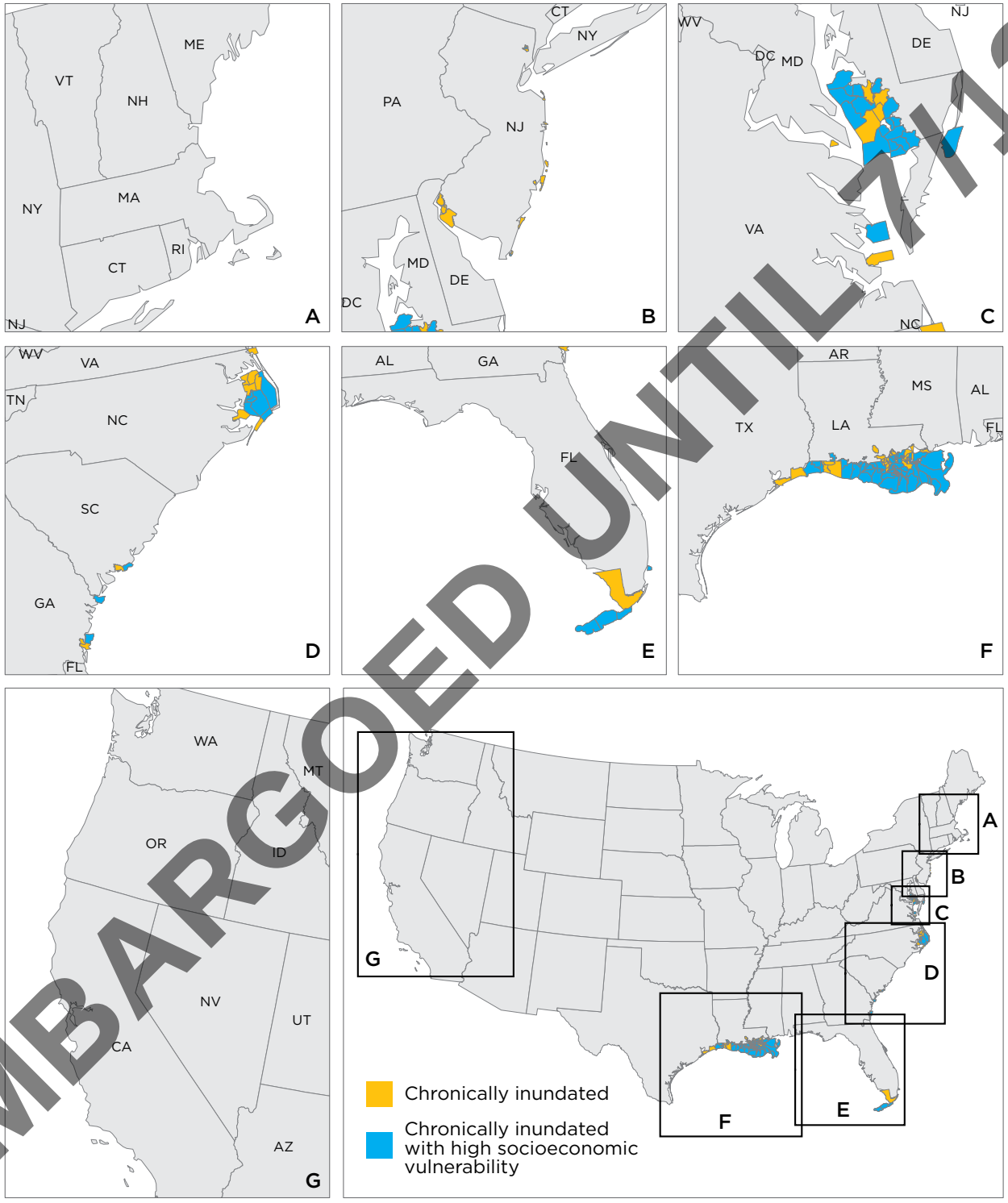
FIGURE 4. Chronically Inundated Communities in 2035, Intermediate Scenario



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Nearly 170 coastal communities, many clustered in the East and Gulf Coasts' lowest-lying regions, face chronic inundation within the next 20 years in the intermediate scenario. In these communities, 10 percent or more of usable land area would be inundated every other week on average. More than half of these communities are home to one or more socioeconomically vulnerable neighborhoods (blue).

BOX 2.

Chronic Inundation Snapshot: Crisfield, Maryland

UCS analysis projects that by 2035, between 20 and 25 communities in Maryland will be chronically inundated. About one-third of them could see half or more of their land area flooded 26 times per year or more often. To get a sense of this future flooding today, one need only visit the state's Eastern Shore.

About a dozen communities on the Eastern Shore, including the city of Crisfield in Somerset County, already cope with disruptive flooding and can provide a glimpse into the conditions and decisions that neighboring communities will face in 20 years' time.

The roughly 3,000 residents of Crisfield have a close connection to the water; the city's shellfishing industry earned it the nickname Seafood Capital of the World. In this region, where subsidence, low-lying topography, and changing ocean circulation patterns contribute to above-average rates of sea level rise, low-lying Crisfield is a hotspot of sea level rise. About 40 percent of Crisfield residents are African American (compared to about 13 percent nationally), and an above-average number of the city's residents are elderly, which can contribute to decreased population mobility when natural disasters hit (Kobell 2014).

Crisfield's residents are increasingly aware of the challenges they face (Cassie 2015). In the wake of Hurricane Sandy, the city's African American community was left behind as rebuilding efforts were directed to affluent downtown areas (Kobell 2015). And in the fall of 2015, Crisfield experienced tidal flooding, compounded by rainfall, that reached up to seven inches deep and put some sidewalks completely underwater. Residents report that flooding has become more frequent, and it typically takes about three days for floodwaters to subside (Mich 2015; Zheng 2015). That same year, in response to this kind of flooding, the Crisfield Housing Authority began assessing the feasibility of moving its 330 subsidized affordable housing units away from the flood zone (Somerset County 2015).

Whereas disruptive flooding affects just 10 percent of Crisfield today, it is projected to affect more than half of the town within the next 20 years (Figure 5). The time tidal floodwaters take to recede will grow longer as the chronic inundation zone becomes more extensive. Having relatively few resources to cope with chronic inundation, Crisfield residents are on the front lines of the country's growing struggle with rising seas.

FIGURE 5. Chronic Inundation in Crisfield, Maryland

The Daily Times/Delmarvanow.com

CRISFIELD, MARYLAND, SEPTEMBER 2016

Present day water

Chronic inundation zone in 2035, high scenario

As sea levels rise and local land subsides, the chronic inundation zone is projected to affect more than half of Crisfield's habitable land area within the next 20 years. By 2035, land that has hosted the town's economically important seafood industry will be subject to frequent, disruptive flooding, as will churches, shops, and homes.

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Ted Blanco/Climate Central

For residents of this Atlantic City neighborhood, tidal flooding is a familiar problem, and the right onshore breeze or rainfall can makes matters worse.

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Midcentury Inundation Hotspots

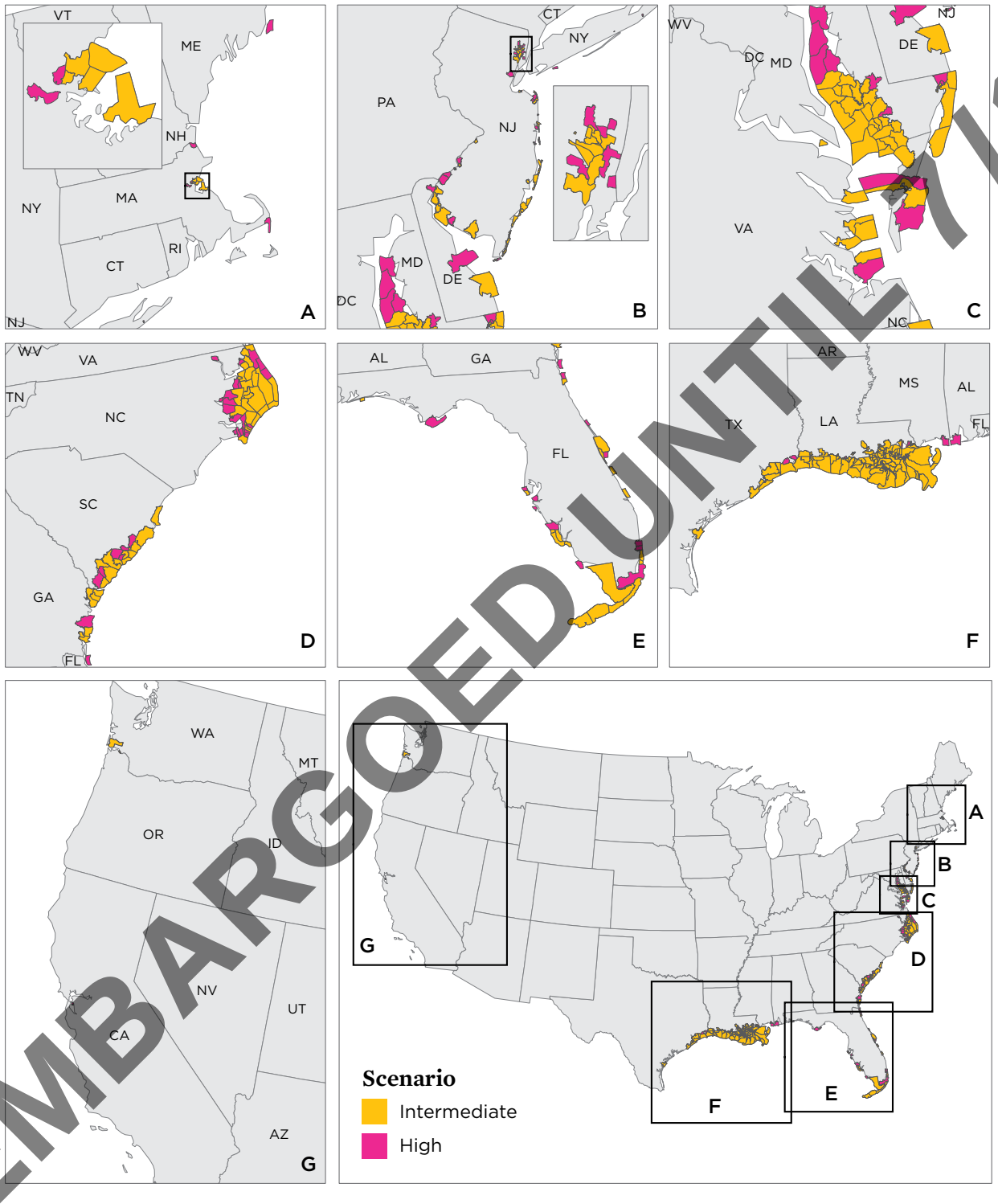
UCS finds that by the year 2060, sea level rise creates chronic inundation clusters in new regions and, in existing regions, shifts extensive areas of land into limited-use zones:

- Many previously unaffected stretches of our coasts will begin to grapple with chronic inundation.
- In the intermediate scenario, more than 270 communities will face chronic inundation.
- In the high scenario, 360 communities would experience chronic inundation in the absence of major investments in defensive measures; this includes about one-third of the oceanfront communities along the East and Gulf Coasts.
- In both scenarios, half or more of currently usable land would become limited-use zones in nearly 40 percent of chronically inundated communities.

Whereas communities projected to experience chronic inundation in the 2030s tend to be already familiar with tidal flooding or adjacent to such places today, entirely new stretches of coastline become exposed by 2060 in both the intermediate and high scenarios (Figure 6, and Figure 7, p. 22). In the greater Boston, Massachusetts, area, for example, five communities, and about 15 percent of the town of Revere, will face inundation every other week on average in the intermediate scenario; none of these communities experience extensive flooding today. Additional communities in northern New Jersey and along the Atlantic coast of the Delmarva Peninsula—including Ocean City, Maryland—also face chronic inundation by 2060.

> ***Entirely new stretches of coastline become exposed by 2060 in both the intermediate and high scenarios.***

FIGURE 6. Chronically Inundated Communities in 2060



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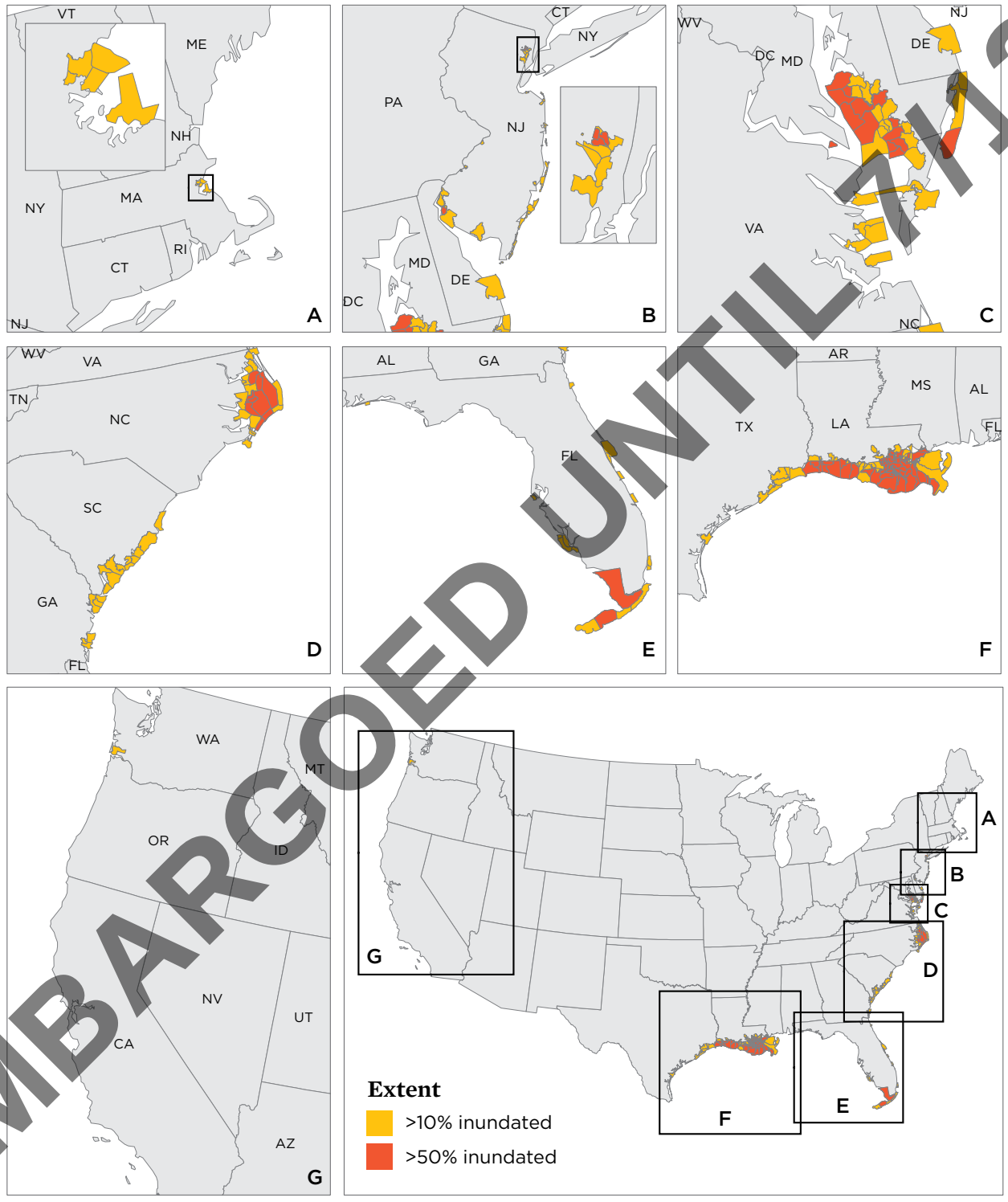
More than 270 communities face chronic inundation in the intermediate scenario by 2060 (yellow). In the high scenario, nearly 90 additional communities (pink)—for a total of 360—are also chronically inundated. In this timeframe, communities that today experience little to no tidal flooding come to experience it on a chronic basis.

FIGURE 7. Extent of Chronic Inundation in Communities, 2060, Intermediate Scenario



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About 100 of the roughly 270 communities facing chronic inundation in 2060 in the intermediate scenario would experience extensive flooding of half or more of their area (orange).

Outside of Louisiana, just a few Gulf Coast communities are projected to face disruptive flooding before 2060. But by 2060, six new communities along the northern coast of Texas and six along Florida's Gulf Coast would be chronically inundated in the intermediate scenario.

By 2060, the chronic inundation zones in affected communities will also be more extensive than they are today: about 100 communities would experience disruptive flooding of more than half their land in the intermediate scenario (Figure 8). On Big Pine Key, Florida, for example, which already experiences disruptive flooding today, the chronic inundation zone would expand so that most of the island would regularly flood. The ability of defensive measures to hold back chronic flooding on this scale is unclear.

At the same time, some of the country's biggest metropolitan areas would experience growing chronic inundation zones that, while below the 10 percent-of-area threshold, can cause major disruption in urban settings. Consider the negative effects of twice-monthly flooding of about 5 percent of Newark, New Jersey; Norfolk; or Miami. In many of the nation's big coastal cities, chronic flooding would have major economic costs long before those places reach the definition for chronically inundated community used here.

By 2060, differences between the intermediate scenario and the high scenario widen substantially. The high scenario shows nearly 90 more communities exposed to chronic inundation by 2060 than does the intermediate scenario, and the high scenario also shows additional land being exposed to chronic inundation within those communities. Fifty of these 90 communities are concentrated in just three states: Florida (14 communities), New Jersey (18 communities), and North Carolina (18 communities). Additional clusters of communities face chronic inundation in 2060 in the high scenario but would be unaffected given the intermediate scenario's slower rate of sea level rise. These include communities in greater Boston, the areas surrounding Charleston, and the San Francisco Bay Area, California. In Charleston proper, more than a quarter of the city's area—including entire neighborhoods, a hospital, and part of the city's historic market—would be chronically inundated in 2060 in the high scenario.

These differences speak to the human consequences of unabated climate change. Left unchecked, sea level rise will shorten the amount of time communities have to adapt to chronic inundation and will affect a greater number of—and a greater area within—coastal communities.

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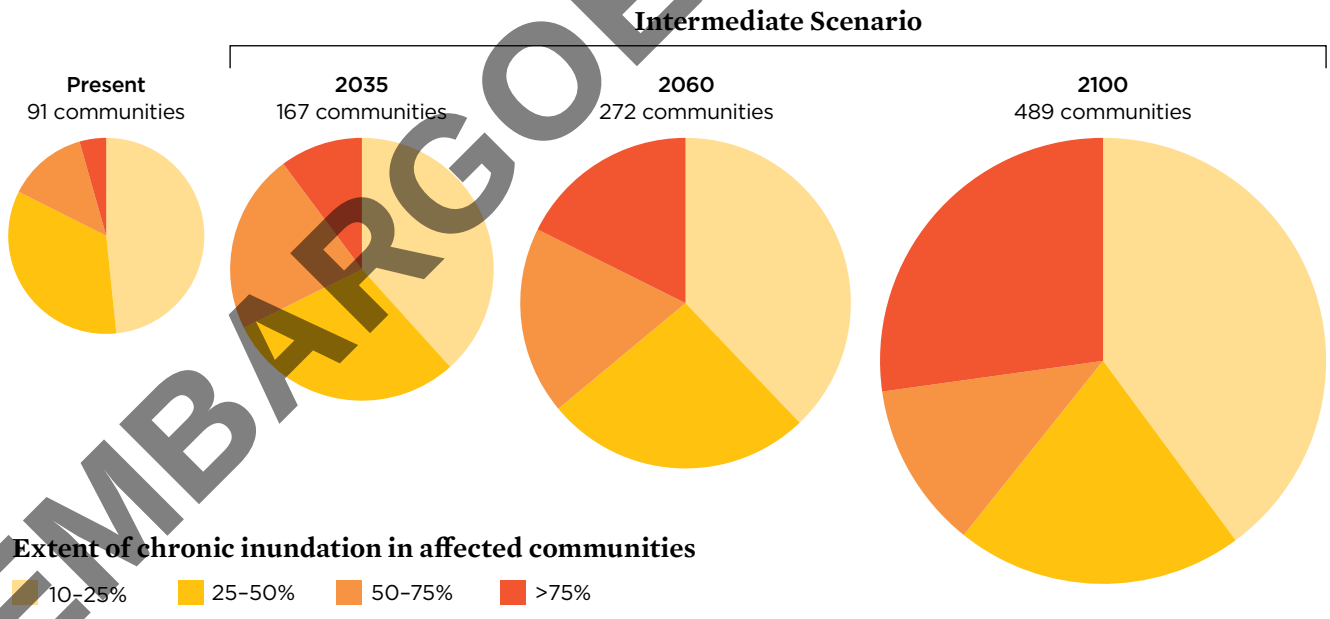
FIGURE 8. Increasing Extent of Chronic Inundation



As sea level rises, the number of communities facing chronic inundation grows, as indicated here by the area of each circle. The extent of inundation within those affected communities grows as well. Of the 91 communities grappling with chronic inundation today, only four experience frequent, disruptive flooding of 75 percent or more of their land area (darkest orange wedge). In the intermediate scenario, 489 communities face chronic inundation by 2100, and more than 130 of them will see 75 percent or more of their land flooded twice per month, on average.

BOX 3.

Chronic Inundation Snapshot: Sanibel and Captiva Islands, Florida

Among the Gulf Coast communities facing chronic inundation in 2060 are Sanibel and Captiva Islands, barrier islands located off the coast of Cape Coral in Lee County, Florida. With large wildlife refuges and long shelling beaches, Sanibel and Captiva Islands have long been havens for people and wildlife alike. Wildlife refuges occupy more than half of Sanibel Island.

Tourism is the primary economic driver for the thousands of people who live year-round on Sanibel and Captiva Islands. The county receives about 5 million visitors each year, and tourism generates about $3 billion each year (Beever and Walker 2013) and employs one of every five people in the county. The geographical configuration of Sanibel's beaches in particular makes for excellent shell collecting; visitors from around the world hunch over looking for rare shells in what locals call the "Sanibel stoop."

However, chronic inundation puts these shelly beaches in danger of being lost. Not only beachfront land, but also the tidal flats and hardwood swamps that characterize the islands' wildlife refuges and provide natural protection from hurricanes will be seriously affected as sea level rises: some estimates suggest that nearly all of the tidal flats and about 60 percent of the hardwood swamps could be inundated due to sea level rise this century (Lowenstein 2015; Morris and Walls 2009; Titus et al. 2009;). Indeed, this analysis finds that while the chronic inundation zone encompasses less than 10 percent of the area of these islands today, the size of the zone jumps by 2060 to about 20 percent in the intermediate scenario and nearly 50 percent in the high scenario (Figure 9). These changes could depress the local tourism industry, render people's homes and businesses unlivable and unusable, and cause economic fallout throughout the region.

While a decline in tourism and the loss of a fragile and crucial ecosystem are daunting prospects, Sanibel, Captiva, and their island neighbors have several decades to respond to these threats and prepare for anticipated changes.

FIGURE 9. Chronic Inundation in Sanibel and Captiva Islands, Florida

Vivid Aerial Media

SANIBEL ISLAND

Present day water

Chronic inundation in 2060, intermediate scenario

By 2060, about one-fifth of Sanibel and Captiva Islands' usable land area is chronically inundated in the intermediate scenario (shown here), and nearly half is inundated in the high scenario. This inundation could affect access to the islands' popular tourist destinations and, in the high scenario, cut off entire neighborhoods from the islands' main roads.

Thanks for the catch, Kristy. I'd inadvertently left a white stroke on the flood layer in this one. Now corrected.

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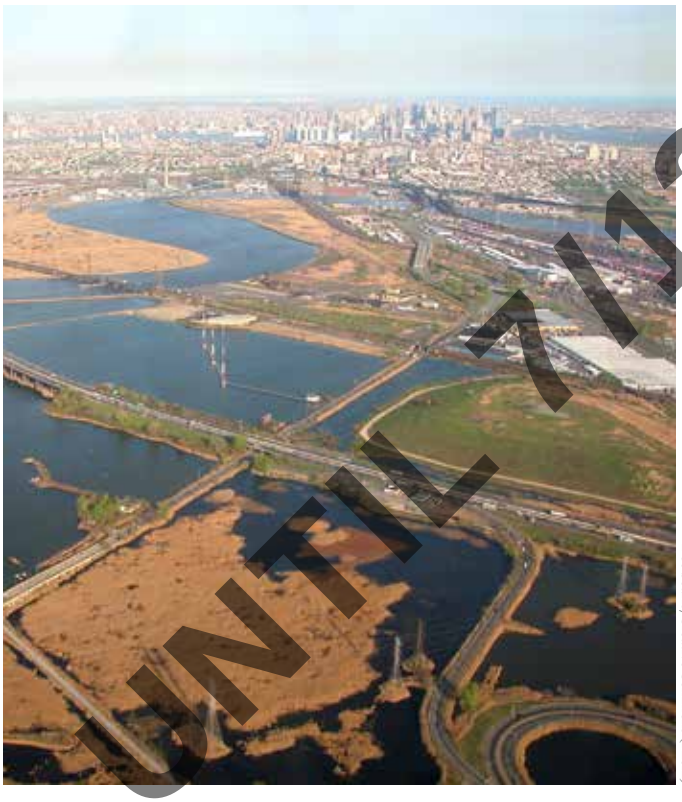
2100: Inundation Nation

UCS analysis finds that by the end of the century, in the absence of a coordinated, advance response, many communities along the US coasts face unprecedented challenges:

- By 2100 in the intermediate scenario, nearly 490 communities will face chronic inundation, including more than 40 percent of all oceanfront communities on the East and Gulf Coasts.[12]
- In the high scenario, about 670 communities will face chronic inundation, including nearly 60 percent of all oceanfront communities on the East and Gulf Coasts.
- In both scenarios, nearly 30 percent of affected communities will see three-quarters or more of their presently usable land area become limited-use, chronic inundation zones.
- In the high scenario, more than 50 major cities will experience chronic inundation, including Boston, Newark, Fort Lauderdale, Oakland, and four boroughs of New York City.

From greater Boston to the tip of Key West, Florida, and from the Everglades in Florida to Corpus Christi, Texas, vast stretches of US coasts will be host to chronically inundated communities by 2100 in both the intermediate and the high scenarios.

Nearly 490 communities nationwide—including about 40 percent of all oceanfront communities on the East and Gulf Coasts—would experience chronic inundation in the intermediate scenario. Affected areas include nearly all of the coastal communities in New Jersey, Maryland, northern North Carolina, South Carolina, Georgia, Louisiana, and northern Texas. Whereas only small, isolated communities on the West Coast face substantial inundation earlier in the century due both to the slower rate of sea level rise and to higher average elevation along the West Coast than along the East and Gulf Coasts, the large communities of San Mateo in the San Francisco Bay Area and North Coast, home to Huntington Beach in the greater Los Angeles region join the ranks of the chronically inundated by 2100. Indeed, 29 of the communities affected by 2100 in the intermediate scenario are metropolitan areas of more than 100,000 residents, including Boston, Newark, and St. Petersburg. Chronic inundation will not be confined to city limits; it will affect many surrounding towns as well, compounding the challenge of building resilience to climate change in ways that ensure the livability of broader metropolitan regions. (Tomkins and Cogswell 2016; Vogel et al. 2016).



Doc Searls/Creative Commons (Flickr)

The low-lying Meadowlands of New Jersey and neighboring New York City remind us that we constructed many major cities on low-lying, often filled land at the mouths of rivers, and how exposed those places are to chronic floods.

The differences between the intermediate and high 2100 scenarios are again striking (Figure 10, p. 26). In the high scenario, roughly 180 more communities face chronic inundation than in the intermediate scenario. Three-quarters of these additional communities are located in eight states: Florida, Louisiana, Maryland, Massachusetts, New Jersey, New York, North Carolina, and Virginia. Each of these states has 10 or more communities that would be chronically inundated by 2100 in the high scenario but spared in the intermediate scenario.

In the high scenario, 668 communities—including nearly 60 percent of all East and Gulf Coast oceanfront communities—will face chronic inundation. Among these communities are more than 50 metropolitan areas, including four of the five boroughs of New York City; New Haven and Bridgeport, Connecticut; Elizabeth, New Jersey; Oakland; and San Mateo. The economic, cultural, and social consequences of losing more than 10 percent of currently usable land in Staten Island, Queens, Brooklyn, and Manhattan alone would reverberate worldwide, and flooding in the other cities would have similar ramifications.

12 *In this analysis, oceanfront communities represent a subset of all coastal communities. Some communities facing chronic inundation today and in the future are not immediately along the shore, but are ultimately connected to the ocean via rivers and inland waterways.*

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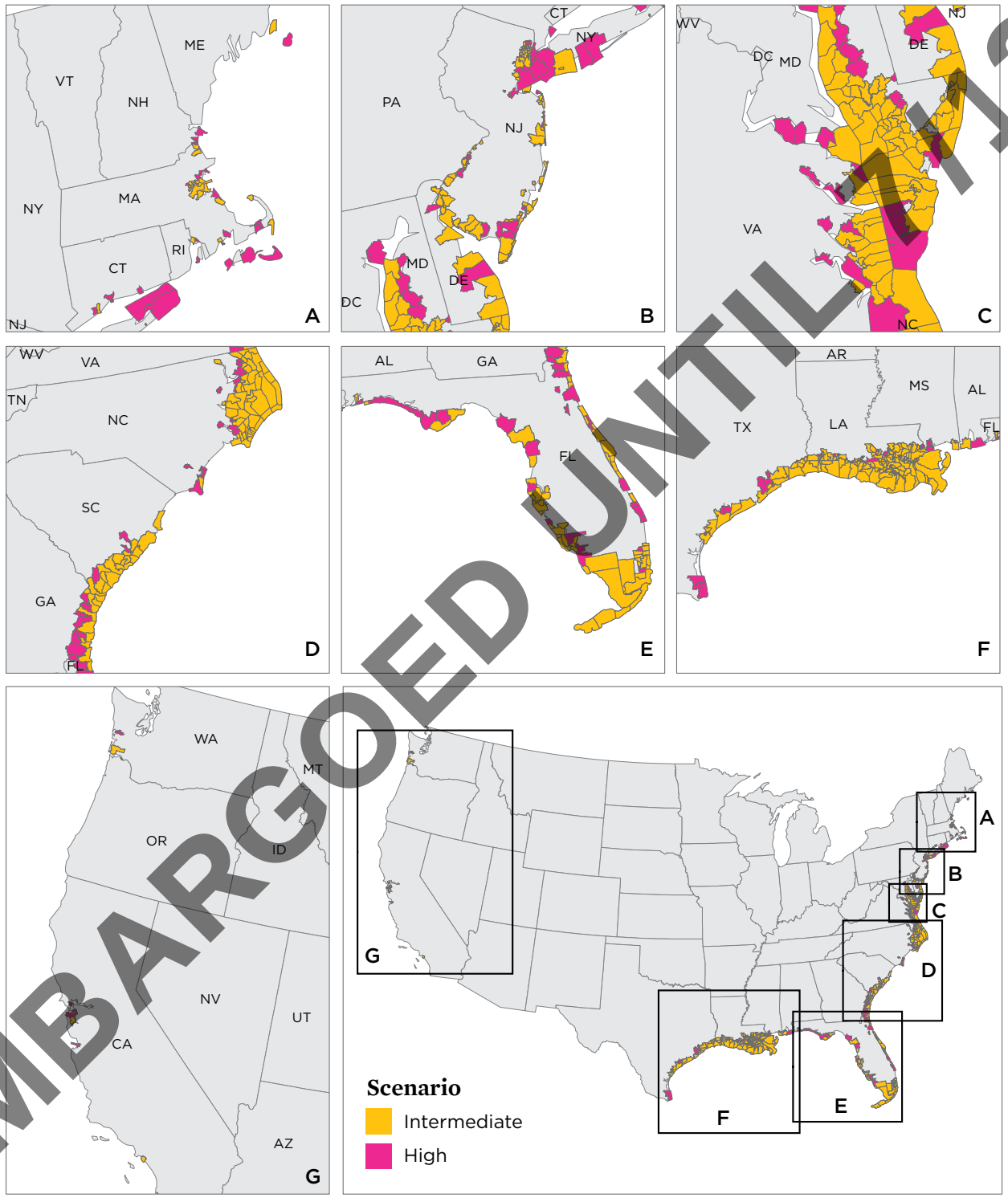
FIGURE 10. Chronically Inundated Communities in 2100



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By the end of the century, 489 communities face chronic inundation in the intermediate scenario (yellow). In the high scenario, an additional 179 communities (pink)—for a total of 668—are also chronically inundated.

Mike Filippoff

Later this century, chronic inundation is poised to become a major problem for many big cities. But even today, along their shores, San Francisco (shown here in 2012, Boston, Miami, and others are seeing previews of the future daily high tide line.

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BOX 4.

Chronic Inundation Snapshot: Great US Cities

Whereas many of the communities facing disruptive flooding in the near term are relatively small towns, home to fewer than 100,000 people, flooding becomes a big-city problem over the course of this century in both the intermediate and high scenarios (Figure 11, p. 28). These big cities include some, such as Boston and New York, that have historically invested heavily in expanding their land area by filling in wetlands and building protective structures along their shorelines (City of Boston n.d.; City of New York 2014.; New York State 2016). In the high scenario, more than 50 cities with populations over 100,000 would experience disruptive flooding and the difficult decisions that go along with it by 2100. These cities stretch from coast to coast and include the following:

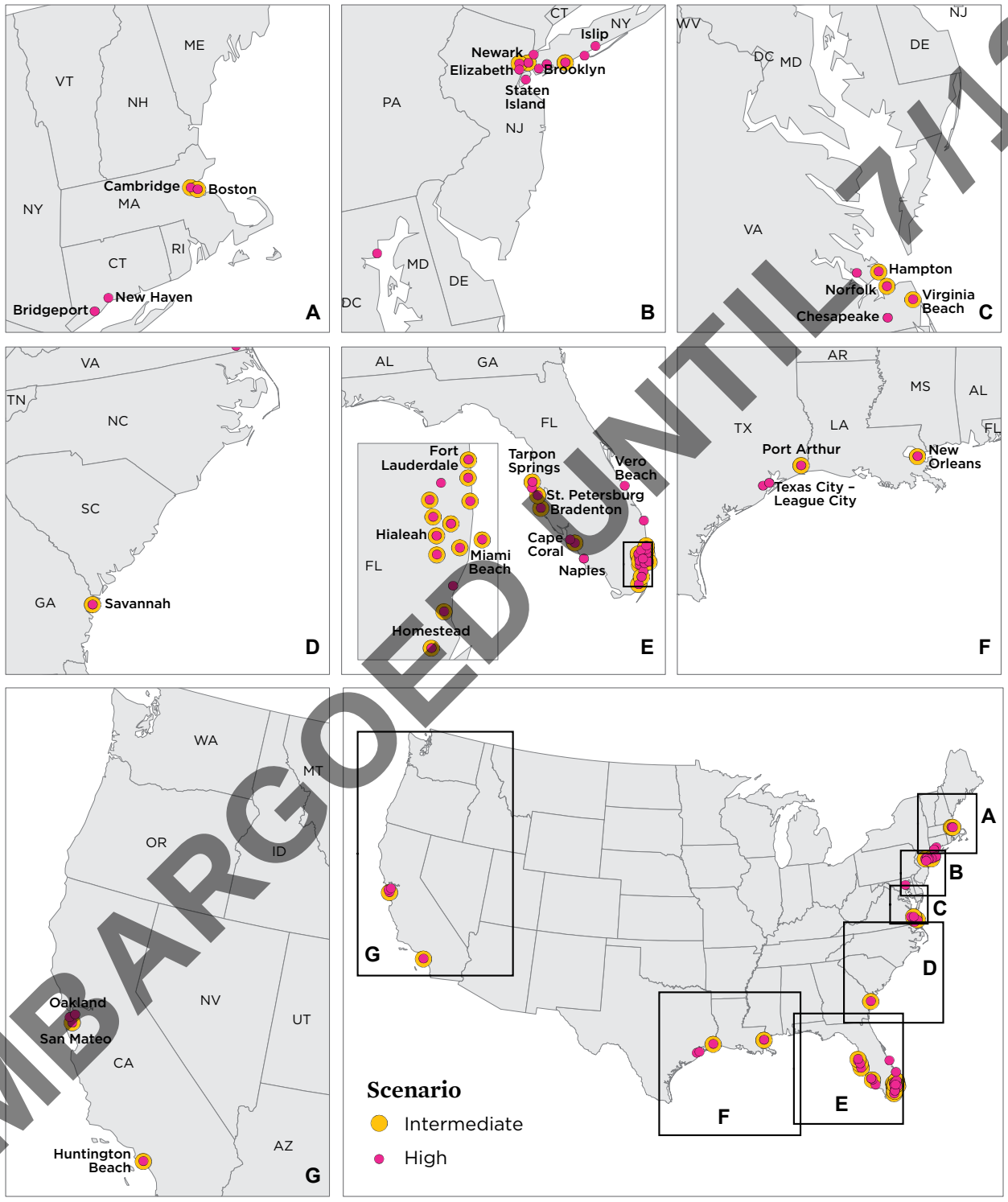
- San Mateo
- Newark
- All the boroughs of New York City except the Bronx
- Port Arthur, Texas
- Miami, Fort Lauderdale, Fort Meyers, and St. Petersburg—and 12 other Florida cities

Today, New Orleans is the only major city where the chronic inundation zone encompasses more than 10 percent of its area.[13] But by 2100 in the high scenario, the chronic inundation zones in Boston, Alameda, and many other cities extend to nearly one-quarter or more of the cities' areas.

The prospect of managed retreat from parts of the coastlines of 50 major cities or of investing significant capital to defend those waterfronts is daunting. The challenges, costs, and inevitable losses involved in holding back the water in 50 large population centers and/or relocating thousands if not millions of their residents would be immense. The low scenario—a proxy for adherence to the Paris Agreement's goal that future warming is held to 2°C or less above preindustrial values—shows nearly all these major metropolitan areas spared chronic inundation this century. This contrast may put the comparative bargain of emissions reduction in perspective (NASEM 2016).

13 *Note that the technical city limits of New Orleans extend far to the northeast of the city. While most of New Orleans proper is protected by levees (and therefore excluded from our calculations of area inundated), the northeastern corner of the broader city region is not. It is the inundation of this low-lying area, unprotected by levees, that causes more than 10 percent of the city to fall within the chronic inundation zone today.*

FIGURE 11. Major Cities Face Chronic Inundation



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By the end of the century, 29 cities with populations above 100,000 face chronic inundation with the intermediate scenario (yellow). With the high scenario, an additional 23 cities (pink)—for a total of 52—are also chronically inundated.

Chronic Inundation Creates Hard Choices

The trajectory of sea level rise effects that face many communities begins with infrequent tidal flooding and progresses to permanent inundation. Chronic inundation is a consequential interim stage of this process. Whatever a community's unique tolerance for flooding, it is at this stage that community members must move beyond standard coping measures and toward hard choices, such as investment in defensive or accommodating measures or even retreat.

While the consequences of chronic inundation in coastal communities will vary depending on what is being flooded and how severe that flooding is, the communities that are already facing flooding today can provide a glimpse of the challenges ahead. This section explores what life could be like in tomorrow's chronically inundated communities and some of the choices that have been made in today's flooded communities.

CHRONICALLY INUNDATED NEIGHBORHOODS

For centuries, Americans have lived and vacationed along our coasts. On Long Island, New York, densely packed neighborhoods run right up to the water. In the small village of Chinook, Washington, near the larger town of Naselle, houses nestle along quiet streets between a small port and the mountains to the east. And in many dozens of Florida beach towns, tourists flock to beachfront condos, bungalows, and cottages. Chronic inundation resulting from sea level rise could make it difficult—if not impossible—to live in these communities that many now call home.

By the end of the century in the intermediate scenario, Chinook would become an island every other week and about one-third of its homes would flood. By the end of the century in the high scenario, Long Island's south shore, including towns such as Lindenhurst, Freeport, and Seaford, would see the same broad areas flooded by storm surge from Hurricane Sandy in 2012 flood twice per month, albeit without the destructive wave action of the storm (see Figure 12, p. 30).

When neighborhoods flood this often and this extensively, residents face painful choices: Remain? Invest in flood protections? Sell and relocate? And while these are hard choices, many low-income residents have fewer choices, or none at all (Kuhl et al. 2014).

In the Larchmont neighborhood of Norfolk, which experiences regular flooding at high tide, homes and streets are being raised, and real estate trends reflect the loss of appeal of living along the waterfront (Jarvis 2017). Individual residents, the city of Norfolk, and the federal government by way of the National Flood Insurance Program have funded measures to keep people in their homes and in their neighborhood (Applegate 2014).

> ***Communities that are already facing flooding today can provide a glimpse of the challenges ahead.***

In other cases, money cannot buy protection. In Isle de Jean Charles, for example, the island's area shrank so rapidly and flooding became so disruptive that residents decided to relocate as a community to higher, drier ground. And on a larger scale, the geology of much of southern Florida allows saltwater to rise through the ground, making investment in defensive measures ultimately ineffective (FOCC 2010).

When individuals choose to leave their homes because of flooding, they leave behind both an asset—a home—and a community. In turn, the community is changed by those departures. The dwindling communities on Smith and Tangier Islands in the Chesapeake Bay are a testament to the loss of ways of life that have been shared for generations (Gertner 2016). And it is not just the communities left behind that are changed: the communities that absorb families leaving the coast will need to adjust to a new normal as well. Recent research suggests that migration away from the coasts in response to sea level rise could significantly redistribute the population of the United States (Hauer 2017).

Rosanna Arias/FEMA

In the wake of a storm, some homeowner's hands can be forced and neighborhoods can be transformed as people choose not to, or are unable to rebuild. Here, a Staten Island home is demolished after Hurricane Sandy. Chronic flooding will work more slowly, but, in the absence of advance planning, can drive similar outcomes.

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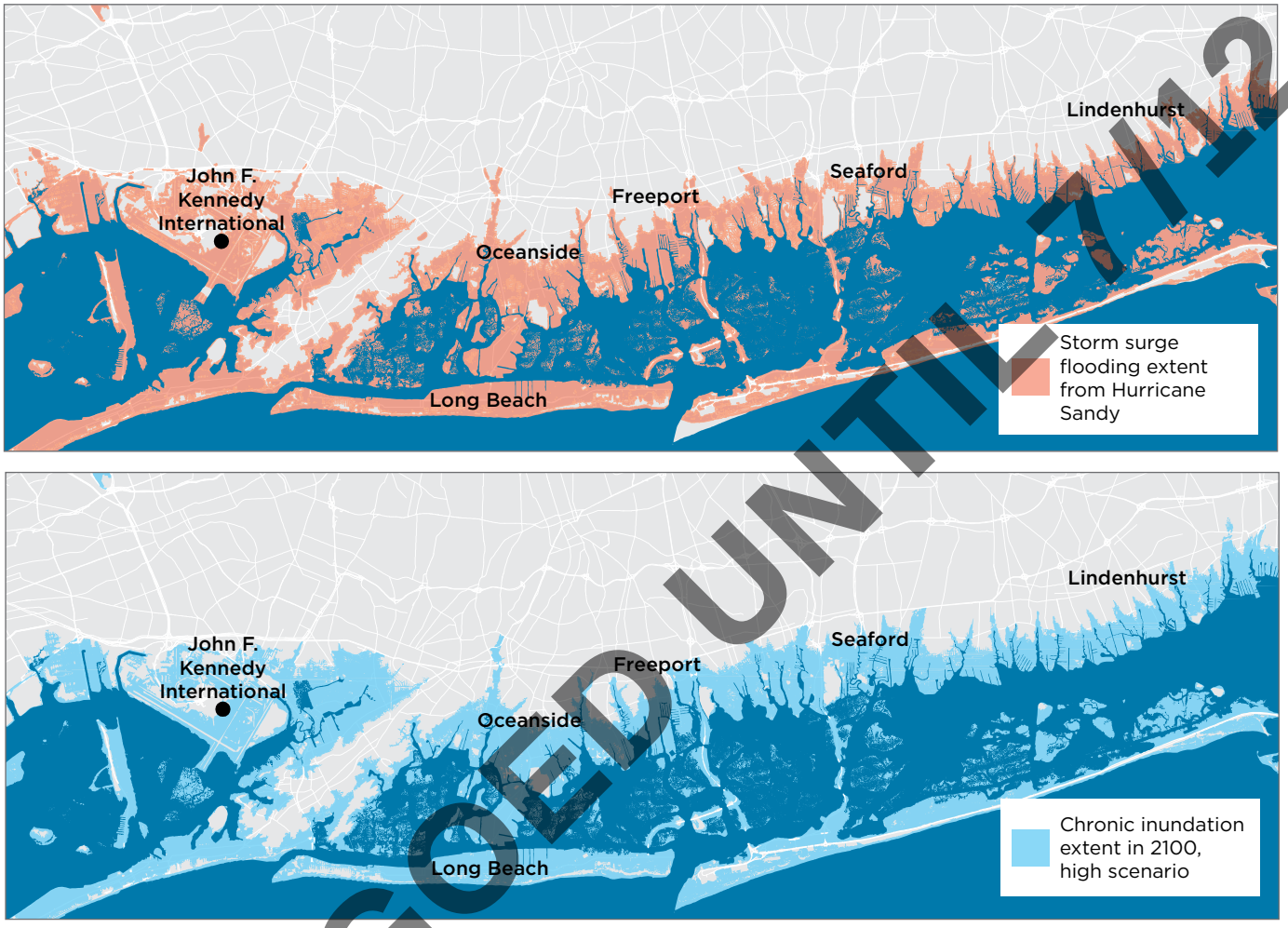
FIGURE 12. Chronic Inundation in Long Island Will Approach Hurricane Sandy Flood Extent



Hurricane Sandy caused widespread flooding and devastation along the southern shore of Long Island in 2012 (top). By 2100 in the high scenario, a similar flood extent occurs every other week on average (bottom). Tidal flooding lacks the destructive wave action of a storm, but the regularity of this flooding could be destructive in its own way.

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LIMITED ACCESS TO CRITICAL INFRASTRUCTURE

A community's safety and viability depend on residents' access to the critical infrastructure and institutions they rely on daily—such as schools and energy-producing facilities—as well as those they rely on in their greatest moments of need—such as hospitals and fire stations. These institutions tend, sensibly, not to be located right on the water, which affords them a certain amount of protection from sea level rise and time to respond to it. However, as waters rise within a community, access to and from these critical facilities can become hampered.

San Mateo becomes a chronically inundated community in 2080 in the high scenario, with more than 10 percent of its land subject to frequent flooding by that year. Twenty years before that, however, in 2060, about 20 of the city's schools would be subject to disruptive flooding every other week on average. This would present severe logistical challenges to families in the city and potentially compromise the safety of school facilities.

In Port Arthur, chronic inundation poses a significant threat to energy infrastructure. The fossil fuel industry currently depends on its ability to transport oil and gas reliably from Gulf Coast locations such as Port Arthur. An earlier UCS

Though Tillamook, Oregon, and surrounding areas, shown here during a 2014 king tide, never reaches the chronic inundation threshold, important infrastructure including roads and a runway, see tidal flooding today. On the left, a flooded road. On the right, an extreme tide covers farmland and nearly reaches a grocery store and other businesses.

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analysis outlined sea level rise and storm surge risks to refineries and corporate shareholders as well as to neighboring communities exposed to toxic waste from damaged facilities (Carlson, Goldman, and Dahl 2015). Chronic inundation poses a slower-moving but potentially quite costly threat. The current analysis shows that, of Port Arthur's 14 energy facilities (including at least one refinery as well as research and development hubs), six fall within the chronic inundation zone by 2070 in the high scenario, when the town itself becomes classified as chronically inundated.

Public safety and emergency response facilities, such as fire and police stations, tend to be costly for communities to construct and, therefore, they are meant to last. Towns along New Jersey's Long Beach Island face choices about maintaining such facilities over the next 30 years, when the high scenario projects many of them to be chronically inundated. In these towns, which include Long Beach, Harvey Cedars, Shipbottom, and Surf City, eight emergency response facilities, including fire and police stations, fall within the chronic inundation zone by 2045. That number rises to nearly a dozen by 2060.

Some coastal communities may be able to relocate critical infrastructure so that it remains accessible to residents. This could work in, for example, Sea Level Township, North Carolina, where the number of critical facilities projected to become chronically inundated, even by 2100, is small even in the high scenario. In other locations, however, there are more significant challenges. In the extremely tight housing market of the San Francisco Bay Area, relocating 20 schools within the town of San Mateo would be difficult, both financially and physically.

LOST BUSINESS REVENUE

When floodwaters seep into business districts, shops become less accessible (particularly to foot traffic) and business owners lose revenue. Many coastal towns' economies rely on tourism, and the loss of business revenue due to flooding can affect a whole town's economic well-being (Diamond 2013). Even when businesses remain open during or after flooding, public perception that they are inaccessible can reduce revenue, as was the case during recent flooding in the United Kingdom (VisitEngland 2014).

This analysis shows that many popular tourist destinations will face chronic inundation in the coming decades. By 2060 in the high scenario, the waterfronts and historic seaports of Ocean City; Key West; and Coney Island, New York would all experience frequent disruptive flooding. The chronic inundation zone in Ocean City would stretch up to the city's famous boardwalk—its many shops, restaurants, and attractions are a key piece of the city's tourism-based economy (Town of Ocean City Finance Department, Recor, and Bennett 2014). Access to Coney Island's theme parks, boardwalk, and aquarium would be similarly affected. And in Old Town Key West, frequent flooding would block access to the restaurants, bars, shops, and rental properties that underpin the island's economy (Key West Chamber of Commerce 2017). With extensive flooding limiting access to these destinations, on average, twice a month, business owners, the real estate market, and, in turn, the surrounding towns, could feel the squeeze.

Business districts that flood frequently become less attractive to business owners looking to set up shop, and local governments facing this loss of revenue grapple with how to

Matt Rath/Chesapeake Bay Program

Annapolis is facing the need for major investment to keep businesses in its vibrant waterfront district alive as flooding increases. Though the city never surpasses the chronic inundation threshold used here, chronic flooding of smaller areas is already taking its toll.

help (Behr, Diaz, and Mitchell 2016). Communities experiencing frequent flooding today are already making difficult choices (Smith 2015). Miami Beach has invested hundreds of millions of dollars into pumps that can alleviate the frequent flooding that afflicts its business areas (Weiss 2016). But, like Gloria Tello, the stylist looking to open her own shop in the Miami area, many business owners are considering how frequently neighboring businesses flood and deciding to look elsewhere. And in Annapolis, where tidal flooding occurs nearly 40 times per year on average, city planners are considering providing business interruption insurance to business owners in the historic district because, while flood insurance helps businesses cope with the physical damage caused by flooding, it does not replace all lost revenue (Craig 2016). Annapolis is already being forced to consider the scale of investment it must make to maintain its thriving business district and to weigh that investment against other needs.

The hard choices confronting communities already grappling with frequent disruptive flooding demonstrate that the solutions to these problems are varied and must be tailored to communities' unique needs. And while individual homeowners or individual communities with enough financial and political means can make sound choices, the scope of the challenge ahead demands the cooperation of local, state, and federal governments. (See chapter 5, p. 35.)

The Best Chance to "Spare" Many Coastal Communities

This analysis finds that significantly curtailing future warming and sea level rise could accomplish the following:

- Spare 90 or more communities from chronic inundation in the next 50 years (by 2060)
- Spare between 200 and 400 communities—depending on the amount of sea level rise—from chronic inundation this century
- Avoid end-of-century chronic inundation in nearly 50 major cities
- Allow roughly 70 to 150 communities to avoid chronic flooding over 50 percent or more of their land this century.

The Paris Agreement, ratified by most countries in November 2016, aims to limit future warming to 2°C (or less) above preindustrial levels in order to avoid catastrophic impacts.[14] UCS analyzed how coastal communities could benefit from international adherence to the agreement by using the low sea level rise scenario as a proxy for sea level rise associated with a warming of about 1.8°C. The magnitude and pace of sea level rise carry major consequences for the number of communities facing chronic inundation this century; the results of this analysis make a clear and compelling case for action. While many coastal communities can only prepare for the flooding to come, hundreds more cities and towns in the United States—and many more than that worldwide—could be spared chronic inundation if the United States and other nations take decisive action today and keep their commitment to the Paris Agreement.

One-third (89 in all) of the communities that experience chronic inundation in 2060 in the intermediate scenario avoid this flooding in the low scenario. These communities include several in the greater Boston area and on the Gulf Coast of Florida and more than 10 communities on the Jersey Shore.

By 2100, nearly 200 communities nationwide could avoid chronic inundation under the low scenario compared to the intermediate scenario (Figure 13). These 200 communities lie along broad stretches of the mid-Atlantic coastline and include Virginia Beach, Virginia; Cape May, New Jersey; and Hempstead, New York, as well as a cluster of communities around Beaufort, North Carolina, and nearly 40 communities in Florida.

14 *On June 1, 2017, President Trump announced his decision to withdraw the United States from the Paris Agreement. Many parties to the agreement, notably European Union members and China, have subsequently signaled a strong commitment to continuing to meet the agreement's goals (BBC News 2017). In the United States, a coalition of cities, states, businesses, and other entities has also pledged to adhere to them (Tabuchi and Fountain 2017).*

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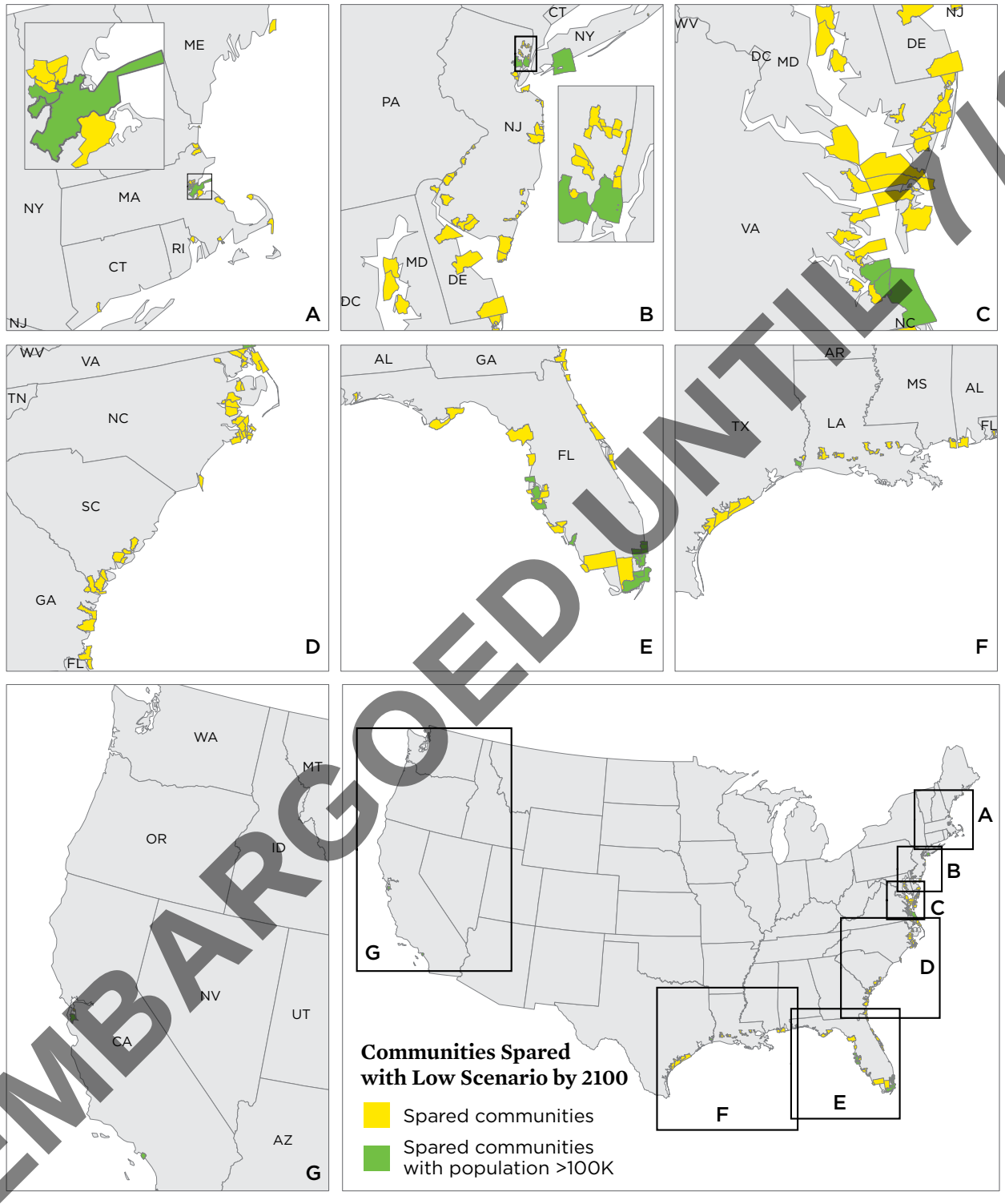
FIGURE 13. Aggressive Emissions Reductions Would Spare Hundreds of Communities from Chronic Inundation



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Adhering to the goals of the Paris Agreement by capping future warming and sea level rise would spare hundreds of coastal communities from frequent, disruptive flooding. Large population centers (green) in particular stand to benefit from limiting future sea level rise.

photo credit to come

Highway 80, which runs between Savannah and Tybee Island, Georgia, regularly floods during high tides. The dramatic storm-driven flooding, shown here on October 28, 2015, cut Tybee Islanders off from the mainland—a disruption they can expect regularly with chronic inundation.

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Limiting sea level rise also limits the reach of the chronic inundation zone, as well as accompanying adaptation costs. In 2100 in the high scenario, more than 270 communities would see half or more of their area inundated, whereas in the low scenario only about 120 would experience such extensive flooding. In the high scenario, Miami Gardens, Florida, experiences exposure of about 80 percent of the community to chronic inundation. In the low scenario, however, it remains almost completely unflooded, with less than 2 percent of the community affected by chronic inundation.

Large cities in particular would fare much better with a slower pace of sea level rise. By the end of the century, just three face chronic inundation in the low scenario: Savannah, Georgia; Miami Beach; and New Orleans. The chronic inundation of these three cities would involve extensive costs and losses. But 49 of the cities with populations over 100,000 that face chronic inundation in the high scenario are spared that flooding in the low scenario. As cities are often top sources of heat-trapping emissions, they represent key opportunities for coastal adaptation as well as reducing emissions to levels of that would contribute to a safer global climate (Rosenzweig et al. 2010). The consequences of inaction, on the other hand, are vast.

While many coastal communities can only prepare for the flooding to come, hundreds more cities and towns in the United States could be spared chronic inundation.

[CHAPTER 5]

Chronic Inundation Response Time: How to Use It Wisely

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Hundreds of US communities, and many more worldwide, have a limited window of time in which to prepare for chronic inundation and prevent it where possible. How much time depends in large part on the ongoing pace of heat-trapping emissions and on how land-based ice responds to warming. This analysis offers decisionmakers—from residents to local, state, and federal leaders—scenarios that can help them plan according to their tolerance for risk. (See Figure 3, p. 11) With so many people and so much property, economic activity, and cultural heritage at risk, preparing for chronic inundation will be complicated and expensive. As this report highlights, action needs to be undertaken quickly in many locations and, as the problem spreads, on a scale that may be unprecedented for our nation.

The key is to use this diminishing time wisely to effect sound adaptation. And the United States must work with other nations to slow the pace of sea level rise through aggressive climate change mitigation in order to allow as many communities as possible to avoid chronic inundation this century and beyond.

Using Response Time Wisely: What *Not* to Do

We cannot waste time either doing nothing or continuing to act in ways that create or heighten coastal risk. Failure to respond will mean that when chronic inundation arrives, communities will be essentially trapped, with limited options. At the point of chronic inundation, it may be too late, for example for programs that offer homeowners buyouts on favorable terms. In many cases, it will also be too late for costly infrastructure projects such as extensive levees or other shoreline protections that take significant time to finance, plan, and construct. Property values, if they have not already done so, would plummet; homeowners would not be able to sell their homes (Becketti and Lacy 2016; Rao 2016). Stripped of their greatest assets, and with home, work, and sense of community badly undermined, the well-being of families and individuals would be affected on many levels (Clayton et al. 2017).

Just as failing to respond is a bad choice, responding with unsound and unwise actions (for example, upgrading infrastructure based on outdated sea level rise projections or without any consideration of sea level rise) would also leave communities trapped when chronic inundation sets in (Spanger-Siegfried et al. 2016). (See Box 6, p. 40)

B137/Creative Commons (Wikimedia Commons)

In parts of Miami-Dade County, like the Brickell neighborhood, hundreds of housing units are still being built on land less than three feet above the high tide line, despite increased flooding.

BOX 5.

Response Types: Defend, Accommodate, Retreat

The solutions that can help protect individual communities from increasingly frequent and extensive flooding fall into three broad categories: defending against the sea, accommodating rising water, and retreating from flood-prone areas (Moser, Williams, and Boesch 2012). In practice, many communities will seek to combine these approaches in response to increased flooding.

Most *defensive* measures are designed to help minimize wave action, reduce erosion, and protect against storm surge (NRC 2014). Many communities along the East and Gulf Coasts have employed armoring or "grey" infrastructure measures such as seawalls, tide gates, and levees. Some have used ecosystem-based or "green" infrastructure measures such as saltmarsh restoration and the creation of new offshore reefs (Grannis et al. 2016; NJRCI 2016).

As sea level rises, however, hard structures can aggravate coastal erosion and beach loss on site and in adjacent areas, diminishing the protective function of natural shorelines and eroding the beaches we enjoy (Vitousek et al. 2017; NRC 2014). Additionally, such structures typically cannot protect against infiltration of saltwater from below ground (Mazi, Koussis, and Destouni 2013; Barlow and Reichard 2010).

There are other issues to consider, as well. Even where defensive measures are effective at keeping tidal floods at bay, how long can they do so, and at what cost? To defend communities against chronic inundation, impervious seawalls, for example, would need to extend along large stretches of shoreline and avoid channeling incoming seas toward other exposed areas (NRC 2014). Or levees would need to be constructed, potentially requiring the use of large tracts of land and encouraging new development (GAO 2016). Where they are possible to implement, such projects are typically costly and can be legally, financially, logistically, and ecologically complicated (Moser 2014). In addition, they have an expiration date; either the defensive infrastructure reaches retirement age, or sea level rise catches up and overwhelms it. Moreover, levees can fail, thus providing a false sense of security to those communities that believe they are safe or are even unaware they are living in a floodplain (GAO 2016).

Some communities already practice *accommodation*: managing floodwater by making space for it and living flexibly with a shifting shoreline (Moser et al. 2014). Homes and vital infrastructure can be elevated, for example, or built to withstand regular tidal inundation (IIBHS n.d.; USACE n.d.). Large-scale pump systems can be installed, such as Miami Beach's $400 million system (Weiss 2016). Projects can range in complexity from individual household measures such as elevating a home to major infrastructure projects such as channel construction along urban waterfronts. Where they are possible, these projects, too, can be very costly and limited in their ability to accommodate rising sea level (EPA 2015).

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Failing to begin effective planning, financing, and coordination now means that the inevitable response to increased flooding will happen without coherence, resulting in significant hardship for individuals, communities, businesses, and local governments (Moser, Williams, and Boesch 2012). In fact, waiting to adapt to climate change will cost significantly more down the road than will planning for it today (Melvin et al. 2016). In contrast to other periods of regional instability, the economic consequences for states, and for the entire United States, of the onset and worsening of chronic inundation could scale up many times as it unfolds simultaneously in hundreds of communities across different regions.

Failure to respond will mean that when chronic inundation arrives, communities will be essentially trapped, with limited options.

Using Response Time Wisely: Meeting Hard Choices Head-On

Individuals and communities will need to use their available response time sensibly and aggressively to avoid incurring major losses. Just as most working people are advised to plan and save for their retirement well ahead of time, coastal communities—particularly those facing nearer-term inundation—must get started now, planning ahead and making choices that align with chronic flooding projections (Figure 14, p. 38; Lowlander Center and GCR 2015; Bierbaum et al. 2014;

The third option, *retreat*, involves transitioning currently utilized land areas—neighborhoods, commercial districts, industrial zones, etc.—to open space. Put simply, this means abandoning chronic inundation zones. Communities will increasingly need to apply this approach in areas at risk of chronic flooding, shifting inland away from places too risky or costly to maintain (Kousky 2014; Agyeman, Devine-Wright, and Prange 2009). Economic incentives to retreat from the shore—or not build there anymore—can assist in this transition.

Retreat can take different forms: unmanaged or managed, voluntary or mandatory (Hino, Field, and Mach 2017). To date, retreat in the United States has been primarily unmanaged and autonomous, as has been the case for the Alaskan west coast communities of Shishmaref, Kivalina, Shaktoolik, and Newtok (Bronen 2013; Bronen and Chapin 2013; GAO 2009). These communities, hit hard by the combination of sea level rise, erosion, and melting permafrost, have had to move away without coordinated relocation plans, federal agency coordination, or federal financing (Hino, Field, and Mach 2017; Bronen and Chapin 2013; GAO 2009). Many residents who have left these communities and many who still remain have found it challenging to maintain important social ties and support networks (Hino, Field, and Mach 2017; Bronen and Chapin 2013; Maldonado et al. 2013). And as flood insurance for coastal homes increases to reflect the true risk associated with flood-prone properties, market forces and individual choices could begin to drive retreat at the household level (Jarvis 2017). On the other hand, managed voluntary retreat, as the Biloxi-Chitimacha-Choctaw Native American band is undertaking with federal funding, can be costly but less disruptive to a community, ensuring that its residents conserve their financial resources and preserve their cultural heritage (Lowlander Center and GCR 2015; Kousky 2014).

These first efforts at retreat have highlighted some of the serious challenges to community relocation, including the lack of adequate resources; the difficulties of finding and developing a new, more resilient location; and the difficult social and economic adjustments that accompany such a decision (Hino, Field, and Mach 2017; Bronen and Chapin 2013; Maldonado et al. 2013). Yet they also point to the human capacity for adaptation in the face of unprecedented change.

Perhaps the most fundamental of the many factors that will challenge retreat efforts is that most people strongly prefer to stay in their communities, where family, job security, shared culture and history, and faith have accumulated, perhaps over generations (Kousky 2014; Agyeman, Devine-Wright, and Prange 2009). This fact is apparent in the rush to rebuild that follows destructive storms. To date, US disaster aid, rebuilding, and insurance policies have helped Americans to stay where they are, despite the inherent and mounting risks of remaining (GAO 2015; GAO 2014; HSRTF 2013).[15]

Not all adaptation measures—defense, accommodation, or retreat—will work everywhere. Many are costly to sustain, and rising seas may simply preclude some options (ERG 2013; Moser, Williams, and Bosch 2012). When choosing the most pragmatic and feasible way forward, communities will need to weigh difficult trade-offs, including their tolerance for risk and their financial constraints.

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Burkett and Davidson 2012). Robust federal and state policies and resources will be required for communities to understand their risks, assess their choices, and implement adaptation plans.

The specifics of how individual communities will respond will vary depending on their particular circumstances and available choices. Nevertheless, there are key principles that can apply broadly (Spanger-Siegfried et al. 2016). Using a science-based approach that prioritizes equitable outcomes can help communities and decisionmakers make sound choices; common sense would also dictate a stop to present policies that put more people and property in harm's way. An equitable approach will focus efforts on low-income and minority communities, engage residents in decisionmaking, and prioritize their needs for resources (Moser 2016)[16]

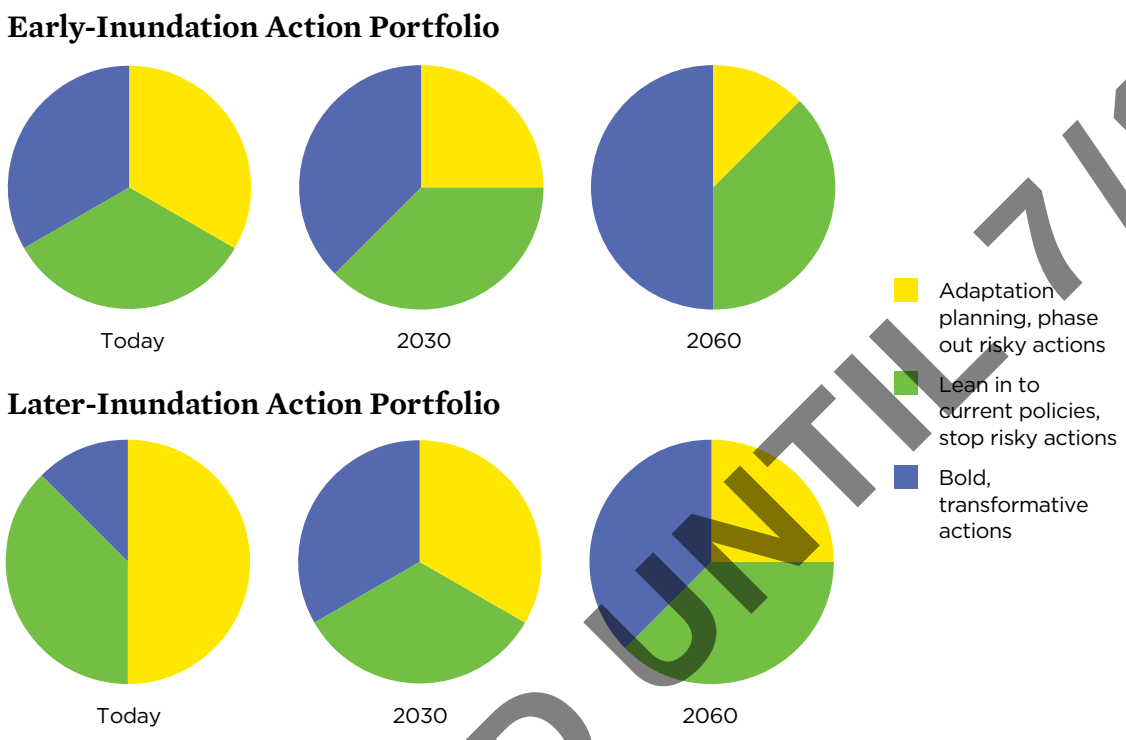
In each community, preparation for chronic inundation will require a progression of steps: assembling solid science that outlines the extent and timing of exposure, bringing that science to bear on local planning decisions and policies affected by sea level rise, and beginning a process of pivoting from business as usual to resilience in a way that takes account of growing flood risks. Outlined below are just a few sensible steps that different actors, from the federal to the individual level, can take, depending on the available response time.[17]

15 *Indeed, the Government Accountability Office, which is tasked with accounting for federal agency activities, recommended that the nation needs a federal mitigation investment strategy to better align and invest taxpayer dollars to mitigate these risks (GAO 2015).*

16 *For a full list of adaptation principles, see:* Toward Climate Resilience *at* www.ucsucsa.org/resilience_principles.

17 *For a fuller examination of the wise use of chronic inundation response time, see:* www.ucsusa.org/RisingSeasHitHome.

FIGURE 14. Aligning Actions with Chronic Inundation Response Time



Communities facing chronic inundation need to adopt a portfolio of actions to prepare and protect themselves. Depending on their inundation response time the emphasis they place on different types of actions will differ. Communities facing early inundation might place a greater emphasis on immediate bold, transformative actions, whereas those facing inundation later this century might focus first on adaptation planning. But at-risk communities should work on all fronts in some measure because the challenges are significant and robust early action can help limit harms.

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- In communities that will be chronically inundated within a decade or two, a pivot to resilience building must happen quickly. Households must have options to move, or be moved, away from the riskiest areas. Fair and favorable buyout terms at the state and local levels can encourage entire neighborhoods to withdraw, as was demonstrated by the nearly 300 homeowners in Staten Island who sold their homes to the state in a voluntary buyout program after Hurricane Sandy (Freudenberg et al. 2016; Kensinger 2016; Henderson 2015). Equity provisions for federal funding will be essential in advance of major funding dispersals, in the wake of a storm for example, to ensure poor and minority communities are not further disadvantaged in the rebuilding (Cleetus, Bueno, and Dahl 2015; Hayat and Moore 2015).
- In communities facing chronic inundation by midcentury, planning, zoning, tax incentives, and other measures must be implemented to immediately put a stop to decisions—such as building in projected inundation zones—that will create risk in future decades (Bierbaum et al. 2014; Burkett and Davidson 2012). In these areas, state- and federal-funded buyout programs could encourage retreat by providing favorable terms for early adopters. Such programs, by their existence, would force homeowners to think differently about their homes' long-term value and the wisdom of staying in place. However, they would also require strong oversight to ensure predatory actors or practices within the private sector do not influence homeowner decisions. To avoid unsound decisions as well as gradual municipal decline, communities should use this timeframe to develop a comprehensive long-term vision. This in turn can provide the basis for long-term planning that effectively shifts residential and/or commercial districts out of future chronic inundation

from "Can't Stop The Water" by Cottage Films

Along the Louisiana coast, some people—and indeed, entire communities, like the tribal residents of Isle de Jean Charles—are seeking to relocate as rising seas and sinking land bring high tide ever closer.

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zones while maintaining a vibrant local economy and culture.

- In communities afforded a longer response time, other options such as defensive measures may come into play, at least initially, as residents try to remain in place and buy time (Bierbaum et al. 2014; Moser et al. 2014; ERG 2013). However, regulatory measures that can immediately curtail unwise decisions and encourage long-term planning that can inform better decisions should also be put into place.

The portfolio of actions that individuals and communities undertake will need to change as response time shrinks and chronic inundation approaches. For a municipality, for example, that portfolio may need to shift from analysis and planning actions to the execution of managed retreat. Again, retirement savings can serve as a useful metaphor. Just as people with the means to save for their retirement are advised to start early because of the challenges of making up for lost time, so individuals and communities should begin as early as possible: planning, implementing measures, and making investments well in advance of chronic inundation (Moser et al. 2014; ERG 2013). Just as the investments individuals make as they save for retirement need to reflect their tolerance for risk, a household or community will need to make plans that reflect its tolerance for flooding (Climate Central n.d). And just as millions of Americans struggle to save for retirement and rely on social safety nets, so will many coastal Americans be unable to afford the steps they need to take to cope with flooding. To help ensure options remain open to these households, government assistance will be essential.

Robust federal and state policies and resources will be required for communities to understand their risks, assess their choices, and implement adaptation plans.

BOX 6.

Policy Responses to the Threat of Chronic Inundation

As our nation readies for the significant challenges posed by sea level rise and coastal flooding, three categories of policy response are critical:

- Halting or phasing out current maladaptive policies and measures that perpetuate risky coastal development
- Fostering resilience by using existing policy frameworks in ambitious ways with scaled-up funding
- Creating and funding bold new policies and measures that respond to the full extent of the challenges communities face

If well planned and resourced, these actions will help ensure that coastal communities continue to thrive, albeit in an altered form. Failing that, communities will suffer severe harm and some, including low-income and minority communities, will likely bear the brunt of the consequences. Given the importance of the coastal economy and way of life to the entire country, the ripple effects will be felt far beyond the immediate zone of inundation.

PHASING OUT POLICIES THAT ENCOURAGE RISKY COASTAL ACTIVITIES

Coastal communities are caught in a struggle to overcome the political, social, and economic urge to continue to build and rebuild exactly as before, despite the growing risk of chronic inundation (Kousky 2014).

Many current policies—ranging from the National Flood Insurance Program (NFIP) to local zoning laws—have features that can perpetuate risky development. Subsidized flood insurance premiums encourage homeowners to live in floodplains. Federal and state governments often help fund and build infrastructure—including roads; bridges; and transit, sewage, and water systems—that supports residences and businesses in flood-prone areas. Public investments in protective infrastructure, such as sea walls and levees, or in beach nourishment can provide a false sense of security to communities, keeping them in place and growing. These types of actions and incentives implicitly or explicitly shield coastal communities from the full consequences of risky development choices and shift some of the costs to other taxpayers.

Rooting out these maladaptive components of federal, state, and local policies is a necessary first step to containing exposure to the harms of coastal inundation. It would also create opportunities to redirect public funds to actions that could truly help protect people and property over the long term. Actions should include:

- Updating flood-risk maps to reflect sea level rise projections
- Phasing in risk-based flood insurance premiums, while ensuring affordability provisions
- Limiting new development in flood-prone areas
- Halting actions that undermine natural ecosystems that provide flood protection
- Ensuring that the latest science is reflected in zoning regulations, flood risk management standards, building codes, and plans for new coastal development and the construction or upgrade of infrastructure.

BOLSTERING EXISTING POLICIES AND FUNDING

Currently, our nation's response to chronic inundation falls short because it is handled primarily through the existing disaster response framework. Chronic inundation requires a much greater emphasis on anticipatory rather than reactionary actions because we are faced with predictable, worsening flooding in a wide swath of specific coastal areas. Nevertheless, the existing policy framework provides important opportunities, provided the predisaster components are enhanced and well-resourced and postdisaster rebuilding takes into account climate projections.

FEMA, the lead agency for disaster response administers programs such as the Hazard Mitigation Grant Program, pre-disaster mitigation grants, Flood Mitigation Assistance, and the Public and Individual Assistance Programs, and works closely with state and tribal authorities to provide resources to help with disaster recovery and rebuilding. Despite the fact that investments in predisaster mitigation have a payoff of at least four to one, the US significantly underinvests in hazard mitigation programs (Thomas and Walther 2014; Rose et al. 2007; MMC 2005). Funding for these types of programs must be retained and ramped up to help limit the impacts of chronic inundation. FEMA's innovative concept for a Public Assistance (PA) deductible, if implemented, could also provide incentives for states to invest more in predisaster mitigation (FEMA 2017).[18]

Federal agencies should work to quickly implement the federal flood risk management standard, which applies to federally funded projects and was recently updated and strengthened to account for climate risks (White House 2015a). Other existing policies and measures that require more investment include funding for flood-proofing measures such as home elevation; investments in the conservation, sustainable management, and restoration of natural ecosystems such as wetlands that provide flood protection; funding for large-scale home buyout and relocation programs; and implementation of robust flood-risk management standards

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and building codes nationwide. State Hazard Mitigation Plans should explicitly include consideration of climate-related risks, as required by FEMA guidance (FEMA 2015). And policies and resources must be actively targeted at low-income communities, communities of color, tribal communities, and others that have been historically marginalized (NAACP 2015; SLTLTFCPR 2014).

FEMA plays a lead role in flood-risk mapping, which is an important feature of the NFIP and is vital for communities' preparation for chronic inundation (GAO 2013). The Risk Mapping, Assessment, and Planning program, a multiyear effort to review and update flood-hazards maps, can help provide information, risk assessment tools, and planning resources essential for homeowners, engineers, local planners, and others. Legislation to implement the recommendations of FEMA's Technical Mapping Advisory Council and scaled-up funding for NOAA's Digital Coast program would be an important step forward to improve current maps and provide data, tools and training for communities (NOAA n.d.; TMAC 2016a; TMAC 2016b; TMAC 2015; US Congress 2015).

However, these efforts are seriously underfunded. An estimated one-sixth of US rivers and coasts have updated flood risk maps,[19] a deficit that could be corrected nationwide with an investment on the order of $4 billion over the next 10 years (ASFPM 2013). In fiscal year 2017, Congress appropriated $178 million for flood mapping (US Congress 2017) but the Trump administration's fiscal year 2018 budget proposes to zero this out. FEMA and other agencies that play important roles in disaster response and flood protection, such as the Department of Housing and Urban Development (HUD), the US Army Corps of Engineers (USACE), and the US Department of Agriculture (USDA) also need more resources and better coordination (GAO 2015).

Many federal agencies—from the Department of Homeland Security to the Department of Defense—have made important strides in taking climate change into account in their work (DOD 2014; DHS 2014; DHS 2013) as well as in assembling tools, data, and information to help state and local governments with adaptation planning (US Climate Resilience Toolkit n.d.). The National Climate Assessment, undertaken by the US Global Change Research Program and conducted on a four-year cycle, is another critical source of information for adaptation planning (USGCRP n.d.). The fourth assessment is due to be completed in 2018. Small-scale efforts are underway to help communities already coping with damaging effects of climate change, including through HUD's 2016 National Disaster Resilience Competition, NOAA's Coastal Resilience Grants Program, and the USDA's Rural Alaska Villages Grant Programs (HUD 2016; White House 2015b). These types of efforts by the federal government to coordinate and lead our nation's adaptation response must be scaled up and clearly communicated to stakeholders on the front lines of chronic inundation.

BOLD, TRANSFORMATIVE ADAPTATION RESPONSES

We also need new, bolder, and more comprehensive solutions to bring transformative change to the coasts because our responses must reflect the reality that communities may have to retreat from the riskiest areas.

The prospect of retreat and relocation can erode property values and local tax bases and cause significant shifts in where economic activity takes place—which has important implications for local jurisdictions and can create significant opposition to change. Yet, with chronic inundation inevitable in many coastal towns and cities, we need to plan ahead and muster the resources communities need to thrive in new locations. This will require substantially increased federal and state funding and coordination. The federal government is uniquely positioned to provide communities with information, tools, and well-resourced programs.

We need innovative, well-funded programs of community retreat, and new economic opportunities and resilient infrastructure in the safer locations that people and businesses relocate to, perhaps galvanized through public-private cooperation. Efforts must also be made to safeguard natural ecosystems and preserve cherished aspects of cultural heritage.

Policy solutions will need to be in place to avoid the wholesale abandonment of disadvantaged communities within chronically inundated zones; to prevent the gentrification of poor and working-class coastal communities; and to ensure more equitable outcomes generally. Disruptive changes also point to the need for community governance models capable of managing difficult decisionmaking and resolving conflicts in equitable ways (Bronen and Chapin 2013; Maldonado et al. 2013).

18 The PA program provides funding for local, state, and tribal governments to help communities recover from major disasters. If FEMA's proposed design for this deductible is adopted, states would first have to meet a minimum threshold of expenditures before the agency would provide PA program assistance. States would be allowed to buy down their deductible through credits earned for qualifying statewide measures that would help build resilience and lower the costs of future disasters. Preparing for chronic inundation could be one type of action that earns credits.

19 The ASFPM research focused on whether communities have maps that reflect their Base Flood Elevation (BFE). FEMA defines BFE as the computed elevation to which floodwater is anticipated to rise during a flood that has a one percent chance of being equaled or exceeded in any given year.

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Rising to the Challenge Together

Chronic inundation will present challenges that are too great for any single actor to handle. The complexity of governance and decisionmaking needed to respond to projected sea level rise will be on a scale that we as a nation rarely encounter (Moser et al. 2014; Bronnen 2013). Coordinated action by households, local and state leadership, and businesses is critical to help communities transition to greater resilience and to limit the damage wrought by flooding. And given the national scope and scale of the coastal challenge, the federal government has an essential role to play in marshaling the policies, science, and resources needed to support communities adapting to sea level rise (SLTLTFCPR 2014). Managing large-scale coastal retreat in a way that limits major social and economic disruption must become a national imperative.

Whether our nation's nascent efforts to respond to coastal flood risks will be scaled up and well resourced in the years ahead or reversed will depend on decisions made by current and future administrations and Congress as well as by state and local policymakers. Americans must rise to the challenge and recognize that it is in our shared interest to help coastal communities. Leaving each to face an uncertain fate on its own is a poor choice because the damage incurred will eventually affect the nation's economy, politics, and social fabric broadly.

As we look ahead to the end of this century, we have a clear choice. Many of our East and Gulf Coast communities will be chronically inundated and we must prepare. For others, if reality mirrors the sea level rise scenario most aligned with the long-term goals of the Paris Agreement, many could be spared this flooding. At this crossroads, reducing global warming emissions must be a national priority. The United States can still make deep cuts in heat-trapping emissions, thereby contributing to global efforts to limit climate change. We are at a turning point where we can still avoid some of the most serious human consequences and losses that our coasts—and indeed coastal communities around the world—face this century. We have time to respond. We must use it wisely.

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For many coastal communities, some difficult choices lie ahead, but open dialogue and effective governance can enable them to find sound, lasting ways forward.

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[KEY TERMS]

Adaptation: The process of adjusting to actual or expected climate change. In human systems, adaptation seeks to moderate harm or exploit opportunities. In natural systems, human intervention may facilitate adjustments to expected climate change and its effects (IPCC 2014a).

Chronic inundation: In this analysis, we define chronic inundation as flooding that encompasses 10 percent or more of a community's usable land 26 times or more per year, causing disruptions to daily routines. UCS chose these thresholds based on conversations with residents in communities that flood frequently today and on published frequency thresholds (Sweet and Park 2014).

Chronic inundation zone: The zone above the high tide line that floods 26 times or more per year (on average every other week). While this zone does not experience daily flooding, regular inundation limits its uses. Substantial investments would be required to prevent the shift to limited-use status in chronically inundated zones.

Community: This analysis uses county subdivisions identified by the US Census Bureau to define communities (US Census Bureau 2012). County subdivisions are the primary divisions within counties and represent recognizable cities and towns such as Boston, Brooklyn, and Fort Lauderdale as well as some rural, remote, low-population, even unnamed areas in places such as coastal Louisiana.

Extreme high tide: Twice a month (during new and full moons), Earth, sun, and moon align, and the combined gravitational pull of the sun and moon exerts greater force on Earth's oceans. As a result, high tides become slightly higher than normal, while low tides become slightly lower. These tides are often called spring tides. Several times a year, when a new or full moon occurs when the moon is at its closest point to Earth, the range of the tides is even larger. These are called perigean spring tides, or king tides. In this report, extreme high tides include both spring and king tides—both of which can result in coastal flooding.

Intertidal zone: The area of the coast that is subject to inundation by ocean water during normal high tides.

Limited-use zone: Used interchangeably here with *chronic inundation zone,* this refers to the area above the high tide line that floods 26 times or more per year (on average every other week). While this zone does not experience daily flooding, its uses will typically need to shift from residential, commercial, or industrial to more limited uses such as open space, coastal buffer zones, and recreational areas due to regular inundation. Substantial investments would be required to prevent the shift to limited-use status in chronically inundated zones.

Mitigation: A human intervention to reduce heat-trapping emissions or remove carbon already in the atmosphere (IPCC 2014a). This is not to be confused with mitigating the risks of disasters, including those that are human-induced, by reducing hazards, vulnerability, and exposure (IPCC 2014b).

Resilience: The capacity to cope with a hazardous event or disturbance. Building resilience entails responding or reorganizing in ways that maintain a community's essential identity, structure, and function while sustaining its capacity for adaptation, learning, and transformation (IPCC 2014a; Arctic Council 2013).

Response time: The amount of time a community has before projected chronic inundation sets in. Communities can prepare for this flooding by using their response time wisely and taking sound measures to defend against, accommodate, and/or retreat from chronic inundation as circumstances and resources warrant.

Retreat: The managed or unmanaged withdrawal from coastal areas at high risk of flooding to allow the land to become buffer zones and/or other open space (Hino, Field, and Mach 2017).

Risk: The potential for consequences when something of human value, including people's lives, is at stake and the outcome is uncertain (IPCC 2014a).

Sea level rise scenarios: Sea levels are expected to rise as Earth's oceans and ice sheets respond to past and future emissions of heat-trapping gases. Because future emissions and how Earth responds to those emissions are uncertain, scientists have developed a range of future sea level rise scenarios. This analysis uses localized projections based on three global sea level rise scenarios developed for the Third US National Climate Assessment (Parris et al. 2012).

Socioeconomic vulnerability (SoVI): The vulnerability of individuals, groups, or communities to a variety of stressors, including environmental change. This analysis uses SoVI, a published index (Martinich et al. 2012; Cutter, Boruff, and Shirley 2003) of US Census tract-level socioeconomic vulnerability, to assess the adverse impacts of chronic inundation on communities.

Tidal flooding: Tidal flooding currently occurs when high tide is running one to two feet above the mean higher high water mark. The cause is typically astronomical high tides during full and new moons, when the gravitational pull of the sun and moon align. Such flooding can occur from the tide on its own but can be exacerbated by other factors—including wind-driven surges, rainfall and runoff (not factored into this analysis)—that are prevented from draining by high tides. Currently considered minor or "nuisance" flooding, this type of inundation is becoming more chronic in some locations due to sea level rise.

Usable land: This analysis defines a community's usable land as that located outside of wetland and federal leveed areas. Wetland areas were defined by the US Fish and Wildlife Service's National Wetlands Inventory (USFWS 2016); leveed areas were defined by the USACE's National Levee Database (USACE 2017). Only usable land is included in the calculation of chronic inundation zones in this analysis.

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When Rising Seas Hit Home

Hard Choices Ahead for Hundreds of US Coastal Communities

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By making sound decisions soon, communities can prepare for chronic inundation and avoid serious losses.

Americans living on all coasts will feel the effects of sea level rise decades before coastal land is permanently underwater. The shorter-term consequences are more extensive, more frequent, and, eventually, chronic flooding, which will dramatically alter the landscape and the livability of many coastal communities.

The Union of Concerned Scientists (UCS) has identified hundreds of US communities that face this chronic, disruptive inundation. Because this persistent flooding can render affected areas—currently neighborhoods, commercial districts, and industrial zones—unusable, UCS has also modeled how much time remains to take preparatory steps before this flooding arrives.

By making sound decisions soon, communities can prepare for chronic inundation and avoid serious losses—not only of homes, schools, businesses, and other infrastructure, but also of regional history, sense of place, local culture, and people's ways of life.

Union of Concerned Scientists

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