SURGE

Coastal Resilience and Real Estate

Urban Land Institute

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COVER PHOTO: Manhattan, New York. (Shutterstock)

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Recommended bibliographic listing: Urban Land Institute. *Surge: Coastal Resilience and Real Estate*. Washington, DC: Urban Land Institute, 2024.

ABOUT THE URBAN LAND INSTITUTE

The Urban Land Institute is a global, member-driven organization comprising more than 48,000 real estate and urban development professionals dedicated to advancing the Institute's mission of shaping the future of the built environment for transformative impact in communities worldwide.

ULI's interdisciplinary membership represents all aspects of the industry, including developers, property owners, investors, architects, urban planners, public officials, real estate brokers, appraisers, attorneys, engineers, financiers, and academics. Established in 1936, the Institute has a presence in the Americas, Europe, and Asia Pacific regions, with members in 84 countries.

More information is available at uli.org. Follow ULI on X (formerly known as Twitter), Facebook, LinkedIn, and Instagram.

ABOUT THE ULI URBAN RESILIENCE PROGRAM

ULI's Urban Resilience program is focused on how buildings, cities, and communities can be more resilient to the impacts of climate change and other environmental vulnerabilities. The program works with ULI members to provide technical assistance, advance knowledge through research, and catalyze the adoption of transformative practices for real estate and land use policy.

RESEARCH CONTRIBUTORS AND PROCESS

ULI is grateful to The JPB Foundation for its support of this project.

To better understand how coastal hazards affect real estate and land use, ULI's Urban Resilience program conducted focus group meetings in the Americas, Europe, and Asia Pacific. The focus groups included more than 70 participants, including real estate developers, designers, public-sector officials, nonprofit leaders, and coastal resilience experts. The authors also worked with a team of ULI member advisers with expertise in coastal resilience and related topics, as well as with colleagues from ULI District and National Councils to draft this report. A full list of the individuals who shared their knowledge and perspectives in focus groups, nominated case studies, edited the text, provided supporting materials, and otherwise advised on the creation of this report is provided in the Report Team and Acknowledgments sections.

The Miami coastline. Miami has some of the world's most valuable coastal real estate.

SHUTTERSTOCK

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Manhattan, surrounded by water, is at risk of coastal hazards.

EXECUTIVE SUMMARY

Surge: Coastal Resilience and Real Estate introduces the challenges associated with coastal hazards such as sea level rise, coastal storms, flooding, erosion, and subsidence, and provides best practices for real estate and land use professionals, as well as public officials, to address them. The report includes sections on the following:

- Coastal risks and their impacts on real estate and communities
- The business case for integrating coastal resilience into real estate
- Strategies and best practices for addressing coastal hazards in real estate and land use
- Public-sector policies and practices that can support coastal resilience
- Profiles of real estate and communities that have adapted to coastal hazards and their outcomes

Approximately 40 percent of the world's population lives within 62 miles (100 km) of a coast, and many of the world's major cities and urban areas lie along coasts.[1,2] Coastal hazards, exacerbated by climate change, are increasingly affecting these coastal communities and their populations.[3] By bolstering the resilience of coastal assets and areas now, we can help protect coastal real estate, communities, and ecosystems in the face of the significant coastal risks that are expected in the coming years—and strengthen them in the process.

With this report, ULI seeks to provide best practices, resources, and case studies to inform private- and public-sector professionals, as well as communities, about the many methods for integrating coastal resilience strategies into land use and real estate practices and policies, allowing coastal regions not just to avert and recover from climate-related disasters, but also to thrive.

The report's key takeaways follow and are explored in further detail throughout the report.

Key Takeaways

- **Climate Change:** Climate change is amplifying coastal hazards, including sea level rise, coastal storms, flooding, erosion, and subsidence. Coastal real estate and communities are increasingly vulnerable to the cascading impacts related to sea level rise and coastal storms, which are projected to significantly increase throughout this century under all greenhouse gas emissions scenarios.
- **Market Outlook:** Coastal properties have been priced at a premium compared with similar properties that are not on the coast. However, coastal hazards are increasing the risks to these properties. Historically, the financial risk associated with coastal hazards has been mitigated by insurance, supporting the inflation of property values. This trend is changing as insurance companies reexamine risk profiles, pricing, and insurance availability. As a result, coastal risks have been shown to be capitalized in the value of property, and properties subject to hazard risks appreciate at a lower rate and are often sold at a discount compared with similar properties that are not subject to risks.
- **Good Business:** Investing in coastal resilience measures mitigates the costs of disaster recovery, rising insurance premiums, and policy changes. It can also garner cost savings and provide long-term value to real estate owners and investors. For every dollar spent on coastal hazard mitigation efforts, US$5 to US$10 are saved from reduced damage during disasters, lowered insurance premiums, and avoided costs of emergency response and recovery.
- **Policy Landscape:** Governments worldwide are progressively updating their approaches to governance of land use and development, environmental protection, and risk disclosure in response to new information and imperatives arising from climate risks. Policy changes will have a significant impact on what types of real estate can be developed, as well as where and how. Implementation of resilience strategies provides real estate owners the opportunity to reduce disclosed risks and get ahead of the curve of these changes.
- **Meeting the Scale of the Problem:** Coastal hazards ignore property lines and jurisdictional boundaries. Integrated, adaptive, systems-level solutions are needed to match the scale of the problem, which can exceed what single owners, agencies, or utilities can deliver on their own. These solutions will require new ways of collaborating across sectors and boundaries.
- **Addressing an Uncertain Future:** Predicting exactly how much climate-related hazards will impact specific areas, and by when, is difficult. Adaptive solutions are needed that allow for incremental improvements as the local risk context changes. An adaptive approach to coastal resilience can aid the selection of risk reduction strategies—which can be built on over time—adding value and longevity to real estate assets. Phased implementation of risk reduction strategies can help spread out costs and avoid catastrophic losses.
- **Hybrid Green and Gray Approaches to Adaptation:** Gray infrastructure—or man-made structures such as dikes, sea walls, and surge barriers—is widely used for protection in many coastal cities and deltas. However, these hard engineering interventions can disrupt natural dynamics and ecosystems that maintain coastlines and land elevation and may ultimately lead to less protection for coastal areas. Nature-based solutions are becoming more popular. They can not only protect coastal areas but also provide ecological benefits, serve as carbon sinks, and offer places for recreation. With the limited space available along the coast in urban areas, a combination of constructed and nature-based solutions is frequently required to advance coastal resilience.
- **Equitable Climate Adaptation:** Mitigating social vulnerability is an important priority during climate adaptation decision-making, since historically marginalized communities are often most affected by climate change. People with the highest exposure and vulnerability are often those with the lowest capacity to respond, so they require the most support. Using cost/benefit analysis alone for investment decisions unfairly disadvantages these groups since it primarily considers property values and tax dollars at risk, and other monetary factors. Decision-making can address both economic impact and strategies for protecting communities with the greatest needs.
- **Opportunities for Thriving Communities:** Climate risk management and adaptation strategies can be used to help communities become more equitable, livable, and ecologically regenerative. Investments integrating coastal resilience strategies into land use and real estate can allow coastal areas to thrive in the long term.

1450 Brickell, Miami, Florida, is a 35-story, 586,000-square-foot class A office tower. The office tower was designed with impact-resistant glass windows that can withstand the force of large, wind-driven projectiles as well as winds approaching 300 miles per hour. When it was completed in 2010, 1450 Brickell incorporated the strongest curtain wall window system of any commercial building in the nation.

1450 BRICKELL, MIAMI

INTRODUCTION

Coasts have attracted human settlement for centuries, resulting in population growth and urbanization in areas that are increasingly at risk.[4,5] Approximately 40 percent of the world's population, and 60 percent of the world's cities with populations over 5 million, are located within 62 miles (100 km) of ocean coasts.[6,7] Ongoing development in coastal areas, driven by increasing population density and demand, has led to the disruption of protective natural systems that, when exacerbated by the effects of climate change, elevates risks to life and property.[8]

Coastal risks are manifold, and they influence and compound upon one another. Rising seas and more severe storms are redefining coasts around the world. As a result, coastal flooding is increasing in intensity and frequency, leading to profound impacts on communities, infrastructure, and natural systems.[9] Wind, waves, and rain in coastal areas can quickly gain enough power to damage or destroy properties and hasten land erosion. Meanwhile, groundwater extraction and coastal urbanization can cause land beneath coastal cities to sink, adding to the effects of local sea level rise and flooding. Development in coastal areas also tends to degrade coastal ecosystems that would otherwise protect communities.[10] The United Nations Environment Programme, in its 2022 Adaptation Gap Report, notes that even with emission reductions, adaptation efforts are necessary to cope with the intensifying climate crisis.[11]

In the United States alone, over US$1 trillion worth of property is at risk within 700 feet (213 m) of ocean coasts.[12,13] Despite the risk, populations in coastal areas continue to grow across the globe.[14] The risks to coastal properties come with significant impacts on human well-being, including potential loss of life.[15] To reduce risk in coastal communities, real estate and land use professionals, public officials, and others must adjust their approaches to development and management of coastal risks.

> The Urban Land Institute defines resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events."
>
> **ULI's report *Ten Principles for Building Resilience***

For these efforts to be successful, measures must be taken sooner rather than later. Coastal hazards such as sea level rise, coastal storms, flooding, erosion, and subsidence are increasingly affecting communities. The cost of the protections needed will be justified by the safety they provide, the losses they avoid, and the value they add.[16] By committing to bolster the resilience of coastal assets and areas now, we can help protect coastal real estate, communities, and ecosystems in the face of the significant coastal risks that are expected in the coming years, and strengthen them in the process.

The Mexican port of Acapulco, damaged by Hurricane Otis in 2023.

SHUTTERSTOCK

COASTAL RISKS AND THE BUSINESS CASE FOR COASTAL RESILIENCE

Coastal real estate and communities are increasingly vulnerable to flooding, erosion, subsidence, and other cascading impacts. All are related to sea level rise and storm surges, which are projected to significantly increase throughout this century under all greenhouse gas emissions scenarios, putting trillions of dollars of real estate at risk.[17,18] The following sections detail the primary coastal hazards facing communities, their impacts, and the business case for coastal adaptation and resilience.

Damaged properties in Ortley Beach, New Jersey, following Hurricane Sandy.

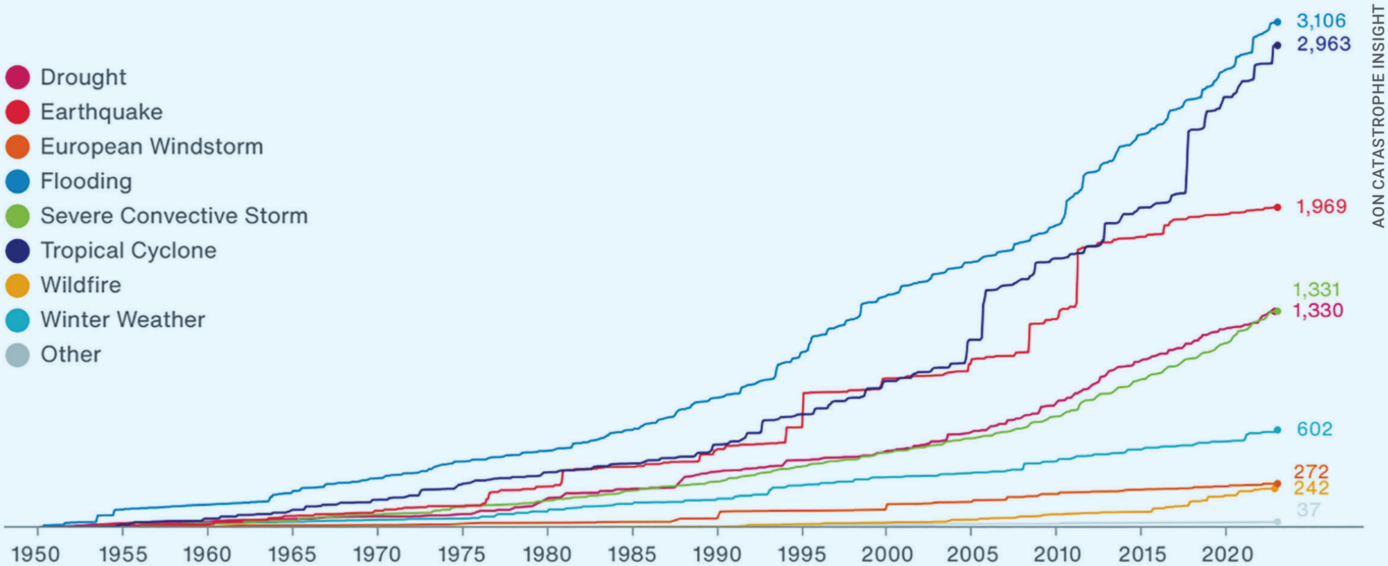
Understanding Coastal Risks and Their Impacts

Climate change is amplifying coastal hazards, including sea level rise, coastal storms, flooding, erosion, and subsidence.[19] The Intergovernmental Panel on Climate Change (IPCC), which is the leading international body for the assessment of climate change, has documented accelerating global sea level rise as well as more intense coastal storms and frequent coastal flooding.[20,21] Coastal hazards are intensifying with faster winds, increased rainfall, and more extreme wave action.[22]

These global changes translate into myriad local impacts including flooding, land and elevation loss, saltwater intrusion into groundwater, degradation of ecosystems, as well as property, infrastructure, and community damage and destruction. The consequences of these impacts compound upon one another, resulting in interrelated economic, environmental, and social effects for both real estate and communities. Understanding these hazards and their impacts can help stakeholders appropriately address them.

Billion-Dollar Losses from Climate-Related and Coastal Hazards

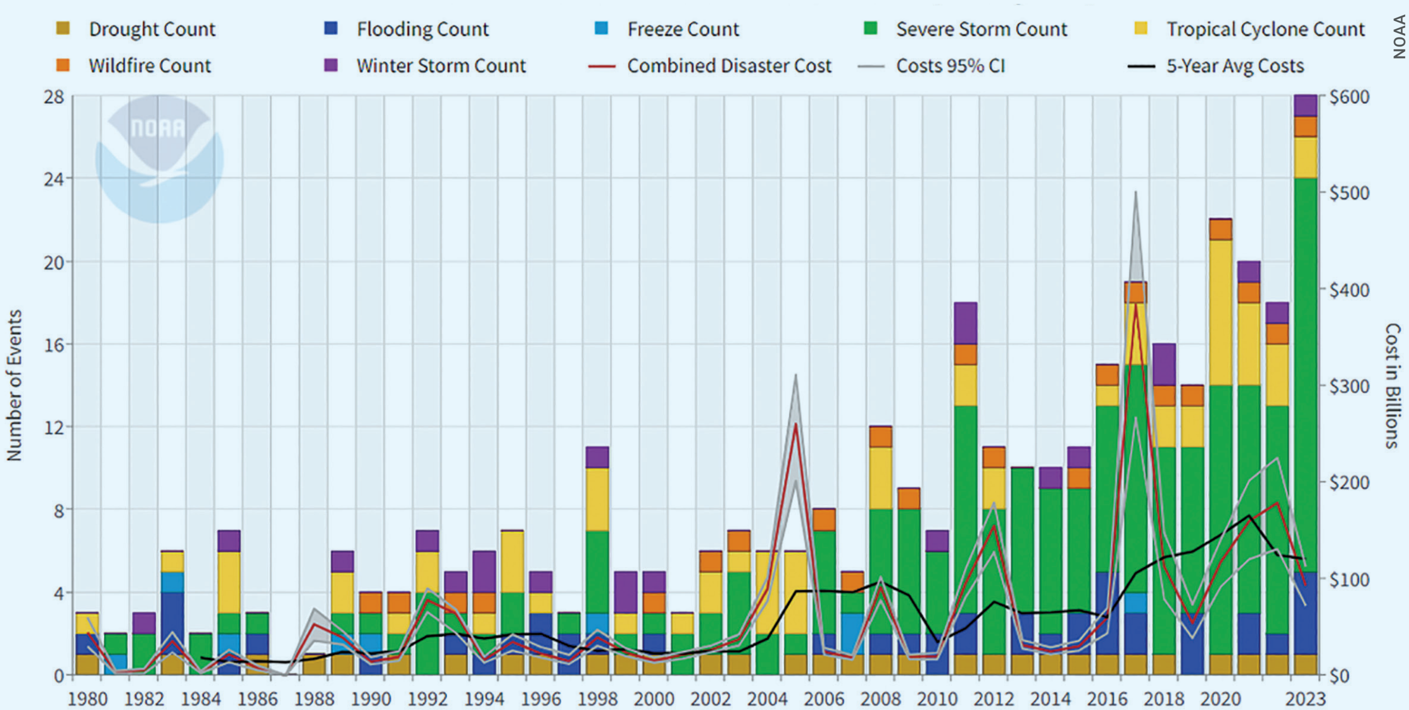
CUMULATIVE GLOBAL ECONOMIC LOSSES BY PERIL (2023 $B)



Cumulative global economic losses from natural disasters increased significantly between 1950 and 2023. Flooding and tropical cyclones have led to the highest economic losses globally.

Fort Myers Beach in Florida in the aftermath of Hurricane Ian (2022).

UNITED STATES BILLION-DOLLAR DISASTER EVENTS 1980–2023 (CPI-ADJUSTED)



From the 1980s to 2023, the United States has experienced an increase in frequency of billion-dollar climate-related disasters. Even without accounting for loss of life, health care–related costs, or damages to ecosystem services, these disasters have cost the U.S. economy over US$7 trillion. The cost of coastal hazards, such as tropical cyclones, has exceeded US$3 trillion.[23]

BILLION-DOLLAR LOSSES FROM NATURAL CATASTROPHES IN 2023

REGION	TOTAL ECONOMIC LOSSES IN BILLIONS OF U.S. DOLLARS (2023)	INSURED LOSSES IN BILLIONS OF U.S. DOLLARS (2023)	PROTECTION GAP IN BILLIONS OF U.S. DOLLARS (2023)
NORTH AMERICA	98	73	25 (26%)
EUROPE	109	27	82 (75%)
AFRICA	10	1	9 (90%)
ASIA	50	8	42 (84%)
OCEANIA/AUSTRALIA	8	4	4 (50%)
LATIN AMERICA & CARIBBEAN	16	5	11 (69%)

Source: Swiss Re Institute.[24]

Total economic losses around the world from natural catastrophes and human-made disasters in 2023 are shown in the table above, indicating a wide gap in insurance coverage in every global region. Europe experienced an outlier year in 2023 in damages and number of victims (nearly 63,000, many times higher than all other regions), driven by “record high severe convective storm losses in Italy and a series of large-scale earthquakes and floods.”[25]

Coastal Resilience along Lakes, Rivers, and Streams

While this report focuses on ocean coasts, it is important to note that lake, river, and stream shorelines can also experience significant storms, flooding, erosion, and subsidence. As an example, the Great Lakes of the United States and Canada are similar to inland seas, and the communities surrounding those lakes face many of the coastal hazards discussed in this report.[26] As is the case for the world's oceans and oceanfront communities, lake water levels and lakeside climate conditions are also affected by ice melt, and land adjacent to lakes and rivers can be similarly damaged by flooding, storms, erosion, and subsidence.[27]

The recommendations and resources in this report can also be applied to lake and river contexts.

Additional guidance and resources are available in the following ULI reports:

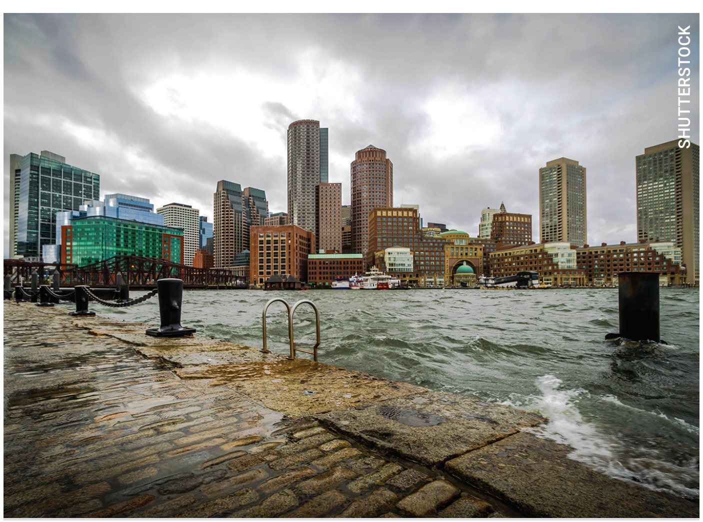
- [The Business Case for Green Infrastructure: Resilient Stormwater Management in the Great Lakes Region]
- [Harvesting the Value of Water: Stormwater, Green Infrastructure, and Real Estate]
- [Cloudburst Infrastructure Workshop for New York City Housing Authority]
- [Resilient Retrofits: Climate Upgrades for Existing Buildings]
- [Enhancing Resilience through Neighborhood-Scale Strategies]
- [Parks that Protect: Leveraging Waterfronts for Resilient Communities]

Global average sea level has risen 8 to 9 inches (21–24 cm) since 1880, and the rate of global sea level rise is accelerating.[28] For most of the 20th century, the sea level rose at a rate of about 0.06 inches (1.4 mm) each year. However, between 2006 and 2015, this rate more than doubled to 0.14 inches (3.6 mm) per year.[29,30] Global average sea level rise is accelerating due to ice sheet melt, glacier loss, and ocean thermal expansion caused by global warming.[31] Global warming refers to the Earth's average temperature increasing, leading to changes in climate and weather patterns.

By the year 2100, experts expect the average global sea level to be between 24 and 86.4 inches (0.6 to 2.2 m) higher than in 2000.[32] The IPCC and the National Oceanic and Atmospheric Administration (NOAA) estimate that by 2050, the global sea level will rise by 9 to 12 inches (about 23–30 cm).[33,34] This future increase is largely due to the greenhouse gases we have already emitted and continue to emit. However, predictions for sea level rise after 2050 are less certain because of the challenges of foreseeing how Earth's natural response systems will react to ongoing warming and how effectively humans will reduce future emissions.[35]

"It is not a matter of if these projections will be achieved; it's only a matter of when."

CM SHUN
Former director, Hong Kong Observatory



The city of Boston is at risk from and adapting to rising sea levels.

It is also important to note that sea level rise and associated impacts can vary regionally and locally.[36,37,38] Topography, erosion, oil and groundwater pumping, subsidence, tectonic plate shifts, and ocean currents can all contribute to higher or lower local sea levels than the global average.[39,40]

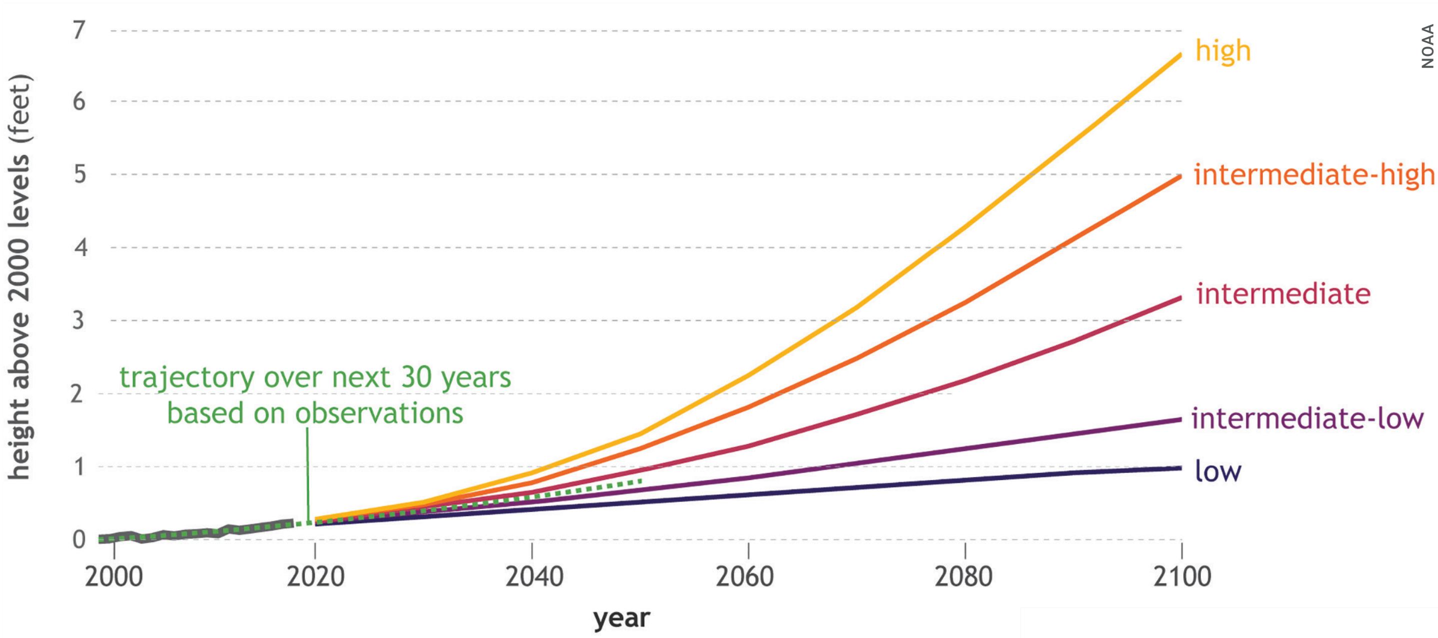
Some cities and regions face heightened vulnerability to sea level rise. The rate of sea level rise along the U.S. East Coast exceeds the global average by two to threefold. Worldwide, Miami, Guangzhou, and New York rank as the top three cities in terms of asset exposure to coastal flooding from 2010 to 2070, valued between US$2 trillion and US$3.5 trillion. Meanwhile, Kolkata, Mumbai, and Dhaka face the highest population risk from coastal inundation, with between 11 million and 14 million people potentially affected.[41,42]

Projected Sea Level Rise Impacts in Hong Kong

China Water Risk mapped 185,000 properties in Hong Kong with projected exposure to sea level rise. With 1.6 feet (0.5 m) of sea level rise, they project that 1,830 residential buildings and 43 commercial buildings will be under water. With 6.6–9.8 feet (2–3 m) of sea level rise, they project that 40,256 residential buildings, 3,010 commercial buildings, and 1,968 industrial buildings will be under water in Hong Kong.[43]

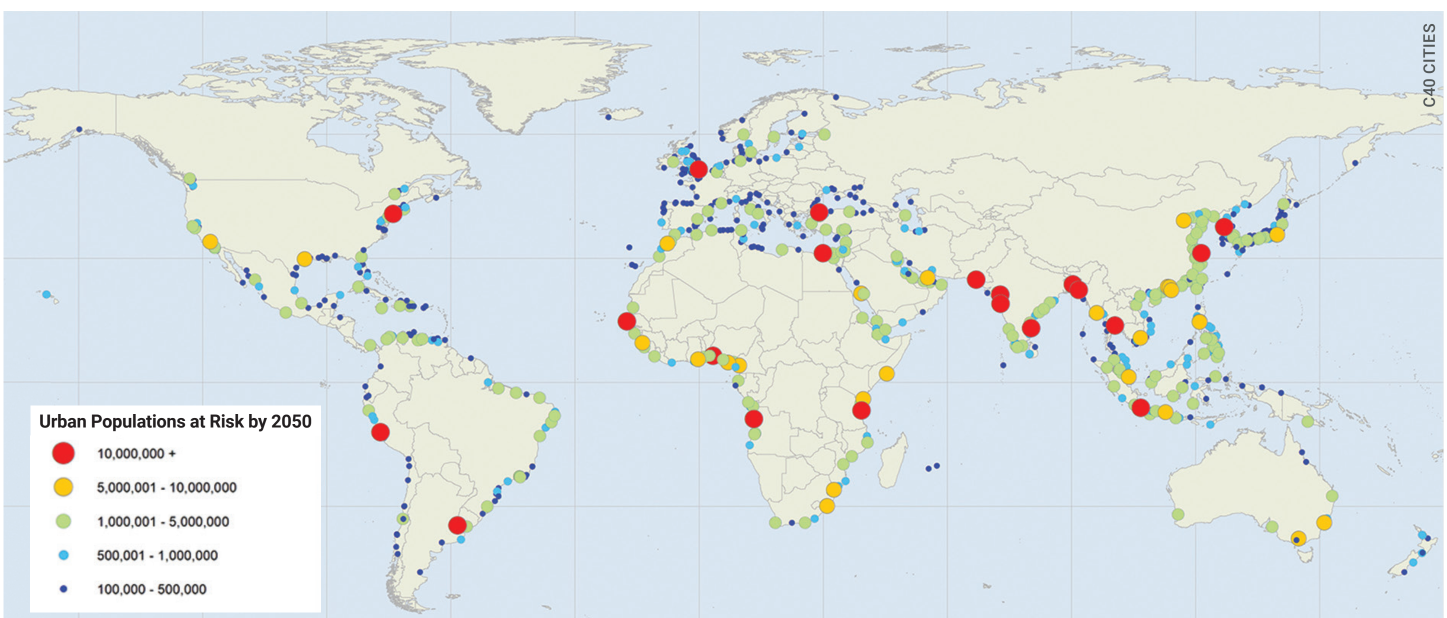
Regardless of what future emissions scenario takes place, sea level rise will continue to heavily impact coastal areas due to past and current emissions.[44] Sea level rise threatens coastal communities through a range of related coastal hazards, including the permanent inundation of land by higher average sea levels and high tides; more frequent and intense coastal flooding; increased erosion; loss and change of coastal ecosystems; salinization of soils, ground, and surface water; and hindered drainage.[45] Extreme sea levels and others coastal hazards will be exacerbated by projected increases in storm intensity and precipitation.[46] By 2050, NOAA estimates that "moderate" flooding that is typically damaging to property will occur more than 10 times as often as it does today on average in the United States, and it can be intensified by local factors.[47]

POSSIBLE PATHWAYS FOR FUTURE SEA LEVEL RISE

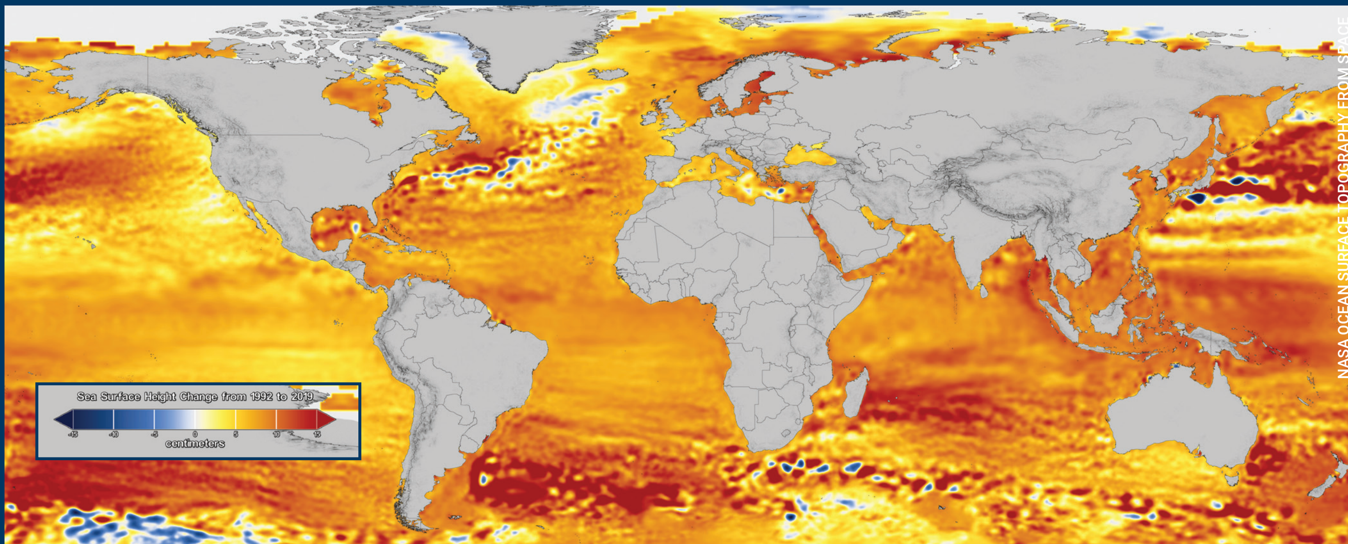


Observed sea level from 2000–2018, with future sea level through 2100 for six future pathways (colored lines). The pathways differ based on future rates of greenhouse gas emissions, global warming, and differences in the plausible rates of glacier and ice sheet loss.

CITIES AT RISK FROM SEA LEVEL RISE BY 2050



Cities at risk from sea level rise of 1.4 feet (0.5 m) by 2050 under a high (RCP8.5) emissions scenario.



Changes in global sea surface height between 1992 and 2019 based on satellite altimetry data from the TOPEX/Jason series of ocean altimetry missions. The red and yellow colors indicate an overall rise in sea surface height; the blue areas indicate regions where sea surface height is falling.

Sea Level Rise Projection Tools and Resources

The National Aeronautics and Space Administration (NASA) Sea Level Projection Tool allows users to visualize and download global sea level projection data from the IPCC 6th Assessment Report. The goal of this tool is to provide easy and improved access and visualization to the consensus projections on future sea levels found in the report. For more detailed local projections, local or national sources may be more accurate since the IPCC provides global projections.

NOAA's Sea Level Rise Viewer is a web mapping tool to visualize community-level impacts from coastal flooding or sea level rise (up to 10 feet [about 3 m] above average high tides) for the United States. Photo simulations of how future flooding might impact local landmarks are also provided, as well as data related to water depth, connectivity, flood frequency, socioeconomic vulnerability, wetland loss and migration, and mapping confidence.

Climate Central's Coastal Risk Screening Tool is an interactive online platform designed to illustrate the potential impacts of sea level rise and coastal flooding worldwide. This tool allows users to explore scenarios of future sea level increases (up to 10 feet [about 3 m] above current levels) and assess the risk to coastal areas. It offers visualizations, including maps and projections, of how rising sea levels could affect various regions, cities, and local landmarks.

Application Guide for the Sea Level Rise Technical Report

The NOAA *Application Guide for the 2022 Sea Level Rise Technical Report* ("Application Guide"), is designed to assist with the application and integration of the information in the 2022 Sea Level Rise Technical Report into local sea level rise planning and adaptation decisions. The Application Guide focuses on the United States and includes examples from different geographic regions of the country. It describes how updated sea level rise scenarios and related science information in the 2022 Sea Level Rise Technical Report can be considered and applied through various coastal hazard evaluation and planning approaches.[48]

COASTAL STORMS

One of the most striking consequences of climate change is the changing pattern of coastal storms. Climate change is leading to more intense coastal storms, primarily as a result of warming temperatures and changing ocean currents.[49,50] Coastal storms can bring with them extreme winds, precipitation, storm surges, and flooding and are known by many names: cyclones, typhoons, hurricanes, nor'easters, atmospheric rivers, and tropical depressions, to name a few.

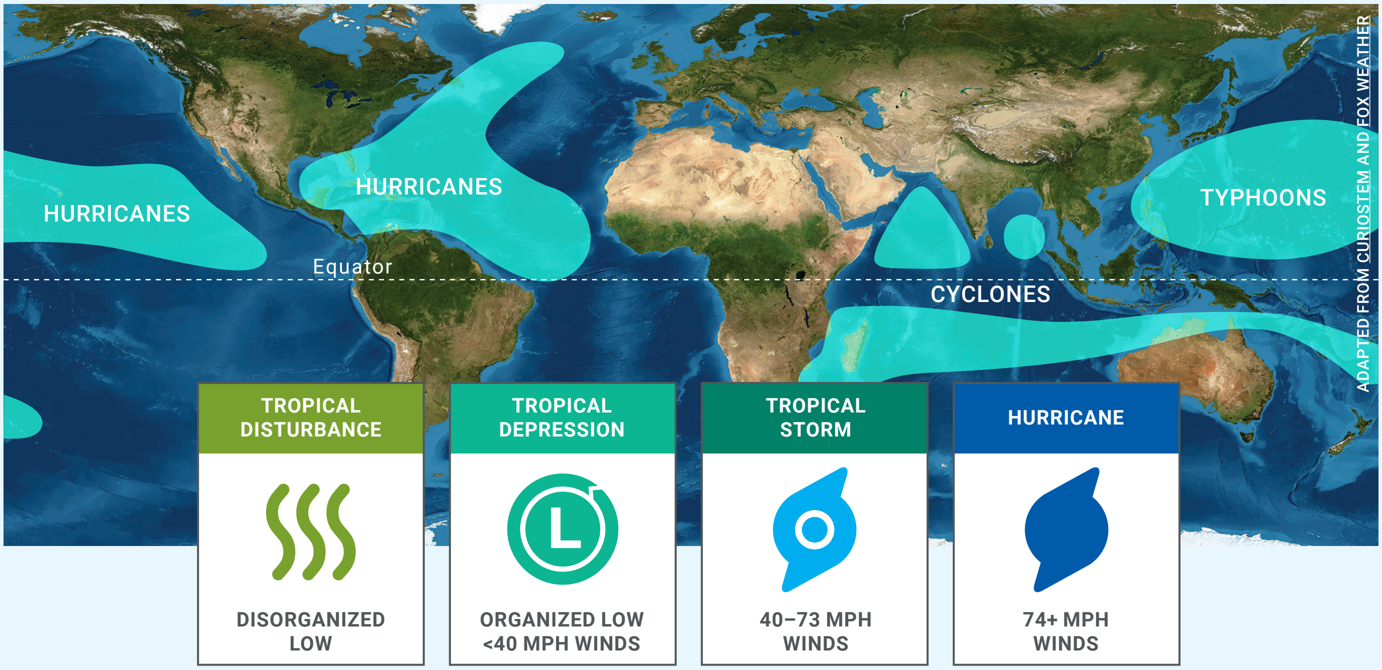
Hurricane aftermath.

Coastal storms can cause extensive damage. The total damages from tropical cyclones globally have reached hundreds of billions of dollars annually. In the United States alone, hurricanes accounted for over US$1.3 trillion in damages from 1980 to 2023, with an average cost of US$22.8 billion per event. On average, around 80 to 90 named tropical cyclones form each year around the world.[51,52] Hurricanes were also responsible for the highest number of deaths of all weather-related disasters in the United States during that same period.[53] Coastal storms are known to damage and destroy properties, which drives up the costs of maintaining real estate assets and displaces people, among many other impacts (see Cumulative Impacts of Coastal Hazards on page 26 for more information).

> "Imagine living in the top floor of a high rise, and suddenly your elevator stops working, your water stops working, your electricity stops working. It leads to a completely dysfunctional and dangerous city."
>
> **STEFAN AL**
> *Founder, Stefan Al Architects*

Commercial Mortgage-Backed Security Property Exposure to Storm Surge on the East and Gulf Coasts of the United States

According to Moody's Climate on Demand tool, 2,733 commercial mortgage-backed securities properties are currently exposed to coastal storm surge on the East and Gulf coasts of the United States.[54] By 2050, the cumulative average damage to these properties due to storm surge in a high emissions (RCP 8.5) scenario is expected to be about US$6.7 billion, which equates to an average damage of nearly US$2.5 million per property. For these properties exposed to sea level rise, 4 percent of them will have cumulative annualized damage rates (ADRs) of 25 percent or more by 2050, while 8 percent will have ADRs of 10–25 percent, and 6 percent will have ADRs of 5–10 percent.[55] ADRs include the expected damage due to coastal storm surge per year as a ratio of total value, combining estimates of financial damage due to impacts on the building and its contents, and losses or increased costs from business interruptions. As these data focus only on storm surge, they do not factor in business interruptions or property damage that are due to high tide flooding or other impacts of sea level rise not associated with hurricanes. Thus, these damage estimates capture only a portion of the financial damage properties can expect from coastal hazards.



How tropical storms develop, and their global naming conventions based on geography.

Hurricanes, Cyclones, and Typhoons

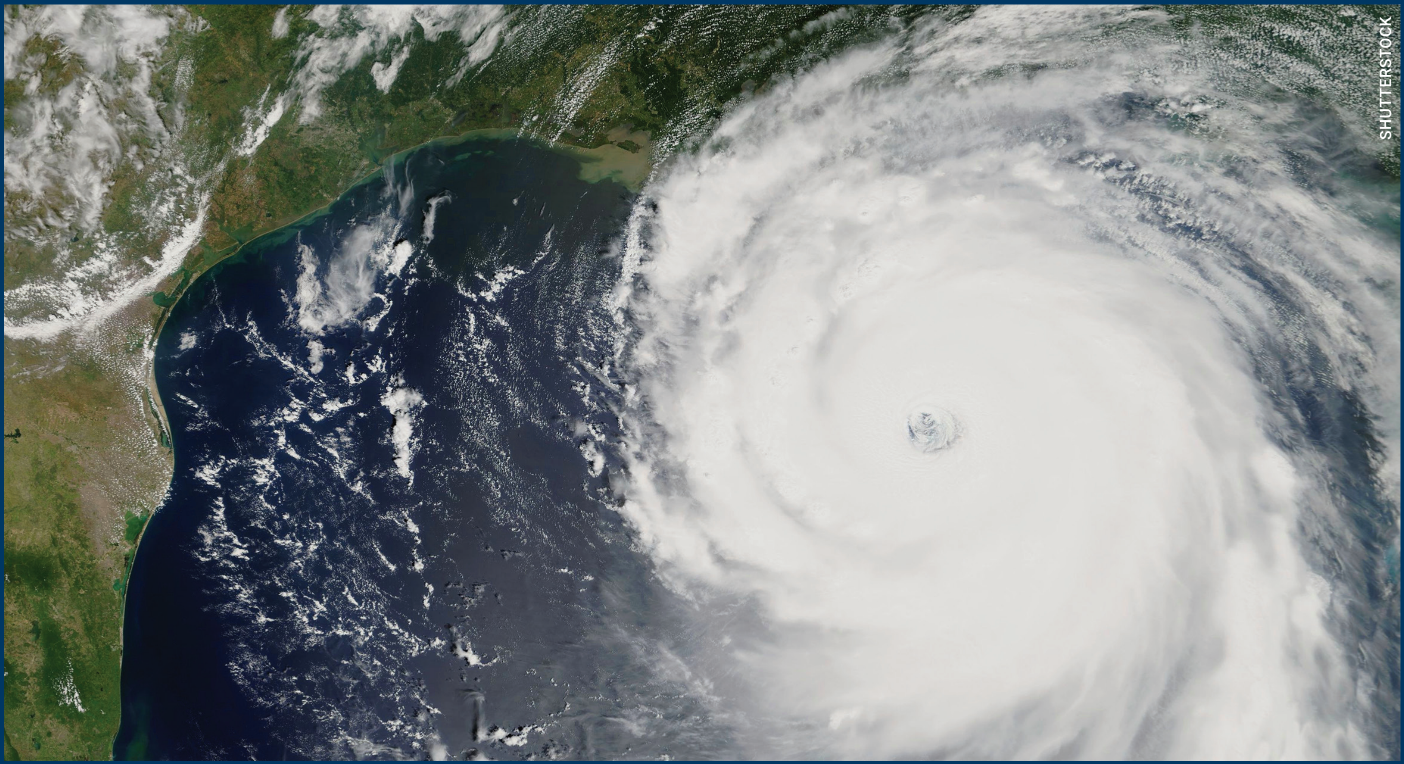
Hurricanes, cyclones, and typhoons are rapidly rotating storm systems formed over oceans. When their wind speeds reach at least 74 miles per hour (119 kph), these storms are categorized on the Saffir-Simpson scale. They are called hurricanes when they develop over the North Atlantic, central North Pacific, and eastern North Pacific, and are known as cyclones when they form over the South Pacific and Indian Oceans, and typhoons when they develop in the Northwest Pacific.

When these rotating storms form over warm waters, they have warm cores and are designated as "tropical." When they form over colder waters (like nor'easters) or lose their warmth, leading to a cold core, they are designated as "non-tropical" or "post-tropical," respectively. It is important to note that the "post-tropical" designation is not a downgrade from a tropical storm; it merely means that the tropical storm has undergone a transition. Tropical storms are more symmetrical, do not have fronts, and have winds that are concentrated near their center, while non-tropical and post-tropical storms are comma shaped, have fronts, and have winds and precipitation that can spread out for hundreds of miles. Tropical, non-tropical, and post-tropical storms can all threaten lives and property.[56]

CATEGORY	SUSTAINED WINDS	TYPES OF DAMAGE DUE TO HURRICANE WINDS
1	74-95 mph 64-82 kt 119-153 km/h	**Very dangerous winds will produce some damage:** Well-constructed homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to powerlines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 83-95 kt 154-177 km/h	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3	111-129 mph 96-112 kt 178-208 km/h	**Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4	130-156 mph 113-136 kt 209-251 km/h	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5	157 mph or higher 137 kt or higher 252 km/h or higher	**Catastrophic damage will occur:** A higher percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

NOAA

The Saffir-Simpson scale is a one-to-five rating based on a hurricane's maximum sustained wind speed and includes the types of damage it is likely to wreak on structures. It does not account for other related hazards like storm surge, rainfall flooding, and tornadoes.



Hurricane Katrina approaches New Orleans (2005).

Impacts of Major Coastal Storms on Communities and Markets

HURRICANE KATRINA (2005)

Katrina made landfall in Florida, Louisiana, and Mississippi as a Category 1-through-3 storm, permanently displacing many residents and altering community character, leading to public policy changes related to natural disasters and cementing climate resilience as a national priority.[57]

Hurricane Katrina was the costliest storm in U.S. history and has had widespread economic and social impacts.[58] Hurricane Katrina was responsible for nearly 1,400 fatalities, displaced approximately 650,000 people, and destroyed or severely damaged around 217,000 homes along the Gulf Coast, resulting in an estimated US$125 billion in damage (2005 USD).[59,60] Private insurance companies paid US$41 billion (2005 USD) on 1.7 million claims, and the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program paid US$16.3 billion (2005 USD) for publicly insured flood damages. The difference between Katrina's total economic damage and insured damages highlights the protection gap from uninsured and underinsured losses.[61]

Damage was especially severe in New Orleans, and while the city has undergone significant redevelopment since Katrina, many low-income individuals and people of color were permanently displaced, causing a shift in the character of impacted communities and throughout the city.[62] More than 75,000 black residents that evacuated the city had not returned 10 years later.[63] Following Hurricane Katrina, the U.S. Army Corps of Engineers updated and recertified New Orleans's Hurricane and Storm Damage Risk Reduction System, which is a 130-mile-long (209 km) system of levees, surge barrier walls, flood walls, and pump stations that protects New Orleans from storm surge and flooding of 100-year storms. Louisiana has since adopted a statewide building code, the Louisiana State Uniform Construction Code, to reduce building vulnerability and wind damage from hurricanes.[64] Federal agencies began to focus more on hazard mitigation and resilience in the aftermath of Hurricane Katrina.[65]

CYCLONE SIDR (2007)

Sidr made landfall in Bangladesh as a Category 5–equivalent tropical cyclone, causing extensive damage and loss of life, but demonstrating Bangladesh's progress in reducing vulnerability.

Cyclone Sidr hit Bangladesh's densely populated Bay of Bengal region and destroyed over 500,000 homes, flooded nearly 5,000 miles (8,000 km) of roads, displaced 600,000 people, and affected nearly 9 million residents, totaling US$1.67 billion (2007 USD) in damages.[66, 67] Despite the disastrous impacts, the storm showed the value of Bangladesh's extensive infrastructure investments since the 1970s in resilience measures such as polders, storm shelters, emergency warning and evacuation systems, as well as higher codes and design standards for infrastructure and buildings. In a major storm in the early 1970s, nearly half a million people died, and a 1991 storm, similar in strength to Sidr, resulted in an estimated 130,000 fatalities. In contrast, Cyclone Sidr's fatalities totaled around 3,000—a devastating loss, but much lower than in previous years.[68]

HURRICANE SANDY (2012)

Sandy made landfall in the Caribbean and along the Mid-Atlantic coast of the United States as a Category 3 and then Category 1–equivalent posttropical storm. It led to the development of resilience plans, programs, and funding in the northeastern United States.

Hurricane Sandy resulted in widespread coastal flooding and over US$70 billion (2012 USD) in economic damages, damaging or destroying at least 650,000 homes and affecting more than 300,000 business properties. Insured losses were around US$30 billion, including US$7.2 billion from FEMA's National Flood Insurance Program. The storm also led to the deaths of 285 people from the Caribbean to Canada.[69] After the storm, New York City became one of the first localities to adopt a resilience plan, called the "Stronger, More Resilient New York" plan. The city invested US$20 billion to manage its risk from future coastal storms and marshalled significant federal funds to support recovery efforts. The funding supported the installation of millions of cubic yards of sand in coastal areas, miles of dunes, thousands of linear feet of bulkheads, and improvements to the city's building code.[70]

TYPHOON MANGKHUT (2018)

Mangkhut made first landfall in the Cagayan province of the Philippines as a Category 5 storm and subsequently impacted Hong Kong and southern China, highlighting how improvements to warning systems, preparedness, and infrastructure can support better storm outcomes.

Typhoon Mangkhut caused around US$3.77 billion (2018 USD) in damage across the Philippines, Hong Kong, Macau, and Guangdong, China, along with at least 134 fatalities and many more affected.[71,72] Mangkhut wrought widespread destruction to the region with its extreme winds and record-breaking storm surge. The estimated direct economic loss due to Mangkhut in Hong Kong alone was about HK$ 4.6 billion (over US$589 million). However, having learned from Typhoon Hato in 2017, Hong Kong had instituted early and effective storm warnings, increased public awareness and typhoon preparedness, and enhanced infrastructure in the major impact areas, all of which likely helped reduce damages.[73]

TYPHOON HAGIBIS (2019)

Hagibis made landfall in Japan as a Category 2-through-5-equivalent tropical storm, causing widespread flooding and significant economic losses that showed room for greater resilience in a nation known for strong disaster preparedness and infrastructure quality.

Typhoon Hagibis dropped record-setting amounts of rain on Japan, causing over 77 rivers to overflow their banks and levees and illustrating interactions between coastal hazards and river flood risks.[74] Over 100 fatalities were recorded and, at one point, nearly 4 million residents were urged to evacuate to safer areas.[75] Heavily urbanized areas were hit hard by flooding that overtopped levees; much of prefectural capital Nagano City was under water, and 10 trains of the Hokuriku Shinkansen Line parked there were flooded, causing US$300 million (2019 USD) of damage alone. Total damages reached at least US$10 billion (2019 USD), US$4 billion of which was later directly attributed to climate change.[76] Hagibis was the costliest typhoon on record for Japan at the time and demonstrated that even highly prepared nations and markets need to strengthen their infrastructure and assets in light of worsening hazards.

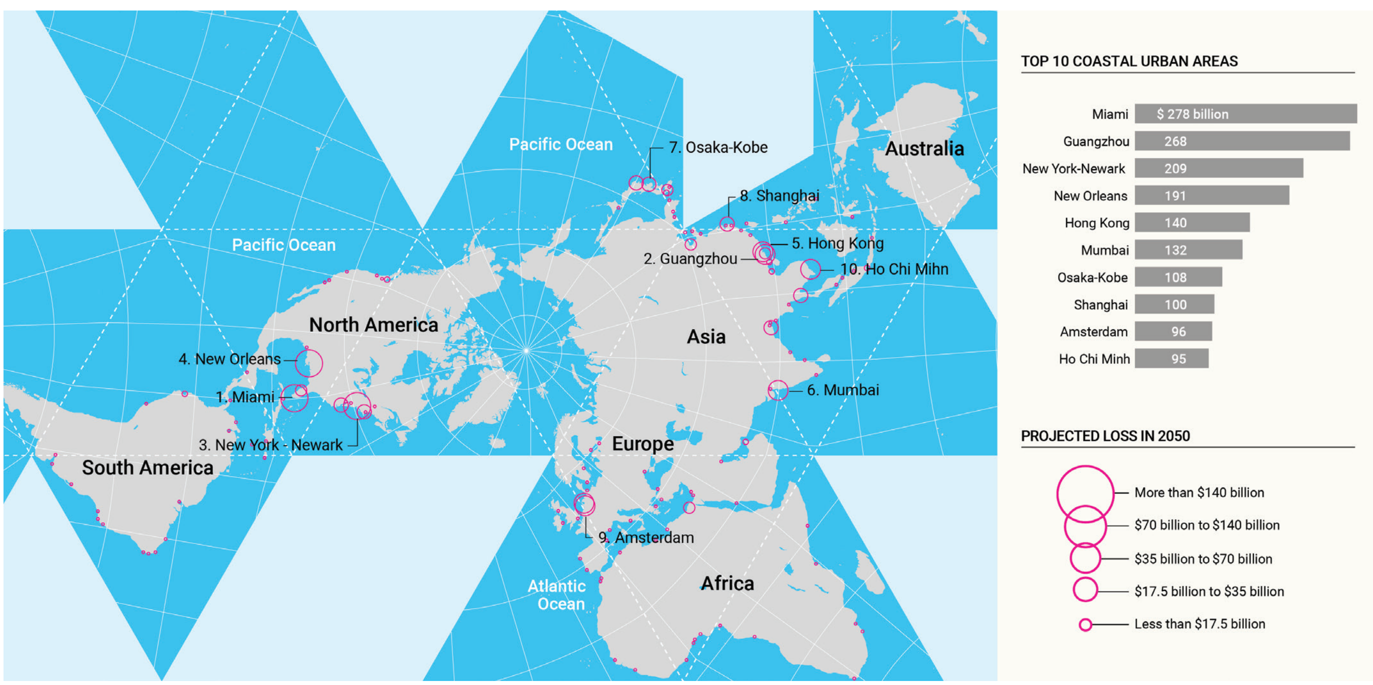
FLOODING

Strong evidence indicates that flood intensity and frequency will increase globally in humid and semihumid regions as the planet warms.[77,78] Heavy precipitation, rising sea levels, coastal storms, erosion, and subsidence all contribute to and exacerbate coastal flooding. In the absence of ambitious adaptation efforts, annual coastal flood damages are projected to increase by two to three orders of magnitude by 2100.[79]

Flooding has caused devastating impacts globally, with estimated damages reaching US$651 billion and affecting 1.6 billion people between 2000 and 2019 alone.[80] Population growth in floodplains and climate change are likely to contribute to a dramatic increase in global average flood losses, from US$6 billion per year in 2005 to over US$60 billion in 2050.[81] By 2100, the value of global assets within future 100-year coastal floodplains is projected to be between US$7.9 and US$12.7 trillion (2011 USD) under an intermediate greenhouse gas emissions scenario, rising to between US$818 billion and US$14.2 trillion under a high emissions scenario.[82,83]

Areas where flooding commonly occurs are known as floodplains. In the United States, more than 41 million people live under the threat of flooding. But because the Federal Emergency Management Agency (FEMA) flood maps generally do not account for climate change, only about 13 million of those people live in a recognized floodplain.[84,85,86] Globally, about 1.81 billion people, or 23 percent of the world population, are directly exposed to 1-in-100 year floods with depths greater than 6 inches (0.15 m), posing risks to lives and livelihoods.[87] Despite the risks from flooding, population growth and urbanization in floodplains have substantially increased over the past several decades in many parts of the world.[88]

There are numerous types of floods, but they can generally be grouped according to three categories: coastal, riverine, and pluvial.

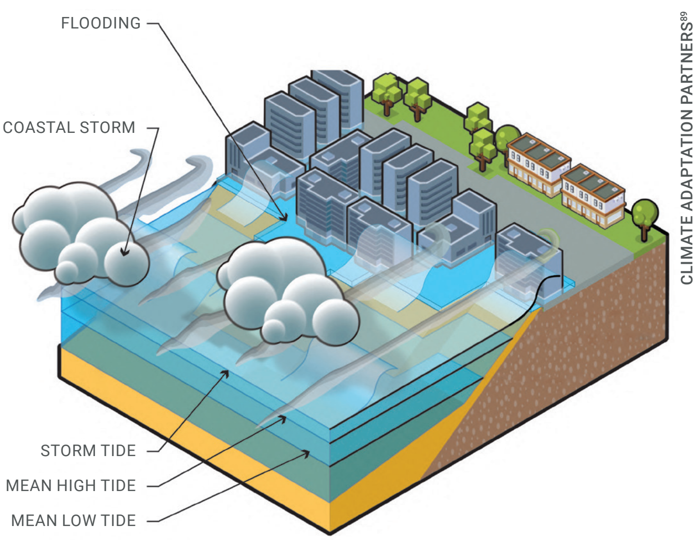


ADAPTING CITIES TO SEA LEVEL RISE: GREEN AND GRAY STRATEGIES BY STEFAN AL, ADAPTED FROM "FUTURE FLOOD LOSSES IN MAJOR COASTAL CITIES"

Projected global flood losses by 2050.

Flooded homes in Florida following Hurricane Ian (2022).

COASTAL FLOODING

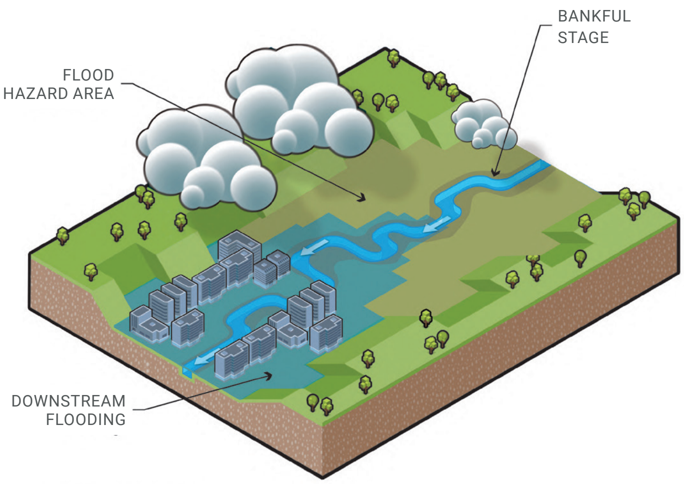


Coastal flooding occurs when low-lying land is submerged by seawater, which can result from coastal storms, coastal erosion, sea level rise, tides, or even tsunamis.[90] The range of coastal flooding depends on the elevation of floodwater, wave heights, and the topography of the coastal land exposed to flooding.[91] More severe coastal storms are generating surges of ocean water that ride higher sea levels farther inland than ever before.[92]

"Storm surges from a hurricane amplify coastal flooding. By how much depends on whether the hurricane makes landfall at high or low tide, whether it coincides with a spring or king tide, how high the winds are, how low the atmospheric pressure is at the center of the hurricane, and how long it remains over the shoreline. In the worst combinations of these conditions, the height and velocity of the flood surge can endanger people, destroy structures, and drive seawater much farther inland than the highest regular tide. Increasingly high tides and more frequent big hurricanes are a dangerous combination for coastal communities."

JONATHAN BARNETT AND MATTHIJS BOUW
Managing the Climate Crisis

RIVERINE FLOODING



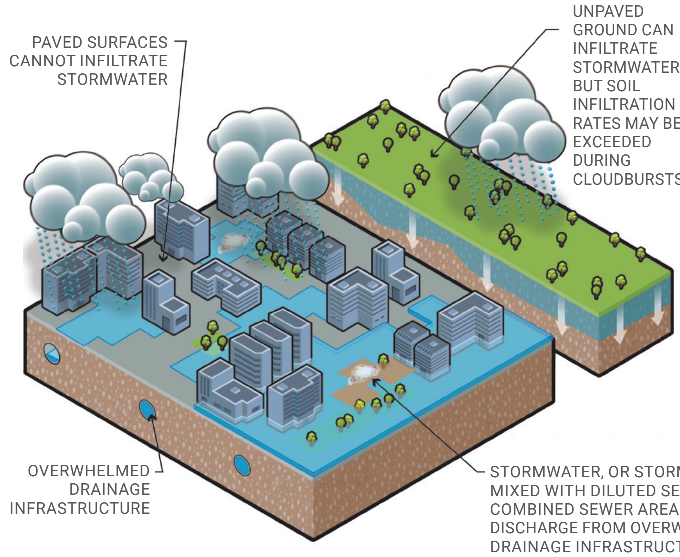
CLIMATE ADAPTATION PARTNERS[93]

Riverine flooding, or *fluvial* flooding, occurs when rivers or streams overflow their banks and flow into surrounding areas, which could be due to torrential rain or snow melt or, in the case of tidal rivers, to sea level rise, tides, and storm surge. These floods happen when water exceeds the capacity of the natural or constructed channels of streams and rivers, and can persist for days or weeks, depending on the terrain.[94]

SHUTTERSTOCK

Buffalo Bayou Park in Houston helps absorb floodwaters from Hurricane Beryl (2024).

PLUVIAL FLOODING



CLIMATE ADAPTATION PARTNERS[95]

Pluvial flooding occurs when increased rainfall creates a flood independent of an existing body of water. It can take place in any location, although coastal areas are increasingly impacted by precipitation and coastal storms. Heavy precipitation, intensified by climate change, is exacerbating coastal risks such as flood and erosion.[96] As global temperatures rise, the atmosphere's capacity to hold moisture increases, leading to more intense and frequent rainfall events and heightened flood risks. Pluvial floods, like fluvial floods, come in two forms: surface water floods and flash floods. Surface water floods result when a drainage system is overwhelmed. Flash floods are triggered by immense rainfall in a short period near low-lying terrain.[97]

How Floods Damage Real Estate

Floods cause damage to coastal properties in many ways. The following list provides a few examples of how floods damage properties according to the 2022 IPCC Working Group II report.

High velocity floods tear buildings from their foundations. Hydrodynamic forces are the forces exerted by moving water.

Debris carried by floodwaters act as battering rams. Debris impact refers to damage caused by floating or submerged debris carried by floodwaters.

Walls and supporting structures give way when floodwaters press upon them. Hydrostatic forces are the forces exerted by stationary or slowly moving water.

Building materials degrade when submerged in floodwater for extended periods of time. Soaking refers to the damage caused by prolonged exposure of materials and structures to water.

Materials absorb harmful substances and pathogens carried with floodwaters. Sediment and contaminants carried by floodwaters can deposit in areas after water recedes. Mold growth on materials is an especially hazardous secondary impact of flooding.

Human activities, notably urbanization and land-use changes, have influenced global flooding patterns.[98] An analysis of 106 major river basins worldwide revealed that these changes, combined with increasing precipitation, are responsible for increased flooding in areas that were historically dry in most basins.[99] In addition, rapid urbanization and population growth in flood-prone areas exacerbates the risk and severity of flooding, highlighting the need for adaptation strategies to address these risks.[100,101,102,103,104]

"Just small increases in the base water level [due to sea level rise] can have profound implications on the frequency and the magnitude of high tide flooding; and that has many implications for our coastal communities."

JOSH MURPHY
Program manager, Office for Coastal Management
National Oceanic and Atmospheric Administration

Additionally, coastal flooding is expanding beyond the vicinity of the historic average high-water mark, impacting inland areas not traditionally prone to flooding. This extended reach of flooding is largely attributed to rising sea levels, exacerbated by climate change and increased storms and precipitation, as well as land uses that diminish natural barriers, such as development on coastal dunes or barrier islands.

This expansion is evidenced by the growing occurrence of "nuisance flooding," a term used to describe minor but frequent flooding events. These events, although seemingly minor, can lead to substantial economic and infrastructure impacts by damaging roads, overwhelming storm drains, and affecting local businesses and property values. NOAA reports that nuisance flooding has increased significantly on all three U.S. coasts, ranging from 300 to 925 percent since the 1960s.[105] For this reason, NOAA now uses the term "high-tide flooding," because the chronic flooding has exceeded nuisance levels.[106] Moreover, a study by the Union of Concerned Scientists found that accelerating sea level rise is projected to worsen tidal flooding, potentially putting as many as 2.5 million homes and businesses in the lower 48 states—totaling US$1 trillion in value—at risk of chronic flooding within the next 30 years.[107]

COASTAL EROSION

Coastal erosion is the process by which sea level rise, waves, currents, flooding, and wind wear away terrain along the coast. While all coastlines are affected by erosion, storm surges and strong waves frequently cause the most damage, such as removing wide beaches and substantial dunes in single events.[108] Sea level rise and increased storm intensity are exacerbating erosion globally, as is coastal development, but erosion rates and impacts are highly localized.[109,110]

In densely populated locations, one or two feet of coastal erosion could be disastrous.[111] Erosive forces can destroy homes, businesses, roads, and other infrastructure, increase risk from future storms, and require people to move inland.

Globally, coastal erosion has led to the loss of about 17,400 square miles (28,000 sq km) of land between 1984 and 2015, which is double the area of land gained from sediment returning to the coast over the same time period.[112] In the United States, coastal erosion causes around US$500 million per year in coastal property losses, including structural damage and land loss.[113] In Europe, the IPCC estimated that the damages from marine erosion cost an average of €5.4 billion (US$5.85 billion) annually between 1990 and 2020.[114]

Large swaths of eastern England are experiencing accelerated erosion by the North Sea, and by some estimates 21 communities and US$744 (£584) million worth of residential properties will be lost to coastal erosion by 2100.[115] Studies have also estimated that up to 70 percent of California beaches could disappear by 2100 due to coastal erosion and sea level rise.[116]

Global Impacts of Coastal Erosion

United States: Scientists are predicting the disappearance of between one- and two-thirds of the beaches by the end of the century along the U.S. West Coast, where buildings have been falling off seaside cliffs due to severe erosion.[117,118] In addition, over 80,000 acres of coastal wetlands are lost to erosion each year in the United States, which is equivalent to seven football fields disappearing every hour, every day.[119]

United Kingdom: The Committee on Climate Change estimated that around 9,000 properties in England will be lost to coastal erosion by 2025. In Scotland, more than 93,000 residential and commercial properties are at risk of coastal flooding and erosion.[120,121] A study found that property values in the United Kingdom dropped between 10 and 25 percent once the risks of erosion became known.[122]

Australia: Increasing coastal erosion will potentially impact AU$25 billion (US$16.7 billion) worth of Australia's residential coastal property within the next three decades.[123] Some of the country's most expensive real estate was listed as highly at risk from coastal erosion currently and over the next 30 years.[124,125]

Japan: Beach loss along the entire coast of Japan is predicted to be around 62 percent under a low-emissions scenario (RCP2.6) and 83 percent under a high-emissions scenario (RCP8.5) from 2081 to 2100 due to sea level rise.[126]

Vietnam: Coastal tourism relies heavily on intact beaches and ecosystems. In Vietnam, around 42 percent of coastal hotels are located near eroding beaches.[127]

The human response to coastal erosion is critical. Ironically, hard infrastructure solutions like bulkheads and jetties meant to control erosion often worsen it through scour.[128,129] Scour occurs when water erodes the sediments that surround hard structures. However, if shorelines are allowed to migrate naturally, erosion rates will continue to increase, especially in areas that are already dealing with low amounts of sediment.[130] Strategies that incorporate and leverage nature-based solutions tend to be the most effective at addressing coastal erosion (for more information, see Adaptation Strategies for Coastal Resilience on page 38).

Tools for Visualizing Coastal Erosion

The Global Coastline Explorer provides visualization and feature identification of Earth's coastlines through a high-resolution map. This resource was developed by the U.S. Geological Survey in partnership with Esri and the Marine Biodiversity Observation Network.

The U.S. Geological Survey's Coastal Change Hazards Portal offers a Coastal Vulnerability Index that can help identify locations where coastal erosion may occur along undeveloped coastlines. Information is also available on various forms of storm-induced coastal change.

SUBSIDENCE

Subsidence, the gradual sinking or settling of the ground's surface, poses a significant hazard in coastal regions. Unlike sudden land collapses, subsidence occurs over time, often unnoticed until its effects become visibly damaging. The primary factors contributing to subsidence in coastal regions include the following:

- **Natural geological processes,** such as the compaction of sedimentary layers and tectonic plate shifting, can cause the land to sink gradually.
- **Excessive groundwater extraction,** for agricultural, industrial, or domestic use can lead to the compaction of aquifers, resulting in subsidence.
- **Fossil fuel extraction,** the extraction of oil and natural gas from beneath the earth's surface, can cause the land above to sink.
- **Urban development** contributes to subsidence as the weight of buildings and infrastructure add downward pressure on the ground.[131]

Around 2.4 million square miles (6.3 million sq km) of land—about 5 percent of the global land area, including dense urban areas—are estimated to be significantly affected by subsidence. This impacts nearly 2 billion people worldwide, posing substantial economic and social challenges.[132] Subsidence poses significant risks to real estate and infrastructure. In the Netherlands, the cost of damages to real estate and infrastructure is estimated to reach €17 billion (US$18.4 billion) by 2050.[133]

Subsidence substantially elevates flood risk in coastal regions. As land elevations lower, areas become more vulnerable to sea level rise, storm surges, and high tides. Along the U.S. East Coast, subsidence rates of 1–2 millimeters per year have exposed up to 14 million people, over 6 million properties, and critical infrastructure in major cities like New York, Baltimore, and Norfolk to increased coastal hazards.[134] Even more dramatically, 16 percent of China's major cities are sinking more than 10 millimeters per year and almost half are losing more than 3 millimeters of elevation per year. Within 100 years, these urban coastal areas could sit below sea level from the combination of subsidence and sea level rise.[135,136,137]

Venice, Italy, is sinking at a rate of around 1 millimeter per year due to natural processes, such as sediment consolidation and tectonic movements, as well as human activities, such as the pumping of groundwater from beneath the lagoon, which is now banned. The subsidence has serious consequences for buildings and infrastructure in the historic city.

Infrastructure damage is another significant consequence of subsidence. Sinking land can result in extensive damage to infrastructure, including the cracking and breaking of underground pipes, damage to buildings, and roadway fractures. Critical infrastructure systems such as roads, railways, airports, and levees are affected by differing subsidence rates in communities like Norfolk, Virginia; Virginia Beach, Virginia; Baltimore, Maryland; parts of New York City, including Queens and the Bronx; and Long Island, New York. Notably, the JFK and LaGuardia airports in New York show several areas, including runways, sinking at more than 2 millimeters per year. Most of this subsidence is caused by groundwater extraction and sediment compaction.[138]

Connections between Subsidence and Saltwater Intrusion

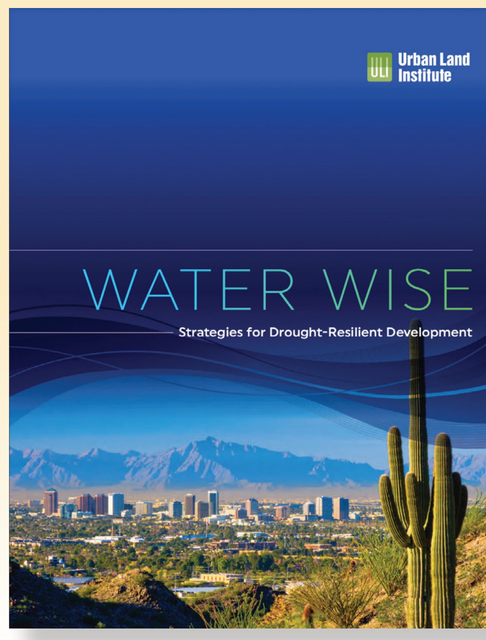
Saltwater intrusion is a process in which saltwater encroaches into freshwater aquifers, typically occurring in coastal and near-coastal areas that have overdrawn their freshwater. Saltwater intrusion contaminates freshwater storage in aquifers, and in extreme cases, can lead to the abandonment of wells and reduce the ability of localities to sustain populations' water demands.[139] Saltwater has intruded into many coastal aquifers, including those of Miami-Dade County in Florida, Los Angeles and Orange Counties in California, Houston, and Mexico City, to name a few.[140,141,142,143]

As subsidence lowers land elevations, it can exacerbate the risk of saltwater intrusion by reducing the natural barriers against sea water, making coastal aquifers more accessible to saltwater, especially in areas with declining groundwater levels. Further, saltwater intrusion can exacerbate the effects of subsidence. The intrusion of saltwater into aquifers can weaken soil and sediment structures, contributing to further ground compaction and subsidence.[144]

ULI RESOURCE

Managing Groundwater

ULI's report *Water Wise: Strategies for Drought Resilient Development* features best practices and case studies for incorporating water-saving measures into real estate development, alongside policy recommendations for integrating land use and water management. The strategies in the report can be leveraged to support freshwater efficiency, conservation, and reuse, reducing or eliminating the need to overdraw groundwater supplies.



CUMULATIVE IMPACTS OF COASTAL HAZARDS

While the coastal hazards of sea level rise, coastal storms, flooding, erosion, and subsidence are distinct phenomena, many of their consequences are interrelated and compound upon one another.

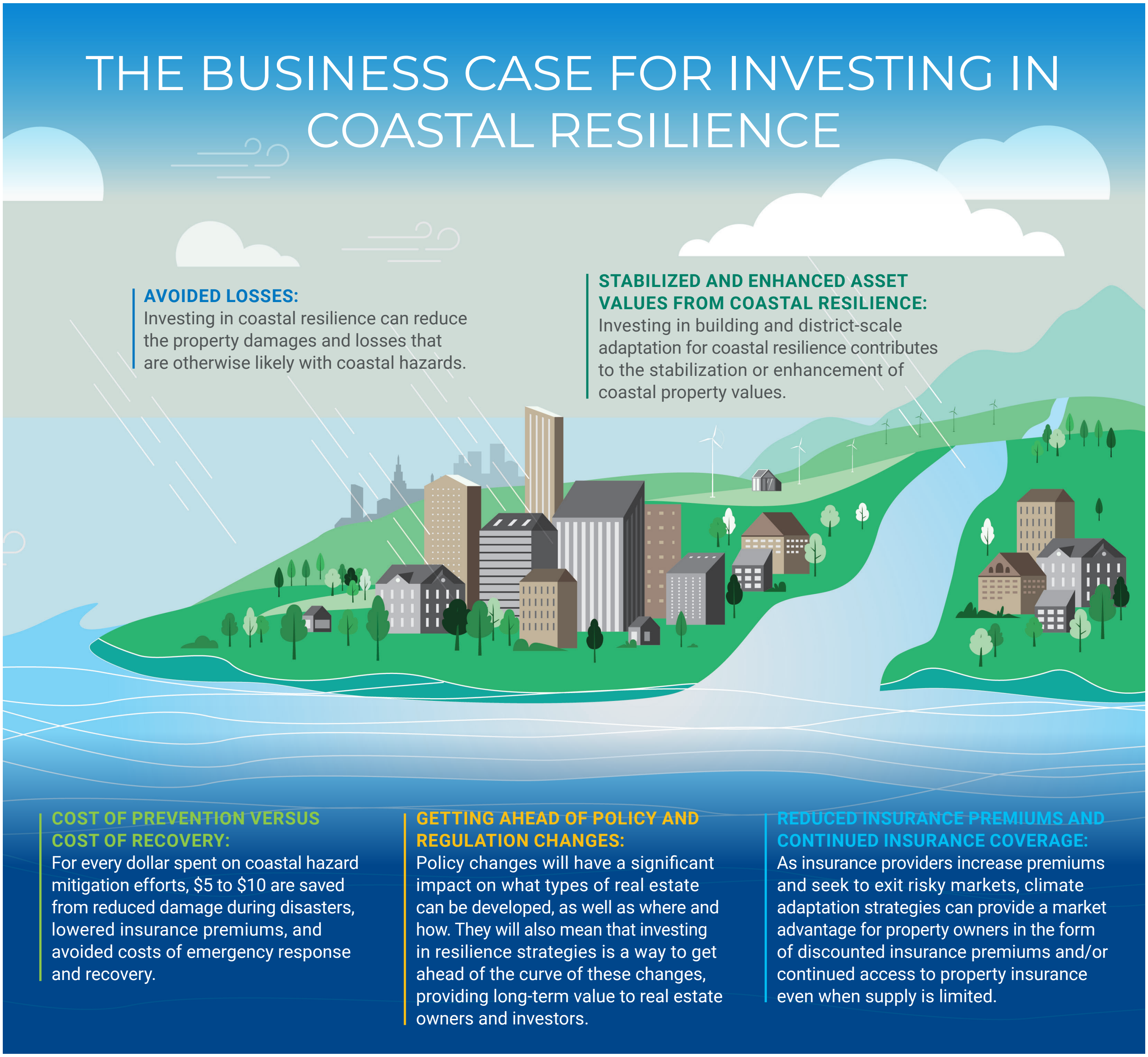
Lessons learned from the interrelated economic, environmental, and social effects of coastal hazards can be put to use addressing future conditions and preventing the worst potential impacts. The following table outlines these effects.

IMPACTS OF COASTAL HAZARDS

ISSUE	IMPACTS
SOCIAL	
Reduced community safety and well-being	Coastal hazards can cause property damage, displace populations, and disrupt social and economic systems. Sudden events like hurricanes or coastal flooding (shocks) can lead to loss of life, property damage, and disruption of essential services. Long-term issues (stresses), such as repairing properties that sustain chronic flooding, can exacerbate a community's vulnerability, impacting public health, socioeconomic stability, and social cohesion.
Population displacement and impacts for those left behind	When faced with chronic and acute coastal hazards, people may be forced to relocate. Between 2000 and 2022, around 3.2 million Americans moved or were displaced because of rising flood risks.[145] Areas that cannot attract and retain residents may struggle to support local businesses and provide essential services, which could lead to negative consequences for the local economy and quality of life.[146] Vulnerable populations, such as low-income households and the elderly, might not have the resources to move away from high-risk areas.[147] For some, including inhabitants of small island nations or those dependent on culture-sustaining ecosystem services depleted as a result of climate impacts (such as people who fish for a living), relocation options can be severely limited; and impacts to food security, local cultures, livelihoods, tourism, and recreation are adversely affected by climate change in the interim.[148]
ECONOMIC	
Diminished property values	Studies in recent years have revealed that climate risk can diminish property value and will continue to impact value negatively in the future as conditions worsen.[149,150,151,152,153,154,155] While the regional variation in how coastal hazards affect real estate markets is considerable, property discounts associated with coastal hazards range from around 1.4 percent (Long Island, New York) to 49 percent (city of Bay St. Louis, Mississippi).[156,157,158,159] In coastal areas where storms are frequent, average land prices are 1.2 to 11.8 percent lower.[160] Properties near roads affected by tidal flooding lost around US$3.70 per square foot of value annually between 2005 and 2016.[161] Overall, a US$15.9 billion loss in property values was found across 18 coastal states along the U.S. East Coast and Gulf Coast due to sea level rise and flooding.[162] Studies have found that properties in floodplains are still overvalued, and further depreciation is expected as information on properties' risk becomes more accurate and accessible.[163] Some observed decreases in demand for properties in high-risk areas cannot solely be attributed to changes in lending and insurance practices, suggesting that buyer perceptions and attitudes toward risk are shifting in the context of climate change.[164] A recent Zillow study found that 80 percent of homebuyers consider at least one climate risk when buying a home, and 49 percent say it is very/extremely important.[165] After gaining access to risk data, Redfin users bid on homes with 54 percent less risk.[166] Property values in high-risk areas are expected to continue to drop as more people become aware of the risks.[167] Migration away from high-risk coastal areas further reduces property values for those who remain, causing more economic distress and uncertainty.[168,169,170] Lower property values result in a decrease in local and state property tax revenue, which could jeopardize funding of critical services and investments in coastal resilience.[171,172]

Higher insurance costs and reduced insurance availability "We have properties that are uninsurable already." **IAN ADAM** *Vice president* *Specialty Practices* *Fuscoe Engineering Inc.*	Coastal hazards can lead to increased insurance premiums and reduced availability of insurance for assets in high-risk locations.[173,174] As the risk associated with coastal properties rises, so does the cost of insuring them. The trend of rising property insurance premiums in coastal areas is already ongoing.[175] Commercial property insurance premiums rose a record of more than 20 percent in 2023. Premiums have been rising by double digits in many markets.[176] Insurance providers are also withdrawing from high-risk coastal markets, including Florida, Louisiana, and California.[177,178] As a result, people are being driven to state-supported insurers of last resort—if they exist—where they may have to pay more for narrower policies.[179] The number of policies written by Florida's Citizens Property Insurance, the state insurance provider, has risen about 50 percent in the last year to 1.3 million, which is about 16 percent of the market and significantly more than any national insurer covers in the state.[180] Insurance affordability and availability in coastal areas across the globe is following similar trends.[181,182] In Australia, for example, home insurance premiums rose 28 percent in 2022–2023, with the highest-risk properties, such as those in flood-prone areas, up by 50 percent.[183] Additionally, insurance coverage is limited in Australia's high-risk coastal areas, creating a protection gap.[184] Availability and cost of insurance coverage are expected to be primary factors driving investor behavior and market liquidity, since property insurance is a prerequisite for financing.[185]
Property damage "A lot of assets are going to be at risk." **DEBRA TAN** *Director and head* *China Water Risk*	Coastal hazards can cause significant physical damage to properties. Acute coastal hazards, such as storms and erosion, can lead to swift and devastating results. The most common forms of property damage from coastal storms include roof, structure, foundation, interior, equipment, and utility damage.[186] These damages can come from direct wind pressure and uplift, internal wind pressure, wind-borne and flood-borne debris, storm surge, waves, and rain.[187] Erosion can cause building and infrastructure damage and loss of land. In places like Southern California, the United Kingdom, and Australia, coastal land and properties have been falling off cliffs into the ocean from erosion.[188,189,190] Even slower, chronic hazards, such as sea level rise, tidal flooding, and subsidence can lead to dramatic results for real estate. Sea level rise can lead to long-term corrosion with both saltwater and salty air intrusion, weakening the structure of buildings until they can no longer hold the weight. As an example, in 2021, the Champlain Towers South, a 12-story, 40-year-old beachfront condominium in the Miami suburb of Surfside, Florida, partially collapsed, destroying at least half of the 136 units and causing 98 deaths, among other injuries. Investigators found that due to severe seawater penetration, the reinforced concrete structural support rusted and cracked.[191] Subsidence is known for causing foundation and infrastructure damage, which can lead to larger structural problems. In coastal areas, subsidence in combination with sea level rise can lead to chronic flooding. Overall, these coastal hazards can result in significantly increased capital and maintenance costs to cover repair, rebuilding, or moving.[192]
Increased maintenance and operations costs	Coastal hazards can lead to increased operations and maintenance costs to cover repairs for both acute and chronic issues.[193] The financial burden of repairing properties damaged by coastal hazards can be substantial. From 1980 to 2024, the United States experienced an increase in frequency of billion-dollar natural disasters, up from one every four months to one every three weeks, including 191 severe storms, 44 floods, and 62 tropical cyclones.[194,195] Globally, economic losses from climate-related disasters vary from year to year but overall have increased.[196,197] In addition to the economic burden imposed by the cost of recovery from disasters, chronic impacts from climate change, such as nuisance flooding, generate maintenance costs comparable to acute impacts over time.[198] Regular exposure to such hazards can lead to a higher frequency of maintenance activities, thereby inflating the overall capital expenditure at procurement and reducing the return on investment over time.[199]
Decreased productivity and business interruption	Coastal regions' business continuity faces direct challenges from coastal hazards.[200] Impacts can include reduced revenue from decreased production capacity such as transport difficulties and supply chain interruptions; reduced revenue and higher costs from negative impacts on the workforce, including health, safety, and absenteeism; reduced revenues from lower sales/output due to extended closures; and business closures or relocation.[201] According to FEMA, about 25 percent of businesses do not reopen after disasters.[202] In Annapolis, Maryland, local businesses lost as much as US$172,000, or 1.4 percent of their annual revenue in 2017, due to high-tide flooding.[203,204] Businesses affected by flooding in the United Kingdom lost an average of £100,000 (US$128,000), with some taking 27 weeks to return to normal in 2007.[205] Reduced business productivity and health can financially impact real estate by decreasing tenant occupancy and rental payments, as well as through foreclosure. Local governments can lose property, sales, and tourism taxes from these disruptions as well, which could result in downgrades to municipal bond ratings.

INFRASTRUCTURAL	
Utility infrastructure at risk	Energy, water, and wastewater utilities and infrastructure, often located along coastlines, are at risk from coastal hazards.[206,207,208,209] Coastal storms, flooding, erosion, and saltwater intrusion in energy utility assets are primary threats to energy infrastructure. The number of U.S. energy facilities exposed to storm surge hazards is projected to increase by 15–67 percent under a fast sea level rise scenario.[210] Power outages during major storms are relatively common occurrences due to high winds, flooding, and falling trees that threaten power lines, substations, and other critical infrastructure. Power outages can be especially disruptive since people are cut off from communication and lose access to refrigeration and electrical medical devices. As an example, in 2017 Hurricane Maria had a significant impact in Puerto Rico because of the island's vulnerable power infrastructure and because the storm hit the island directly. The entire island (3.4 million people) lost power and many areas of the island remained without power for months.[211] Water and wastewater infrastructure is vulnerable to sea level rise, coastal storms, flooding, erosion, and subsidence. These coastal hazards can corrode and degrade infrastructure, lead to saltwater intrusion and sewage overflows, and flood facilities. As an example, sea level rise has been compromising drinking water supplies in Florida and causing septic system failures with saltwater intrusion.[212] Higher rainfall associated with coastal storms and sea level rise can exceed the capacity of stormwater and wastewater systems, leading to flooding and sewage backups and overflows. Groundwater inundation and subsidence can exert pressures on buried water infrastructure, which can change the gradient driving sewer flow and break lines.[213]
Transportation infrastructure at risk	Transportation infrastructure, such as roads, bridges, tunnels, railways, airports, and ports along coastlines, are also at risk from coastal hazards. Coastal hazards can lead to failures or destruction of critical infrastructure and transportation system breakdowns and immobilization. Coastal storms, flooding, erosion, and subsidence can make transportation infrastructure vulnerable to failures, necessitating more frequent and extensive maintenance and rehabilitation. Impacts can include erosion, subsidence, buckling, and cracking of pavement; flooding of airports, roads, ports, rail lines, and tunnels; traffic congestion; and infrastructure damage.[214,215] These infrastructure system failures affect business continuity, safety, accessibility, and value of coastal properties; and costly repairs, relocation, or fortification of vulnerable coastal transportation assets may require higher taxes or fees for coastal residents to fund the work, increasing the cost of coastal living.[216]
ENVIRONMENTAL	
Loss of biodiversity and ecosystems that protect coastal communities	Coastal hazards deeply impact ecosystems and natural resources, which in turn affect the people who depend on them. Coastal ecosystems protect coastlines from storms and erosion and help buffer the impacts of sea level rise. Nearly 50 percent of the world's coastal wetlands have been lost over the last century from the combined effects of local human pressures, sea level rise, global warming, and extreme coastal storms. Impacts on coastal ecosystems from sea level rise, ocean warming, acidification, loss of oxygen, and salinity intrusion include habitat contraction, geographical shifts of species, and loss of biodiversity and ecosystem functionality. As an example, warming waters have already resulted in worldwide reef degradation and mortality and pose high risks to rocky shore ecosystems as well.[217] These impacts are aggravated by direct human disturbances and constructed barriers that prevent ecosystems like marshes and mangroves from growing and shifting.[218] Coastal storm and flood events also produce significant waste and debris that impact ecosystem and public health.[219] The degradation and loss of these ecosystems significantly impact the coastal communities that depend on them. Many coastal communities depend on beaches, reefs, and other natural amenities for tourism and other economic benefits.[220] Additionally, coastal communities are at higher risk from coastal hazards without robust ecosystem buffers and protection.
Loss of carbon storage	Vegetated coastal ecosystems are important carbon stores, and their loss is responsible for the current release of 0.04–1.46 gigatons of carbon per year, roughly equivalent to building 10 million new single-family houses.[221] Ecosystem degradation and loss related to climate change, coastal hazards, and real estate development can lead to the further release of previously stored carbon back into the atmosphere, exacerbating climate change and associated coastal impacts.



The Business Case for Investing in Coastal Resilience

A significant concentration of economic power lies within the coastal regions of the world, particularly within urban areas. Sixty percent of the world's cities with populations over 5 million are located within 62 miles (100 km) of the coast, including 12 of the world's 16 cities that have populations over 10 million.[222] In the United States alone, coastal states contribute 83.7 percent of the national gross domestic product.[223]

With so much global economic activity coming from coastal areas, investing in coastal resilience to protect these areas, their people, and their assets is of great importance.

Investments in coastal resilience measures can mitigate the costs of disaster recovery, rising insurance premiums, and policy changes. They can also garner cost savings and provide long-term value to real estate owners and investors, as well as to the public sector.

COST OF PREVENTION VERSUS COST OF RECOVERY

The wisdom in managing coastal risks through preventative measures is clear: prevention is more cost-effective than facing the aftermath of disasters. The National Institute of Building Sciences Multi-Hazard Mitigation Council articulated the economic rationale behind this strategy in a cost/benefit analysis of natural hazard mitigation measures, building code updates, building retrofits, and investment in utility and transportation infrastructure to withstand natural disasters. The analysis indicated broad economic benefits from such investments and found that, for every dollar spent on coastal hazard mitigation efforts, US$5 to US$10 are saved from reduced damage during disasters, lowered insurance premiums, and avoided costs of emergency response and recovery.[224]

"Actions to prevent and reduce damages from extreme weather events not only protect people and property, they are a sound investment: one dollar spent on prevention saves [at least] four dollars in damages."

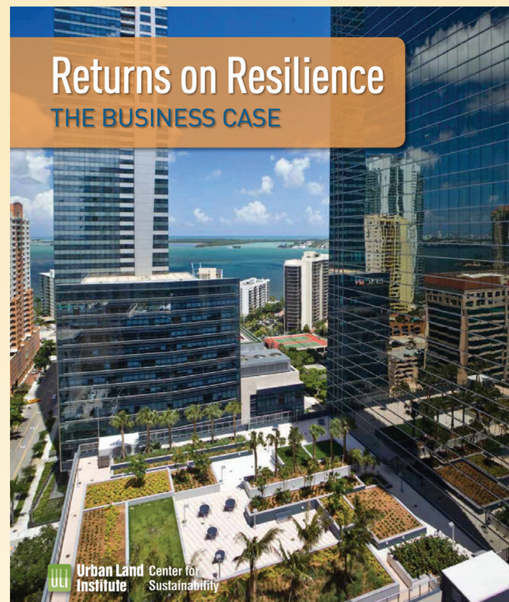
ULI's report *The Urban Implications of Living with Water*

Actual savings can vary geographically, but they often present an even higher benefit in high-risk areas. These findings are particularly valuable to communities, public-sector officials, building owners, investors, insurance underwriters, and real estate industry professionals more broadly, and have served as a call to action to many people across sectors to proactively address climate hazards. The savings are particularly salient as climate change amplifies the frequency, unpredictability, and severity of coastal hazards across the globe.

ULI RESOURCE

The Resilience Return on Investment

ULI's report *Returns on Resilience* discusses the impact of climate change on the land use industry and the growing risks and uncertainties that affect the way projects are selected, designed, financed, and built. The report underscores the need for the real estate development sector to be aware of climate and other risks so it can adapt to future risks and mitigate known impacts, to protect buildings and sites—and ultimately tenants and residents.



ULI's *Developing Urban Resilience* website includes profiles of real estate and land use projects that further demonstrate the business case for integrating resilience strategies locally.

ECONOMIC BENEFITS OF HAZARD MITIGATION MEASURES

	ADOPT CODE	ABOVE CODE	BUILDING RETROFIT	LIFELINE RETROFIT
OVERALL BENEFIT-COST RATIO	11.1	4:1	4:1	4:1
COST ($ BILLION)	$1/year	$4/year	$520	$0.6
BENEFIT ($ BILLION)	$13/year	$16/year	$2,200	$2.5
RIVERINE FLOOD	6:1	5:1	6:1	8:1
HURRICANE SURGE	NOT APPLICABLE	7:1	NOT APPLICABLE	NOT APPLICABLE
WIND	10:1	5:1	6:1	7:1

Source: National Institute of Building Sciences.

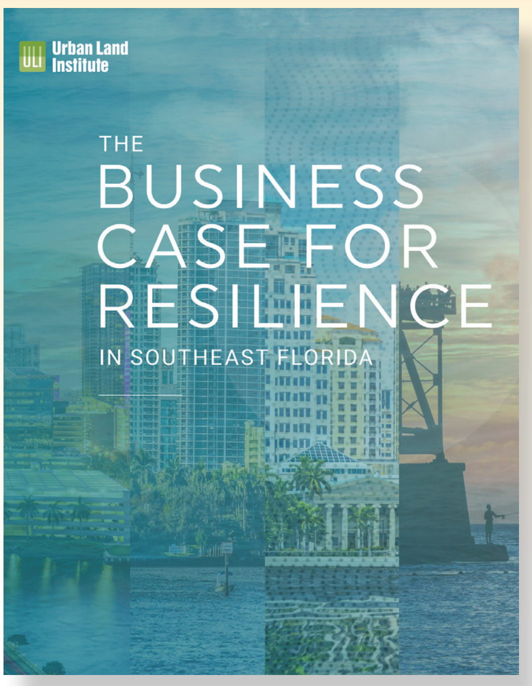
U.S. national average benefit-cost ratio by hazard and mitigation measure. Benefit-cost ratios can vary geographically and can be much higher in some places.

The Perez Art Museum in Miami, Florida, is raised to allow a flood surge from Biscayne Bay to flow underneath, providing viewing terraces for museumgoers.

ULI RESOURCE

Resilience Returns in Southeast Florida

ULI's report *The Business Case for Resilience in Southeast Florida* explores the economic risks to Southeast Florida—including Broward, Miami-Dade, Monroe, and Palm Beach Counties—from rising sea levels and frequent flooding, and analyzes the return on investment associated with building-level and community-wide adaptation investments. The report quantifies a compelling business case for the region to make significant investments in resilience infrastructure. The report also identifies opportunities for the real estate industry to achieve a positive return on investment by future-proofing developments and investing in community-wide resilience infrastructure over time. Incremental solutions can protect people and property, while helping to grow the economy of Southeast Florida in years to come.



AVOIDED LOSSES

Investing in coastal resilience can reduce the property damages and losses that are otherwise likely with coastal hazards. The resulting site resilience and safety reduce long-term management, maintenance, and reconstruction costs related to coastal hazards.[225]

Avoided damages, characterized as a reduction of potential harm, losses, or costs that would have occurred without preventative actions or investments, might include structural damage, damage to building interiors, or damage to goods and property. They might also include degradation or interruption of other functions such as business or governance.[226]

Without investment in coastal resilience, the following effects could compound:

PRIVATE SECTOR LOSSES

- Loss of wealth and/or income for property and business owners
- Job and wage losses
- Property and infrastructure damages
- Increased cost and/or barriers to access insurance coverage and financing

PUBLIC SECTOR LOSSES

- Foregone property, sales, and tourism taxes
- Property and infrastructure damages
- Increased cost and/or barriers to access insurance coverage and financing
- Downgrades to municipal bond ratings

These cascading effects could alter the desirability of living and working in a coastal area, which may result in the redistribution of populations and public and private investment—all of which can impact local, regional, and state economies.[227]

REDUCED INSURANCE PREMIUMS AND CONTINUED INSURANCE COVERAGE

Property owners in coastal regions depend on property insurance for both financing and disaster recovery. As insurance providers increase premiums and seek to exit risky markets, climate adaptation strategies can provide a market advantage for property owners in the form of discounted insurance premiums and/or continued access to property insurance even when supply is limited.[228,229,230,231,232] See Adaptation Strategies for Coastal Resilience on page 38 for a compendium of strategies that can be used to address coastal hazards, prevent and reduce damages, and build the case for insurance premium discounts and continued coverage.

"Developers need to look beyond their typical development costs and evaluate how changing insurance premiums and increased flood risk over a much shorter time frame might influence the resiliency strategies they build into developments."

ULI's report *The Urban Implications of Living with Water*

Insurance providers have caught on to the significant cost savings that come with installation of preventative measures and are providing incentives, including premium discounts, to policyholders who adopt risk mitigation strategies on site.

"With the increasing frequency of disruptive events around the globe, our clients need the tools and resources to invest in risk mitigation solutions and support business continuity."

MALCOLM ROBERTS
President and chief executive officer
FM Global

Property insurance firm FM Global, for example, offers a Global Resilience Credit, which is a 5 percent premium reduction in exchange for on-site risk mitigation strategies, such as flood barriers and levees. According to a 2023 study, the credit has the potential to reduce up to US$20 billion of loss expectancy for clients.[233,234]

Property owners can also independently take action to reduce their insurance premiums. The Eddy, a 4.4-acre (1.8 ha), 267,150-square-foot (24,819 sq m) mixed-use development on East Boston's waterfront, showcases how integrating resilience measures into coastal real estate not only safeguards the property against the increasing risks of storm surge, sea level rise, and flooding. It also can lead to significant financial savings from insurance premium reductions. By locating power equipment above the 500-year-flood elevation and providing physical protection against flooding, the potential flood-loss expectancy dropped from US$10 million to US$1 million, leading to a significant premium reduction from Affiliated FM. A building without the features that The Eddy incorporated would likely pay annual premiums that were 10 times higher for flood insurance.[235]

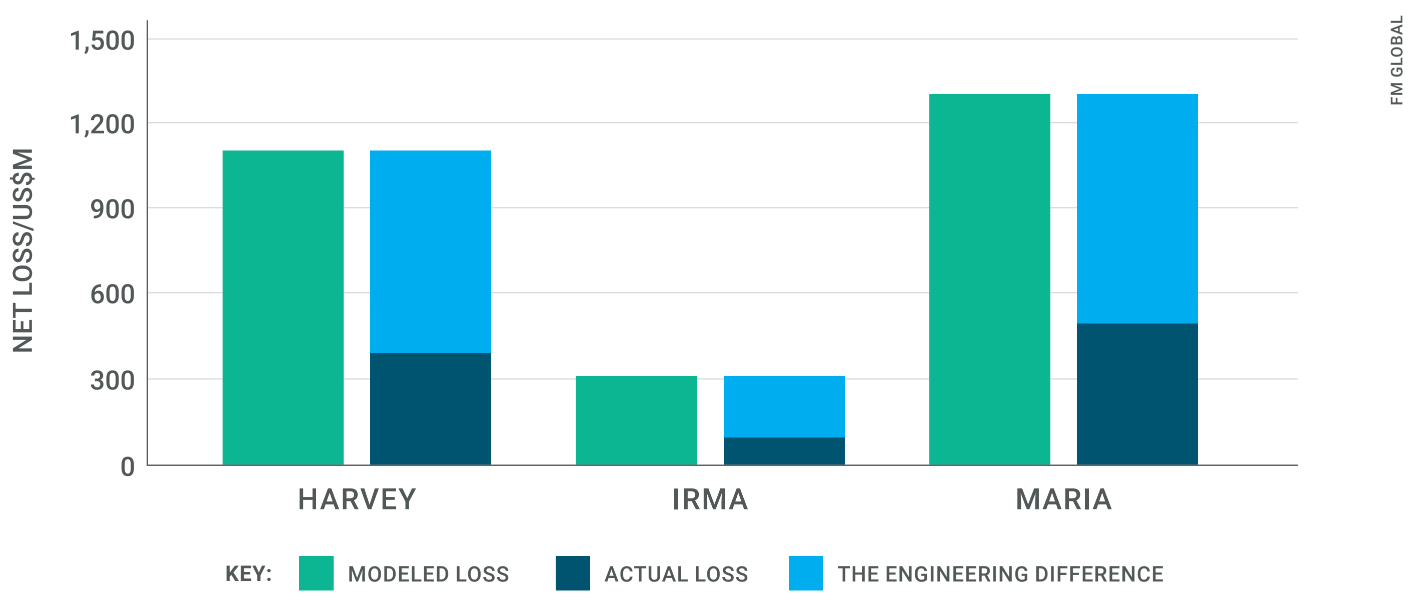
"Resilience strategies can save money on construction, insurance premiums, insurance deductibles, and by expediting the entitlement process so the building can be finished and leased sooner. Not having to build a basement to house the electrical room and emergency generator saved the project money; the required waterproofing, given the shallow depth of the water table, would have been difficult and costly to install."

MOLLY BORDONARO
Partner
The Green Cities Company
Developer of The Eddy

Premium reductions are also supported by public-sector programs. The U.S. National Flood Insurance Program (NFIP) offers discounted premiums to owners who implement flood mitigation measures, such as elevating utilities, filling in basements, installing flood openings, elevating the property, and relocating.[236] Various states—including Alabama, California, Florida, Louisiana, Maryland, Mississippi, New York, South Carolina, and Texas—require insurance providers to offer premium discounts for specific hazard mitigation investments or have state insurance programs that offer discounts.[237]

Some insurance providers, reinsurance providers, and governmental authorities are introducing new products such as parametric and index-based insurance, catastrophe and climate bonds, resilience insurance, nature-positive insurance, and risk pools that require, incentivize, or help finance resilience improvements. Innovative insurance and financial models and products, such as these, support implementation of adaptation strategies and increase insurance coverage and availability, benefiting property owners, taxpayers, and the insurance sector.[238]

THE NATURAL HAZARDS ENGINEERING DIFFERENCE



In the Houston-Galveston Bay region, FM Global's Global Resilience Credit has already yielded returns in the aftermath of severe storms. Actual losses are far lower than modeled losses from hurricanes in the Houston-Galveston Bay area due to adaptation strategies implemented in 2017.

GETTING AHEAD OF POLICY AND REGULATION CHANGES

Policies and regulations that affect land use and real estate are being adopted with the aim of bolstering resilience to coastal hazards. These policy changes will have a significant impact on what types of real estate can be developed, as well as where and how. They will also mean that investing in resilience strategies is a way to get ahead of the curve of these changes, providing long-term value to owners and investors.

> "The rules are changing, codes are changing, and designing to meet the minimum code requirements is not enough."
>
> **ULI's report *The Urban Implications of Living with Water***

Governments worldwide are progressively updating their approaches to the governance of land use and development, environmental protection, and risk disclosure in response to new information and imperatives arising from climate risks. In New York State, for example, the Coastal Management Program (CMP) has 44 coastal policies that guide development, use, and protection of coastal areas. These policies cover a wide range of goals, including promoting waterfront revitalization, protecting fish and wildlife habitats, and enhancing public access. The CMP requires that proposed projects be consistent with all coastal policies and that local waterfront revitalization programs can adopt refined local policies as well.

In many countries, areas prone to flooding are subject to mandatory flood insurance requirements. Policies that subsidize flood insurance (e.g., the NFIP in the United States) can make owning coastal property more feasible but may also rely on outdated information about current and future conditions, potentially encouraging development in risk-prone areas. As more and better information about risks becomes available, changes to these policies could negatively affect coastal real estate value. By steering clear of floodplains or designing to beyond-code standards, real estate owners and investors can sidestep these political and financial hurdles.

Arverne by the Sea in New York City emerged from Hurricane Sandy nearly unscathed, unlike most nearby areas. Its developers, the Beechwood Organization and the Benjamin Companies, reinforced beach dunes, raised the site on fill three to nine feet above the 100-year floodplain, added a large below-grade stormwater drainage system, installed utilities underground, and built storm-resistant buildings. Learn more at the Developing Urban Resilience project profile.

Regulators worldwide are also adopting policies mandating disclosure of physical climate risk.[239] The United States, European Union, United Kingdom, Brazil, Hong Kong, Japan, New Zealand, Singapore, and Switzerland all have reporting requirements for companies consistent with the Task Force on Climate-Related Financial Disclosure framework.[240] The presence or anticipation of adoption of such regulations may be a major driver behind investors' responses to current and future risk.[241,242] By implementing resilience strategies, real estate owners can reduce disclosed risks and encourage investor interest. As an example, Empire Stores in Brooklyn, New York, received increased support and capital from institutional lenders because the developers not only identified local risks, but also took action to reduce onsite vulnerabilities.[243]

For more information on policy and regulatory changes, see The Policy Landscape for Coastal Resilience section starting on page 65.

STABILIZED AND ENHANCED ASSET VALUES FROM COASTAL RESILIENCE

In addition to the benefits of avoided losses and insurance access and potential reductions in premiums, investing in adaptation also contributes to the stabilization or enhancement of coastal property values, and associated tax revenues.[244,245,246,247]

Coastal properties are typically priced at a premium compared with similar properties that are not on the coast. However, coastal hazards are increasing the risks to these properties. Hazard risks have been shown to be capitalized in the value of property, and properties subject to hazard risks appreciate at a lower rate and are often sold at a discount compared with similar properties that are not subject to risks.[248,249,250,251] For more information, see "Diminished property values" in Impacts of Coastal Hazards on page 26.

Coastal Property Overvaluation and Increasing Coastal Risks

Many counties along the U.S. Gulf, Atlantic, and Pacific coasts are experiencing significant property overvaluation due to unrecognized flood risks. One study found that U.S. residential properties exposed to flood risk are overvalued by US$121 billion to US$237 billion. In some coastal counties, properties were overvalued by more than 10 percent on average. Highly overvalued properties are concentrated in counties along the coast that lack flood risk disclosure laws and where people are less concerned about climate change. Property owners are falsely comforted by out-of-date federal flood maps and government-subsidized flood insurance.[252]

South Beach, Miami.

Properties that are exposed to coastal hazards are frequently discounted because unpriced flood risk props up their values higher than they would be otherwise, considering the risks. Overvaluation can also incentivize continued development in floodplains and underinvestment in hazard mitigation. As hazards mount with climate change, price deflation could have a significant impact on coastal real estate markets, and municipalities that rely on property taxes are vulnerable to budgetary shortfalls.[253]

Given current trends in sea level rise, coastal storms, flooding, erosion, and subsidence, a reassessment of risk evaluations, property valuations, and planning strategies is warranted. Recently, pricing has started to shift, especially in response to the NFIP's new pricing methodology, Risk Rating 2.0, which determines flood insurance premiums based on individual assessments of flood risk and rebuilding costs for each property, and as mortgage lenders start to insulate themselves from credit risk related to flood risk.[254,255,256,257]

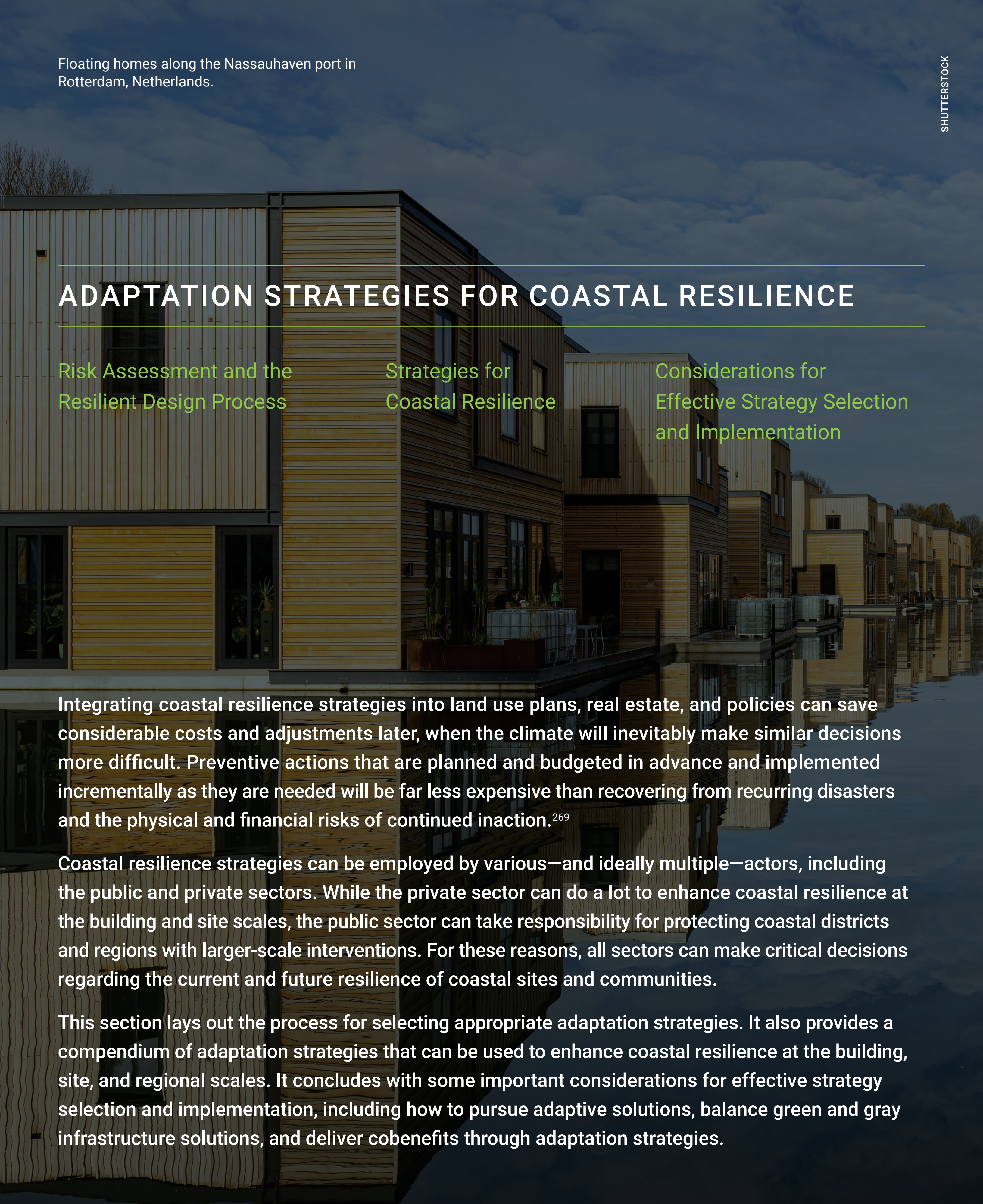
Greater capitalization of flood risk in real estate prices is expected as information on properties' risk becomes more accurate and accessible. To that end, FEMA has received additional funding to improve its outdated flood maps, and property-level flood risk estimates are now widely available on real estate websites, such as Redfin and Realtor.com. While these price adjustments will reduce the incentive to develop in floodplains, decreasing the overall costs of flooding, they could also lead to negative financial consequences for existing property owners in floodplains and coastal municipalities dependent on property taxes.[258] Real estate developers and investors, as well as local governments, will need to adapt to these evolving risks and their implications for market dynamics and property prices.[259]

The Ritz-Carlton in Grand Cayman. After damage from Hurricane Ivan in 2004, new owners Five Mile Capital Partners installed multiple building and landscape resilience measures for coastal storms, including mangrove restoration. They note these features have enhanced property value, reduced annual utility costs by $300,000, and provide attractive and unique amenities, all while supporting their relationship with local government.

Building- and district-scale adaptation strategies for coastal resilience could help minimize devaluation of real estate and mitigate economic and social effects from coastal hazards.[260] Resilient projects have been shown to enjoy advantages, such as greater marketing, sales, and leasing success, by demonstrating the integrity and protective features of the project and its ability to function through or recover quickly from hazards.[261,262] For example, after Bayshore Villas in Puerto Rico integrated resilience measures that enabled it to withstand Hurricane Maria, 2,400 households applied to live in its 40 apartments. More resilient projects can also benefit from better financing options, lower insurance premiums, long-term savings on maintenance, and higher overall value compared with more vulnerable properties.[263,264] As an example, property values near high-quality parks, which can double as green infrastructure, have been shown to increase by 8–10 percent in the United States and by similar amounts in European, Chinese, Japanese, and Australian contexts.[265,266]

Developing real estate to green building certification standards can also support a project's resilience and bottom line.[267] For example, impact-resistant windows can protect a building from high winds and projectiles common to coastal storms while also saving energy and reducing utility bills. Project sustainability and resilience, as well as green building certification, can also attract investors, who are increasingly interested in environmental, social, and governance performance.[268]

> "Where resilience efforts are planned in tandem with sustainability measures, the results are likely to lead to success in better financing, faster and higher lease rates, more competitive insurance premiums, lower utility costs, and greater returns on investment."
>
> **ULI's report *Returns on Resilience***



Floating homes along the Nassauhaven port in Rotterdam, Netherlands.

SHUTTERSTOCK

ADAPTATION STRATEGIES FOR COASTAL RESILIENCE

Integrating coastal resilience strategies into land use plans, real estate, and policies can save considerable costs and adjustments later, when the climate will inevitably make similar decisions more difficult. Preventive actions that are planned and budgeted in advance and implemented incrementally as they are needed will be far less expensive than recovering from recurring disasters and the physical and financial risks of continued inaction.[269]

Coastal resilience strategies can be employed by various—and ideally multiple—actors, including the public and private sectors. While the private sector can do a lot to enhance coastal resilience at the building and site scales, the public sector can take responsibility for protecting coastal districts and regions with larger-scale interventions. For these reasons, all sectors can make critical decisions regarding the current and future resilience of coastal sites and communities.

This section lays out the process for selecting appropriate adaptation strategies. It also provides a compendium of adaptation strategies that can be used to enhance coastal resilience at the building, site, and regional scales. It concludes with some important considerations for effective strategy selection and implementation, including how to pursue adaptive solutions, balance green and gray infrastructure solutions, and deliver cobenefits through adaptation strategies.

Modera Revere Beach in coastal Massachusetts, by Mill Creek Residential. In response to coastal flood risk identified during Mill Creek's risk assessment, the company developed an innovative flood "pass-through" system (openings visible at base of building, detail in inset image) for water to safely flow under the building garage. Compared to traditional elevation on piles (an economically unviable cost of $175,000 per unit), the pass-through cost only $3,000 per unit extra and maximized unit count.

Risk Assessment and the Resilient Design Process

It is critically important to understand the local vulnerabilities of an area or site—*before* selecting specific adaptation strategies—to ensure the selected strategies effectively mitigate the identified impacts. The process involves the following steps:

- **STEP 1:** UNDERSTAND HAZARDS AND EXPOSURE
- **STEP 2:** ASSESS VULNERABILITY AND RISK
- **STEP 3:** INVESTIGATE RISK REDUCTION STRATEGIES
- **STEP 4:** PRIORITIZE AND PLAN IMPLEMENTATION
- **STEP 5:** IMPLEMENT AND REFINE

STEP 1 UNDERSTAND HAZARDS AND EXPOSURE

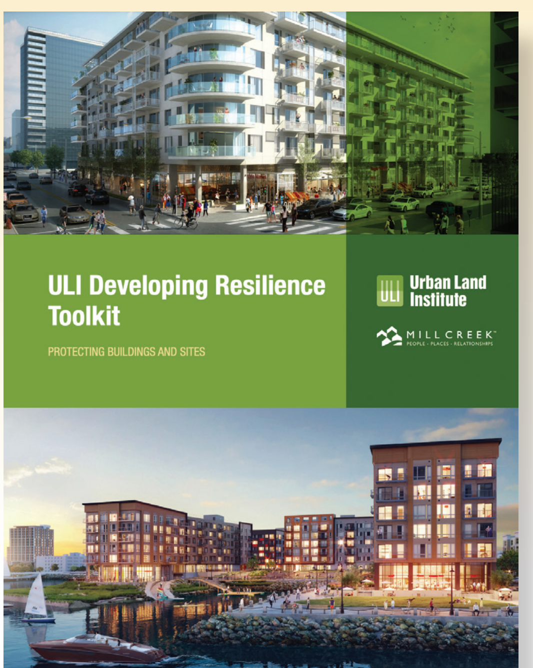
Building more resilient sites and areas begins with the question, *resilient to what?* Decision-makers must first identify which hazards the asset or area in question may be exposed to given its geographic location.

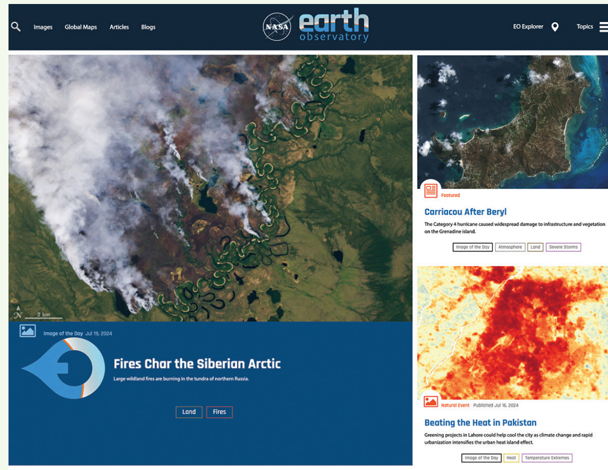
This assessment can draw on historic hazards the asset or area has experienced, but it should also incorporate projections of future risk, as a changing climate will intensify the severity and frequency of many hazards. Many assets and areas will be exposed to multiple hazards, sometimes simultaneously and in ways that compound on one another.

ULI RESOURCE

ULI Developing Resilience Toolkit

The Risk Assessment and Resilient Design process presented here is based on the U.S. Climate Resilience Toolkit's *Steps to Resilience* and is tailored to global real estate needs in the *ULI Developing Resilience Toolkit*. Key points are described in the following subsections. Readers can learn more about the process and explore a 140+ strategy matrix of multihazard mitigation strategies in the *ULI Developing Resilience Toolkit*.





Sources of Hazard Information

Hazard information can be found in publicly available sources, such as the following:

- State, county, or city hazard mitigation plans (in the United States, required by FEMA to qualify for various funding sources)
- Local or regional climate adaptation or resilience plans
- NASA Earth Observatory
- World Bank Climate Change Knowledge Portal
- European Space Agency Climate Change Initiative
- UN Environment Programme's World Environment Situation Room
- European Environment Agency
- Asia Development Bank Climate Change and Disaster Risk Management
- FEMA's National Risk Index (United States only, historical data)
- Climate Explorer
- Climate Central's Coastal Risk Screening Tool
- Climate Mapping for Resilience and Adaptation

Peer-reviewed local and regional sources tend to provide more relevant local information than national or global sources. More detailed information can be gathered for a fee through climate risk analytics providers. Guidance on using this information can be found in ULI's report *How to Choose, Use, and Better Understand Climate-Risk Analytics*.

Coastal Development Best Practices

In 2007, ULI published *Ten Principles for Coastal Development*, which provides guidance for implementing better land use practices along coasts to prevent the degradation of coastal systems as growth and development occur. The principles for responsible coastal real estate development are still relevant and include the following:

- Enhance value by protecting and conserving natural systems.
- Identify natural hazards and reduce vulnerability.
- Apply comprehensive assessments to the region and site.
- Lower risk by exceeding standards for siting and construction.
- Adopt successful practices for dynamic coastal conditions.
- Use market-based incentives to encourage appropriate development.
- Address social and economic equity concerns.
- Balance the public's right of access and use with private property rights.
- Protect fragile water resources on the coast.
- Commit to stewardship that will sustain coastal areas.

STEP 2 ASSESS VULNERABILITY AND RISK

After exposure to hazards has been identified, the next step is to determine the vulnerability of the site or area and its occupants in the face of each hazard.

Vulnerability increases when a site, area, or occupant

1. Is exposed to a hazard (*exposure*),
2. Is likely to experience damage from that hazard (*sensitivity*), and
3. Has limited ability to respond to and recover from the hazard (*adaptive capacity*).

The greater the damage and disruption experienced from a hazard due to exposure, sensitivity, and lack of adaptive capacity, the more vulnerable the building, area, or individual. Asset, site, and community indicators of exposure, sensitivity, and adaptive capacity can be used to develop a vulnerability assessment that can serve as the basis for selecting appropriate strategies for coastal resilience.

"We have not yet internalized community-scale impacts around assets as standard practice. Folks are quick to say, 'My asset is elevated or in some other way protected,' but they are not routinely conducting community risk assessment about, say, accessing those facilities."

CHRIS PYKE
Chief innovation officer, GRESB

Coastal homes in Carolina Beach, North Carolina, face the Atlantic Ocean.

Vulnerability assessments are powerful tools, but they come with challenges—such as technical capacity and data availability and suitability—which should be carefully considered to effectively inform decision making. Understanding the scope and frequency of potential coastal hazards in specific areas is difficult since future conditions and regional variability are challenging to predict with accuracy. However, context-specific monitoring and forecasting is constantly improving, and the best available data should be used to inform vulnerability assessments and decision-making. Scenario planning can also be used to identify suites of adaptation strategies that align with potential future conditions, risk tolerances, and affordability.

"The good news is we know more about the possible scenarios in the next 30 years. The bad news is that coastal hazards are still accelerating."

BECKY SMYTH
West Coast regional director
Office for Coastal Management, NOAA

Resources for Conducting Vulnerability Assessments

ASTM International, formerly known as the American Society for Testing and Materials, is currently working on a Guide for Property Resilience Assessment. It will provide an overview of a systematic approach for conducting a property resilience assessment, consisting of (1) identifying the natural hazards likely to affect a property; (2) evaluating the risks posed by those hazards along with the capacity of the property to prepare for, adapt to, withstand and recover from those hazards; and (3) identifying conceptual resilience measures to enhance property-level performance and recovery.

Natural Resources Defense Council's *Guide to Community Climate Vulnerability Assessments* is a primer for communities and community partners on how to complete a climate vulnerability assessment (CVA). The purpose of this guide is to introduce the concept of CVAs: what they are, why they matter, who should participate, and how they are developed. The guide can be applied to either a region or a project specific to where people live. Community organizations may find this guide most useful at the inception phase of a CVA as an overview of the process, enabling them to achieve better outcomes in their communities.

NOAA's Community Vulnerability Assessment Tool (CVAT) is a risk and vulnerability assessment methodology designed to assist emergency managers and planners in their efforts to reduce hazard vulnerabilities through hazard mitigation, comprehensive land-use, and development planning. CVAT analysis results provide a baseline to prioritize mitigation measures and to evaluate the effectiveness of those measures over time. This methodology is flexible, as results may be achieved using a geographic information system (GIS) or static maps with overlays and data. The CVAT methodology has seven steps: (1) hazard identification and prioritization, (2) hazard analysis, (3) critical facilities analysis, (4) social analysis, (5) economic analysis, (6) environmental analysis, and (7) mitigation opportunities analysis.

NOAA's Digital Coast also provides resources for conducting vulnerability assessments. They include the following:

- Vulnerability Assessment–Informing Adaptation Actions: Questions to help scope a vulnerability assessment
- Checklist for Risk and Vulnerability Assessment: Checklist of potential stakeholders to engage in risk and vulnerability assessment
- Additional Data Needs and Information for a Community Risk and Vulnerability Assessment: List of data and information needs and sources as well as topics for consideration during community risk and vulnerability discussions

How a Real Estate Firm Leverages Vulnerability Assessments and Scenario Planning

Real estate firms can conduct vulnerability analyses for assets and portfolios. These also frequently involve scenario planning to understand the range of possibilities for future physical risks, policy responses, and changing market or demographic conditions that affect relevant risk mitigation measures. For example, Lendlease, a multinational construction and real estate company headquartered in Australia, created four potential scenarios representing pathways of global alignment on climate action and accompanying degree rises in global temperatures:

- Resignation (>4°C rise): Resources and efforts focus solely on adaptation and survival.
- Polarization (3–4°C): National self-interest prioritizes local adaptation over multilateral action.
- Paris alignment (2–3°C): Multilateral governmental climate regulation is based on the Paris Agreement.
- Transformation (<2°C): Collective self-limitation and sharing of resources enable a just zero-carbon transition.

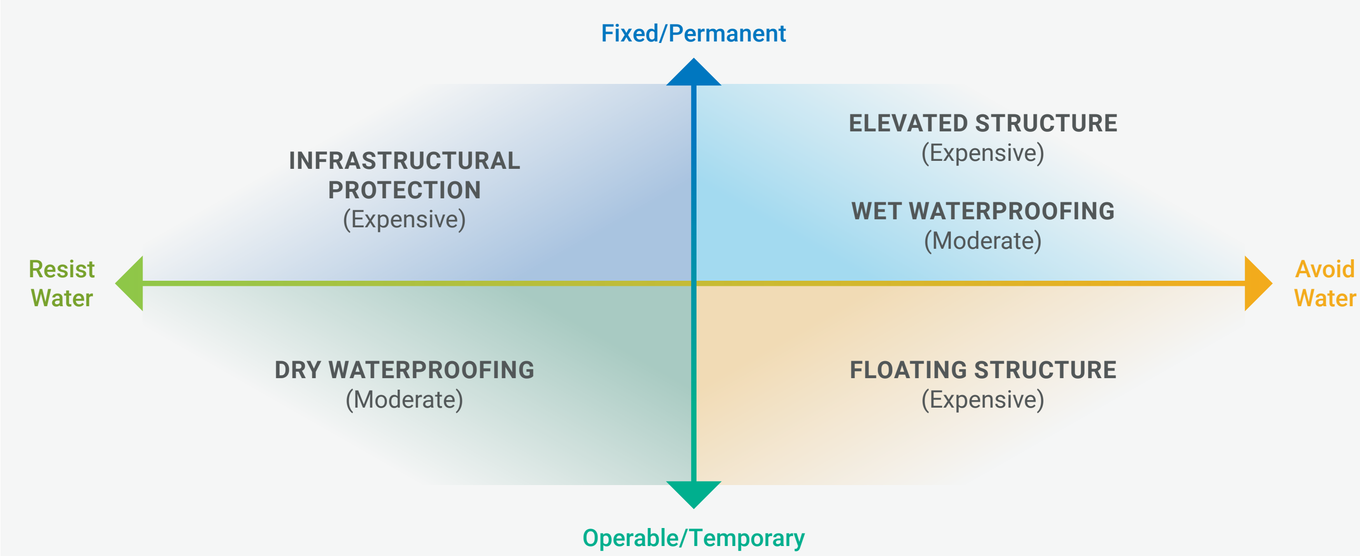
Each scenario explores various political, economic, and ecological spillover effects, such as increased conflict, supply chain disruption, or air quality issues. Next, the scenarios are mapped for levels of risk and opportunity for development, construction, and investment activities. Then they are integrated into Lendlease's corporate risk management framework and used to refine the company's physical risk assessment across eight physical hazards. Finally, they inform asset-scale design. For example, anticipating significant sea level rise and coastal storms at the Clippership Wharf development in Boston, Massachusetts (see page 96 for full profile), the project was designed to withstand flooding using raised ground floors, living shorelines, redundant mechanical systems, and other adaptation strategies.

STEP 3 INVESTIGATE RISK REDUCTION STRATEGIES

This step involves exploring strategies to reduce risks from identified hazards. See the Strategies for Coastal Resilience section starting on page 46 for examples of adaptation strategies that can be used to enhance coastal resilience.

Considerations while investigating the suitability of strategies include factors such as cost, maintenance, and feasibility considerations; cobenefits; and applicability of solutions to relevant hazards. Designing solutions for multiple hazards is essential: many strategies can create synergies by reducing risks from multiple hazards or providing benefits such as energy or water efficiency, or health and well-being. As examples, an office tower at 1450 Brickell in Miami, a South Florida resort, and the Ritz-Carlton, Grand Cayman all have employed adaptation strategies that address multiple coastal hazards simultaneously (follow the links for full profiles on each).

Relevant risk reduction strategies will vary considerably across contexts of geography, climate, surrounding development, and more. They will also need to evolve and adjust continually in response to changing climate science and regional/local hazard projections. Incorporating flexibility in planning and design will help ensure strategies remain effective in the long term. For more information, see the Pursuing Adaptive Solutions section on page 56.



ADAPTING CITIES TO SEA LEVEL RISE: GREEN AND GRAY STRATEGIES BY STEFAN AL, ADAPTED FROM "COST ESTIMATES FOR FLOOD RESILIENCE AND PROTECTION STRATEGIES IN NEW YORK CITY"

Relative cost of waterproofing strategies.

STEP 4 PRIORITIZE AND PLAN IMPLEMENTATION

In this step, teams fully evaluate the costs and benefits, feasibility, and additional information gathered in the previous steps to determine which strategies will be implemented, over what time frames, and in what order.

Risk tolerance is a central criterion in strategy prioritization and will significantly influence which strategies may be most relevant. For example, the relevant strategies for an asset that cannot tolerate any floodwater entering the building will differ significantly from the strategies for an asset that can tolerate floodwater entering and exiting ground floors safely with minimal cleanup and repair.

After strategies have been prioritized, teams will need to plan out when each strategy will be implemented for each at-risk asset or area, and in which order each will be addressed if they cannot be addressed simultaneously, based on available resources (e.g., staff and funding).

Considerations for Strategy Prioritization

During strategy prioritization, several other planning considerations may be helpful:

- Which strategies best reduce vulnerability to anticipated hazard damage and disruption over time?
- Which strategies are most cost-effective, in terms of level of protection needed/provided versus upfront and lifetime costs?
- How many hazards can the strategy mitigate? Strategies that address multiple relevant hazards should be prioritized.
- How many or which cobenefits can the strategy deliver? Strategies that provide a greater number of, or specifically desired, cobenefits—such as enhanced health and wellness or air and water quality—should be prioritized.
- Which strategies have a greater number of funding/financing opportunities?

See the Considerations for Effective Strategy Selection and Implementation section on page 56 for additional guidance, including how to pursue adaptive solutions, balance green and gray infrastructure solutions, and deliver cobenefits through adaptation strategies.

STEP 5 IMPLEMENT AND REFINE

This step is both the simplest and the most challenging: integrating adaptation strategies into sites or areas according to the prioritization plan developed in Step Four, which may change as conditions evolve.

It is important to ensure this step is iterative. Successful teams monitor the performance of adaptation strategies to inform ongoing implementation and change their approach where and when necessary, especially as new risk and vulnerability information becomes available.

The Brock Environmental Center, located in Virginia Beach, Virginia, where the Chesapeake Bay meets the Atlantic Ocean, draws tens of thousands of visitors as one of the world's best examples of sustainable and resilient design. The Living Future–certified building is set back 200 feet from the shoreline and elevated 14 feet above sea level on cast-in-place concrete columns—exceeding FEMA elevation requirements for 500-year flood and sea-level-rise projections. It also is designed to withstand 130-mile-per-hour winds, exceeding local code requirements. Learn more at the Developing Urban Resilience project profile.

Strategies for Coastal Resilience

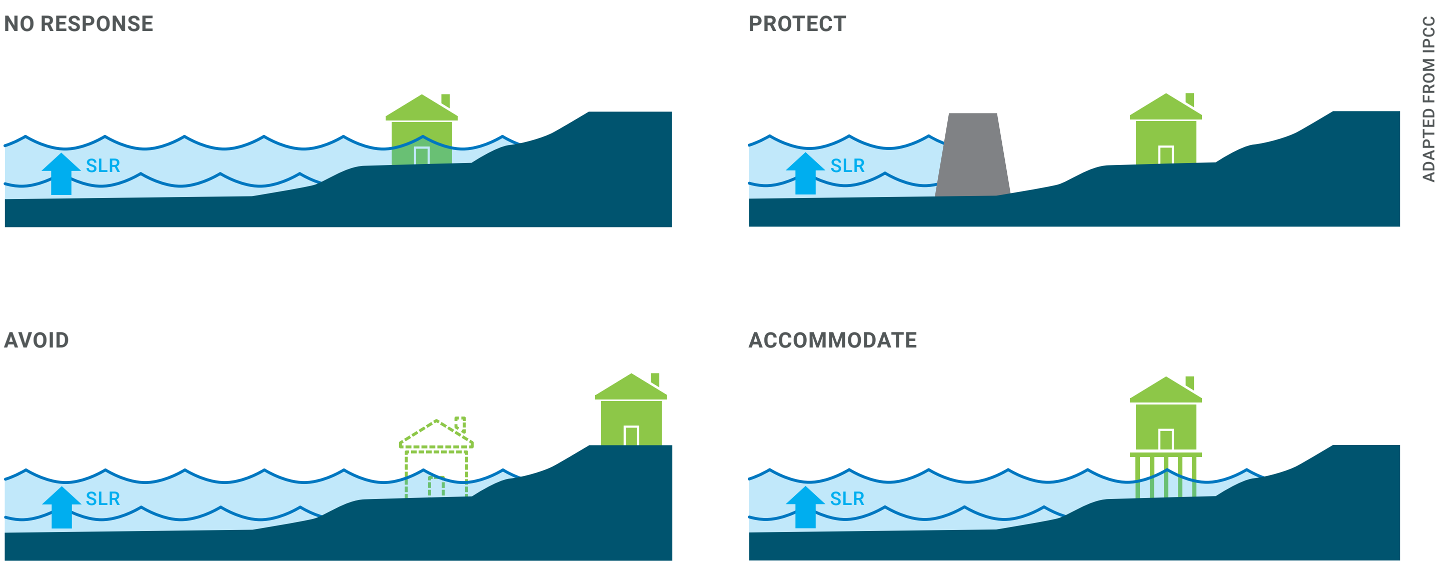
This section features a compendium of adaptation strategies to enhance coastal resilience at the building, site, and regional scales. The strategies are categorized into three primary coastal resilience methods:

- **Avoid:** This approach involves steering real estate development and critical infrastructure away from high-risk areas and flood-prone zones. By avoiding high-risk areas, communities can reduce potential damage and bypass costly adaptations.
- **Protect:** This approach uses physical defenses—such as sea walls, hazard-resistant building materials and designs, and natural barriers like dunes and mangroves—to minimize damage from coastal hazards.
- **Accommodate:** These measures allow for or adjust to sea level rise, flooding, and other coastal hazards, such as elevated sites and structures, flood-safe uses, and floating structures.

For each area, a different strategy or combination of strategies may work best to enhance coastal resilience. Overall, strategies work best when they are designed to meet the specific needs of the site or area. More strategies are available in the *ULI Developing Resilience Toolkit*.

> The cheapest coastal protection is the one that you don't need to build, because the building has a proper setback."
>
> **ESTEBAN BIONDI**
> *senior principal, Geosyntec Consultants Inc./ATM*

COASTAL RESILIENCE METHODS



Types of responses to coastal hazards, such as sea level rise (SLR).

Breakwater at Magic Island, O'ahu, Hawaii.

Scale of Adaptation Strategies

Many property owners are taking steps to make their buildings and sites more resilient to coastal hazards. Such investments can prevent damages, support insurance availability and savings, save lives, restore ecosystems, and create economic opportunities.

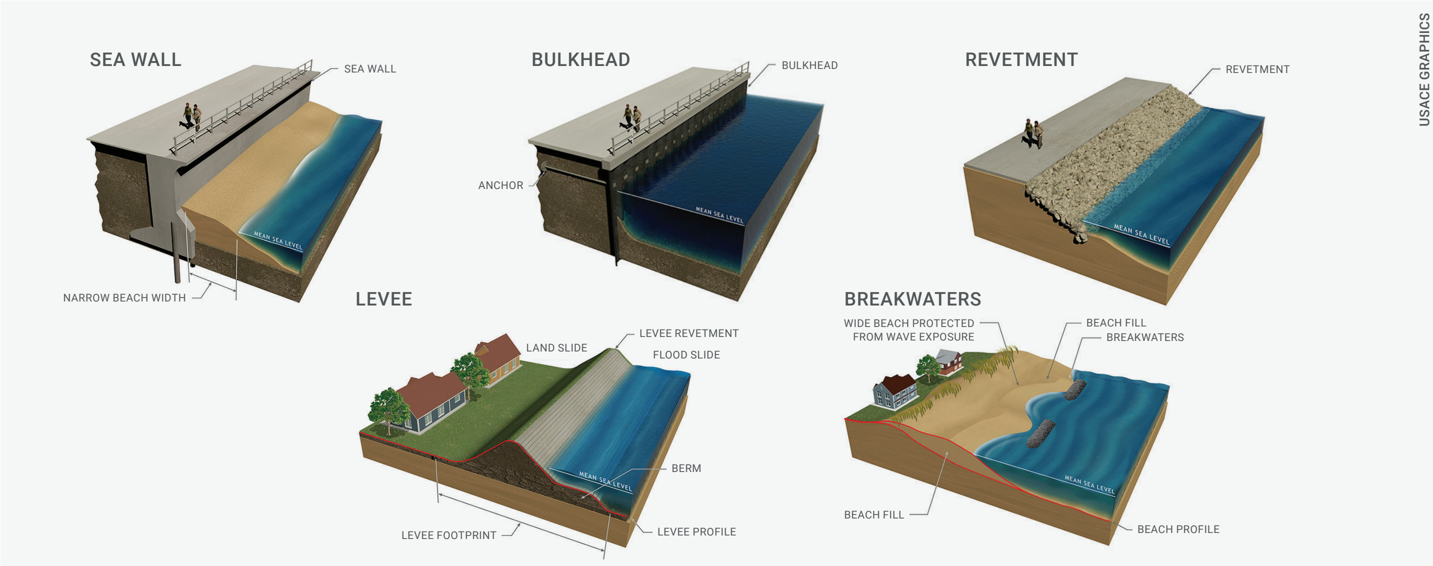
However, building and site protections can only go so far in coastal areas that are experiencing accelerating changes. While these measures are important, they alone may not make a property—or the access to and utilities that serve the property—completely resilient. Regional or districtwide protection systems are often necessary to effectively defend larger areas, utilities, transportation and stormwater infrastructure, schools, community buildings and spaces, and more. Regional public infrastructure is necessary to keep any area viable, and it must be protected at a larger scale.

The regional Oosterschelde storm surge barrier in the Netherlands.

ADAPTATION STRATEGIES FOR COASTAL RESILIENCE

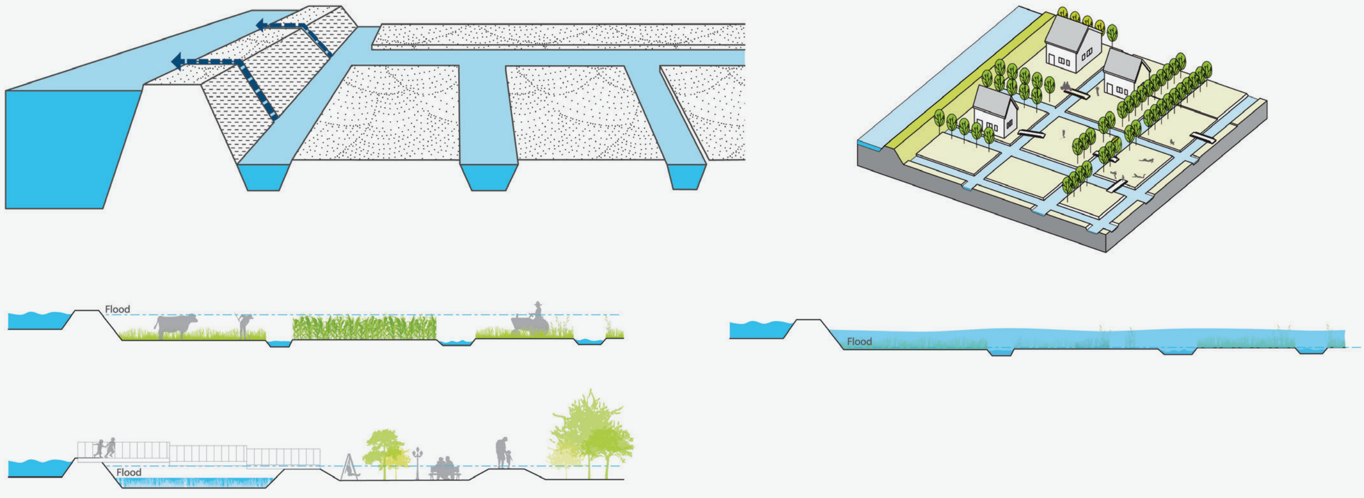
TYPE	STRATEGY	DESCRIPTION
SITE		
AVOID	Limited development in high-risk areas	Areas highly prone to one or more hazards are best avoided. Site selection (avoiding high-risk sites entirely) and site design (e.g., building in setbacks and/or buffers from high-risk areas on site) can complement larger regional planning efforts to direct development toward safer areas and to preserve natural landscapes as buffers against coastal hazards.
AVOID	Coastal retreat	Retreat of human occupation from coastal areas may involve the relocation of people, structures, infrastructure, and/or communities.
AVOID	Reduced reliance on groundwater and limited underground extraction to curb subsidence and saltwater intrusion	Limiting groundwater extraction and extraction of minerals, improving groundwater management, and developing alternative water supplies (including recharge of aquifers) can help reduce subsidence. Water efficiency, conservation, and reuse can also reduce reliance on groundwater, which in turn can help reduce subsidence and saltwater intrusion into groundwater. Strategies include water efficient water fixtures and appliances, smart metering and submetering, leak detection and repair, water reuse, native landscaping, water-efficient or no irrigation, rainwater harvesting, and permeable hardscapes, to name a few. For more information, see "*Water Wise: Strategies for Drought-Resilient Development*."
PROTECT	Deployable flood barriers, such as stop logs, flood doors/gates, sandbags, and inflatable barriers	This type of barrier is set up before a flood and removed afterward to prevent water from entering specific structures or areas. Self-closing flood barriers offer increased reliability and reduce the need for manual intervention but still require more intervention than permanent flood barriers. Pump systems can be included to reduce the potential for rain-induced flooding inside the protection area. Deployable barriers are best used for building and area protection only, not for buildings that are occupied during flood events.
PROTECT	Permanent flood barriers, such as perimeter flood walls, retaining walls, and berms	Permanent flood barriers can safeguard areas from floodwaters. Flood walls are typically reinforced concrete walls built on solid foundations and engineered to support flood loads. They are effective against unanticipated events and can be built as berms if space allows. Berms are raised earth mounds that can direct water away from buildings, pathways, or other areas meant to remain dry and toward areas that can accommodate temporary flooding. Permanent flood barriers support dry floodproofing. Certain barriers may block waterfront views and access, redirect water to other unprotected locations, or cut off important ecological processes that require connections between inland and marine environments. Permanent flood barriers can trap stormwater on site, requiring pumping or an outlet, and access must be provided for occupants/emergency personnel. Pump systems or an outlet can reduce the potential for rain-induced flooding inside the protection area. There may be restrictions on usage in some instances as they can increase flooding at adjacent properties by deflecting floodwaters. Permanent barriers are best used for building and area protection only, not for buildings occupied during flood events.

Curved sea walls are more effective at dissipating wave energy than vertical walls, which means they may take less damage.



PROTECT	**Coastal barriers/ shore stabilization, such as sea walls, bulkheads, revetments, dikes, levees, and breakwaters**	Barriers along or near coastal or riverine edges prevent water from moving inland and reduce erosion and wave forces. Certain barriers may block waterfront views and access, redirect water to other unprotected locations, or cut off important ecological processes that require connections between inland and marine environments. • Coastal barriers/shore stabilization can take various forms: • Sea walls are vertical structures designed to protect the area from wave and tidal action and reduce wave-induced overtopping and flooding. • Coastal bulkheads are typically vertical retaining walls intended to protect against erosion and flooding. • Revetments are sloped structures placed on banks or cliffs to protect the shoreline from erosion. Revetments typically consist of a cladding of stone, concrete, or asphalt to armor sloping shorelines. • Dikes (or levees as they are known in the United States) are embankments constructed along a waterfront to protect against flooding and can be used for multiple purposes, such as roads or recreation. • A breakwater is an in-water structure that protects the shore from waves or erosive forces. It can be used to form a harbor and basin that provides a safe place for boats to dock.
	Surge barriers	Fixed dam structures with moveable gates provide some of the highest levels of protection from coastal storm surge. This type of barrier is most appropriate for navigable channels and waterways that can be closed off (e.g., inlets) because it must connect to the shoreline on both sides of the barrier. During normal conditions, a surge barrier's gates remain open to allow the flow of water and vessels. Prior to a storm, the gates are closed. Types of surge barriers include sector gates, vertical lifting gates, and tide gates. These barriers work best when paired with other measures, such as levees, sea walls, and/or pumps.
	Coastal advance/land reclamation	This strategy involves creation of new land by building seawards. Extending the coastline can help protect inland areas from coastal hazards. Land reclamation has a long history in areas with a dense coastal population and a shortage of land, but it can come with significant environmental impacts.
	Groins and jetties	Groins are structures built perpendicular to the shore and used to maintain updrift beaches or restrict longshore sediment transport. Jetties are another type of shore-perpendicular structure and are placed adjacent to tidal inlets and harbors to control inlet migration and minimize sediment deposition within the inlet. These structures are meant to capture sand transported by the longshore current, which can deplete the sand supply to the beach area immediately down-drift of the structure. Down-drift property owners often install groins or jetties on adjacent properties to counteract the increased erosion, leading to a cascade of groin installation. These structures may disrupt natural sediment regimes, which is why beach nourishment and examples like the Sand Motor may be more successful.
	Tidal outfall gates (also called tide gates, floodgates, box gates, or flap gates)	Installation of tidal outfall gates at the sea mouth of a river, waterway, or tidal inlet can protect against flooding. These devices close during incoming tides, storms, or flooding to prevent floodwater from flowing upstream and inundating inland areas. They open during outgoing tides to drain upland areas. Higher average sea level elevations can reduce the effectiveness of tidal gates by impacting the hydraulics of the system.

POLDERS

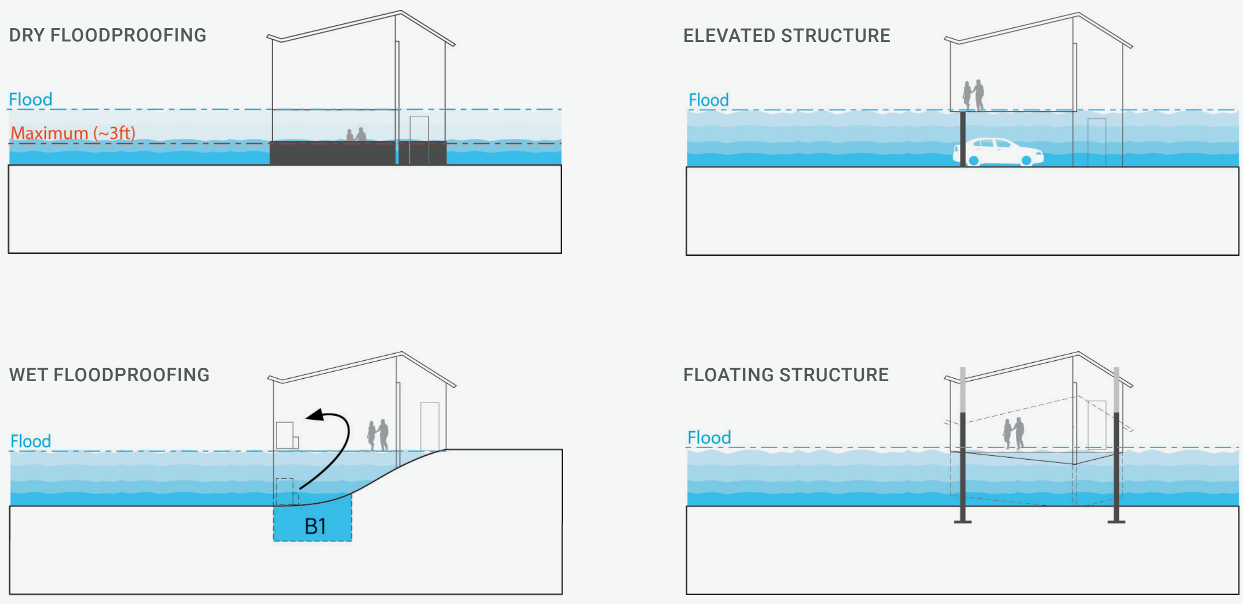


FROM ADAPTING CITIES TO SEA LEVEL RISE: GREEN AND GRAY STRATEGIES BY STEFAN AL

PROTECT	**Tidal backflow valves**	Tidal backflow valves prevent seawater from entering the pipe network and flooding development at high tides or when the sea level is higher.
	Culverts and drainage pipes	Culverts and drainage pipes allow water from various sources to flow beneath infrastructure like bridges and roads, thereby helping prevent flooding and manage water flow effectively. Ensuring these structures are properly sized is crucial for their effectiveness in transporting large volumes of water and avoiding overflow into adjacent areas.
	Pumping systems	For areas where gravity-based drainage is insufficient, pumping systems are recommended. These systems are essential for relocating floodwaters away from critical facilities or areas at risk, offering a solution for both stormwater management and limited riverine and coastal flooding mitigation.
	Polders	Polders are low-lying strips of reclaimed land or drained marshes enclosed by levees. Polders include a hydraulic transport system of drains to store and transport water to pumping stations, helping to keep water levels steady and store pluvial and fluvial water. Polders can lead to subsidence, so some are being returned to floodplains.
	Living shorelines	Living shorelines, created using natural elements, can aid shoreline stabilization and flood-risk mitigation. This approach is recommended to protect coastlines from erosion and reduce storm surge by preserving, creating, or enhancing natural systems such as marshes, beaches, and dunes. Elements can include riparian, marsh, and aquatic vegetation; bio-logs and organic fiber mats; managing, restoring, enhancing, or creating new wetlands, coral reefs, oyster reefs, or other habitats. See the profile of Clippership Wharf on page 96 for an example of how living shorelines can be integrated into real estate development.
	Dune and beach preservation, restoration, and nourishment	Dunes and beaches are crucial for absorbing wave energy and reducing coastal storm impacts. Beach dunes can act as natural coastal flood barriers, while providing ecological habitat and amenity value. They provide a buffer against erosion and wave action, attenuation of wave energy, barrier/resistance to inundation, and overland flow. Long-term nourishment projects periodically add sand to these natural barriers to ensure their effectiveness in protecting inland areas.
	Ecosystem protection and restoration and added vegetation	Protecting and restoring ecosystems to pre-development conditions in targeted areas can improve ecosystem function and biodiversity. These actions, in turn, can improve coastal hazard buffering, flood absorption, groundwater recharge, heat reduction, carbon sequestration, and other ecosystem services. Coastal ecosystems such as reefs, barrier islands, dunes, beaches, wetlands, forests, river systems, and floodplains may require specialized protection and restoration efforts. Adding vegetation to sites can also help provide these benefits. Terrestrial and submerged vegetation can dissipate wave energy, help retain sediment, and increase water infiltration.

PROTECT	**River channels, river restoration, and river creation**	Removing constructed hard edges and channelization around rivers and expanding green space along waterways to accommodate natural ebbs and flows often enhances flood control and riparian ecosystems. These strategies may not be possible for all river systems, depending on specific characteristics (e.g., intensity of peak flow events). Adding river channels alongside main river channels can help boost flow capacity, facilitate main channel movement, encourage sediment retention and stormwater infiltration, and mitigate flood impacts. These strategies can also help store water upstream during coastal storms, reducing flooding around coastal river delta areas.
	Windbreaks	Vegetation such as trees and hedges can reduce wind speeds and damage from coastal storms while also providing other risk reduction services. Walls and other nonvegetated structures can serve as windbreaks, but the vegetated versions also provide cooling through evaporation and help slow and absorb stormwater. In coastal areas, some windbreaks (e.g., berms or coastal tree species, such as mangroves) may also provide flood protection.
	Raised or inverted primary roads and pathways	Roads, rights-of-way, and pathways that are elevated above the flood level help preserve access in and out of a community during periodic or chronic flooding. This strategy can present accessibility and urban design challenges when harmonizing street level with adjacent properties and can increase flood risk to existing buildings if not designed appropriately. Fort Lauderdale, Florida, is developing criteria for road elevation projects to minimize coastal flooding and navigate harmonization challenges. An alternative to raising roads and paths is inverting them from crowned shape, which sheds water to roadsides and buildings, to a V-shaped profile that collects water at the center. Inverted roads and paths drain normally during average rain events and fill and convey water during flood events. Inversion may not provide sufficient drainage during storm surge or high-tide flooding.
	Pathways graded to direct stormwater flow to open spaces	Pathways can be intentionally graded to direct stormwater to adjacent open spaces. This strategy can be coupled with reducing pathway width to expand open space, de-paving or permeable pavement, and raised primary pathways. It may also help with groundwater recharge.
ACCOMMODATE	**Green streets**	Green streets incorporate absorbent landscaping with stormwater drainage features (e.g., permeable pavements), to slow, filter, and cleanse stormwater runoff from streets and sidewalks, reducing flooding. Elements could include retrofitted medians, curbs, ponding areas, trees, plants, water retention ponds, and bioswales.
	Expanded/enhanced parks and open spaces	Parks and open spaces can provide stormwater management, coastal barriers, windbreaks, and cooling through evaporation. Expanding and enhancing parks and open space can support coastal resilience, especially if salt-tolerant, native plants are used.
	Large water retention and detention features, such as wetlands and ponds	Interconnected bodies of water can safely retain and slowly absorb floodwaters while creating ecosystem habitat and urban amenities. Water bodies also provide cooling effects and help recharge groundwater or provide water supplies.
	Site elevation	If permitted by regulations, a site can be raised above the current base flood elevation and/or higher than future flood projection levels with fill via site grading (this strategy may not be allowed in areas subject to wave action). In riverine environments, elevation with fill may have adverse impacts on adjacent, upstream, or downstream sites.
	Floodable plains and squares	Floodable plains are flat areas adjacent to a body of water that can be flooded when the water body's capacity is exceeded. They use existing natural or urban environments to catch stormwater and control flooding. During normal conditions, they can remain dry and be used for other purposes, such as recreation. Floodable plains are relatively inexpensive and easy to maintain but require significant amounts of land. Floodable squares are usually sunken active or passive recreational areas designed to safely receive and retain or absorb large volumes of floodwater with minimal damage, reducing flood damage in other areas. They can include water storage basins, drainage systems, and/or permeable pavements and soils that facilitate groundwater recharge. They provide combined community amenities and floodwater management features.

ACCOMMODATE	**Subsurface galleries/ storage, such as infiltration galleries or crates/boxes**	Underground crates, chambers, pipes, or other detention systems with high storage capacity capture stormwater runoff and slowly discharge into groundwater. This strategy is primarily useful for reducing flooding from rainfall during coastal storm events.
	Green infrastructure, such as rain gardens, bioswales, stormwater planters, dry wells, curb cuts, tree wells, and structural soils	This strategy refers to a combination of features that slow, store, and infiltrate water into the ground, reducing flood damage to buildings and structures. These features help recharge groundwater, provide natural cooling, enhance biodiversity, and—when vegetated—elevate landscape interest. They are primarily useful for reducing flooding from rainfall during coastal storm events.
	Reduced use of impervious surfaces, for example by de-paving or installing pervious pavement	Pervious surfaces allow stormwater to infiltrate into the ground, reducing flooding and recharging groundwater supplies. Pervious materials in parking areas can improve water drainage and reduce water accumulation. They are primarily useful for reducing flooding from rainfall during coastal storm events.
BUILDING/STRUCTURE		
PROTECT	**Community shelters and resilience hubs**	Shelters (or safe rooms) designed to withstand coastal hazards can protect life and provide safety during emergencies. Shelter facilities can double as resilience hubs—community or recreational facilities that support residents and provide resources, programs, and services to improve well-being year-round. They can also serve as cooling centers and should be located outside or above flood levels to provide shelter during hurricanes or flood events.
	Minimize below-grade spaces in flood-prone areas	Minimize the creation of below-grade spaces (e.g., basements and parking garages) in floodplains and flood-prone areas to reduce the likelihood of flooding. This strategy can help reduce construction and insurance costs. Existing buildings that feature below-grade spaces can be filled in using compacted structural fill to the nearest adjacent grade to reduce flood risk. Note that fill material can be hard to compact in tight spaces and requires a structural evaluation to address any modifications needed for the foundation. Consider whether any underdrain systems in a filled basement are necessary. This strategy may be part of wet floodproofing or elevating a building on solid foundations.
	Elevation of first floor with external or internal access features	If internal ceiling heights are sufficient, the floor level of the first floors can be raised above flood elevations, with interior or exterior stairs or ramps added for accessibility. Landscaping or other enhancements can beautify exterior stairs/ramps, or they can become onsite open-space amenities or gathering areas.
	Dry floodproofing	Dry floodproofing is a combination of techniques intended to prevent water from entering buildings. These techniques include flood barriers and waterproof coatings for walls and openings; elevated or sealed mechanical equipment; sealed cracks or gaps in exterior; sump pumps with backup power; and backflow valves for sewers and drains. This approach is appropriate when floodwaters are below 3 feet (0.9 m), move slowly (no wave action), and persist for less than three days. Dry floodproofing is best for building protection only, not for occupied buildings during flood events.
	Backwater valves	A backwater valve installed in the drainage system prevents sewage from flowing back into a building during heavy flooding.
	Improved drainage control at building edge	Proper grading, drainage, siting of infiltration, and use of waterproofing layers can reduce water intrusion through foundation cracks or walls/slabs. This approach is primarily useful for reducing damage from rainfall during coastal storm events.
	Deeply anchored building foundations	Building foundations directly transfer loads from the roof and building exterior to the ground. Buildings sited in coastal zones may require deep foundations, including columns with spread footings in deep soil or deep piles with caps to anchor the footings and main structure of the building.



FROM ADAPTING *CITIES TO SEA LEVEL RISE: GREEN AND GRAY STRATEGIES* BY STEFAN AL.

ACCOMMODATE	**Building designs sensitive to aerodynamic forces**	To reduce vulnerability to high winds, building designs can include aerodynamic principles such as symmetry, strategic redundancy, and safety margins. Wind tunnel testing is recommended for large or unique buildings.
	Wet floodproofing	Wet floodproofing is a combination of techniques to reduce structural damage from floodwater. These techniques include flood vents in foundation/enclosure walls in areas below living space to allow water in and out; anchoring to resist flotation, collapse, or lateral movement; water-resistant materials in floodable areas; elevated or relocated mechanical systems; and backflow valves to prevent sewer and drain backups. These strategies do not protect from the force of flowing water, scour, erosion, or debris.
	Water-resistant and durable materials	Water-resistant materials such as concrete, tile, and terracotta can be used in floors below flood elevation to reduce damage and cleanup costs and risks of mold. Water-resistant and durable materials may be used as part of wet floodproofing and for outdoor materials. Selecting durable materials increases the building's lifespan and ability to withstand multiple hazards.
	Conversion of ground floor to flood-safe use, such as parking or storage	Converting ground floors to parking, storage, or building access restricts flooding to unoccupied spaces only, limiting damage and repair costs. In coastal wave zones, floodplain regulations may require ground floor space to be unenclosed or have breakaway walls. This strategy may result in loss of usable floor space (residential units or commercial area), though lost floor space may be relocated to a roof addition if permitted by zoning.
	Elevation of the building	The entire building can be raised above current base flood elevation and/or higher than future flood projection levels. The building can be elevated on piles/columns that allow water to pass underneath or elevated on fill via site grading if permitted by regulations (this strategy may not be allowed in areas subject to wave action). In riverine environments, elevation with fill may have adverse impacts on adjacent, upstream, or downstream sites.
	Floating buildings and other structures, including houseboats	Buildings and other structures can float during flood events or float permanently in water bodies, accommodating flooding and sea level rise. Floating buildings and houseboats are more common in places with limited wave action. Construction of floating communities is being considered in several places. Artificial floating islands that support plant growth can be used to dampen wave energy in sheltered water bodies.

ENVELOPE		
PROTECT	Impact- and pressure-rated wall systems (Exposure Category C or D)	High winds during coastal storms create both uplift force (pressure from below) and shear forces (lateral force in opposite directions) that exert pressure on wall systems, in addition to risks from wind-driven debris. Wall systems or structural sheathing designed to withstand impacts and these pressures will reduce risk of severe structural damage or collapse. Systems should be selected using the building's design wind speed.
	Impact- and pressure-rated windows, skylights, doors, and garage doors	Windows and doors are structural weak points that are vulnerable to windborne debris and wind pressure during coastal storms, and failure can cause significant damage as winds enter the structure. Glazed openings and exterior doors that are rated to withstand debris impacts and wind speeds can reduce vulnerability. Use of hurricane shutters, impact-resistant glass, and smaller glass sheets supported by strong metal frames can help mitigate damage from flying debris during storms, as can increasing the gauge of metal bracing, size, and quantity of fasteners.
	Storm shutters and panels	Storm shutters for windows provide additional protection or an alternative to impact-rated windows. A variety of designs enhance aesthetics. Shutters may reduce water intrusion during flood events but may not provide the same protection as flood barriers, especially against storm surge.
	Anchored or engineered attached structures, such as porches, decks, and cantilevered overhangs	High winds and floodwaters can create uplift under attached structures and pull them away from the building, causing damage to the structure, main building, and other structures. Strong anchors and connections can reduce risk.
	Reinforced building corners and exteriors (e.g., bollards)	During floods, floating debris can damage building exteriors. Bollards or other features at corners and along walls on the upstream side of buildings can deflect the debris that can arise during floods. This technique can help reduce damage.
	Braced or engineered parapets and facades	Parapets and building facades can be torn off by high winds during coastal storms, damaging the structure and potentially nearby structures. Risk can be reduced by adequately bracing and anchoring parapets and facades.
	Rainscreen cladding	This construction detail provides air space between exterior cladding and the structural wall system to allow the cladding or siding to dry out between precipitation and storm events, block the vapor drive of moisture through cladding materials, and allow water vapor from inside the building to escape without degrading walls or growing mold. Rainscreen systems should be designed in accordance with the building's design wind speed.
ROOF		
PROTECT	Use of appropriate materials and methods of installation for improved redundancy, anchoring, and performance of roofs	Roofs installed using methods that increase redundancy and anchoring, such as combining foam adhesives with mechanical nailing for stronger roof tile adhesion, are better able to withstand expected wind uplift forces during coastal storms. In hurricane-prone areas, hip roofs, which slope in four directions, are preferred over gable roofs for their superior performance in wind tests.
	Rooftop equipment secured or designed for high winds	Rooftop equipment can puncture the roof membrane and expose the interior to wind-driven rain during coastal storms. To minimize damage, mechanical systems, such as HVAC systems, lightning protection systems, and solar panel equipment, can be securely/mechanically attached to the roof, creating a continuous load path to the ground.
	Strengthened/ sealed/impact-rated roof deck	Roof decks are vulnerable to damage from high winds, potentially exposing the interior to wind forces and water intrusion from wind-driven rain, both of which can cause significant damage. Roof deck assembly (e.g., thickness of sheathing, type, and number of fasteners) that is adequately constructed to withstand uplift forces and impact is more likely to remain attached to the building, minimizing damage. Sealing can include a full layer membrane or sealing of joints between sheathing, along with drip edge flashing to direct water away from underlayment.
	Diversion and use of roof runoff	Roof water runoff can be diverted through external leaders into green infrastructure features, cisterns, or subsurface storage. The captured stormwater can be used for irrigation, which can help recharge groundwater. This strategy can also help reduce flooding from rainfall during coastal storm events.

ACCOMMODATE	Green roof	A vegetated roof system can absorb rainwater and solar heat, reducing local flooding and cooling costs while boosting biodiversity (particularly for intensive green roofs) and creating an amenity (if accessible). Green roofs may not be suitable for hot, arid areas as they may require more water to maintain than they are worth for risk reduction. Additionally, in wind-prone regions, green roofs can be vulnerable to uplift and structure damage, or create windborne debris that can impact surrounding buildings, whose upper glazing systems may not have the same impact protection as lower floors due to code exemptions. Green roofs should be designed in accordance with the building's design wind speed. As an example, the University of Miami's hurricane-strength green roof system on the Lakeside Village student housing development is designed for high wind conditions. Green roofs are primarily useful for reducing flooding from rainfall during coastal storm events.
	Blue roof	A waterproof detention system integrated into the roof surface can detain and slowly release stormwater, reducing flooding. Blue roofs can reduce heat gain on the roof and can be combined with green roofs. Blue roofs may not be appropriate in hurricane-prone regions as high winds can push water to one side of the roof and, unless properly designed, exceed design loads for a section of roof. Blue roofs are primarily useful for reducing flooding from rainfall during coastal storm events.
BUILDING SYSTEMS		
PROTECT	Elevation, relocation, or hardening of utility/mechanical systems	Utilities (e.g., HVAC systems, server rooms) can be located, or relocated, to roof, upper floor, raised platform in basement, or flood-proofed/elevated annex building (if space and systems allow). If it's not feasible to relocate/elevate systems, add dry floodproof solutions, such as flood doors or barriers, around them. This strategy is often part of dry and wet floodproofing. Moving equipment may be an opportunity to replace older equipment with more efficient electric equipment, such as heat pumps.
	Flood-resistant elevator and elevator water sensors	Elevator pits often extend below the lowest floor and are highly vulnerable to flooding. In new construction, basement machine rooms and elevator pits should be avoided. In both new construction and retrofits, the elevators should have motors and controllers above flood levels and sump pumps to remove flood seepage, reinforced shaft portions below flood levels, sensors and controls set to prevent the cab from lowering into floodwater, and dry floodproofing of components that cannot be elevated.
	Separate circuits for critical building loads	Wiring critical loads separately ensures backup power can be sized down as needed, reducing battery costs or amount of fuel needed on site to keep building operational during emergencies.
	Redundant telecom conduit entrances	Design redundant telecommunications conduit entrances for multiple carrier entry. Telecom conduit should run to diverse maintenance holes when possible and have a backup power supply above flood elevations.
	Backup on-site power (e.g., solar plus battery storage or generator)	A backup power supply ensures the building (or critical systems) can remain operational in case of power outage during emergency events. Critical facilities are equipped with backup generators capable of powering essential systems, including life safety and mechanical equipment, for durations ranging from 24 to 72 hours during floods.
	Energy efficiency measures (e.g., efficient appliances, HVAC, LED lighting)	Energy efficiency reduces grid strain and/or energy needed from onsite renewables or backup power, helping buildings and grids remain operational during emergencies. Some measures or performance standards may be required by building/energy code.
	Building electrification	Buildings can be designed or retrofitted to eliminate all fossil fuel–based building systems (e.g., HVAC, hot water, cooking). All-electric buildings are better prepared for on-site or grid-delivered renewable energy and, if connected to on-site renewables, are more prepared to keep operating during power outages caused by various hazards.
	Emergency lighting	Emergency lighting systems, operated by battery, can be installed in critical areas and exit paths, with regular checks to ensure functionality.
	Electrical panel upgrades	Electrical panels can be enhanced with remote-control capabilities to allow for swift disconnection in emergency situations.

Langone Park and Puopolo Playground in Boston, Massachusetts, protects the surrounding community from sea level rise and flooding while preserving access to the waterfront. In an adaptive approach, a second sea wall was constructed behind an existing sea wall to add protection to the site. The approach greatly reduced permitting and construction complexities, and the wall works effectively as a wave action barrier.

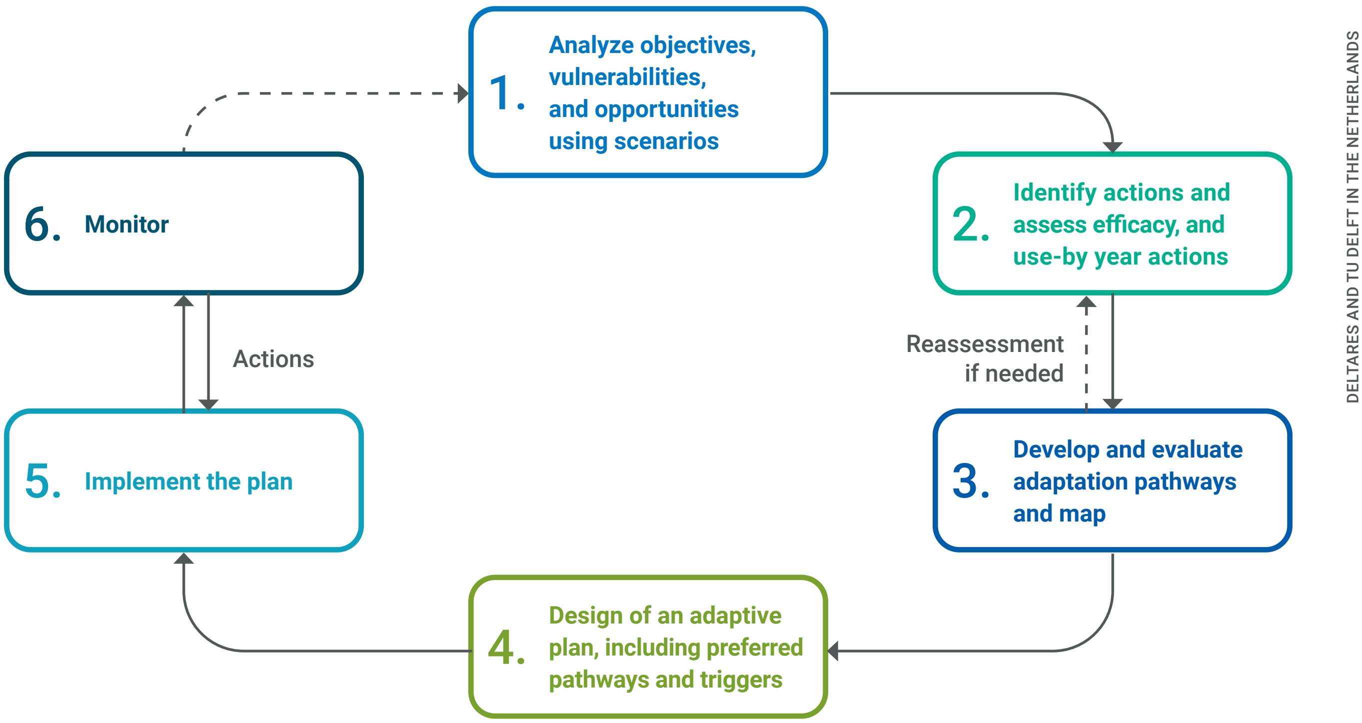
Considerations for Effective Strategy Selection and Implementation

When considering which strategies to select for coastal resilience, some additional factors beyond costs, benefits, and feasibility may become increasingly important as hazards intensify, and conditions and ecosystems change over time. The following information on pursuing adaptive solutions, balancing gray and green infrastructure, and harnessing cobenefits provides additional guidance for selecting resilient and adaptive solutions for coastal sites and communities.

PURSUING ADAPTIVE SOLUTIONS

Predicting exactly how much and by when climate-related hazards will impact specific areas is difficult. Adaptive solutions are helpful because they allow for incremental improvements over time. Ideally, real estate and land use decisions should account for the entire life cycle of assets with the knowledge that assets will need to perform in different climate realities than those that currently exist.

Adaptive solutions generally include multilayered approaches that add a new layer of protection when risks increase, building adaptive capacity as it is needed. Flood protection systems, for example, are frequently designed with adaptive capacity. In the East Side Coastal Resiliency project in New York City, the foundations are prepared for a higher flood protection system than what is currently being built (see page 93 for a full profile of Lower Manhattan Coastal Resiliency Project and East Side Coastal Resiliency in New York City).[270] The key is that adaptive solutions can be adjusted over time as the local risk context changes.



Dynamic Adaptive Policy Pathways approach.

One example of an adaptive process is the Dynamic Adaptive Policy Pathways (DAPP) approach created by Deltares and TU Delft in the Netherlands. According to the Deltares website, "An adaptive plan specifies actions to be taken immediately to be prepared for near futures as well as actions to be taken to keep options to adapt open in more distant futures if needed. The exploration of adaptation pathways is one of the main ingredients of an adaptive plan. A monitoring system collects information to receive early warning signals for implementation of actions or for reassessment of the plan."[271]

Organizations in any sector can develop an adaptive approach to resilience by following the DAPP process. The process begins with identification of objectives, constraints, and uncertainties relevant to resilience decision-making. Scenario planning is used to address the uncertainties. Plausible futures in the scenarios are compared with the resilience objectives to determine if and when any tipping points may occur and thus when additional adaptation will be needed.[272]

A tipping point occurs when external changes, such as sea level rise or other coastal hazards, exceed the capacity of the adaptation strategy to meet its objectives. At that point, new strategies are needed to achieve the resilience objectives. Using scenario planning with tipping points (also referred to as adaptation thresholds) can simplify the process of updating plans and strategies as climate conditions change over time.[273]

Adaptation pathways, or a sequence of resilience measures, can be developed to respond to the various scenarios and their tipping points. An analysis of the costs and benefits of adaptation pathways, as well as risk tolerances, can help with the selection of near-term actions and longer-term options. An adaptive approach to resilience is developed from these selections. The approach, or plan, works best when it is complemented by a monitoring system that collects information on the changing conditions that will require further adaptation.[274]

The secondary sea wall at Langone Park and Puopolo Playground in Boston, Massachusetts, offers overlooks and seating with expansive harbor views, while breaks in the wall allow people to get down to the harbor and some water to enter and leave the site. The new sea wall's foundation is designed to hold additional weight so that it can be built upon if flood projections change in the future.

An adaptive approach to coastal resilience enables teams to make decisions and take actions without locking in future investments, allowing for flexibility over time and avoidance of maladaptation. Such an approach is extremely helpful for getting started on needed adaptations without waiting for certainty on future conditions, which will likely come too late, if at all.[275]

For real estate developers and owners who have short hold periods, investments in adaptation can still support the bottom line (see The Business Case for Investing in Coastal Resilience section on page 29 for more information). An adaptive approach can help them select adaptation strategies that can be built on over time, as opposed to strategies that will have a short lifespan, adding value and longevity to the asset. For the entire real estate industry, phased implementation of risk reduction strategies can help spread out costs over time and avoid catastrophic losses.

The Dynamic Adaptive Policy Pathways Approach

The Dynamic Adaptive Policy Pathways (DAPP) approach has been used in many contexts worldwide. It was initially applied in the Netherlands to inform the Dutch Delta Programme's adaptive delta management approach, which provides flood risk and freshwater availability strategies for the area (see page 99 for a full profile of the multilayered flood management strategies in the Holland region of the Netherlands). Other applications of the DAPP approach include the following:

- Adaptive flood risk management for Danish municipalities
- Plan alignment for coastal resilience for the city of Santa Cruz, California
- Development of short- and long-term flood resilience strategies in Miami-Dade County, Florida
- Adaptive strategies for water utility infrastructure upgrades in Australia
- Climate-resilient investment pathways to support economic development and disaster resilience for ports and infrastructure in the Solomon Islands

BALANCING GREEN AND GRAY INFRASTRUCTURE

Gray infrastructure—or man-made structures such as dikes, sea walls, and surge barriers—is widely used for protection in coastal cities and deltas.[276] However, these hard engineering interventions can sometimes disrupt natural dynamics and ecosystems that maintain coastlines and land elevation, which could lead to less protection for coastal areas. Another risk with large-scale gray infrastructure is that it can be so expensive that the debt burden—and a false sense of safety—can inhibit further adaptation when it is necessary.[277,278,279,280]

"A lot of traditional approaches have been on the defensive side, and it's been hard engineering—gray infrastructure, bulkheads, riprap—that you see in every city in terms of the way in which we've traditionally defended against the ocean. Nowadays, we do a lot more on the green side in terms of how we incorporate ecology and more natural solutions into that coastline to be able to defend over time."

SCOTT DUNN
Chief strategy officer, Asia, AECOM

Nature-based solutions, sometimes called green infrastructure in the context of stormwater management, are becoming more popular worldwide. They not only protect coastal areas, they also provide ecological benefits, such as habitat creation, serve as carbon sinks, and offer places for recreation.[281,282] In coastal contexts, nature-based solutions can include restored wetlands, living shorelines, living barriers such as mangroves or oyster reefs, and more. In addition to providing multiple benefits, these strategies can self-reinforce over time as their ecosystems mature, increasing their effectiveness without additional large investments. Sometimes, all that is needed is protection of existing natural areas, which is very affordable. However, natural systems such as dunes and wetlands may need to be restored or enhanced to provide needed protection to communities.

"Building with nature avoids disruption of sediment flows as rivers approach the sea. Such disruptions cause both buildup of sediments where they might not be desirable and sediment starvation farther along the coast, as well as the many other pitfalls that come with hard engineering projects. The engineered stability of constructed coastal systems can also have negative effects on ecosystems, which in general benefit from more diverse relationships between land and water."

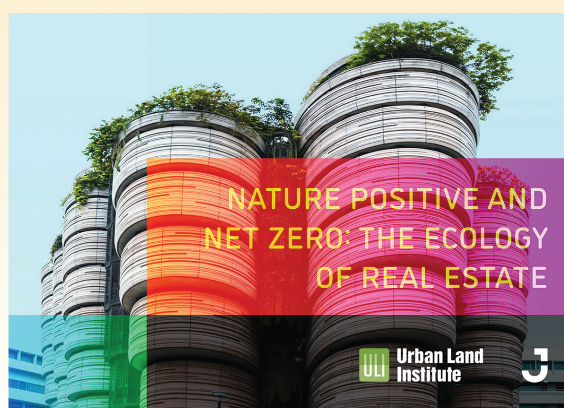
JONATHAN BARNETT AND MATTHIJS BOUW
Managing the Climate Crisis

With nature-based solutions, it is important to remember that natural systems take time to grow and evolve. To avoid running out of time as coastal hazards accelerate, projects involving natural systems benefit from starting sooner rather than later.[283]

ULI RESOURCE

Nature and Real Estate

ULI's report *Nature Positive and Net Zero: The Ecology of Real Estate* highlights key global market drivers for real estate developers and owners to preserve and enhance biodiversity in real estate as part of their overall climate strategy. It also provides guidance on best practices for implementing nature-positive solutions at multiple scales.

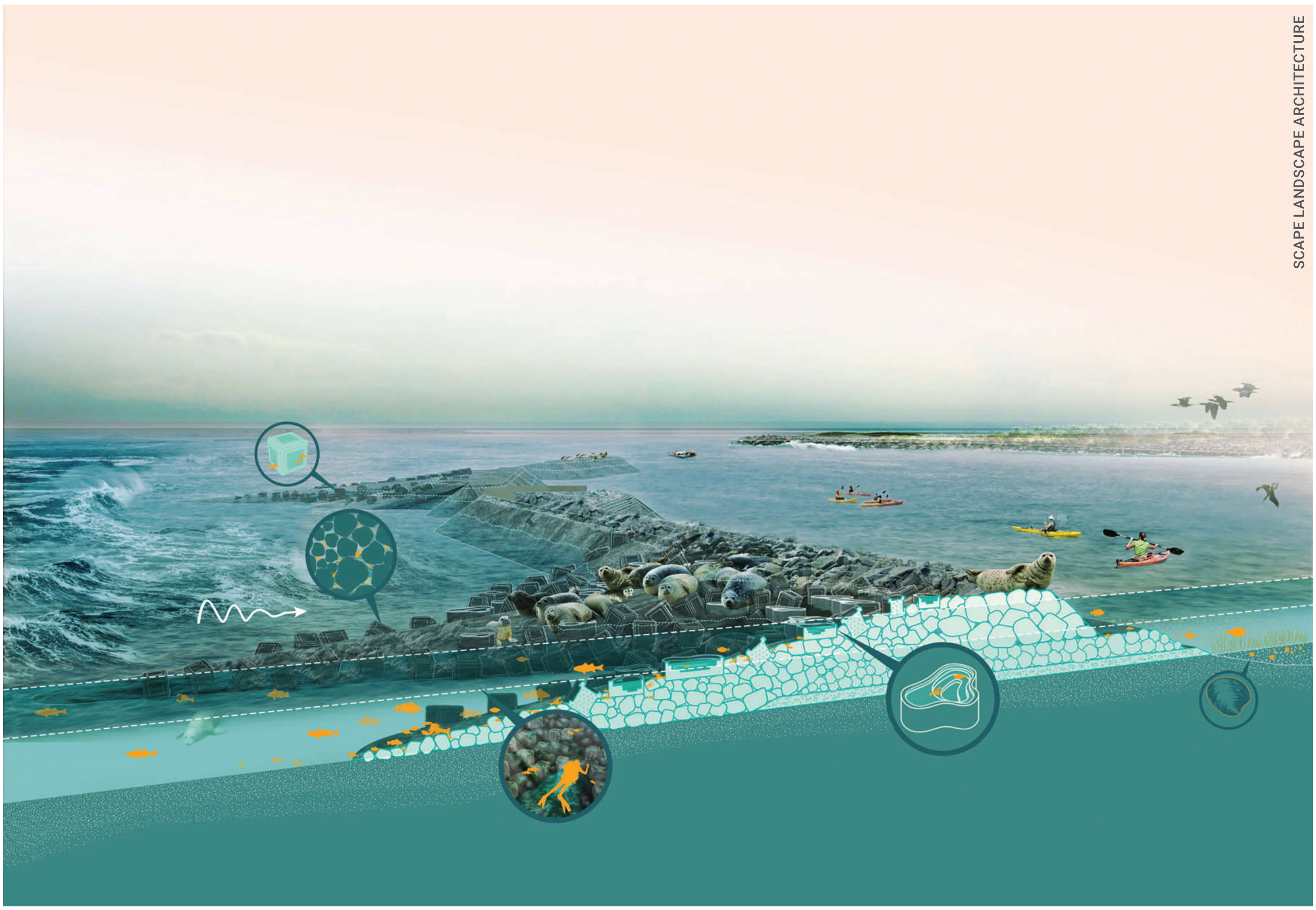


Netherland's Room for the River initiative, which gives rivers more space to expand with flooding, is an example of how to give natural processes the room needed to protect communities adequately. For more information, see the Holland profile on page 99.

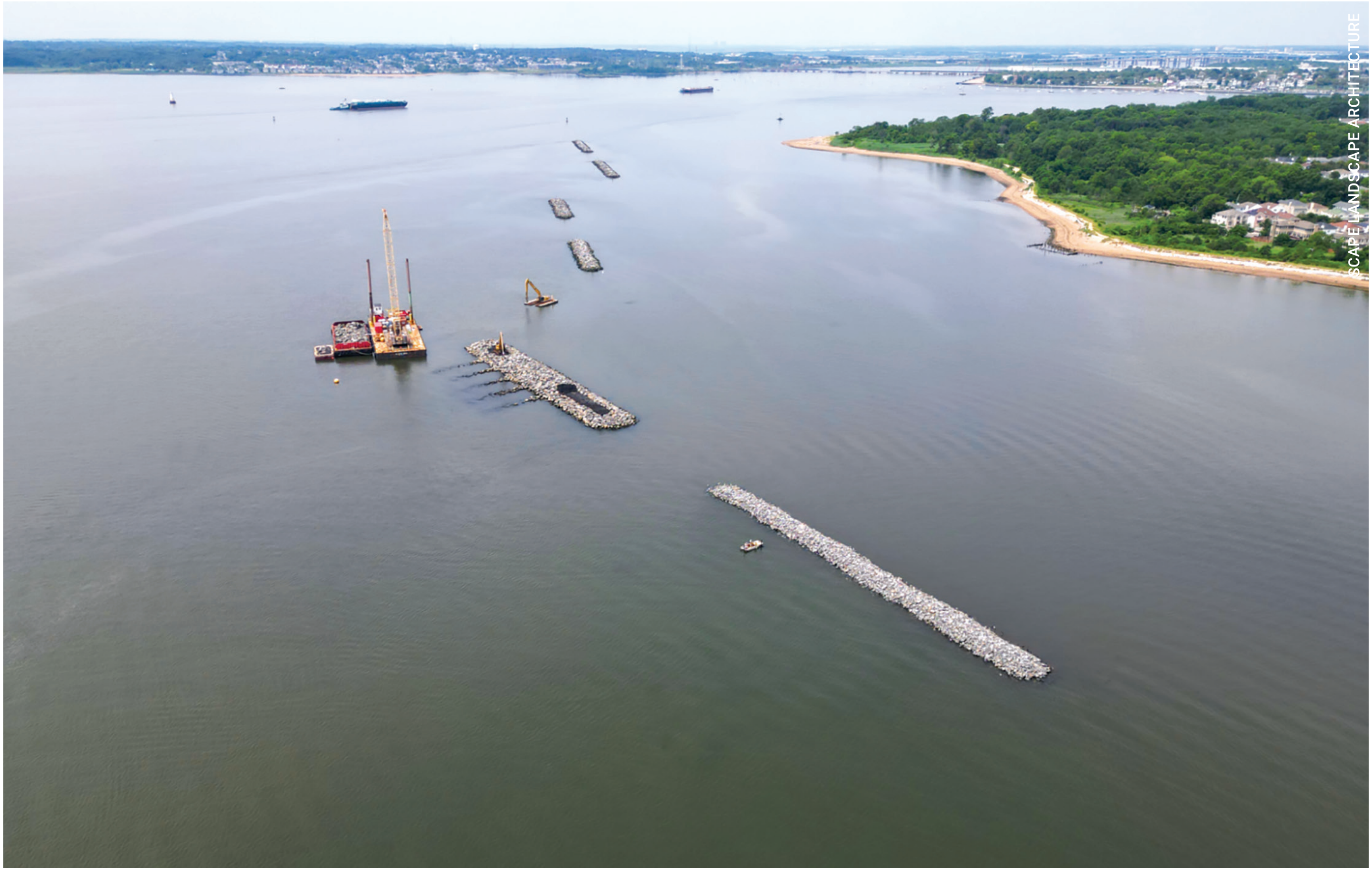
Ecosystems usually require a significant amount of space to thrive. However, in many urban places, natural areas are severely limited, and continued human impacts can make it difficult to restore them fully. Networks of protected areas can help maintain the needed ecosystem services, particularly when a single urban area does not have enough space. These networks allow for species and ecosystem movements and adaptations that occur in response to warming and sea level rise. Removing geographic barriers, protecting and connecting habitats, restoring ecosystems, reducing pollution and other stressors, and coordinating regionally on proactive ecosystem management can support the development of healthy and connected ecosystems and result in many societal benefits, including hazard risk reduction.[284] Real estate actors can integrate natural areas and nature-based solutions into developments to contribute to such ecosystem networks (see the profile of Clippership Wharf in Boston on page 96 for an example).

Effective use of the limited space available along the shoreline in urban areas frequently requires a combination of constructed and natural systems. Hybrid approaches can be multilayered so that the various elements work together in a complementary way. These multilayered strategies can also create redundancy, which is a critical characteristic of resilient systems.[285]

An example of hybrid gray and green infrastructure is the Living Breakwaters project being built in New York Harbor along the southeastern coast of Staten Island. The project by SCAPE Landscape Architecture uses structural elements with shapes that create habitat for oysters and other marine life to reduce the impact of storm surges. The project is part of the Rebuild by Design program funded by the U.S. federal government after Hurricane Sandy caused severe erosion and flooding in 2012.[286]



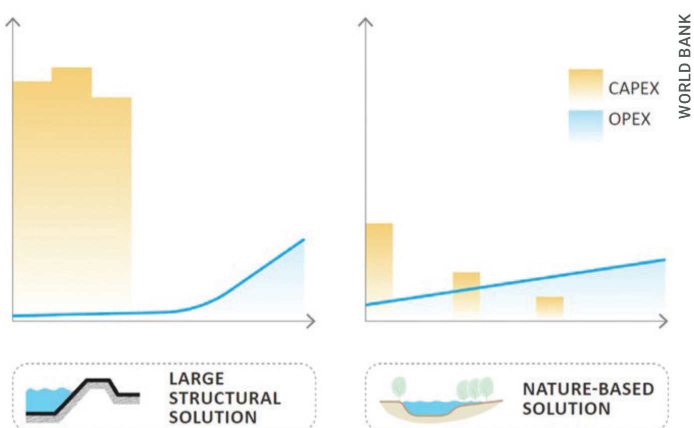
Living Breakwaters project in New York Harbor.



Living Breakwaters project in New York Harbor.

Nature-based solutions are generally regarded as lower cost than gray infrastructure, but costs will vary depending on the scale and scope of the strategies. Typically, with gray infrastructure (e.g., sea walls and levees), capital expenditures—such as the costs of design, planning, and construction—are significantly higher, while operating expenses—including the costs of monitoring, maintenance, and operation—can be relatively low in the first years of operation. Conversely, nature-based solutions, such as mangrove restoration or forest protection, may entail lower capital expenditures but can necessitate some ongoing operational expenditures.

As gray infrastructure ages, its operating expenses often exceed those of nature-based solutions.[287] Over time, gray infrastructure will eventually need to be replaced or will require new capital expenditures to be updated. In contrast, nature-based solutions tend to grow and improve over time. Depending on the strategy used, nature-based solutions may require larger land footprints than gray infrastructure, which may involve more land ownership considerations and costs.[288,289]



Cost comparison for nature-based solutions and gray infrastructure solutions, comparing capital expenditures (CapEx) and operating expenses (OpEx).

Sample Costs of Gray Infrastructure and Nature-Based Solutions

NOAA's "Nature-Based Solutions Installation and Maintenance Costs" provides the costs of implementing and maintaining nature-based solutions to reduce the impacts of coastal hazards, based on the best available figures from a variety of sources.

"The Cost of Shoreline Protection: A Comparison of Approaches in Coastal New England and the Mid-Atlantic" compares the monetary costs of gray infrastructure, nature-based solutions, and hybrid approaches based on information collected from shoreline protection projects in the New England and Mid-Atlantic areas of the United States.[290]

NATURE-BASED SOLUTION	AVERAGE COST	MAINTENANCE COST
Dune restoration	$2,000–$5,000 per linear foot	$100–$500 per linear foot
Natural plus structural	$117–$603 per linear foot (vegetation, structure, fill, and average costs of hybrid options from $56 for coir logs to $336 marsh plus sill or breakwater per linear foot)	Less than $100 per linear foot annually
Hardened shorelines	$457–$966 per linear foot ($125 per linear foot for vinyl bulkhead to $1,952 per linear foot for sea wall)	$100 to over $500 per linear foot

NOAA

Excerpt from "Nature-Based Solutions Installation and Maintenance Costs."

DELIVERING COBENEFITS FOR COASTAL RESILIENCE

Investments in coastal hazard management and resilience can be opportunities for communities to become more inclusive, livable, and ecologically regenerative. Adaptation measures can be selected and designed to maximize cobenefits, or additional benefits, to people, the economy, and the environment, such as the following:

ENVIRONMENTAL COBENEFITS	SOCIAL COBENEFITS	ECONOMIC COBENEFITS
• Protection and restoration of natural areas, processes, and ecosystems • Habitat protection, restoration, and connection • Space for species and ecosystem movement and migration in response to coastal and climate changes • Carbon sequestration • Reduced pollution and environmental stressors (e.g., human interference) • Stormwater management • Groundwater recharge • Enhanced air, land, and water quality • Coastal hazard risk reduction	• Enhanced safety • Improved physical and mental health • Higher quality of life • Increased community engagement, collaboration, and support • Supportive community facilities, services, and networks • Recreational opportunities • Reduced vulnerability to shocks and stresses • Improved disaster resilience and recovery • More equitable outcomes • Minimized population displacement • Enhanced socioeconomic stability	• Business continuity and productivity • Job and wage continuity • Job creation • Enhanced property values • Improved utility and transportation infrastructure • Affordable and accessible insurance coverage and financing • Protection of property, sales, and tourism tax • Improved municipal bond ratings • Increased tourism • Increased investment • Cost savings • Reduced liability related to damages

The St. Pete Pier is a 26-acre reimagined waterfront park in St. Petersburg, Florida—making it the largest waterfront park in the U.S. Southeast. The revitalized St. Pete Pier has become a landmark for community gathering and recreation along its pedestrian-only green spaces and quarter-mile-long (402 m) promenade. Pier amenities include an interactive playground, a splash pad, retail, an environmental education center, a market, event spaces, public art, and green space. An award summary prepared by ULI provides more information, including how the pier integrates multiple cobenefits, such as social and green infrastructure.

ULI RESOURCE

Building Social Benefits into Real Estate

ULI's report Social Spaces, Resilient Communities: Social Infrastructure as a Climate Strategy for Real Estate articulates the significance of social infrastructure in enhancing urban resilience while offering guidance to real estate developers on incorporating social infrastructure into projects. The report illustrates how social spaces not only offer shelter and aid community response to climate risks, but also contribute to mitigating social vulnerabilities exacerbated by these hazards. Drawing on research and expert insights, the report outlines the benefits and practical applications of social infrastructure in real estate, underscoring its role in asset value enhancement, market stability, and long-term investment returns, aligning with broader environmental, social, and governance goals.

Large storm waves batter the coast of Portugal at the delta of the river Douro.

SHUTTERSTOCK

THE POLICY LANDSCAPE FOR COASTAL RESILIENCE

Best Practices in Public Policy for Coastal Resilience

Collaborating across Stakeholders to Advance Coastal Resilience

Coastal hazards ignore property lines and jurisdictional boundaries. In response, solutions need to match the scale of the problem. Integrated, adaptive, systems-level solutions are required that single owners, agencies, or utilities cannot deliver on their own. These solutions necessitate new ways of collaborating across boundaries.

With some exceptions, public-sector efforts in coastal resilience to date have tended to be underfunded and frequently uncoordinated with neighbors, ecosystems, and infrastructure.[291] Accelerating climate-related hazards increasingly challenge governance efforts, given the uncertainty about the magnitude and rate of future sea level rise, vexing tradeoffs between societal goals (e.g., safety, conservation, economic development, and equity), limited resources, and conflicting interests and values among diverse stakeholders.[292]

Despite these challenges, governments must shift paradigms from disaster recovery to preparation and prevention. If preventative actions are planned and budgeted in advance and implemented incrementally as needed, they will likely better suit the financial capacity of governments and be far less expensive than recovering from recurring disasters.[293] These investments also create opportunities for making cities and regions safer, more inclusive, and more livable.

Since adequately securing communities against coastal hazards takes significant time, the work must begin as soon as possible, starting with the areas that are already suffering from impacts. The following best practices provide guidance on how to engage effectively in these efforts for long-term success.

Large waves arrive at Saint Malo on the French coastline. Built infrastructure, such as this stone pier, have often been coastal communities' first line of defense, though many places are now turning to more nature-based solutions.

Best Practices in Public Policy for Coastal Resilience

"Community preparedness, building adaptation, and infrastructure investment will be prioritized and layered together to prepare Boston's core for climate change. In the dense environment of the commercial core, protections will be designed to provide multiple benefits wherever possible, such as improved open spaces and public realm."

IMAGINE BOSTON 2030: A PLAN FOR THE FUTURE OF BOSTON

Governments possess a wide array of instruments for proactive coastal resilience planning and implementation, including local and comprehensive planning, climate adaptation strategies, codes, regulations, and capital improvement plans. Strategies may include leveraging planning mechanisms to restrict new development along coastlines or in floodplains, reinforcing the preservation of critical natural habitats such as wetlands and dunes, considering relocation initiatives for communities impacted by coastal hazards, or investing in nature-based solutions to increase stormwater retention capacity and reduce the impacts of storm surge. Policy and legislative frameworks can mandate the construction and upkeep of infrastructure and structures to improve resilience against both present and future climate-induced challenges, such as the erection of sea walls to combat rising sea levels, or the enhancement of stormwater management systems to accommodate increased precipitation.

The following high-level guiding principles, published by the American Planning Association, apply to any plan, policy, or administrative rule intended to address climate action:

1. Set ambitious, yet achievable goals.
2. Provide a strong fact base using the best available data.
3. Outline diverse strategies to achieve goals.
4. Engage the public and foster justice.
5. Coordinate efforts across actors, sectors, and plans.
6. Include a clear process for implementation and monitoring.
7. Address climate change uncertainty.[294]

The following policy and process tools can be used to bolster coastal resilience.

COMPREHENSIVE PLANS FOR A CLIMATE-CHANGED FUTURE

The comprehensive planning process plays a significant role in shaping the future of communities by setting long-term intentions and linking local visions to specific policy changes and actionable solutions. Integrating coastal resilience priorities from the outset and preparing communities for future adaptation efforts in the face of persistent and evolving impacts of climate change can support coastal communities on their path toward resilience. One approach to embedding coastal resilience into comprehensive plans is to adopt a longer time horizon for policy considerations within these plans. Given the long timespan over which climate change impacts are expected to affect communities and the heavy and long-term investment of funds needed to make cities resilient against forthcoming and ongoing impacts, a longer-term planning horizon—beyond the usual 20-year time frame of a traditional comprehensive planning process—may be warranted.[295]

In the last decade, comprehensive plans for municipalities in the United States have begun to include "climate" or "sustainability" chapters, or elements describing the localities' approach to addressing known climate vulnerabilities. The State of Washington has made the inclusion of a "climate change and resiliency element" mandatory for all comprehensive plans in the state.[296] The guidelines included in state's Climate Element Planning Guidance document and similar guidelines in other states can be instructive.

The city of Boston, Massachusetts's, comprehensive plan, "Imagine Boston 2030," integrates climate change mitigation and adaptation, including coastal resilience, throughout its pages. The plan lays out five primary citywide goals, including promoting a healthy environment and preparing for climate change. As part of this goal, the comprehensive plan commits the city to adapting to a changing climate by reducing economic loss and the number of people exposed to climate-related flooding and increasing tree canopy coverage. Actions mentioned in the plan to enhance flood resilience include flood protection infrastructure, as well as climate-ready zoning and building regulations. The plan also highlights local climate resilience plans and Climate Ready Boston, the city's climate-adaptation strategy.

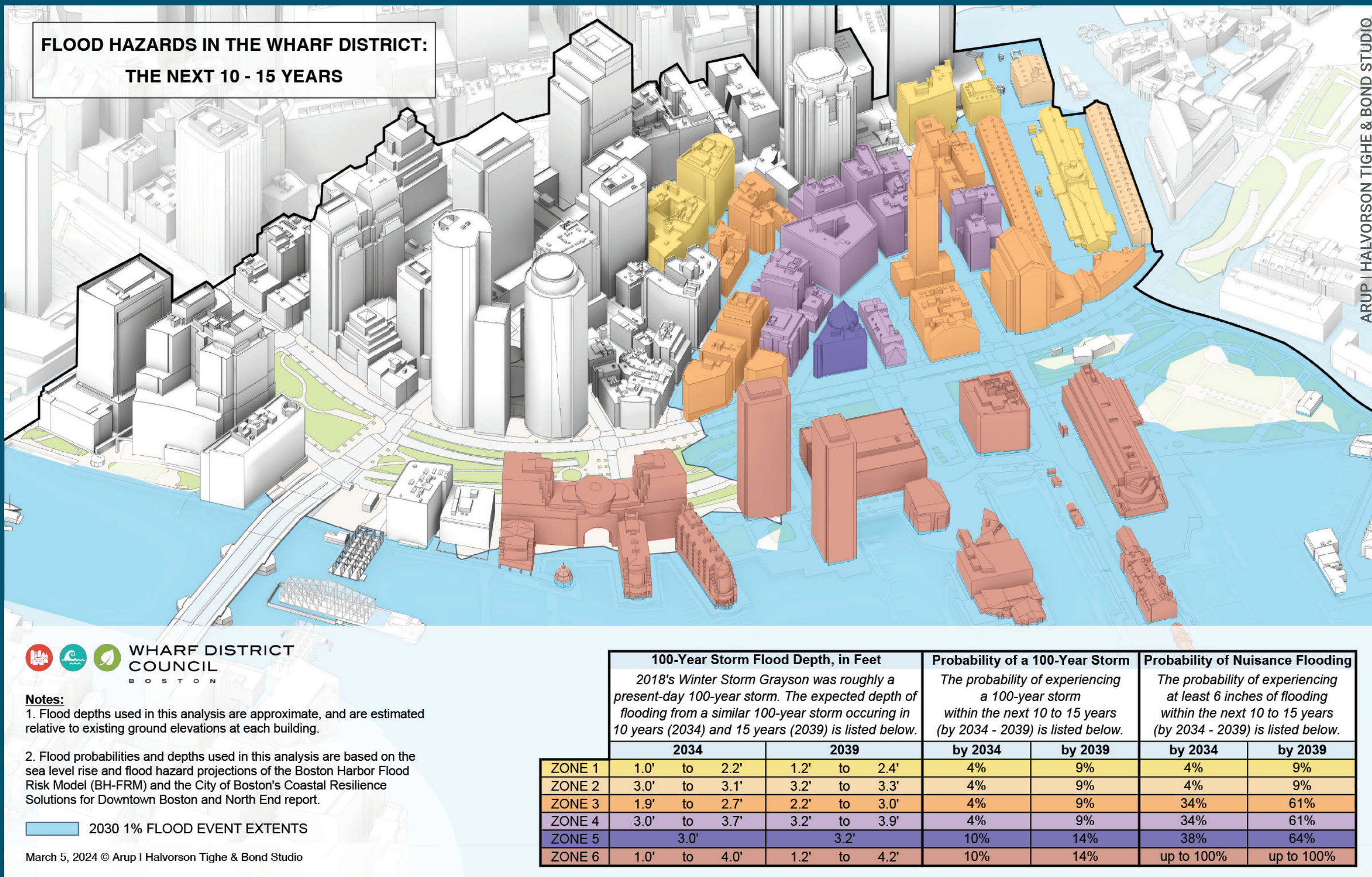
DISTRICT-SCALE ADAPTATION PLANS AND RESILIENCE DISTRICTS

District-scale plans guide development of subareas within municipalities.[297] They enable local governments to experiment with innovative climate adaptation and mitigation strategies and allow for tailoring of strategies to meet the needs and suit the characteristics of specific parts of a locality. District-scale adaptation planning can help direct the design and construction of features such as green infrastructure, water management systems, and other measures to improve the coastal resilience of a district.

Although the concept of forming districts specifically for enhancing resilience to coastal hazards is relatively new, communities in New Orleans, Portland, Seattle, and Singapore have already taken steps to create resilience districts.[298] Resilience districts sometimes go by other names, but the general concept, as described by the city of Seattle, is "a geographic strategy focused on adapting to flood risk and other climate change impacts as a key first step towards adapting to a changing climate, while taking a comprehensive approach that fosters community resilience."[299] Forming resilience districts can help communities provide resilience investments at the local level while enhancing local climate governance and social resilience.[300]

In Seattle, efforts are underway to create the city's first resilience district—to "create a policy, organizing structure, and funding framework that will help the city address flooding and sea level rise, in addition to community revitalization, health equity, and local wealth building in ways that allow residents and businesses to stay and thrive in place."[301,302] In Singapore, the Jurong Lake District plan specifies green infrastructure and water management systems for flood hazard mitigation in alignment with Singapore's broader climate resilience goals.[303] The Singaporean government describes the district as a "living lab" and regulatory sandbox, which serves as a testing ground for piloting new urban solutions and refining sustainability-centric initiatives.[304]

It is worth noting that governance of these districts can be further supported by zoning laws that codify the boundaries of districts and specify parameters for development occurring within. Such is the case of the city of Norfolk, Virginia, which created a special zoning district for development occurring within flood hazard areas (see the Resilient and Equitable Zoning section on page 70 for more information).



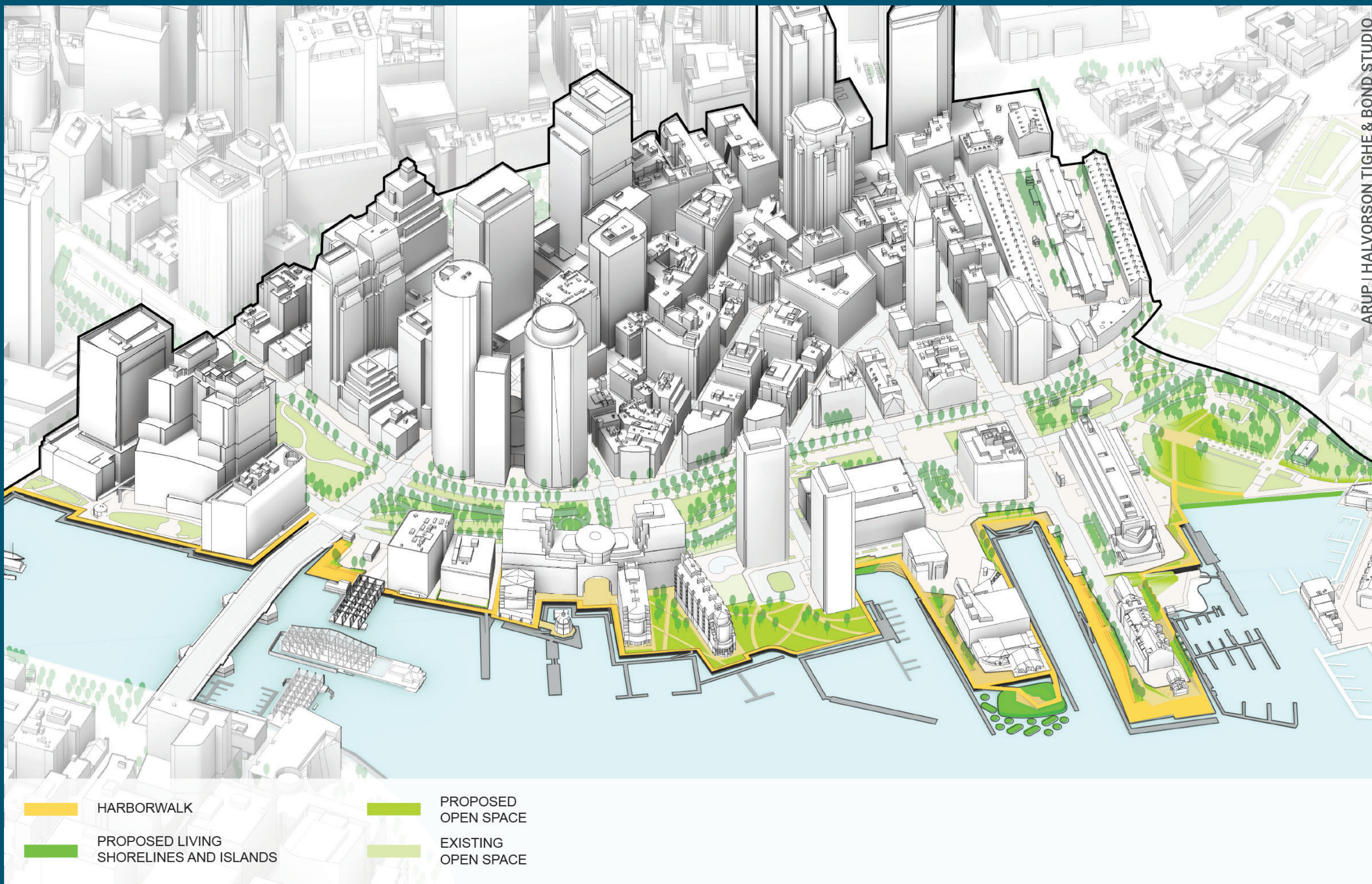
	100-Year Storm Flood Depth, in Feet: 2018's Winter Storm Grayson was roughly a present-day 100-year storm. The expected depth of flooding from a similar 100-year storm occuring in 10 years (2034) and 15 years (2039) is listed below.		Probability of a 100-Year Storm: The probability of experiencing a 100-year storm within the next 10 to 15 years (by 2034 - 2039) is listed below.		Probability of Nuisance Flooding: The probability of experiencing at least 6 inches of flooding within the next 10 to 15 years (by 2034 - 2039) is listed below.	
	2034	2039	by 2034	by 2039	by 2034	by 2039
ZONE 1	1.0' to 2.2'	1.2' to 2.4'	4%	9%	4%	9%
ZONE 2	3.0' to 3.1'	3.2' to 3.3'	4%	9%	4%	9%
ZONE 3	1.9' to 2.7'	2.2' to 3.0'	4%	9%	34%	61%
ZONE 4	3.0' to 3.7'	3.2' to 3.9'	4%	9%	34%	61%
ZONE 5	3.0'	3.2'	10%	14%	38%	64%
ZONE 6	1.0' to 4.0'	1.2' to 4.2'	10%	14%	up to 100%	up to 100%

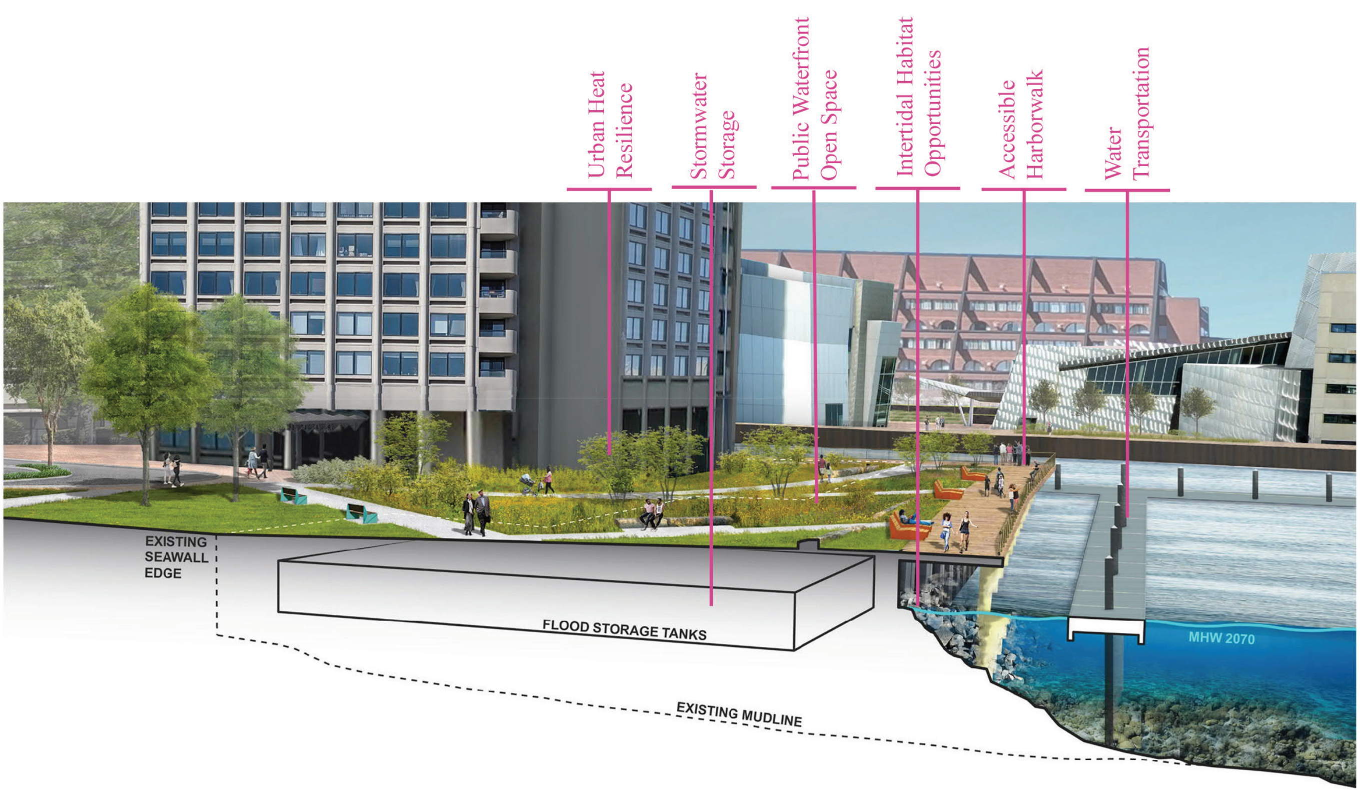
Flood hazards in Boston's Wharf District in the next 10 to 15 years without a district-wide flood protection system.

The Wharf District Climate Resiliency Task Force

Over the coming decades, the Wharf District in Boston, Massachusetts, will become increasingly vulnerable to sea level rise, storm surge, and inland flooding. In 2019, recognizing that rapid and coordinated action will be needed to protect the community, a diverse group of nearly 50 public- and private-sector leaders formed the Wharf District Council Climate Resiliency Task Force. The group was charged with producing a conceptual district-scale resilience plan to support the longtime viability of the neighborhood and protect billions of dollars in public and private assets from current and future coastal flood events and sea level rise.

The task force's Conceptual District Protection & Resiliency Plan builds on prior flood resilience planning initiatives conducted by the city and offers tailored solutions for each of the district's 16 waterfront parcels. The task force evaluated resilience strategies for each waterfront property against five criteria: effectiveness, feasibility, adaptability, social equity and access, and environmental and additional benefits. Through this process, the task force oversaw the development of a district-scale flood resilience system, along with resilience guidelines for individual buildings, permitting considerations, cost estimates, a cost/benefit analysis, an implementation timeline, and a list of potential funding sources. The cost/benefit analysis indicated that, if implemented, the project would avoid US$3.9 billion in losses and have an approximate net benefit of US$2.6 billion.[305]



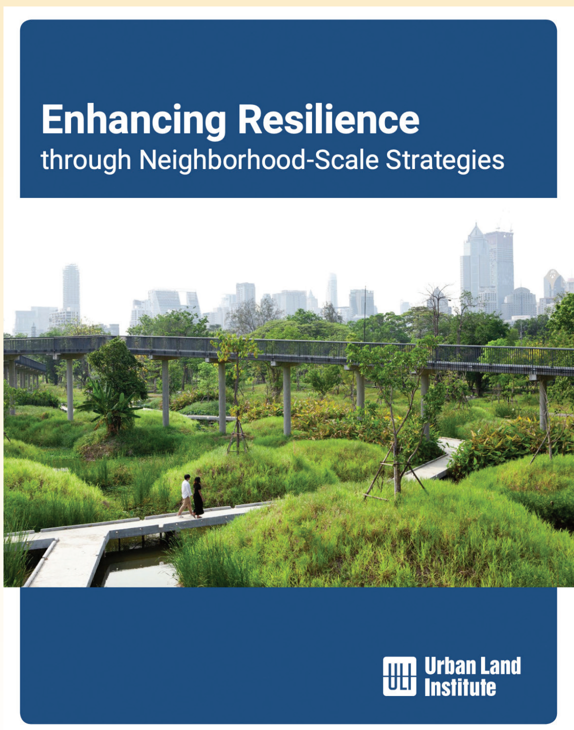


Elements of the Wharf District's Conceptual District Protection & Resiliency Plan.

ULI RESOURCE

Neighborhood-Scale Resilience

ULI's report *Enhancing Resilience through Neighborhood-Scale Strategies* provides an overview of neighborhood-scale strategies to address accelerating physical climate risks associated with extreme temperatures, floods, storms and high winds, seismic risks, water stress and drought, and wildfires. The report also summarizes public-sector policies that influence the resilience strategy context as well as financing solutions and funding mechanisms applicable to neighborhood-scale solutions.



RESILIENT AND EQUITABLE ZONING

Localities can adopt zoning code provisions with specifications that anticipate future risk from climate change impacts, require or incentivize resilient and equitable development, and support low-impact development. In the United States, such provisions might take the form of municipal zoning laws, by-right zoning policies, overlay zones, floating zones, and zoning incentive programs that encourage development outcomes in alignment with municipal goals for environmental sustainability and resilience.[306,307]

Norfolk, Virginia, for example, instituted a Coastal Resilience Overlay zone. The zone's regulations require that all new development and redevelopment within the 1 percent annual chance flood zone be elevated 3 feet (0.9 m) above base flood elevation. The district also restricts construction of basements in residential construction, limits impermeable area, and requires use of native and salt-tolerant plants.[308]

ULI RESOURCE

Zoning for Climate

ULI's report *Reshaping the City: Zoning for a More Equitable, Resilient, and Sustainable Future* provides guidance on how to use zoning to promote healthy mobility, support increased housing affordability, build more resilient places, and accelerate climate action.

CLIMATE-INFORMED MUNICIPAL CODES

Municipal codes can be applied to ensure new development is prepared for local hazards according to best available climate data. Codes can address building design specifications such as freeboard (height above base flood elevation to elevate or floodproof a structure's lowest floor) and structure elevation requirements in floodplains, site design specifications such as wider setbacks from local high-water levels, and provisions guiding land use and land development to promote elevation or lower density in areas vulnerable to storms and floods. In Fort Lauderdale, Florida, to protect residents from tidal flooding, municipal codes are being used to set a minimum height for new sea walls, sea walls that are in significant disrepair, or sea walls that are being breached.[309]

"One solution to accommodate higher freeboard without sacrificing available building area due to height restrictions is to encourage the communities to do their height restrictions based on the Base Flood Elevation (BFE) versus using street elevations. As these BFE values creep up, the allowable building height automatically creeps up also. Communities in New Jersey adopted this approach following Hurricane Sandy, and it allowed them a whole lot more flexibility."

ADAM REEDER
Principal, CDM Smith

HAZARD-RESISTANT BUILDING CODE ADOPTION AND ENFORCEMENT

Building codes vary widely throughout the world. In some countries, including the United States, governmental jurisdictions rely on model codes developed by third-party organizations such as the International Code Council (ICC). Others, such as China and Singapore, have developed national building codes.[310]

Building codes may be improved upon by jurisdictions to ensure properties are safeguarded against local hazards, including hurricanes, flooding, and other coastal hazards. Such changes may increase construction costs but can reduce hazard vulnerability and insurance premiums. According to the U.S. National Institute of Building Sciences, adopting model codes alone can save up to US$11 per dollar spent.[311]

Regulatory requirements for construction in coastal areas have increased over the past decade in response to the increased prevalence of hazards and lessons learned from past storms, resulting in more effective hazard provisions in building codes that protect both lives and property.[312] FEMA estimates that the ICC model codes save the United States an average of US$1.1 billion annually from hurricane wind damages and US$484 million annually from flood damages.[313]

Building to Beyond-Code Standards

With the increase in climate-related hazards, more real estate developments are being built to "beyond-code" standards. Standards programs, such as FORTIFIED, REDi, and Waterfront Edge Design Guidelines, provide guidance on designing or retrofitting buildings and sites for protection against coastal hazards above the levels required by local building codes, which can help to minimize property damage and disruption.

International Code Council Model Codes

The International Code Council (ICC) has published a family of International Codes that includes the International Building Code, International Residential Code, International Existing Building Code, and International Energy Conservation Code, among others.

In the United States, state and local governments usually adopt the International Building Code for commercial and multifamily structures and the International Residential Code for single- and two-family structures. Adoption and enforcement of these model codes varies significantly across the country. However, for a community to participate in the National Flood Insurance Program, it must adopt and enforce floodplain management regulations that meet or exceed the minimum NFIP standards and requirements, and ICC's International Codes exceed those minimum requirements.[314]

The ICC has also launched initiatives to build capacity for climate-resilient structures, including an initiative dubbed "Building Capacity for Resilient and Sustainable Buildings."[315] Through this initiative, the ICC aims to "help global communities reach their resilience and decarbonization goals by providing resources and tools to support the effective implementation and enforcement of building codes."[316]

Examples of Building Code Provisions Related to Coastal Resilience in the International Building Code

Chapter 16 – Structural Design:

- Section 1609 – Wind Loads
- Section 1610 – Soil Loads and Hydrostatic Pressure
- Section 1611 – Rain Loads
- Section 1612 – Flood Loads
- Section 1615 – Tsunami Loads
- Section 1616 – Structural Integrity
- Appendix G – Flood-Resistant Construction
- Appendix M – Tsunami-Generated Flood Hazards

Despite this proven success, a surprisingly low number of jurisdictions have adopted hazard-resistant building codes. According to FEMA Building Code Adoption Tracking, as of the second quarter of 2024, only 32 percent of natural hazard–prone jurisdictions in the United States have adopted current hazard-resistant building codes.[317] In light of the low adoption rate, federal initiatives were launched in 2022 to accelerate code adoption in areas with outdated codes in place.[318] By adopting and enforcing hazard-resistant building codes, jurisdictions can enhance and protect their building stock and people from coastal hazards.

The Value of Hazard-Resistant Building Codes

In 2018, following the development of disaster preparedness and recovery plans, Charleston County, South Carolina, adopted building codes that require roof tiedowns, window protection, and higher freeboard. The state of South Carolina followed the county's lead by adopting statewide hazard-resistant building standards (ICC 2015). The estimated savings in avoided property damage over 20 years is US$1.9 billion.[319]

A study conducted by the Insurance Institute for Business & Home Safety (IBHS) following Hurricane Charley in 2004 found that improvements to the codes adopted in 1996 in Florida resulted in a 60 percent reduction in residential property damage claims and a 42 percent reduction in damage severity (cost of claims).[320,321]

DEVELOPMENT REGULATIONS FOR COASTAL ADAPTATION

Municipal codes can act as a bridge between the aspirational objectives of planning documents and physical development outcomes. For instance, in Sweden's urban coastal areas, local governments have leveraged these regulations to require that building approvals include elements of the local authority's climate risk mitigation strategy.[322]

Implementation of development regulations depends on both the contents of and local government capacity to interpret and apply the requirements set forth in municipal code and comprehensive and strategic planning documents through administrative processes. At the core of these processes are guiding documents, including design standards and guidelines. These documents articulate the regulatory vision for land use and development, ensuring that each project advances the community's goals for sustainable growth and resilience.

Cities like New York and Boston supplement their codes of ordinances with special design guidelines for waterfront development. New York City's Climate Resiliency Design Guidelines translate advanced climate science into actionable design strategies, ensuring that infrastructure projects are robust enough to withstand future extreme weather events.[323] Boston's Coastal Flood Resilience Design Guidelines similarly address the looming threat of sea level rise and coastal flooding. By setting forth design principles that anticipate significant sea level rise by 2070, these guidelines direct developers toward practices that not only mitigate immediate flood risks but also safeguard the city's infrastructure and communities against future climate impacts.[324]

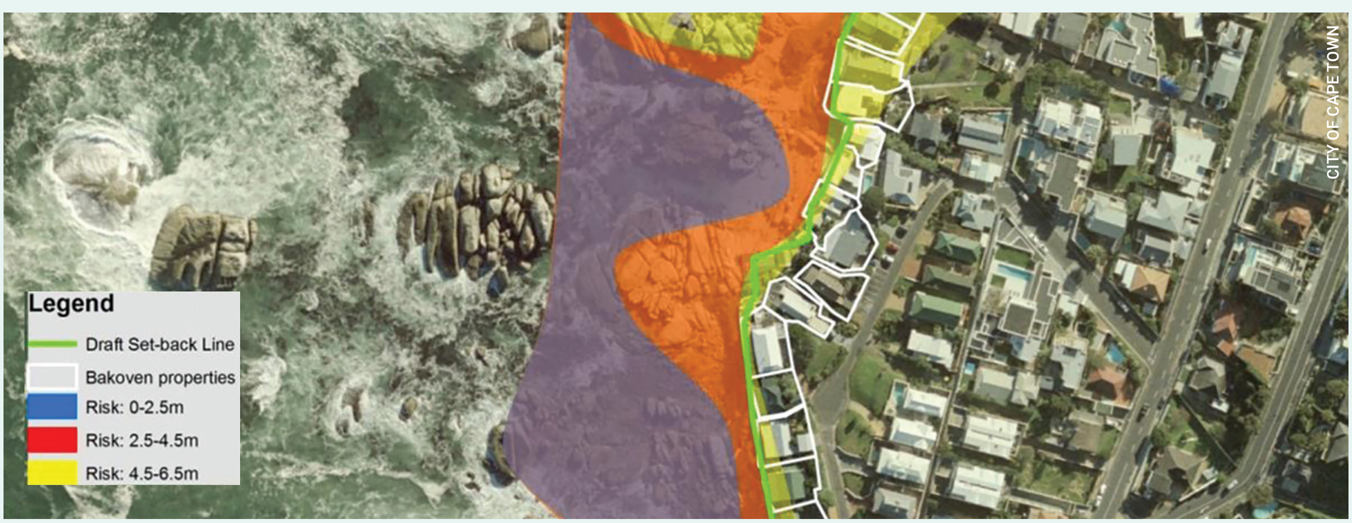
Cape Town's Coastal Management Line

Cape Town, South Africa's Coastal Management Line (CML) leverages spatial information relating to coastal risks and hazards to inform the location of development, promoting risk-averse coastal land use that takes into account climate change. Construction and maintenance of structures seaward of the line are restricted, protecting against future liabilities that might arise because of inappropriately located structures and supporting beaches.

The CML also defines nodal growth areas to connect historically disadvantaged communities to the coast.

Restorative justice principles have been key considerations in the establishment of Cape Town's CML due to South Africa's unequal past and Apartheid—the spatial legacy of which remains today.

Cape Town used a multidisciplinary approach to develop the CML. Consensus was built over approximately five years with broad-based stakeholder engagement. In addition, empirical analysis of biophysical modeling of coastal processes and hazards was used to consider a range of socio-political and environmental factors. This multipronged approach reflected the complexity of coastal systems and the area, ultimately leading to successful implementation of the CML as an effective coastal adaptation tool.[325,326]



The city of Cape Town mapped properties at risk from sea level rise, erosion, and storm surges to develop the Coastal Management Line, which has supported coastal resilience and restorative justice goals.

Explanation of Development Incentives

- **Density Bonuses:** Density bonuses are zoning variances that allow for extra height, volume, number of units, and other options that relate to density to compensate for increased project costs or reduction of usable space related to resilience investments on site. Density bonuses can be used to encourage compact development in safer areas.
- **Expedited Entitlements:** Expedited entitlements and development review allow local governments to fast-track the permitting process for projects that incorporate sustainable design, energy efficiency, or climate resilience measures. Speeding up the often-lengthy approval process allows developers to save money on project-related soft costs, such as architect and legal fees, as well as insurance payments and property taxes incurred during the development period. Saving money and time during the development review process can facilitate more efficient and affordable delivery of resilience-related projects.
- **Transfer of Development Rights:** The transfer of development rights allows landowners to transfer the development potential of their property in high-risk or environmentally sensitive areas to a different location, where higher density or intensity of development is permitted. Such transfers allow for conservation of sensitive areas and denser development in safer areas.

INCENTIVES FOR ADAPTATION

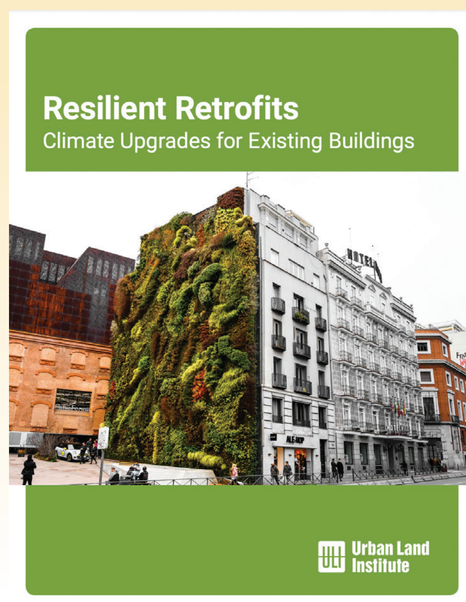
One way to bolster implementation of coastal resilience is to incentivize adaptation investments. Governments can offer incentives—tax deductions, grants, low-interest loans, rebates, direct installation opportunities, and the like—for projects that enhance resilience, such as elevating buildings and utilities, creating natural barriers, or installing more robust infrastructure. These incentives can lower the cost of implementing resilience measures and ultimately help protect people, structures, and natural areas from coastal hazards.

Incentives to bolster the resilience of private-sector development can come in a number of other forms, such as public investment, public/private partnerships for land assembly and financing, expedited entitlements and development review, tax incentives, transfer of development rights, and density bonuses. Public investments in infrastructure can also influence development, as can reducing code requirements for hard-engineering solutions when nature-based solutions are employed.[327]

ULI RESOURCE

Retrofits for Resilience

ULI's report *Resilient Retrofits: Climate Upgrades for Existing Buildings* offers building retrofit strategies, policies, and financing mechanisms to address physical climate risks, including extreme temperatures, floods, storms and high winds, seismic risks, water stress and droughts, and wildfires.



In the United States, some hurricane-prone states are actively incentivizing building retrofits for resilience. Examples include South Carolina's Safe Home program and the Strengthen Alabama Homes program, which provide grants of US$5,000 and US$10,000, respectively, to owners who strengthen their properties against wind and hurricane damage in partnership with IBHS's FORTIFIED program. The Florida Hurricane Loss Mitigation Program offers reimbursement grants to fund retrofits for storm and flood resilience for residential and commercial properties. Many states along the Gulf and Atlantic coasts require insurance companies to offer discounts to residential and commercial property owners who achieve the FORTIFIED designation or implement specific upgrades in the standard.[328] Some states also offer tax credits to homeowners who strengthen their properties against storms. Although these amounts are smaller, they may be sufficient to pay for low-cost, effective retrofit techniques for the vast number of smaller buildings vulnerable to coastal hazards.[329]

CLIMATE-ALIGNED INFRASTRUCTURE INVESTMENTS

Much of the world's existing infrastructure—including stormwater systems, levees, and flood barriers—is aging and was designed for climate conditions that are no longer relevant.[330] Additionally, a great deal of infrastructure follows shorelines, making it especially vulnerable to coastal hazards. Utility, transportation, and communications infrastructure must be updated, protected, and/or relocated as a result. Beyond gray infrastructure investments, green and social infrastructure investments are also needed to bolster local and regional resilience to climate changes.

Large public expenditures are required to fund adaptation strategies that can meet the magnitude of climate-related threats facing coastal areas. The World Bank has projected that by 2050, safeguarding global urban infrastructure against climate-related risks will cost between US$11 billion and US$20 billion annually.[331] The World Bank has also estimated that defending against sea level rise globally over the course of the 21st century could cost as much as $18.3 trillion (2014 USD).[332] Public authorities will need to develop funding and financing plans to pay for these critical investments.

Global Infrastructure Investment Needs for Adaptation

- **United States:** The American Society of Civil Engineers has identified a significant shortfall in infrastructure investment, highlighting a US$2.59 trillion gap over 10 years across all infrastructure sectors in the United States.[333]
- **Europe:** The European Investment Bank's 2021 estimates indicate that between €35 billion and €500 billion (US$37.5 billion and US$535 billion) in annual investment will be required to address the needs for climate adaptation within the European Union.[334]
- **Asia Pacific:** The Asian Development Bank estimated a need for approximately US$1.7 trillion per year in infrastructure investment between 2016 and 2030 to meet its development goals. Of that amount, US$200 billion is specifically allocated for addressing climate change mitigation and adaptation costs.[335]

Weaving adaptation investments into infrastructure and capital improvement projects presents an opportunity to streamline processes and implement them efficiently. Adding a climate lens to local government budgeting processes and capital improvement plans can help to fund adaptation strategies as part of planned infrastructure investments. Governments can use climate-smart criteria to evaluate alternatives for each proposed project, helping them understand how a project can contribute to local resilience.[336] The World Bank is developing a climate-smart capital investment planning methodology to help cities prioritize municipal financing of resilient, low-carbon, and cost-effective infrastructure.[337]

New York City is the first major U.S. city, and among a small group of cities internationally, to implement "climate budgeting:" a system that integrates climate targets and science-based climate considerations into the budget process to help achieve the city's climate-related goals, including resilience to climate hazards and greenhouse gas emission reductions. As part of the process, climate impact is now one of many factors considered during the city's budget review and planning, which helps ensure that the city's investment decision-making is aligned with resilience and sustainability needs.[338] The Mayor's Office of Management and Budget leads the initiative in partnership with the Mayor's Office of Climate and Environmental Justice to ensure that climate is considered in all future city investments.[339]

While including adaptation strategies in municipal budgeting processes and investment decisions allows for efficiencies, for many cities, normal budgeting processes and other traditional financing mechanisms fall short of adequately funding climate-resilient infrastructure.[340,341] These shortfalls likely occur because climate-related infrastructure needs are so large, local government revenue streams are under pressure from competing needs, and federal dollars are not always available or sufficient.[342] Leveraging diverse revenue streams can help communities advance resilience-related projects.[343]

Funding and Financing Options for Coastal Resilience Projects

Funding and financing for coastal resilience projects can come from a variety of sources including tax proceeds, fees, grants, public/private partnerships, crowdfunding, voluntary surcharges, loans, revolving funds, government bonds, environmental impact bonds, resilience bonds, and event-based insurance. Communities should consider a number of factors when choosing appropriate funding and financing approaches, including project scale, complexity of selected investment method, and time frame, among others. Review NOAA's "Funding and Financing: Options and Considerations for Coastal Resilience Projects" to learn more.

"Financing and Funding Tools: Paying for Equitable Adaptation" by the Georgetown Climate Center is another resource on options to support equitable resilience and adaptation projects, including bonds and bank loans, insurance-related finance options, tax credits, tax increment financing and land value capture, and public/private partnerships.

Because the financial needs for coastal resilience projects are likely to extend over many years, innovative approaches to funding and financing may be required. For example, financial instruments could be developed that add up the costs avoided through preventative measures, and the money saved could be used to cover the costs of resilience investments. Similarly, lower future insurance costs could be capitalized to pay for adaptation strategies.[344] Nationally, disaster relief programs could be expanded to pay for preventative resilience projects. A dedicated stream of revenue could be created for climate resilience investments, similar to the gasoline taxes that funded the U.S. Interstate Highway System.[345] As an example, the city of Boulder, Colorado, levies a tax on natural gas and electricity, called the Climate Tax, which it uses to fund city-level climate resilience efforts.[346]

A Resilience Authority in Maryland will monetize publicly owned parcels to fund climate adaptation efforts.

Innovative Resilience Funding and Financing in Maryland

One example of an innovative funding approach is Maryland's Senate Bill 457, passed in 2020. It authorizes local governments to establish and fund a Resilience Authority, which can draw on diversified funding options to invest in large-scale infrastructure projects aimed at addressing the effects of climate change, including sea level rise, flooding, increased precipitation, and erosion. The law enables a Resilience Authority to charge and collect non-tax-related fees, issue or sell state or local tax-exempt bonds, and collect funding from state and local governments as well as nonprofit contributions. More than one local government can create a Resilience Authority to fund infrastructure investments and facilitate climate adaptation on a regional scale.[347]

Anne Arundel County and Annapolis, Maryland, formed a Resilience Authority to identify new revenues for resilience investments. Authority staff found that the level of investment needed far exceeded what the government could cover. Next, they participated in a Putting Assets to Work incubator lab in which they conducted a physical assets inventory and identified publicly owned, developable land. The Authority is in the process of planning how to monetize parcels through development, from which proceeds will be directed to climate mitigation and adaptation efforts. Alternatively, the Resilience Authority could develop resilience infrastructure on those publicly owned sites.[348]

Establishing Resilience Authorities and leveraging publicly owned physical assets allow local governments to accelerate infrastructure financing and climate change adaptation—and could serve well as a blueprint for other state and local governments to follow.

PROTECTION AND RESTORATION OF NATURAL AREAS

A key to reducing coastal vulnerability is the preservation and restoration of ecological systems. A strong environmental strategy, including land and habitat conservation and enhancement, reduces risk to structures. Working with nature will almost always be the most effective and economical way to manage climate hazards.[349]

Natural areas can be protected with or without public acquisition through conservation easements or transfer of development rights.[350] The Chesapeake Bay region in the United States has permanently protected about 1.64 million acres of land since 2010. Most of the protected land is in state and national forests, parks, and wildlife areas, but conservation easements were used to protect privately owned land as well.[351] As part of this effort, Maryland uses Coastal Resilience Easements to restrict development activity within its Wetland Adaptation Buffer to allow for the inland migration of coastal wetlands from sea level rise, subsidence, and coastal erosion.[352,353]

Calvert Cliffs State Park, Maryland, along the Chesapeake Bay.

Rolling Conservation Easements for Coastal Hazards

Like traditional conservation easements, rolling conservation easements permanently restrict development to protect natural systems. The boundaries of rolling conservation easements are based on the coastline and "roll" inland as sea level rise and coastal erosion cause coastline encroachment. Policies in Maine, Texas, North Carolina, and Hawaii use rolling conservation easements to safeguard ecosystems and communities that face coastal hazards.[354]

In Norfolk, Virginia, a rolling conservation easement is being used not only to allow wetlands to migrate with rising seas, but to plan for building obsolescence due to sea level rise. The easement, agreed to by the Elizabeth River Project, Wetlands Watch, and the Coastal Virginia Conservancy, prohibits future development and requires the Elizabeth River Project's headquarters to be removed when a sea level rise threshold is met. This agreement enables sustainable coastal development to occur in the short term while accounting for coastal impacts over time.[355,356]

Transfer of Development Rights for Managed Retreat

Transfers of development rights (TDRs) allow landowners to transfer the development potential of their property in high-risk or environmentally sensitive areas to a different location, where higher density or intensity of development is permitted. TDR programs allow a local government to protect vulnerable coastal areas that are impacted by sea level rise, flooding, and land loss and shift development to more appropriate sites.

Since the concept of using TDRs in the context of managed retreat from coastal areas is so new, jurisdictions are still exploring its use (for more information on managed retreat, see the Buyouts, Leasebacks, and Land Swaps section on page 80).[357,358] Miami-Dade County, Florida, conducted a TDR program study in partnership with ULI to explore its use for climate adaptation, and the city of Norfolk, Virginia, is piloting a TDR program to lower flood risk and increase mixed-income housing. Local governments can also look to existing TDR programs, like that of King County, Washington, for takeaways. However, TDR in the context of managed retreat may require some political and legal innovation.[359] Pilot programs with community engagement may help local governments inform the development and implementation of TDR programs in the context of managed retreat.

State-level coastal zone management regulations are also critical tools for protecting valuable environmental systems as well as providing land use planning guidance to communities for sea level rise. For example, Maine's Sand Dune Rules protect fragile sand dune ecosystems that act as natural barriers to coastal flooding, erosion, and sea level rise while benefiting the local economy through recreational opportunities. The rules prohibit new construction in areas subject to sea level rise and restrict gray infrastructure—such as sea walls—that can damage dune ecosystems through scour and prevent inland migration of ecosystems as sea levels rise.[360]

Coastal zone management or Integrated Coastal Zone Management (ICZM) originated as a policy framework in the Coastal Zone Management Act passed by the U.S. Congress in 1972. Internationally, ICZM was introduced as a public policy approach at the 1992 Global Earth Summit, inspiring many countries to establish ICZM policies that promote sustainable management of coastal zones. Since many of these policies do not yet account for climate resilience, the Inter-American Development Bank and the World Resources Institute developed Climate-Resilient Integrated Coastal Zone Management Performance Indicators in 2020 to support climate-resilient sustainable development in coastal areas.[361,362]

Beyond protection of existing natural ecosystems, restoring and enhancing natural systems—and even creating new multifunctional green spaces—can help with retention, absorption, and distribution of stormwater and floodwaters while also providing opportunities for recreation. For examples, see the Lower Manhattan Coastal Resiliency Project profile on page 93 and the Regional Coastal Protection in Holland, Netherlands, profile on page 99.

Ecosystem Restoration at Cramer Hill Waterfront Park in Camden, New Jersey

Cramer Hill Waterfront Park in Camden, New Jersey, used to be an 86-acre (34.8 ha) municipal landfill. It has been transformed into an urban oasis containing abundant green space, recreational amenities, and direct access to the Cooper and Delaware rivers. The park's wetlands, extensive green space, rain gardens, and swales absorb and filter stormwater, reducing flooding and combined sewer overflow pollution from flowing into waterways and surrounding neighborhoods.

The project capped the solid waste and contaminated soil that was exposed on the surface of the landfill and polluting water. Over 3,000 feet (914 m) of shoreline were regraded and stabilized, almost 400,000 cubic yards (306,000 cu m) of soil were moved to the center of the site to create an elevated buffer against riverine flooding, and seven acres (2.8 ha) of new wetlands were created along both rivers, further protecting the shorelines and providing habitat for plants and animals. Existing trees were preserved and 375,000 more were planted. Habitat structures for fish and turtles were added to the park's fishing pond.

Cramer Hill Waterfront Park was designed to withstand flooding and reduce its impacts on the surrounding area. Over 3,000 feet (914 m) of shoreline was regraded and stabilized to create a buffer against riverine flooding.

It is now Camden's largest park and includes walking and biking trails, a picnic area, a playground, exercise stations, a fishing plaza, and a kayak launch. The shoreline observation areas show off stunning views of the Philadelphia skyline, downtown Camden, and the restored wetlands and woods along the river's edge.[363]

BUYOUTS, LEASEBACKS, AND LAND SWAPS

In some places, the risk is so high from severity or frequency of hazards that attempts at protection in place may be ineffective or come at an economic and social cost too great for owners and governments to bear. The idea of a managed retreat is to proactively move people, structures, and infrastructure out of harm's way to avoid damage, maximize benefits, and minimize costs for communities and ecosystems. Ideally, managed retreat involves a coordinated process of voluntarily and equitably relocating communities away from vulnerable coastal areas to safer locations inland.[364]

"Retreat is essentially about moving to safety and moving to other opportunities where you know property and livelihoods will be safer and more financially secure. It's just as much about what you are moving toward as it is about what you are moving away from."

SCOTT DAVIS
Principal, SGD Urban Solutions, and adjunct faculty Member, Georgetown University Graduate Urban and Regional Planning Program

The process of managed retreat is inherently complex and involves challenging legal, financial, social, and planning considerations. The people who will be affected must be extensively involved in designing and implementing the processes to ensure that outcomes are equitable for the communities involved.[365] Low-income communities often occupy the most vulnerable real estate in high-risk areas, usually because of exclusionary land use policies and practices, and some of these households may lack the resources to move on their own. Even people with adequate financial resources will need to make heart-wrenching decisions about where to move and whether and when to break off their connection to a place where they may have lived for a long time. These discussions are frequently fraught with political turmoil. However, it is better to begin these discussions early, when all options can be considered, than to wait for another disaster.

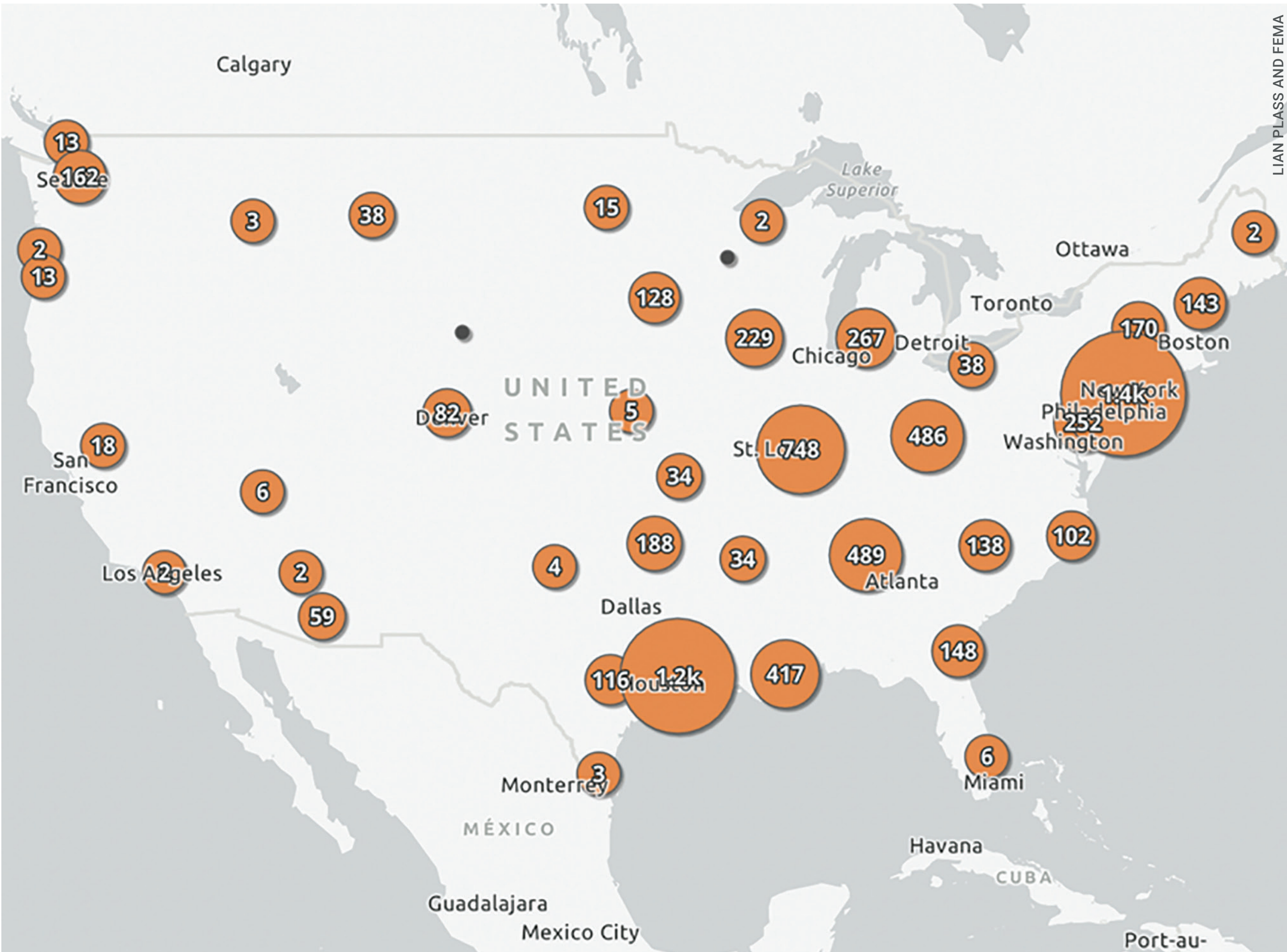
"How long do you shore up your existing infrastructure and buildings versus at what point, or at what level of risk, do you stop investing in, for example, new subways?"

JULIE WORMSER
Senior policy advisor, Mystic River Watershed Association

Costs will be high whether for protecting or for buying out or relocating people and businesses. As the costs of protecting coastal communities and their infrastructure rise, especially with frequent disasters and recovery, the consideration of buyouts or relocation may make increasing sense. The costs will be more manageable if they are incurred incrementally, well before worst-case scenarios become reality.[366]

The Internal Displacement Monitoring Centre projects that approximately 14 million people could be displaced each year by sudden-onset disasters such as storms, floods, and wave action, including hundreds of thousands of individuals in North America and Europe.[367,368]

Buyouts, leasebacks, and land swaps are several tools that can be leveraged for managed retreat. A **property buyout** is a property acquisition in which a government agency purchases private property in a high-risk area, such as a floodplain or coastal zone prone to sea level rise and storm surge, incentivizing property owners to relocate away from vulnerable areas. After a buyout, a government agency will usually demolish any structures on the property and preserve the land as open space. Most property buyout programs are voluntary, meaning that properties are purchased only from willing sellers, as opposed to the process associated with eminent domain. Buyout programs do not necessarily provide relocation services to help households remain within the communities or regions they have come to call home.



Voluntary buyouts in the United States since 2019.

> “Buyouts break the cycle of flood damage and recovery.”
>
> **FAWN MCGEE**
> *Director, New Jersey Blue Acres Buyout Program*

In addition to the NFIP-sponsored buyout activities facilitated by FEMA, 1,100 counties across 49 states have used voluntary buyouts as of 2021.[369] The United Kingdom’s Environment Agency has facilitated property buyouts in flood-prone areas as part of its flood risk management strategies. Additionally, in the aftermath of natural disasters, countries such as Japan have also implemented property buyout programs to reduce future risks and protect communities.[370]

Governments use **leasebacks** to rent acquired properties to their original owners while the property is still safe to inhabit. Leasebacks encourage property owners to participate in buyout programs by offering them additional time in their home to facilitate the transition to a new one. As an example, Charlotte-Mecklenburg Storm Water Services in North Carolina has used leasebacks with elderly homeowners and people who need additional time to purchase new homes. However, leasebacks may not be a viable option if the property is no longer safe.[371]

The Los Cerritos Wetlands Oil Consolidation and Restoration Project in Long Beach, California, is an arrangement to swap 154 acres of wetlands used for oil production for five acres of wetlands currently owned by the Los Cerritos Wetlands Authority, allowing for the restoration of a major portion of the wetlands.

A **land swap** is the exchange of title to land between two or more property owners. Land swaps usually involve an in-kind exchange of property between parties, as opposed to the purchase of land, but money can be used to supplement in-kind exchanges. Land swaps can take diverse forms, involve different numbers and types of property owners, and can be complex, but they also provide an effective means of retreat on a large scale. Land swaps can occur between a government and private landowners, such as residents or businesses, or involve third parties, such as nonprofits and land trusts. Governments, and especially those that own public land, can use this mechanism to facilitate retreat from unsafe areas, allowing at-risk homeowners and business owners to relocate to a safer area.[372]

Notable land swaps include the New Orleans, Louisiana, Project Home Again Land Swaps implemented after Hurricane Katrina that enabled low- and middle-income homeowners to relocate to less vulnerable areas with new affordable, clustered housing. The Los Cerritos Wetlands Oil Consolidation and Restoration Project in Long Beach, California, is an arrangement to swap 154 acres of wetlands currently used for oil production for five acres of wetlands currently owned by the Los Cerritos Wetlands Authority. The land swap will allow for the restoration of a major portion of the wetlands, increase public access, and reduce oil production in the area.

ULI RESOURCE

Buyouts for Long-Term Resilience

ULI's report *On Safer Ground: Floodplain Buyouts and Community Resilience* explores how the buyout process not only reduces sources of potential loss but also protects communities and offers valuable amenities and benefits to residents. The report highlights best practices and private-sector partnership models for floodplain buyouts.

Counties in Southeast Florida are collaborating to advance regional climate mitigation and adaptation strategies. For more information, see page 90.

Collaborating across Stakeholders to Advance Coastal Resilience

Now more than ever, cross-sector collaboration is essential to foster coastal resilience for the future security of coastal communities and environments. Cities and regions that have seen the greatest success with coastal risk management, such as the Holland region of the Netherlands (see full profile on page 99), have often done so by establishing supportive ecosystems of actors all working toward risk reduction and resilience. This section addresses how best to bridge the gaps between sectors, across jurisdictions, and with diverse stakeholders to advance best practices in coastal resilience and policies that support adaptation in the face of projected changes.

"To be able to deal with how you might defend, retreat, or adapt requires a lot of integration across multiple disciplines."

SCOTT DUNN
Chief strategy officer, Asia, AECOM

To increase the adoption of coastal resilience measures, building stakeholder awareness about risks and possible solutions is vital.

BUILDING AWARENESS ABOUT RISKS AND POSSIBLE SOLUTIONS

To increase the adoption of coastal resilience measures, building stakeholder awareness about risks and possible solutions is vital. Investments in education and capacity-building at various levels and scales enable context-specific responses to reduce risk and enhance resilience.[373] By fostering an environment where education and awareness are prioritized, the public sector can help communities navigate the transition from planning to implementation.

"Never let a disaster go to waste. In the Bay Area, we have places we can point to every year that show what sea level rise looks like or what seismic vulnerability looks like. That's the starter yeast, and it may take several years to amalgamate an understanding and movement to create a political imperative [for action]."

DIANE OSHIMA
Special project manager and adviser
Port of San Francisco

UNDERSTANDING RISKS AND POSSIBLE SOLUTIONS

Leveraging all available knowledge sources, investing in monitoring and forecasting, and sharing data and information are essential to climate education and literacy. According to the IPCC, there is high confidence in the positive impact of investing in these areas, particularly when multiple knowledge systems—including local, Indigenous, and scientific—and regional climate information are integrated into the decision-making processes.[374]

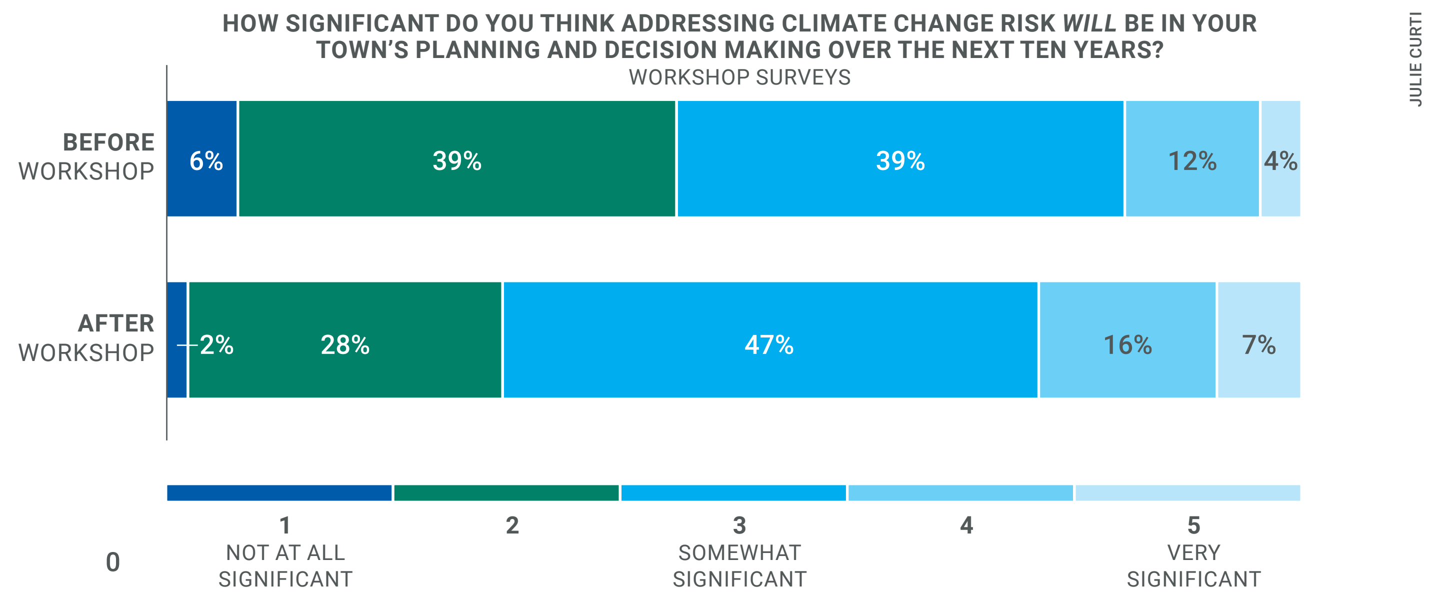
Evaluating vulnerabilities and identifying, analyzing, and prioritizing adaptation strategies are crucial early steps. Guidance on conducting vulnerability assessments to gather and analyze relevant data is included on page 86. Through risk and vulnerability assessments, communities can determine where they are most exposed and sensitive and can then direct their efforts more effectively.[375]

AWARENESS BUILDING

Engaging with local communities and relevant stakeholders in adaptation planning can help to both share and collect information. During awareness building, communities or organizations lay an educational foundation for action, galvanize political support, form teams, and identify key stakeholders. Building awareness about coastal risks and solutions requires a coordinated effort and involves identifying resources, laying out objectives, and scoping for the stages of adaptation planning to come.[376]

Many communities struggle with preparing for hazards. Discussing vulnerability to hazards can be difficult, as can keeping people engaged and motivated to act. Gaining an understanding of and connecting with stakeholders' diverse values and concerns can improve community engagement and help motivate action to reduce risk.[377]

BUILDING AWARENESS ABOUT CLIMATE CHANGE RISKS AND ADAPTATION



Change in participant confidence in town planning and decision-making before and after the New England Climate Adaptation Project's workshop in the beachfront town of Wells, Maine. Executed between 2012 and 2014, the workshop "aimed to increase public awareness about climate change risks and adaptation opportunities in Wells and build support for local efforts to address the challenge of adaptation."[378]

Best practices for public-sector officials in advancing climate education and literacy emphasize tailored engagement with local stakeholders both within and outside of government. The National Association of Counties offers guidance to local governments for coastal resilience risk communication, noting that "frequent, genuine, inclusive conversations are critical, as communication is a two-way street that requires coastal management practitioners to ask for input, listen, and remember that collaboration is key."[379] Key points from the guide are summarized in the table below.

Educating Stakeholders on Coastal Resilience

A wide range of educational materials is available to educate diverse audiences about coastal resilience. One example is the Association of State Floodplain Managers' Reduce Flood Risk tool, which offers educational materials about flood risk tailored to the type of stakeholder.

SUMMARY OF LOCAL GOVERNMENT GUIDANCE FOR COASTAL RESILIENCE RISK COMMUNICATION

1. Identifying stakeholders and developing messaging	• Stay clear of jargon. • Contextualize the message. • Focus on interest, not positions. • Keep your messages positive and motivating.	• Engage a small core test group. • Remember the end goal: building resilient communities.
2. Tailoring the message, understanding stakeholder groups	• Elected officials are jacks of all trades. • Elected officials are balancing varied and often conflicting priorities. Local elected officials in particular have the shared duty and goal of serving the best interests of their communities and constituents.	• Public engagement activities are well-served by study of the local context through activities such as focus groups, with emphasis on positively received language, equity, and inclusion.
3. Communicating the message	• Be prepared to address common questions and statements of resistance. • Empower storytellers. • Continuously and aggressively engage as many stakeholders as possible.	• Ensure outreach and engagement are conducted in an equitable and inclusive way. • Plan for aggressive public outreach using a variety of creative methods.

Source: National Association of Counties.[380]

MEANINGFUL COMMUNITY ENGAGEMENT FOR EQUITABLE COASTAL RESILIENCE

Managing coastal hazards and related community protections entails making difficult decisions about where investment should be directed, what types of adaptation projects should be pursued, when investments should be made, and how much money should be borrowed to support resilience investments in a way that is commensurate with expected risks. Community members who are affected should be informed of the issues, given the opportunity to take part in decisions related to proposals, and treated fairly in decision-making processes. Meaningful stakeholder participation that goes beyond public comment periods after plans are developed can strengthen adaptation decision-making by making it more responsive, robust, and proactive. Creating safe settings for meaningful public participation, deliberation, and conflict resolution can help communities address social vulnerability and equity in efforts to advance climate resilience and sustainable development.[381] Processes that include transparent evaluation frameworks further enhance community trust and understanding of how and why decisions are made.

"Pursuing equity means purposefully addressing racial, social, environmental, and economic injustices to build stronger communities and to support the most vulnerable communities in reducing risk."

ULI's report *Ten Principles for Building Resilience*

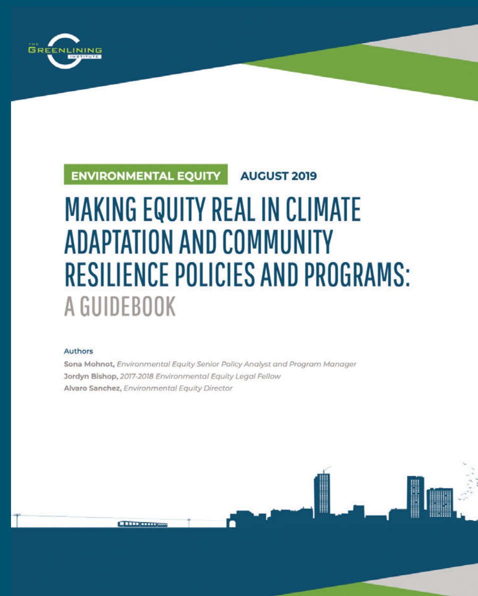
Mitigating social vulnerability should be a priority during climate adaptation decision-making, since historically marginalized communities, such as low-income communities and communities of color, are often most affected by climate change. Discriminatory land use and planning policies and practices advanced at the federal and local levels over time have contributed to these vulnerabilities. People with the highest exposure and vulnerability are often those with the lowest capacity to respond, so they require the most support.[382] Using cost/benefit analysis alone for investment decisions unfairly disadvantages these groups since it primarily considers property values and tax dollars at risk and other monetary factors.[383] Decision-making should address both economic impact and strategies for protecting communities with the greatest needs.

Engagement is most effective when it begins well before decisions are made so that input can shape plans and designs. Guided by San Francisco's first Equitable Development Plan, India Basin Waterfront Park is a catalyst for environmental remediation, resilience, and public health in the underserved neighborhood of Bayview-Hunters Point. The Equitable Development Plan Leadership Committee meets monthly to help drive project design and ensure that the resulting park best serves the Bayview-Hunters Point community. Once complete, India Basin Waterfront Park will unite seven waterfront parcels into 1.7 miles (2.7 km) of contiguous public open space.

Strategies for Successful Community Engagement

Several resources for enhancing meaningful community engagement and social equity in climate adaptation decision-making and implementation are available. They include the following:

- NOAA Office for Coastal Management's "Resource List": This list features links to valuable resources that offer guidance on equity and inclusion, community engagement for equity and inclusion, risk communication for equity and inclusion, regional coordination and collaboration, risk reduction, and enduring capacity for coastal resilience projects.
- Georgetown Climate Center's "Equitable Adaptation Legal & Policy Toolkit": This digital toolkit was created to help communities and policymakers address the dual challenges of climate resilience and social inequality. Among other sections, the toolkit includes guidance on procedural equity and community-driven engagement processes.
- Greenlining Institute's Guidebook, *Making Equity Real in Climate Adaptation and Community Resilience Policies and Programs*: This guidebook provides recommendations on how to operationalize social equity in the goals, process, implementation, and analysis of policies and grant programs focused on climate adaptation. It includes examples from existing policies and grant programs to illustrate what the recommendations look like in practice.



ULI RESOURCE

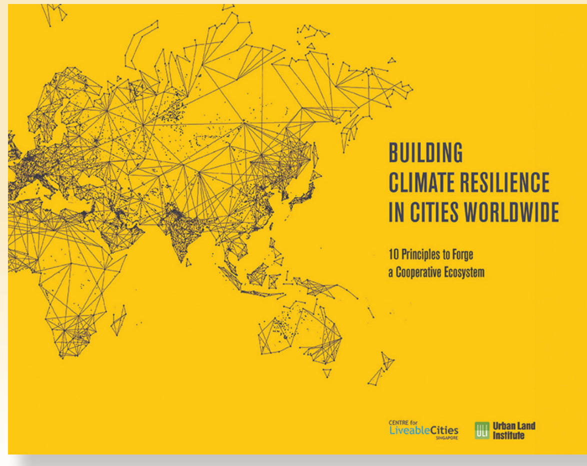
Racial Equity in Real Estate

ULI's report *10 Principles for Embedding Racial Equity in Real Estate Development* shares guiding ideas to help developers, investors, and other practitioners make racial equity a central part of their real estate practice. Each principle distills insights from industry leaders and includes specific best practices that can be applied to different sectors, markets, and geographies.

ULI RESOURCE

Collaborative Resilience Ecosystems

ULI's report, *Building Climate Resilience in Cities Worldwide: 10 Principles to Forge a Cooperative Ecosystem*, provides principles and guidance on cross-sector and interagency cooperation and partnerships to advance climate resilience. The report shares international examples of collaborative resilience-building from Singapore, Hong Kong, Rotterdam, New York, and Miami and synthesizes lessons learned that are transferable to other contexts.



REGIONAL AND INTERGOVERNMENTAL PARTNERSHIPS FOR ENHANCED RESILIENCE

Coastal areas often span multiple jurisdictions, and the environmental systems within them do not adhere to political boundaries. Effective management of shared resources requires a coordinated approach that can only be achieved through regional collaboration. Governing authorities can enhance the resilience of coastal communities and ecosystems by pooling resources, sharing knowledge, and developing unified strategies.

Regional policy frameworks have been shown to support adaptation action and prevent damages. Institutional arrangements that provide strong multiscale linkages and coordination between local, state, regional, and national authorities and their policies support efforts to address coastal risks.[384]

Leadership and convening power are essential to assist collaboration. Bringing stakeholders together to develop and implement solutions is necessary to address the problems of coastal hazards at the appropriate scales and time frames. Sharing data and information, collaborating on financial mechanisms, and offering institutional support across traditional boundaries and silos are also vital to success. These investments enable capacity building and multiscale participation in adaptation, as well as negotiation between tradeoffs and realization of cobenefits related to reducing risks and building long-term resilience and sustainability.[385]

Worldwide, governments at the local, regional, and federal levels coordinate on coastal resilience issues in diverse ways. The city of Vancouver's Climate Emergency Action Plan is supported by the provincial government of British Columbia. The province provides funding, technical assistance, and expertise through entities such as the Ministry of Environment and Climate Change Strategy and collaborates with federal agencies such as Environment and Climate Change Canada. This cooperation ensures the plan aligns with national climate change adaptation strategies, addressing issues including sea level rise and storm surge. In the People's Republic of China, the central government establishes overarching regulations and policies, encouraging local governments to enact those policies through local initiatives and private-sector engagement.[386]

The Southeast Florida Regional Climate Change Compact is a coalition of Monroe, Miami-Dade, Broward, and Palm Beach Counties in Southeast Florida that advances climate mitigation and adaptation strategies throughout the region.

Regional Climate Governance in Southeast Florida

The Southeast Florida Regional Climate Change Compact is a coalition of the four counties in Southeast Florida—Monroe, Miami-Dade, Broward, and Palm Beach—that advances climate mitigation and adaptation strategies throughout the region. The Compact works collaboratively to address vulnerabilities caused by climate change and sea level rise, implement adaptation strategies, and build climate resilience across municipal and county lines. The Compact represents a new form of regional climate governance, creating the first case in the United States where counties voluntarily committed to a joint regional effort to address climate change.

Local government officials in Southeast Florida started the Compact in 2009 when they came together to discuss the climate change threats facing over 6 million residents in the region. Recognizing the shared challenge and the opportunity to position Southeast Florida as a leader, their call to action solidified a coordinated, regional response in the form of the Compact, which aims to ensure that the region continues to thrive in the face of shared climate change challenges.

The four counties have successfully collaborated on mitigation and adaptation strategies, built bipartisan support for climate action, and forged partnerships with key stakeholders. Stakeholders include federal, state, and municipal governments and agencies; economic development entities; community-based organizations; and the academic community, enabling the development of a regional voice and vision for future prosperity in Southeast Florida.

The Compact's efforts have three overarching objectives:

- **Share regional tools and knowledge.** The Compact serves to create regional tools and standards and to transfer knowledge that builds local government capacity to implement regional climate solutions and avoid duplicative efforts.
- **Increase public support and political will.** Through its unified voice, the Compact provides the nonpartisan credibility, legitimacy, and continuity necessary for meaningful government action to address projected climate impacts.
- **Coordinate action.** The Compact catalyzes and supports the region's coordinated actions to accelerate the pace and impact of efforts that will increase the region's climate resilience.

PUBLIC/PRIVATE PARTNERSHIPS

Leveraging the private sector is important to address the coastal risks posed by the changing climate—risks that are too great for any single sector to tackle alone.

One way to work with the private sector on coastal resilience is through public/private partnerships (P3s). Partnership arrangements are diverse, but in general, P3s can reduce the financial burden on both sectors' resources by providing additional capital investment, expertise, services, efficiencies, and innovation.[387] P3s can also open up new possibilities for creative financing models and pave the way for positive long-term benefits by providing funding for maintenance, monitoring, and evaluation of project outcomes.[388] Overall, by working together, the public and private sectors can ensure that comprehensive environmental, economic, and community benefits are realized through P3 projects.

Public/Private Partnership Guidance

For additional guidance on public/private partnerships (P3s) for coastal resilience, see the following resources:

The Center for Climate and Energy Solutions' *Guide to Public-Private Collaboration on City Climate Resilience Planning* lays out the value in public-private collaboration on city climate resilience planning and recommends specific actions that city resilience planners can take to bring the business community into the climate resilience planning process.

The Global Center on Adaptation's *Knowledge Module on Public-Private Partnerships for Climate-Resilient Infrastructure* provides advice and resources on how to structure P3s to incorporate climate resilience into infrastructure investments.

EXAMPLES OF SUCCESSFUL PUBLIC/PRIVATE PARTNERSHIPS FOR COASTAL INFRASTRUCTURE DEVELOPMENT AND MANAGEMENT

JURISDICTION	INSTRUMENT	DESCRIPTION
Bilbao, Spain	"Flood-proof" urban district	The Zorrotzaurre project in Bilbao transformed an abandoned industrial peninsula into a "flood-proof" residential district. Structured as a P3, landowners and public authorities collaborated through the SPV Comisión Gestora de Zorrotzaurre, with financial contributions based on land ownership. The project integrates nature-based solutions to enhance sustainability and resilience against increased flood risks due to climate change.[389]
Puerto Morelos, Mexico	Coastal erosion and storm damage mitigation	In response to beach erosion and storm damage, Puerto Morelos collaborated with the National Autonomous University of Mexico (UNAM) to develop an artificial reef. This reef, constructed from pH-neutral marine-grade concrete, dissipates wave energy, supports natural beach replenishment, and fosters marine biodiversity. Since its placement in 2010, it has stabilized the beach and attracted coral, enhancing local ecosystems and tourism.[390]
Staten Island, New York	"Living Breakwaters" coastal resilience and habitat restoration project	The Living Breakwaters project combines offshore breakwaters to reduce wave energy and erosion, enhancing coastal resilience and biodiversity. The collaboration among government, nonprofit, and private sectors showcases sustainable coastal development.[391]

This art installation, “Support” by artist Lorenzo Quinn, is a pair of 5,000-pound white hands that appear to prop up Venice, Italy’s Ca’Sagredo Hotel from falling into the water. The installation symbolizes the threat of climate change and the power that mankind has to address it.

SHUTTERSTOCK

PROJECT PROFILES

AMERICAS

Lower Manhattan Coastal Resiliency Project and East Side Coastal Resiliency in New York City, New York

Clippership Wharf in Boston, Massachusetts

EUROPE

Regional Coastal Protection in Holland, Netherlands

Tidal Barriers and Historic Building Adaptation in Venice, Italy

ASIA PACIFIC

Rain Tunnels and Coastal Barriers in Hong Kong, Special Administrative Region of China

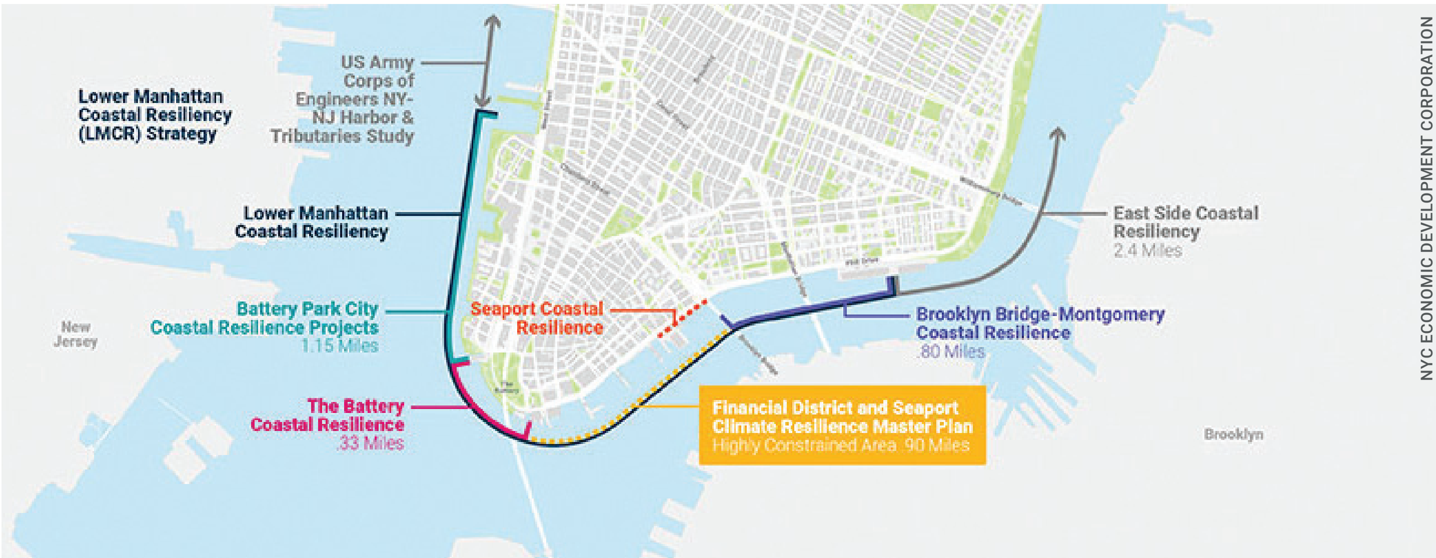
Oasis Terraces in Punggol, Singapore

Lower Manhattan Coastal Resiliency Project and East Side Coastal Resiliency in New York City, New York

Graphic imagining the original BIG U, created by architecture firm Bjarke Ingels Group (BIG).

New York City is no stranger to climate disasters. Hurricane Sandy, which tore through the northeast United States in 2012, flooded 17 percent of the city's land area, caused 44 deaths, and created US$19 billion in damages and lost economic activity.[392] New York City's 520 miles (837 km) of coastline—greater than Miami's, Boston's, Los Angeles's, and San Francisco's combined—expose it to intense and interacting flood risks from sea level rise, tidal flooding, groundwater rise, and coastal storm surges and waves.[393]

Lower Manhattan, the historical origin of modern New York City, is home to multiple dense residential neighborhoods, with more than 300,000 residents.[394] It is home to one of the largest business districts in the United States, the Financial District, encompassing Wall Street, the New York Stock Exchange, and the Federal Reserve Bank of New York. It is a vital urban and regional hub of activity: millions of people visit this small geographic area every year, and half a million travel through it every day; the Financial District alone hosts 75 percent of the city's subway lines; 17 ferry routes, commuter buses, and rail lines; 10 percent of the city's jobs and assessed property value; and US$6.5 billion in estimated tax contributions in 2019.[395]



The extent and components of the LMCR and ESCR in Lower Manhattan.

The city is vulnerable to coastal risks given its low-lying shoreline. With so much at stake, the city, federal government, nonprofits, community groups, and consulting design teams have concentrated significant effort and funding toward developing a coastal protection strategy for the area, using a combination of gray and nature-based infrastructure.

After Hurricane Sandy, the strategy took shape through two successive design competitions: Rebuild by Design (hosted by the New York City government in 2013) and the National Disaster Resilience Competition (hosted by the federal government in 2014 with New York City as the applicant).

Rebuild by Design saw the creation of the BIG U, a contest submission led by architecture firm Bjarke Ingels Group for a 10-mile (16 km) system of interconnected parks and flood protection elements that would encompass Lower Manhattan and shield it from coastal storms and flooding. The design intended to leverage flood risk management as an opportunity to enhance quality of life, based on "the idea that flood infrastructure should also be 'social infrastructure' that reimagines our coastlines as parks, rethinks coastal highways, and provides multiple benefits for local communities."[396]

Only the lower portion of the BIG U received funding from the design competitions and has since taken shape under new names as the Lower Manhattan Coastal Resiliency (LMCR) and East Side Coastal Resiliency (ESCR) projects. The LMCR strategy consists of several components, as shown in the map below, named for the areas of Manhattan they protect.

ESCR and the components of LMCR take different approaches to coastal protection, but all include a combination of permanent and deployable flood barriers and sea walls, elevation of waterfront spaces above flood levels, and green infrastructure, such as enhanced drainage and salt-tolerant landscape plantings.[397] For example, a wharf in the Battery will be raised six feet (1.8 m); a playground on the East Side has been rebuilt with storm-resilient materials, 320 linear feet (97.5 m) of new floodwall, and a 79-foot (24 m) sliding floodgate; the ESCR project will elevate the whole park and use a combination of floodwalls, berms, and moveable gates; and the Brooklyn Bridge–Montgomery area will receive floodwalls and deployable flip-up barriers that activate during storms to protect from 100-year storm surges on top of sea level rise projected to the 2050s. All components are under construction and completion is anticipated by the mid-2020s, except for the Financial District and Seaport component, which is still in design as of early 2024. Total project cost estimates vary, but they will likely exceed US$10 billion (including US$7 billion for the Financial District and Seaport component,[398] nearly US$2 billion for ESCR,[399] and several hundred million dollars each for the remaining components[400]), meaning this small but critical part of Manhattan constitutes roughly half of the US$20 billion total New York City is spending on coastal resilience.[401]

The new waterfront imagined for the Financial District.

The Financial District and Seaport component stands out in its ambition. The extreme density of buildings and infrastructure, above- and underground, in the Financial District leaves little space for protective systems. For this reason, the city plans to build out 200 feet (61 m) into the East River and create a new multilevel shoreline park. The lower deck will be elevated 3–5 feet (0.9–1.5 m) to protect against sea level rise, and the upper level, 15–18 feet (4.5–5.5 m) to withstand severe storms. This new esplanade will feature floodwalls buried in the landscape, a pump station, green infrastructure, resilient ferry terminals, and space for habitat restoration.[402]

Meanwhile, the ESCR project stands out in its complexity. The project became controversial when the Mayor's Office reversed course after several years of planning and community engagement and decided to pursue a redesign, for the stated reason that the original plan was logistically infeasible to construct and would take too long to build.[403]

The earlier plan preserved many existing park features, such as sports facilities and mature trees, and elevated only the inland end of the park to protect inland neighborhoods but store water during storms while remaining usable in dry weather (in the style originally inspired by Dutch water management). In the new plan, the park would instead be scraped clean and rebuilt higher throughout, and rely more on floodwalls and retractable floodgates, aiming to serve as an impenetrable flood barrier.[404] This new plan is designed to protect the neighborhood and the park itself from a 100-year flood event (the previous design would eventually have allowed the park to flood monthly from higher tides), and construction can begin a year sooner, finish earlier, and avoid conflicts with nearby underground high-voltage lines and highway infrastructure.

This shift was accompanied by strong pushback from some community groups who wished to preserve the existing park and its ecology (including over a thousand mature trees). However, the new plan was eventually embraced by communities near the park, especially in the adjacent public housing complex, where residents felt their safety was being compromised by delays and deprioritized by outsiders who cared more about the park's well-being than their own.[405] Ultimately, the second design was approved, and the new park is expected to be completed by 2026, 14 years after Sandy made landfall.

New York's coastal resilience efforts demonstrate what can be achieved with significant funding and the support of a rich ecosystem of local and federal governments, architecture and engineering firms, and community groups. Their relatively slow pace, however, also reveals the difficulty of creating large-scale infrastructure in highly developed places with a great deal at stake, and the challenge of building cultural consensus on how to live with water in time to protect cities from the next major disaster.

AMERICAS

Clippership Wharf in Boston, Massachusetts

Clippership Wharf has enabled public waterfront access in East Boston for the first time in more than 30 years.

Over the past several decades, Boston Harbor has seen a sharp increase in the number and intensity of extreme events, with 100-year and 500-year storms becoming more common every year. Higher sea levels increase the frequency of dangerous high-tide flooding, increase the intensity of storm surges and wave height, and erode shorelines. This type of sea level rise could be devastating for large areas of the city, nearly half of which was built on low-lying landfill just above the high-tide line. The city also lacks a robust sea wall, making waterfront properties even more vulnerable to flooding during storm events and high tides.

As a result, when Lendlease Americas acquired a 12-acre (4.8 ha) East Boston waterfront site, five acres (2 ha) of which are watersheet (tidelands), the firm had a lot to consider. A desire to build an asset that would operate successfully for more than 100 years drove the project team to embed resilience and sustainability into all aspects of the development. After conducting robust climate risk analyses and engineering studies for the site, it became clear that innovative solutions were necessary to ensure that the property—and its 1,700 linear feet (518 m) of harbor frontage—would weather future storms.

Clippership Wharf's living shoreline invites the tide to move in and out of the site naturally. With the lowest residential floors sitting 14 feet (4.3 m) above current high tides, the property can safely accommodate sea level changes.

The innovative mixed-use development project, now called Clippership Wharf, is built to be resilient against future sea level rise. It consists of 478 residential units across four structures: two condominium buildings with 194 residences and two apartment buildings with 284 market-rate rental units. The site also contains 30,000 square feet (2,800 sq m) of common, amenity, and public areas, including three retail outlets.

A central courtyard space anchors the site and features a variety of amenities for both residents and the public, including a large amphitheater, a dog park, art, and natural plantings. The development also knits together a section of Boston's 43-mile (69 m) Harborwalk system, connecting the project with the broader neighborhood and providing active transportation opportunities along the waterfront.

However, Clippership Wharf is best known for its innovative approach to safeguarding against sea level rise and urban flooding. A variety of unique elements advance resilience on the site while adding green space and waterfront access in East Boston.

Shoreline mitigation measures include a raised-ground plane, stabilization of existing sea walls, new coastal wetland areas, rain gardens and bioswales, as well as the update of neighborhood stormwater infrastructure. Lendlease also set entrances to the residential units 14 feet (4.3 m) above mean high tide, well beyond FEMA guidelines.

Rather than adding seawalls and other fortifications to hold back water from building structures, the design's living shoreline naturally buffers the project from changing tides. The shoreline features a series of salt marsh terraces that dissipate waves during storm surges. Granite blocks from the site's previous uses were repurposed to create the terraces, which provide habitat for repatriating native species in the intertidal zone.

Anchored by a publicly accessible central courtyard, the property also features significant green and open space with native plantings that absorb rainfall to reduce the risk of flooding on site and on neighboring properties. Green infrastructure includes rain gardens and a groundwater recharge system to capture and improve the quality of stormwater runoff. The site's open space not only mitigates flood risk, but also incorporates amenities—such as a large amphitheater, a dog park, and docks—that the community is invited to enjoy.

Instead of having a central plant, the site has multiple air-handling units to allow for continued operations in the event of an emergency in which building segments might be damaged. Rooftop solar panels ensure grid resilience in case of power outages and support a transition to renewable energy sources. The solar panels generated 200 megawatt-hours in the first year of operation, enough energy to power 25 to 50 homes annually.

Finally, in addition to investing in what Lendlease referred to as "hard" mitigation strategies, such as elevating the ground plane, the company incorporated "soft" mitigation measures into the project, which focus on the day-to-day operations of the facilities. The soft mitigation elements range from deployable flood barriers to protect low-lying areas to instructions for staff in case of an emergency, safe egress routes, and methods for accessing important supplies. The combination of hard and soft mitigation techniques has been so successful that Lendlease has incorporated similar strategies into other waterfront projects the company is developing.

Clippership Wharf has been successful in terms of climate resilience, high tenant demand, and industry recognition. As a result of its resilient features and living shoreline, Clippership Wharf has created value by avoiding up to an estimated US$2 million in insurance claims per major storm event. The development was 96 percent leased less than a year after it opened, with the first 80 condominium units selling in just eight weeks prior to the development's full opening and rents reflecting a 5 to 10 percent premium due to the desirability of the resilience and sustainability features.

In addition to its impressive financial performance, Clippership has delivered significant benefit to the East Boston community. The development enabled public waterfront access in the area for the first time in more than 30 years and also provided affordable housing. To fulfill the city's affordable housing requirement, Lendlease partnered with Winn Development and the Boston Housing Authority to enable the development of 22 deeply affordable rental units and 30 mixed-income condominiums on an adjacent site, 14 of which are affordable.

The development process was not without challenges. At the time of development in the late 2010s, the regulatory environment was not set up to approve the higher ground plane or the living shoreline concept. Initially, local agencies were skeptical and thought that the higher elevation of the site would block public access and limit integration with the broader neighborhood. In response, Lendlease redesigned internal roadways, ramps, and stairs to prioritize pedestrian pathways to and through the site, preserving water views and expanding public access.

The Lendlease team patiently worked through many regulatory obstacles to realize their aspirations for the site. Now, Clippership Wharf is held up as a prime example of resilient waterfront design, and the same agencies that initially pushed back are asking other waterfront developers to model their projects on Clippership. "The lasting legacy of the project will be how it pushed the dialogue around resilience in Boston," says Nick Iselin, executive general manager at Lendlease Americas.

EUROPE

Regional Coastal Protection in Holland, Netherlands

The Oosterschelde flood barrier, part of the Delta Works in the Holland region of the Netherlands.

As ever-growing numbers of regions have been confronted with their vulnerability to coastal flooding, the Netherlands has become recognized worldwide for its expertise in water management, particularly in its Holland region.

Holland is densely populated and home to major economic and industrial centers like Rotterdam, Europe's busiest port. It is also well known for lying below sea level, protected by a system of levees and dikes dating back to the 1300s[406] that has since been updated and expanded with feats of modern engineering.

Dutch strategies have come to be sought after in many places seeking solutions to severe sea level rise and storm surge impacts. As a result, in 2015 the Netherlands appointed a special envoy for International Water Affairs who works to share Dutch water expertise internationally. (The first, Henk Ovink, collaborated with New York City's Rebuild by Design competition and the U.S. Department of Housing and Urban Development.)

Initiatives such as the Dutch Dialogues have also emerged, particularly in New Orleans after Hurricane Katrina, as a series of workshops and publications that brought in Dutch water planners to work with public officials and local stakeholders and explore how Dutch knowledge and methods can be applied in other contexts. The Dialogues, developed by architecture firm Waggoner & Ball, have since been hosted in other areas of the United States, such as Charleston, South Carolina, and the Hampton Roads area of Virginia.

The "exported" Dutch approach to flood control focuses primarily on allowing water in and out of developed areas safely and using it as a resource to improve urban livability.[407] Sometimes that concept clashes with local cultures and government approaches to water management, as observed in the evolution of coastal protection strategies for lower Manhattan in New York City (see profile on page 93). However, it has been enthusiastically adopted in other locales, such as Singapore, which has begun using the Dutch "polder" method for new land reclamation projects—a core strategy in a low-lying, land-scarce island state (see profile on page 108).

The Netherlands itself has taken a layered approach to flood protection, building on governance structures such as regional "water boards" that have been around since the 13th century and more recent city and national government bodies. The national approach to flood risk consists of a combination of large-scale flood prevention measures and the thorough integration of water management into urban planning and design.[408]

In Holland, these prevention measures include a robust system of barriers and land management strategies for managing the flow of the four rivers that form the delta region as they join the North Sea.

Of the abundant infrastructure that comprise this system, the Delta Works could be called the heart. Consisting of 13 sections of dams, sluices, locks, dikes, levees, and storm surge barriers, and constituting the largest flood protection system in the world, the Works were begun after devastating flooding in 1953 killed thousands, and they were completed in the late 1990s, at a total cost of US$5 billion.[409]

The system includes large elements, such as the Maeslant Barrier—one of the world's largest moving structures, consisting of a pair of steel gates that close off when water levels rise above a certain threshold—and other large barriers, such as the Eastern Scheldt Barrier, made of 62 steel doors that are each 138 feet (42 m) wide.

CENTRAAL BUREAU VOOR DE STATISTIEK

The Netherlands, with the provinces of North and South Holland highlighted.

Along with dunes, canals, and pumping stations, the system's 10,250 miles (16,495 km) of dikes and around 300 flood protection structures are designed to withstand up to a 1-in-4,000-year flood, far beyond the level provided by most other flooding defense systems. Nonetheless, the Netherlands's Delta Programme (a national entity composed of central government, province and city authorities, water boards, and private-sector and civic actors) has recognized that changing climate conditions threaten even this leading system. Work has already begun on continual upgrades and multibillion dollar investments in 100 projects to strengthen long stretches of dikes, through the Delta Programme's annually updated plan.[410]

As a region of river deltas, Holland and its millions of residents are also vulnerable to inland flooding that arrives via the multiple waterways. To address this risk, after additional severe floods in the mid-1990s, water management entities adapted the approach of keeping water out and developed the strategy they now advise of working alongside nature to give water the space it needs to move through areas safely.

This approach is exemplified by projects such as the Room for the River initiative, a US$2.3 billion project that expanded the flood storage capacity of space surrounding four rivers at more than 30 locations. The initiative uses nature-based strategies, such as relocating dikes further back from riverbanks, digging naturalized secondary channels for overflows, creating new open spaces for water retention, and elevating farmland, to reduce the amount of water that arrives at the coast and threatens cities like Rotterdam. The program, completed between 2006 and 2015, has been effective at reducing the interacting coastal, riverine, and stormwater flooding and complementing the relatively harder coastal barrier system.[411]

Other large-scale, nature-based solutions include an innovative project known as the Sand Motor, which created a large artificial peninsula off the coast of The Hague by depositing over 706 million cubic feet (20 million cu m) of sand. Natural dynamics of water currents, wind, and waves gradually distribute the sand along the shore to reinforce the shoreline and create new beaches and habitats, while reducing the need for more frequent and costly sand replenishment.

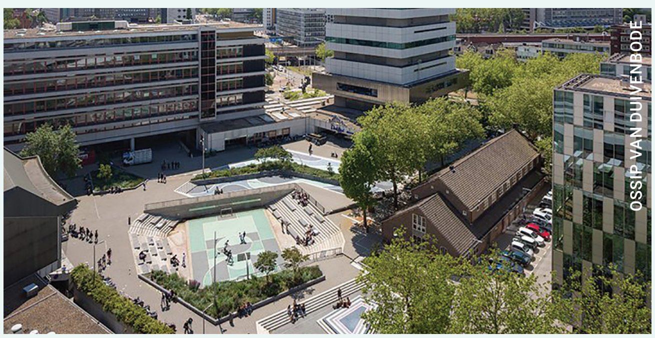
Finally, these national and regional programs are complemented by city-level flood protection measures in Rotterdam, The Hague, and other cities throughout the region. The city-level measures focus primarily on managing heavy rain and stormwater by encouraging creation of green roofs and public spaces in overflow areas that can store water during heavy rain but remain accessible during dry weather, and working with building owners to install small-scale flood protection systems or relocate electrical equipment above flood levels.[412]

Holland's success with water management thus far is widely attributed to its collaborative governance model, sometimes called the "Dutch Diamond" approach", which consists of close partnerships between governments, the private sector, civil society, and knowledge institutions.[413] This "whole of society" approach also rests on the fact that funding for water management is a national priority. For instance, the Delta Programme receives an average of US$1.34 billion per year from the central government's budget, earmarked through 2032.[414]

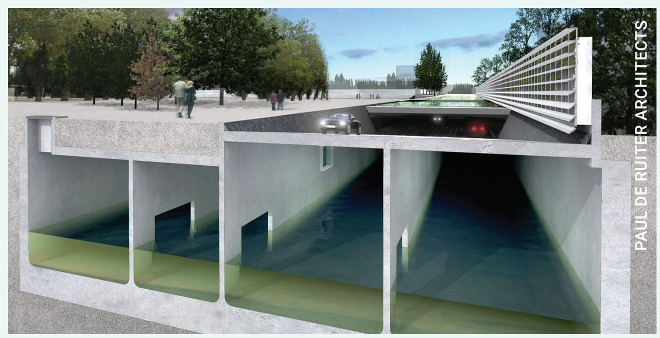
Though the combination of engineering and nature-based strategies are important to learn from, embedding adaptive, multipronged water management into the cultures of governance, land management, and partnerships across sectors—in short, the creation of a supportive ecosystem for coastal resilience—may be the most important lesson for coastal communities.

Examples of Sites in Holland Developed with Coastal and Flood Resilience

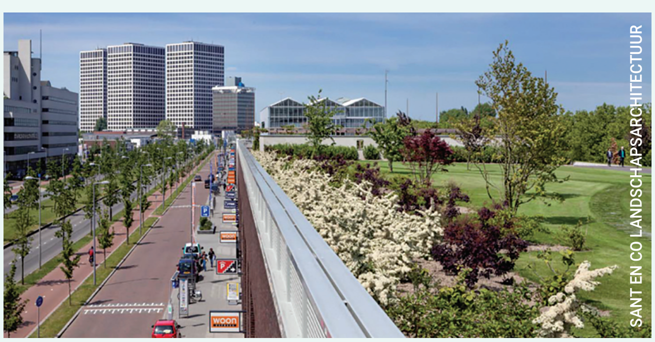
In Rotterdam and other cities in Holland, a wide array of built and natural projects have integrated flood protection features into buildings and public spaces, related to both coastal and inland flooding. The following are examples.



The Benthemplein, or Water Square, a public park in Rotterdam by De Urbanisten, uses sunken sport courts to double as recreational space and stormwater storage.



The Museumplein parking garage in Rotterdam, an underground car park for the city center and Museumpark area, provides over a thousand parking spaces and can contain 353,000 cubic feet (10,000 cu m) of water during heavy rains.



The Dakpark, a 0.6-mile-long (1 km) green rooftop park atop a shopping center in Rotterdam (one of Europe's largest), has a built-in dike for flood protection and stormwater absorption features.

An underground parking garage, embedded seamlessly amidst the dunes of the seaside resort town Katwijk aan Zee, protects the coastline while providing access to the shore.

EUROPE

Tidal Barriers and Historic Building Adaptation in Venice, Italy

High-tide flooding in Venice, Italy.

Venice was built centuries ago on a lagoon next to the Adriatic Sea by engineers who devised a system of wooden platforms built on thick wooden piles driven deep into the layers of mud, clay, and dense sand underwater. The city has coexisted with water for a millennium and a half. It sits on more than a hundred islands, crisscrossed by over a hundred canals and linked by several hundred bridges.[415]

As sea levels rise in the Adriatic, the city is reckoning with how to preserve its structures for a third millennium. The rising seas are leading to ever more frequent inundation by tidal flooding, upward of 15–20 times per year, with some locations such as the Piazza San Marco flooding more than 100 times a year.[416] Venice also saw disastrous high-tide events in 1966, in which three-quarters of the city's shops, businesses, and studios were damaged, and again in 2019, when 80 percent of the city was inundated.[417]

These tides rose 6.4 feet (194 cm) and 6.1 feet (187 cm) above sea level, respectively, and even moderate climate projections indicate that seas could rise another foot (30 cm) by midcentury.[418] Exacerbating the problem is the reality that Venice has sunk six inches (15 cm) in the past century due to groundwater removal by industry through the 1970s and the pile foundations sinking slowly under the city's weight.[419]

Over the centuries, the city shaped its lagoon and barrier island ecosystem to protect its urban and economic growth, by diverting rivers, constructing jetties at inlets from the ocean, building barrier islands, and dredging deep navigational channels from the 15th through the 20th centuries. Small-scale, spontaneously implemented flood-response measures are widespread at the building level, especially in the historic center. These measures include building with impermeable limestone to keep out saltwater and humidity, raising floor levels, waterproofing floors and walls, and installing pumps and flood barriers.[420]

Local government has also undertaken an effort to raise the pavement in most of the city to 3.6 feet (110 cm) above sea level, and some landmarks, such as the famous Basilica di San Marco, have installed their own glass flood barriers to reduce the threat of constant saltwater exposure.

The MOSE system in Venice was built to defend the city against high waters.

However, the highest-profile protection measure—one that demonstrates the national dedication in Italy to preserving Venice as a world heritage site—is the MOSE barriers: Modulo Sperimentale Elettromeccanico, or Experimental Electromechanical Module.[421] MOSE is a system of 78 barriers, each five stories tall, at the three inlets connecting the lagoon to the sea. When the tide is predicted to rise more than 4.3 feet (130 cm, or 1.3 m) above sea level, the barriers are filled with air and rise to the surface, creating a barrier that holds back tidal waters and storm surges. They are designed hold back floods reaching up to nearly 10 feet (3 m) above sea level.[422]

First conceived in 1984, the project has cost roughly US$6 billion and has been under planning and construction for 30 years. Local and national governments have bet big on MOSE as a high-tech solution for flood control. Despite a history of delays and corruption scandals, the project recently saw a historic victory in late 2022 when a tide rose nearly as high as that of the 2019 floods and was successfully blocked by the barriers.

> "Viewed up close, the scale of the MOSE is stunning. The yellow barriers, end-to-end, span nearly a mile and are operated in part from an artificial island that workers liken to a concrete fortress."
>
> ***The Washington Post***

The MOSE design was intended to demonstrate sensitivity for local ecology. The barriers' usual home on the sea floor was expected to preserve ecosystem function by allowing saltwater to flow in and out normally and keep the lagoon from festering.

Elevated pathways and other small-scale adaptations accompany major infrastructure investments such as the MOSE system.

Despite these achievements, the system is not without critics. MOSE is designed to block only the highest of tides and was conceptualized in the 1990s before anyone understood just how fast climate change and sea level rise would occur. With high-tide events becoming so frequent, the system will at some point be strained beyond capacity, closing too frequently for maintenance and marine access. Closing that often would also cut off the flow of water that is critical to maintain the ecological health of the city's lagoon. Despite allowing saltwater to keep the lagoon clean, some ecologists suggest that MOSE is already impacting the health of the lagoon by changing sedimentation regimes, putting the region's vital coastal wetlands at risk.[423]

Raising the barriers also costs US$300,000 every time in energy, staffing, and the closure of marine traffic,[424] raising questions of fiscal sustainability as well. Depending on how quickly greenhouse gas emissions can be lowered, the system may only have a useful life of 50–100 years, despite its cost.

Alternative proposals include injecting fluid cement or water below ground to lift the city by a foot (30 cm) over 10 years.[425] Others would change the approach from pure engineering solutions to nature-based strategies—for example, restoring the flow of long-diverted rivers to resupply sediment and strengthen the wetlands,[426] "re-naturalizing barrier islands" to hold back tides, or ending industrial activity that necessitates dredging the lagoon.[427] These methods would lean closer to the Dutch strategy of using simpler technology and making room for water and ecosystems, with the goal of providing longer-term protection.

The consortium of companies operating MOSE has already begun some salt marsh and barrier island restoration and reinforcement through sand deposits, breakwaters, and sea walls.[428] This combination of green and gray water management infrastructure is intended to reduce strain on the system and provide better protection to the city.

Venice's next thousand years are far from assured. What seems certain is that balancing the city's priorities—protecting its cultural treasures, preserving its tourism economy, and remaining livable without destroying its natural beauty—will require reimagining its relationship with water once more.

ASIA PACIFIC

Rain Tunnels and Coastal Barriers in Hong Kong, Special Administrative Region of China

Hong Kong is surrounded by water and hills behind the city that make it vulnerable to flooding.

Hong Kong, one of the world's densest and wealthiest cities despite its relative youth, has always had to contend with the threat of annual typhoons, which bring storm surges, high winds, and intense downpours that would strain the infrastructure of any city.

Historically, these coastal hazards have caused horrific damage, including two storms in 1906 and 1937 that respectively caused 15,000 and 11,000 deaths. The former figure represents nearly 5 percent of the city's population at the time[429] while the latter storm saw a tidal surge of 18 feet (5.5 m).[430] Storms regularly caused hundreds of deaths in the mid-to-late 20th century.

In keeping with the city's rapid ascendance to become one of the world's top centers of trade and finance, the city has invested billions of dollars in flood protection, with dramatic results. The largest of these infrastructure projects is a US$3.8 billion (HK$30 billion) network of enormous drainage tunnels, begun in 1995 and constructed by the city's Drainage Services Department.

Hong Kong's west drainage tunnel collects stormwater with 32 wells and linking tunnels that expel the water into the sea.

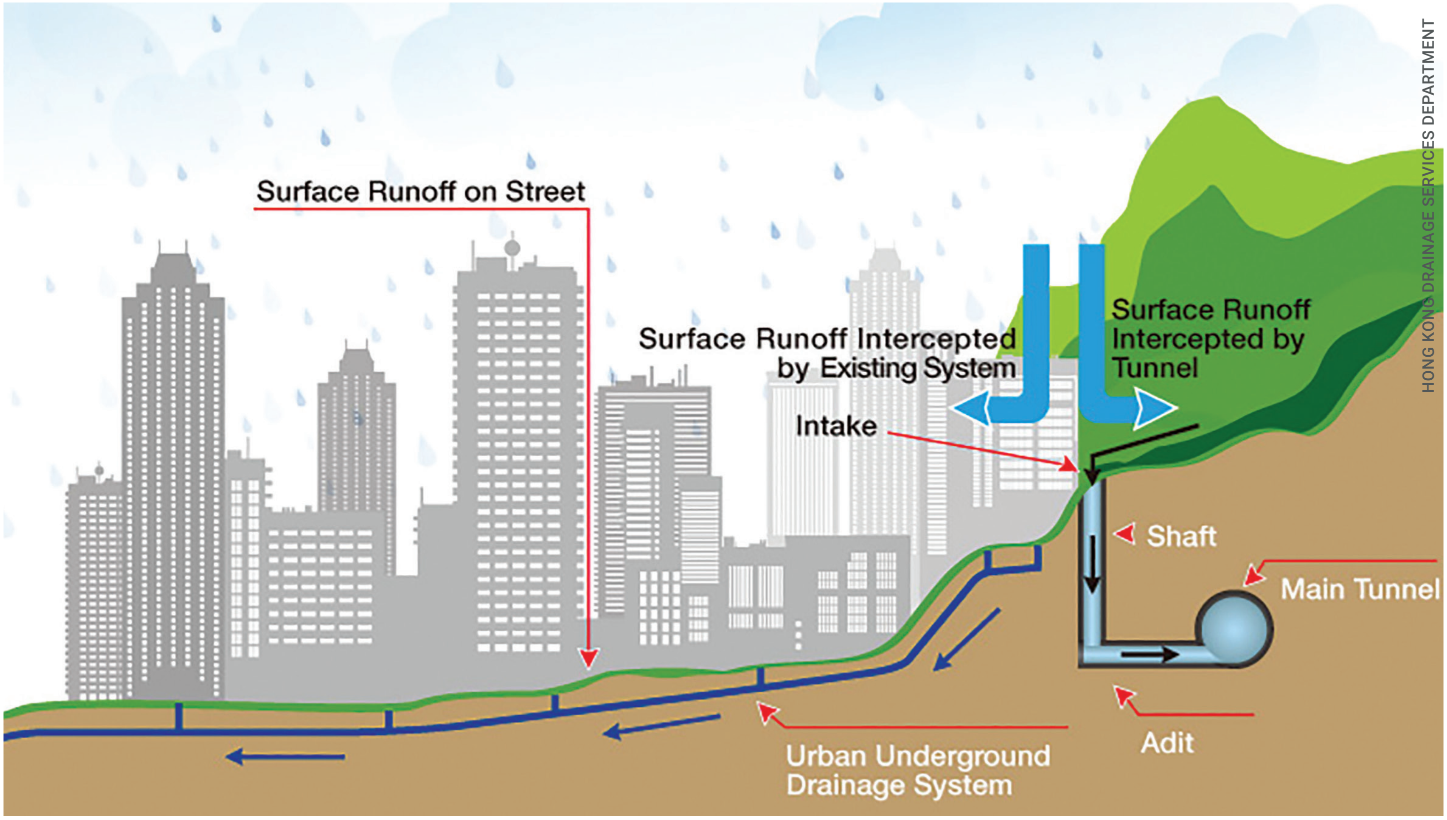
The network is still under construction, and four tunnels are complete: the Hong Kong West Drainage Tunnel, the Tsuen Wan Drainage Tunnel, the Lai Chi Kok Drainage Tunnel, and the Kai Tak Transfer Tunnel. Some of these tunnels run over 6.5 miles (10.5 km) in length and reach 23.7 feet (7.25 m) high—built to handle the city's annual 94 inches (2,400 mm) of rain, most of which falls in a few months during typhoon season.[431]

In addition to tunnels built beneath the city, stormwater infrastructure is also built into the hills behind the city, where it can intercept rainwater before it travels downhill, thus preventing erosion and damage in the lower-lying developed areas. Some of this rainwater is stored in large tanks, reducing the amount that must be discharged into the bay at once—a key strategy for managing backups during high tides. This surgical approach of cutting the water off early and releasing it in stages represents the Drainage Services Department's three-prong strategy of "stormwater interception at upstream, flood storage at midstream, and drainage improvement at downstream."[432]

All told, since 1995, the department has worked to transform the city's flood infrastructure, through projects including the four tunnels (totaling 13 miles [21 km]), 1,500 miles (2,400 km) of drains, 224 miles (360 km) of river channels, and four stormwater storage tanks. Construction of the tunnels took only five years—a remarkable feat—while another 11 tanks are under construction.[433]

The underground storage tanks are a critical part of this infrastructure. One tank, built under the famous Happy Valley Racecourse, can hold nearly 16 million gallons (60,000 cu m) of water, equivalent to 24 standard swimming pools.

Though flooding remains a serious issue for the city, this infrastructure strategy has brought improvements: flooding "blackspots" (locations with chronic flooding) decreased from 90 in 1995 to just four in early 2024, and no blackspots rated as "major" have existed since 2009.[434]



Hong Kong's stormwater drainage tunnels are built into the hills behind the city as well as below the city.

Hong Kong has also worked to address storm surge, building barriers around outlying villages at the edge of the city, including breakwaters, sea walls, dikes, and channels. Now the city is exploring greater integration of the "sponge city" concept through widespread absorptive green infrastructure, such as floodable lakes and green areas, river revitalization, bioretention systems, and more in new developments, to store water when it is plentiful and release it when it is scarce.[435]

The city's success with managing rainwater thus far will continue to be tested by typhoons that are becoming increasingly ferocious. A typhoon in September 2023 overwhelmed the city's defenses, dropping a record-setting 6 inches (158 mm) of rain per hour and causing widespread flooding and disruption, though the city's modern new infrastructure limited loss of life to two fatalities. Experts suggest that these systems, designed for a less volatile climate, will need to be updated and strengthened to keep up with the ever-increasing volumes of water.

Accordingly, the government announced plans in November 2023 to invest US$1 billion (HK$8 billion) to further enhance drainage capacity and update the city's already advanced typhoon warning system. Despite its scale, the stormwater infrastructure is designed for a 1-in-200-year storm, while the September 2023 typhoon reached a 1-in-500-year severity.[436]

Hong Kong's achievements and ongoing resilience investments for coastal typhoons and flooding demonstrate that large infrastructure projects in dense cities can be completed quickly and successfully. However, the rising challenges of climate change dictate that they must also be designed flexibly, continuously updated, and complemented by an array of decentralized solutions that can expand as needed to keep pace with increasingly intense coastal hazards.

ASIA PACIFIC

Oasis Terraces in Punggol, Singapore

HUFTON + CROW

Oasis Terraces—which combines a polyclinic with a community plaza, communal gardens, play spaces, gyms, retail, dining, and more—includes an elevated ground floor and basement retention tank to help protect the structure and surroundings from flooding.

Singapore, a prosperous and densely populated tropical, low-lying island state, faces extreme risk from sea level rise, storm surge, and heavy rains. Thirty percent of its land area is less than 16 feet (5 m) above current sea levels, which themselves may rise up to three feet (1 m) by 2100. Singapore can experience high water levels of up to 13 feet (4 m) if high tide, high average sea levels, and high storm surges coincide. Accordingly, the Singapore government has committed to spend US$75 billion (S$100 billion) over the next 100 years to protect the country's coastlines from rising seas.[437]

Oasis Terraces is richly planted with terrace greenery maintained by neighborhood residents. The plants help to absorb stormwater and cool the building from Singapore's rising heat.

Much of that funding will go to shoring up sea walls and stone embankments, which already cover 70 to 80 percent of the country's coastline (the rest is natural shoreline, such as mangroves and beaches).[438] Singapore's national water agency, the Public Utilities Board, has been conducting island-wide studies on the adequacy of existing coastal flood protection infrastructure, including nature-based, gray, and hybrid infrastructure.[439]

The agency has already begun working to expand and restore protective mangrove and coral habitat and soften sea walls by using more sloped systems that can better serve as marine habitat. The agency has also raised the elevation requirement for reclaimed land from 13 to 16 feet (4 to 5 m) above sea level and has begun using polder systems for reclaimed land (as has been used in the Netherlands for centuries). A Coastal and Flood Protection Fund has been established to pay for these projects, with an initial outlay of US$3.7 billion (S$5 billion).[440]

The Public Utilities Board has also collaborated with the National University of Singapore to create a coastal resilience research center, the Coastal Protection and Flood Resilience Institute, to develop innovative resilience strategies, enhance coastal science knowledge, and train students in coastal protection.[441]

Government agencies are also adapting important sites for intensifying climate risks. For example, Singapore's Punggol neighborhood is home to a neighborhood center and polyclinic known as Oasis Terraces. Designed by London-based Serie Architects for the Singapore Housing and Development Board, the building was designed to serve as the mixed-use social heart of the neighborhood.

A third of the building hosts health care facilities, while the rest is dedicated to a community plaza, communal gardens, play spaces, gyms, retail, dining, and learning spaces. A sloped pedestrian walkway lined with plantings leads from a nearby waterway and multiuse trail at the site's edge, up to the community gardens on the roof.

The project's goal of creating connections is enhanced by the sloping terrace gardens, which are maintained by residents as a community garden. Serie's project website notes, "Our design is about the successive framing of community space with garden elements. The plaza at the heart of the scheme is framed by a series of garden terraces sloping towards the waterway."

The waterway in question is the Punggol Waterway, Singapore's longest human-engineered water course, also constructed by the Housing and Development Board. The new river enhances the ecological and recreational features of the Punggol neighborhood and links two other larger river and reservoir water bodies, Sungei Serangoon and Sungei Punggol, as part of the country's larger water management strategy.[442] The entire area is near the edge of the island and requires protection from both inland and coastal flooding.

Serie Architects took several steps to reduce flood risk. The building is set back from the waterway, with open green space, trees, and pathways that can be flooded more safely, and the ground floor was elevated above base flood levels.

Christopher Lee, principal with Serie, notes that "there is a detention tank at the basement, to collect the surface run-off from the first story, terraces, and roof, and to contain the runoff and discharge it slowly back to the waterway. This slows down the run-off into the surrounding area and reduces the risks of flooding" to the rest of the neighborhood. "The run-off that is collected in the detention tank is also filtered and cleaned from debris before it is being discharged into the waterway."

Lush plantings cover nearly the entire exterior, and community gardens are on the roof. Both double as rain gardens and vegetated bioswales, which also help capture stormwater on site. Beyond the flood resilience components, the project includes water features such as jumping jets, water wheels, and rhythmic water geysers as community recreational amenities.

These design features earned Oasis Terraces a certification from Public Utility Board's Active, Beautiful, Clean Waters program, which recognizes projects that successfully integrate water features into development as community recreational resources.[443] They also demonstrate the Housing and Development Board's commitment to providing sustainable, resilient neighborhoods in concert with Singapore's larger coastal protection strategy.

Manhattan at sunrise.

SHUTTERSTOCK

CONCLUSION

Climate risk management and adaptation strategies provide an opportunity to create a better future. They can be used to help communities become more equitable, livable, and ecologically regenerative, ultimately enhancing social cohesion, economic opportunity, and environmental performance.

For these benefits to be realized, however, timely, ambitious, coordinated, and enduring action is needed. Delayed action escalates both risks and costs.[444] Managing the transition to the new coasts of tomorrow wisely can save lives, reduce costs, support ecosystems and local economies, and manage major infrastructure and property investments.

These investments integrating coastal resilience strategies into land use and real estate practices and policies will allow coastal areas not just to avert and recover from crises, but also to thrive.

ACKNOWLEDGMENTS

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