American Planning Association
Creating Great Communities for All

PAS REPORT 596

PLANNING FOR INFRASTRUCTURE RESILIENCE

Joseph DeAngelis, AICP, Haley Briel, and Michael Lauer, AICP

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Michael Lauer, AICP, principal of Michael Lauer Planning, LLC, has served local governments from coast to coast over the last 36 years. He has developed and helped implement award-winning growth management programs for urban and rural jurisdictions. In addition to developing comprehensive and strategic plans, he has developed plan implementation programs addressing redevelopment, concurrency management, and development/design regulations. In recent years, he has focused on a mix of land-use, growth management, and mobility projects, including projects in Florida, Mississippi, North Carolina, Georgia, and Louisiana.

ON THE COVER

Flood-resilient features of the Chicago Riverwalk's "Jetty" section include floodproof hardscape and floating gardens (©2017 Christian Phillips Photography; christianphillipsphoto.com)

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PREFACE

Tomorrow isn't what it used to be.

Increasingly, coastal conditions include all the risks of the past, but risks that are amplified by a changing climate, rising seas, and more rapidly fluctuating Great Lakes. The same is true away from our coasts; flooding from swelling rivers, streams, and lake basins in the country's interior is also a concern. With finite resources and escalating risks, communities need to make smart investments to ensure that they can withstand the seas and storms of tomorrow. We can't afford not to.

A capital improvement process provides a good opportunity to chart a new course. Including planners at the table with public works staff, engineers, and elected officials will help communities move in the right direction. The guidance in this report gives planners the tools they need to broker that important discussion, inform decisions with the best available science, and consider future conditions when allocating present and future resources.

NOAA's Office for Coastal Management is proud to partner in this effort, and others like it, to provide communities with tools to approach climate and other natural hazards with the best and most sensible solutions. The goal is to help communities create a future that keeps people and the places they love safer and stronger.

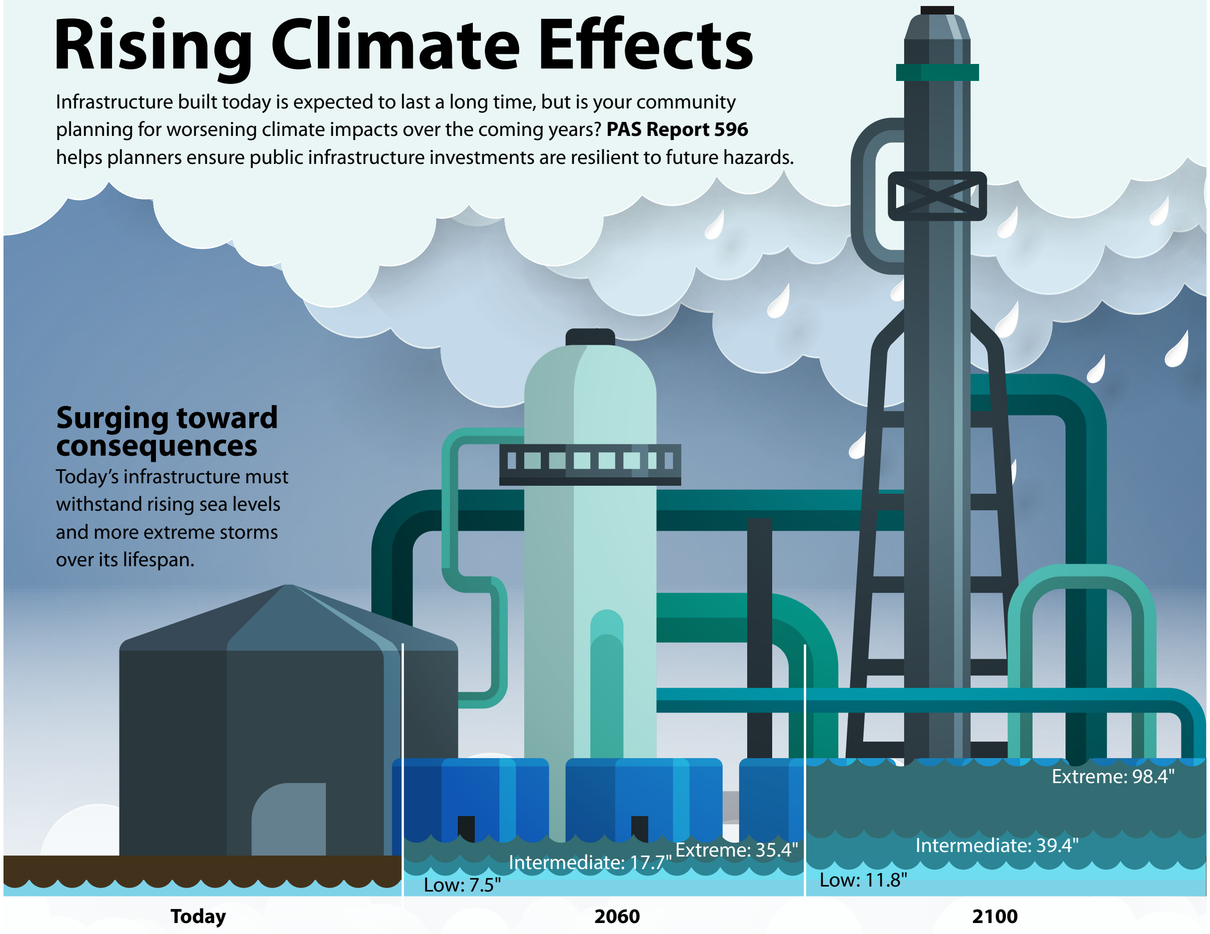
Jeffrey L. Payne, PHD
Director, Office for Coastal Management
National Oceanic and Atmospheric Administration

Rising Climate Effects

Infrastructure built today is expected to last a long time, but is your community planning for worsening climate impacts over the coming years? **PAS Report 596** helps planners ensure public infrastructure investments are resilient to future hazards.

Surging toward consequences

Today's infrastructure must withstand rising sea levels and more extreme storms over its lifespan.



Not built to last

Without accounting for climate impacts, infrastructure built today adds up to a risky investment for local governments.

Prepare for the future

Add climate and flood resilience policies to comprehensive plan.

+

Use comprehensive plan to inform capital improvement plan priorities.

=

Public investments yield more resilient infrastructure.

EXECUTIVE SUMMARY

The impacts of climate change are no longer a distant threat. They are here. As the unprecedented becomes the precedent, communities will see more frequent and intense flooding—and their infrastructure facilities and systems, often expected to last for decades or more, will be at higher risk.

The coastal highway and bridge connecting a town to its hospital will be threatened by record high tides. The stormwater network on a county's drawing board will be inundated by record rainfall events—year after year. The wastewater treatment plant being completed next month will endure successive years of storm surge in a city historically unaccustomed to hurricanes.

To ensure that today's infrastructure will stand the test of time, communities must plan for infrastructure that is resilient to the flooding of tomorrow. PAS Report 596, *Planning for Infrastructure Resilience*, defines the threat posed by more frequent and severe flooding to public infrastructure and outlines the role of planners and plans in ensuring that infrastructure is prepared for an unpredictable future.

While infrastructure is not immune to other climate-exacerbated hazards such as drought or wildfire, this PAS Report focuses primarily on how climate change will intensify flood risks from hazards such as sea level rise, coastal storms, and extreme precipitation. It provides guidance to help planners and their communities consider future flood impacts to public municipal infrastructure: the infrastructure financed, constructed, and maintained by local governments and special districts. The information provided in this report is intended for planners across the United States, regardless of their proximity to the coasts; rivers, streams, lakes, and urban stormwater systems will all be affected by future changes.

CHANGES ARE COMING

While the need to ensure infrastructure is resilient to future climate conditions is increasingly accepted across many overlapping areas of practice, active measures to realize this on the ground are comparatively rare. Cities across the United States are taking major steps toward considering and integrating climate change and its impacts into infrastructure planning processes, but these efforts often rely upon strong political will, dedicated streams of funding, and staff capacity. Mainstreaming the use of climate information, data, and tools into planning, capital improvement processes, and infrastructure standards and guidelines is not yet common practice. Yet mainstreaming is precisely what is necessary to ensure that future climate conditions are major elements of the local community and infrastructure planning process.

Infrastructure is expensive, and it is often intended to last for a long time. Current practice for considering flood hazards in infrastructure planning and decision making is often limited to static snapshots based on historical precedent. The regulatory datasets used to establish floods of record are all based on historical models, which assume a future that is much like the present.

Climate change, however, introduces substantial uncertainties into broadly accepted and widely used but historically based flood, precipitation, natural hazard, meteorological, and climatological data. Use of historical models, while far better than not considering flood hazards at all, discounts the significant negative impacts of future changes in climate—especially the severity and frequency of flooding— on local infrastructure.

To ensure that capital investments in infrastructure expected to last decades are not at risk, local practitioners—including planners, floodplain managers, public works and engineering staff, and others—must be prepared to factor these anticipated future changes into the many processes that touch upon the planning, siting, design, and finance of these facilities and systems.

FUTURE FLOODING AND INFRASTRUCTURE IMPACTS

In the context of climate change, a series of interrelated flood hazards stand out. They are sea level rise, coastal storms and storm surge, tidal flooding and inundation, and extreme precipitation. It is critical that planners understand what these hazards entail and the potential impacts they may have on their communities. These hazards are explored in depth in Chapter 1 of the report.

Sea level rise is a gradual long-term threat to coastal communities as well as a key factor in intensifying acute coastal storm impacts through more destructive storm surge events. The current likeliest projections for 2100 point to a range of one to four feet of sea level rise on average across the globe. While this may not sound especially impactful, four additional feet of water will pose a serious existential threat to coastal communities across the United States. And not only might certain geographical contexts create local sea level rise that far exceeds these global averages, but more extreme average sea level rise scenarios of up to eight feet are entirely possible in the event of both unchecked greenhouse gas emissions and further destabilization of the Antarctic ice sheet.

While current climate models do not anticipate significant changes in the overall number of named coastal storms, these models do predict an increase in the severity of these events. Fostered by warmer oceans, severe coastal storms are likely to bring more destructive impacts not only to communities already grappling with recurrent coastal flooding, but also to communities historically unaccustomed to tropical storms and hurricanes. Flooding in the form of extreme and unprecedented rainfall (most recently exhibited by Hurricane Harvey) and highly destructive storm surge are a major consequence of coastal storms. Compounded further by rising sea levels, flooding during coastal storm events is expected to worsen considerably over the coming decades.

Heavy precipitation is a significant consequence of climate change that will impact communities across the United States, regardless of location. Some regions will see increases in average annual precipitation, while others will see less rain on average, but more heavier rainfall events. Extreme precipitation events are likely to increase in frequency, leading to severe riverine and inland flooding as well as recurring nuisance flooding.

Local public infrastructure assets and systems will bear the brunt of these coming changes. Increasingly severe and frequent rainfall may exceed the capacity of existing stormwater systems. Coastal and riverine flooding may overtop bridges, roads, and public transit infrastructure. Fire and police stations, schools, and public parks and recreational facilities in areas vulnerable to sea level rise, coastal storm surge, and tidal flooding may face interrupted operations and the possible need for relocation.

Direct flood impacts to local infrastructure will in turn cause a variety of unpredictable secondary impacts to people and the built and natural environments. Impacts as diverse as flooded roads or damaged ports could have significant negative affects on local economies. Disrupted transportation networks may impede the mobility of emergency services. Recurrent flooding of schools or public parks may seriously impact educational outcomes and quality of life. Combined sewer overflow events may precipitate public health crises.

Communities rely on infrastructure in myriad ways. When that infrastructure is damaged, impaired, or in dire need of replacement due to recurrent flooding, the potential impacts to the community can be vast and unpredictable.

The age of infrastructure and the costs of its replacement are already significant issues across the United States, independent of increasingly severe flood events. Sea walls, levies, natural infrastructure, stormwater and wastewater networks, and deteriorating drinking water facilities will require hundreds of billions of dollars in replacement, adaptation, and maintenance costs to ensure continuity of operations and resilience in the face of climate change.

Planners stand at the intersection of long-term climate resilience and infrastructure implementation. They can ensure that the plans and policies that inform public investments as directed by capital improvement planning and budgeting processes take climate risks into consideration. From finding and using data and tools, to assessing vulnerability, to linking comprehensive planning with on-the-ground actions, planners should play a critical role in advancing infrastructure resilience.

GATHERING DATA, ASSESSING VULNERABILITY, AND PLANNING FOR THE FUTURE

Chapters 2 and 3 of this report discuss two of the most critical challenges in ensuring infrastructure is resilient to future flooding: (1) understanding data and decision support tools, and (2) applying them to assessing the vulnerability of infrastructure to climate change. Only with this foundation in place can planners then begin the work of integrating long-term infrastructure goals, objectives, and actions into capital improvements planning.

Understanding the available data, information, and decision-support tools for future flooding is crucial to ensuring that local infrastructure can withstand climate change. Climate models, while always evolving, largely agree on the bigpicture impacts of climate change as they relate to flooding. It is vital for planners to understand the basics of climate science to make informed decisions on the use of data, tools, and resources as they work to plan for resilient infrastructure.

There are many interactive decision-support tools and resources available that can greatly benefit the work of planners, as discussed in Chapter 2 of this report. Resilience clearinghouses such as the National Oceanic and Atmospheric Agency's (NOAA) Climate Resilience Toolkit, and specific geospatial and visualization tools such as NOAA's Sea Level Rise Viewer or Great Lakes Lake Level Viewer, should form the foundation for planners seeking to apply climate data to infrastructure planning. These and other tools allow users to directly download geospatial data for use in GIS software, which can be critical to establishing the vulnerability of communities and infrastructure assets.

Once a community has gathered its data, the process of determining the vulnerability of infrastructure systems and assets is the next essential step to effectively plan for the future. A bridge or power station expected to function to the end of the century but designed based on flood or storm surge risk from the year 2000 will not be ready for coming impacts requiring costly maintenance or early replacement. Planners must evaluate the vulnerability of existing assets and assess future threats to upcoming projects to maximize community resilience.

The vulnerability assessment process requires assessing a planned or existing project or asset's exposure, sensitivity to flooding, and the degree to which it can accommodate more severe flood impacts. Spatial analysis combined with an understanding of asset lifespan and condition forms an effective base upon which infrastructure planning can be built. When combined with a thorough analysis of social vulnerability to more frequent and severe flooding events, the picture becomes complete and planners can take the first steps to more effective planning for an uncertain future. Chapter 3 of this report walks planners through the steps of conducting these analyses.

THE ROLE OF PLANS AND PLANNERS IN INFRASTRUCTURE RESILIENCE

Developing and overseeing the implementation of plans is the backbone of a planner's work. All too often, however, plans and infrastructure implementation processes operate independently at the local level. The prospect of more severe and frequent flooding is an opportunity to integrate and align these functions to ensure that the infrastructure planned and built today is equipped for future social and environmental conditions.

Planning for flood resilient infrastructure will require communities to use of all of their planning tools. Comprehensive planning should be at the core for local action on infrastructure resilience. As the most complete picture of where a community is today and where it wants to be at some point in the future, local comprehensive planning must play a major role in infrastructure planning processes. And to maximize future resilience outcomes, the full array of local plans and planning functions—including community visioning and public outreach, hazard mitigation planning, climate adaptation planning, open space planning, and many others—must be aligned, with goals and objectives clearly linked to actions and outcomes. Detailed guidance on the role of planners in advancing infrastructure resilience through plans can be found in Chapter 4.

As the primary link between long-term planning and the implementation of infrastructure, the capital improvements planning (CIP) process stands out as playing a key role in community resilience. CIPs document the process of providing and maintaining the infrastructure to support a community's quality of life. They assess infrastructure needs within a jurisdiction over a defined time frame, weigh these needs against overall goals and objectives, and then evaluate and prioritize specific infrastructure projects for future funding. Given the role of the CIP in determining near- and long-term infrastructure needs, resilience to future flooding must be deeply embedded within this process. Chapter 5 of this report describes the importance of planners' involvement.

Practical consideration for infrastructure resilience should center on the long-term value of investments. If the community has identified certain areas as especially susceptible to sea level rise or recurrent flooding within 25 years, does new stormwater infrastructure in those areas have long-term value? These are the types of questions that must be answered in the CIP process. Planners should play a major role in facilitating these conversations and ensuring that investment outcomes link strongly with established community goals.

IMPLEMENTING RESILIENT INFRASTRUCTURE

Currently, no formal nationwide standards for resilient infrastructure have been widely accepted by engineering and public works professionals. While there has been some recent movement toward formalizing standards, and several larger cities have begun establishing basic guidelines to increase the resilience of infrastructure assets to future flood impacts, communities are still largely on their own when seeking to integrate flood resilience into the siting, design, and construction of infrastructure. By drawing from established vulnerability assessments, community-wide goals and objectives, and the resilience considerations integrated into the CIP, planners can help to oversee local processes for the development of local standards, regulations, and guidelines.

Generally, local guidelines should be based on selecting flood scenarios within the defined lifespan of a project, constructing to the most probable scenario, and building redundancies into a project to allow for further adaptation based on observed impacts and changes. In practice, this can be challenging and heavily constrained by funding availability. Planners, while not driving the adoption of technical engineering standards, can help inform their development and ensure strong links to vulnerability assessments and long-term plans. More on this topic can be found in Chapter 6.

Finding the money necessary to finance expensive infrastructure projects has always been a challenge. The prospect of higher costs given the impacts of more frequent and severe flooding complicate this picture even further. While providing services and maintaining existing infrastructure are likely to be high priorities for many municipalities, longer-term adaptation of already expensive infrastructure, especially given the uncertainty of the scale of flood impacts, may not be a prime driver for local decision making. For these reasons, planners should have a clear understanding of local finance and the avenues that exist for financing resilient infrastructure.

Beyond the established mechanisms for financing local infrastructure, planners can bring to their communities awareness of emerging financial tools such as catastrophe bonds, environmental impact bonds, and resilience bonds that are specially tailored for flood hazard and climate resilience. Further, planners can leverage their knowledge of federal programs to identify funding opportunities through the Federal Emergency Management Agency's various pre- and post-disaster mitigation grant programs, post-disaster appropriations through the Community Development Block Grant program, and grant opportunities from federal agencies such as NOAA and the U.S. Environmental Protection Agency. Along with summarizing local government funding sources, Chapter 7 outlines these emerging opportunities and identifies how planners can responsibly advise financial decision making to advance infrastructure resilience.

CONCLUSION

There is no simple resolution to the difficult problem of ensuring that the infrastructure of today can meet the flooding challenges of tomorrow. It requires strong commitment to developing plans that consider future climate conditions, local willingness to actively use these plans as roadmaps for the future, and acceptance of the need to iterate, revise, and continue to improve the processes through which local infrastructure plans become on-the-ground realities.

Planners, capable of balancing the needs of today with the aspirations and challenges of the future, are uniquely suited to harnessing the many local planning tools necessary to advance resilience in the face of future flood conditions. PAS Report 596 is an affirmation of the planner's critical role in this process and a call to confront and overcome the complex challenges that more frequent and severe flooding pose to infrastructure and the long-term health and vitality of communities across the United States.

CHAPTER 1

WHY PLAN FOR INFRASTRUCTURE RESILIENCE?

Over the coming decades, the risk of flooding and cascading impacts to communities across the United States is expected to worsen because of climate change. With each passing year, these future risks become clearer, largely due to a seemingly never-ending parade of present-day coastal storms and record flood events.

However, while the age of the billion-dollar storm, typified by Hurricanes Katrina, Sandy, Harvey, and Maria, is emerging as a new normal (Figure 1.1), flood hazards and the risk they pose to communities are far more complex than a succession of once- or twice-a-year coastal events. Sea level rise is likely to have an amplifying effect on not only the impacts of named coastal storms, but also on the mundane but increasingly common threat of "sunny day" tidal flooding to coastal communities. Coastal communities confronting these threats both large and small must also grapple with the longer-term existential dangers of water that continues to rise year after year.

Inland communities face similarly uncertain futures, given the threats posed by extreme precipitation in the form of catastrophic riverine flooding, disruptive stormwater flooding, and even the smaller-scale nuisance flooding that can close streets and fill basements.

As communities become more aware of worsening flood hazards, they must also begin to consider how those flood hazards may impact long-lived and expensive infrastructure.

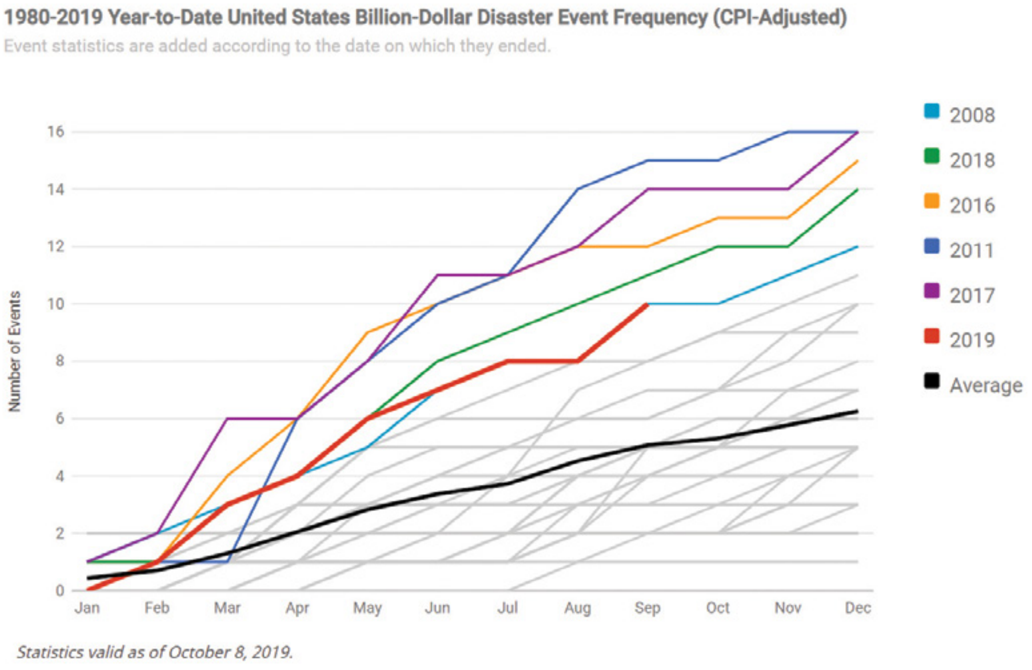


Figure 1.1. The frequency of billion-dollar disasters (adjusted for inflation) in recent years has far exceeded the historic average (NOAA NCEI 2019)

TABLE 1.1. LIKELIEST SCENARIOS FOR SEA LEVEL RISE TO 2100

Year	Very Likely Sea Level Rise Scenario
2030	0.3 – 0.6 feet
2050	0.5 – 1.2 feet
2100	1 – 4 feet

Source: USGCRP 2018

Given the state of public infrastructure in the United States—most recently graded D+ by the American Society of Civil Engineers (ASCE 2017)—the impacts of extreme weather could be catastrophic on already aging and deteriorating railways, bridges, wastewater treatment plants, stormwater sewers, and public buildings.

New infrastructure will also be at risk if not planned, designed, and constructed to account for climate-related stresses well into the future. Public infrastructure and capital assets are expected to last for decades, often well in excess of their intended design life. New infrastructure that does not account for worsening future flood-related hazards runs the risk of not only squandering significant amounts of public money, but also putting current and future generations of citizens at risk of climate change-related impacts.

Infrastructure that accounts for or has the capacity to adapt to long-term changes in climate and the resulting impacts can help to reduce future risk to communities. Yet incorporating future climate risk into the planning, siting, design, and construction of public infrastructure can be a complex undertaking.

Climate change introduces substantial uncertainties into broadly accepted and widely used but historically based flood, precipitation, natural hazard, meteorological, and climatological data. Federal Emergency Management Agency (FEMA) data sets that establish floods of record, likely rainfall, or potential storm surge are all based on historical models that assume a relatively stable and unchanging climate. If a community relies solely upon these historical data sets when planning and designing an infrastructure system or public building, then future changes in the climate could have substantial unanticipated negative impacts upon the project and the community well into the future. Local practitioners, long used to planning, designing, and developing infrastructure projects based on well-established historical models, may find the prospect of accounting for changing rates of precipitation or sea level rise daunting and confusing.

Understanding the available data and information on climate change impacts as they relate to flooding—and integrating them into local plans and processes—is critical to ensuring that local infrastructure can absorb future shocks and stresses. Planners are uniquely suited to account for and incorporate these future uncertainties. Throughout the visioning, planning, and implementation processes, planners can ensure that infrastructure—and communities as a whole—are both resilient and adaptable to future flood hazards and long-term risk.

FLOOD HAZARDS AND CLIMATE CHANGE

Climate change is likely to worsen existing flood hazards and increase flood risk to people and their communities. Sea level rise is a gradual long-term threat to coastal communities as well as a key factor in intensifying acute coastal storm impacts through more destructive storm surge events. More severe coastal storms may threaten communities in parts of the country unaccustomed to dealing with major tropical events. Increased rainfall in the form of both heavy precipitation and prolonged wetter periods may endanger coastal and inland communities alike through riverine flooding, flash flooding, and nuisance flooding. Shifting patterns of precipitation and the long-term unpredictability of extreme rainstorms can make these hazards particularly difficult to plan for.

The following section is an introduction to how a changing climate is likely to increase flood risk to communities.

Climate Change, Sea Level Rise, and Coastal Flooding

Sea level rise is due to the warming of oceans (which expand as they heat up) and the melting of land-based ice, both direct results of a warming climate.

Since 1900, sea levels have risen globally by about seven to eight inches, and the rate of sea level rise has accelerated over the last 25 years due to increasing greenhouse gas emissions and corresponding temperature increases (USGCRP 2018). The likeliest scenarios point to an additional one to four feet in sea level rise by the year 2100 (Table 1.1). More extreme scenarios in excess of eight feet by 2100 are being studied by climate scientists, largely due to concerns over the stability of the Antarctic ice sheet (Figure 1.2, p. 13) (USGCRP 2018).

It is important to note that these are global averages, and there are wide variations in relative sea level rise depending on location, ocean circulation, and the sinking of land. The Northeast and the western Gulf coastline are likely to see sea level rise above the average in existing lower sea level rise scenarios, while nearly all of the U.S. coastline (except for Alaska) is likely to exceed the average under higher sea level rise scenarios.

Tidal Flooding

Sea level rise amplifies the impacts of high tides and leads to more coastal flooding and erosion. Over the last half-century alone, with just one to three inches of average sea level rise, daily high-tide flooding has become up to 10 times more frequent in coastal communities throughout the United States. Sea level rise in excess of one foot, well within the likeliest scenarios for the end of the century, would mean widespread and destructive high-tide flooding for communities on the East Coast (USGCRP 2018).

Additionally, increasingly destructive tidal flooding is likely to accelerate the rate of coastal erosion and ultimately compound the effects of daily floods and coastal events on communities and infrastructure.

Coastal Storms and Storm Surge

Greenhouse gas emissions and the resultant warming of the atmosphere and oceans leads to stronger hurricanes and tropical storms. While the total number of tropical storms is unlikely to change, the number of the most intense tropical storms is likely to increase.

Hurricanes and other tropical storms of increasing intensity and frequency will lead to a wide variety of direct flooding impacts, including storm surge, major freshwater flooding due to precipitation, and a host of secondary impacts including landslides and tornadoes (USGCRP 2018). Warmer oceans that help to fuel storm intensity are also likely to bring the direct impacts of major hurricane and tropical events to coastal communities less prepared for dealing with them.

Storm surge tends to be the most destructive element of coastal storms on people and their communities. Storm surge is the height of the sea during a coastal storm that is above the expected level for a location and time of day (USGCRP 2018). It is primarily a product of water pushed toward the shore by storm winds. The severity of surge impact on a particular location depends on a storm's direction, speed, intensity, pressure, and the geography of the impacted area.

Sea level rise amplifies the depth, breadth, and destructive potential of storm surge. Even the more conservative sea level rise projections to 2100 point to more impactful and destructive storm surge events.

Precipitation and Climate Change

Annual precipitation since 1901 has increased across the United States by an average of four percent. Average annual

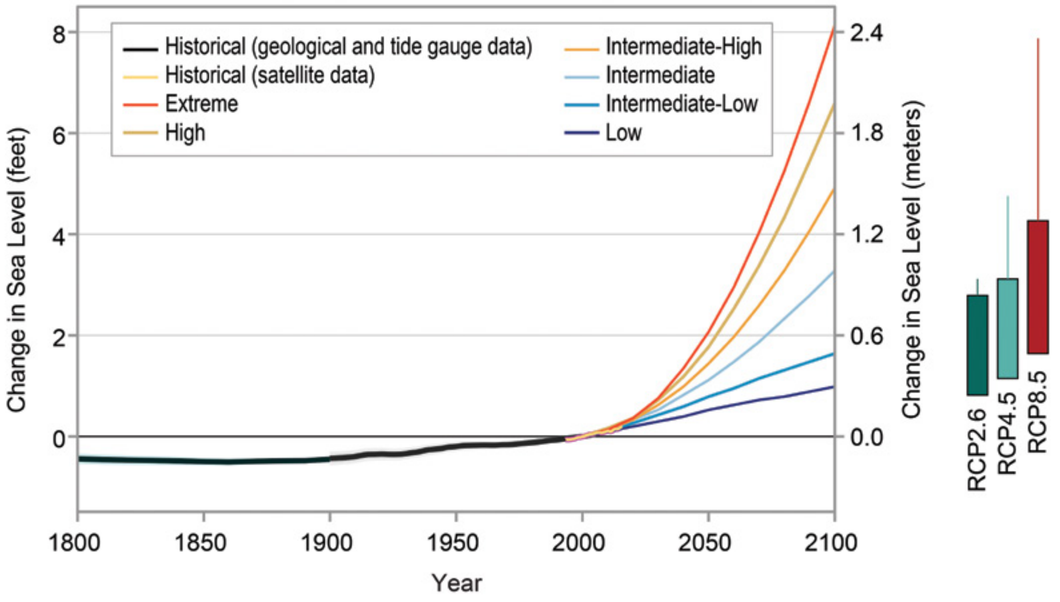


Figure 1.2. Sea level rise scenarios through 2100: RCP2.6 represents the lower bound of sea level rise pathways based on lower emissions as established by the International Panel on Climate Change, while RCP8.5 represents more extreme sea level rise scenarios under higher emissions (USGCRP 2018)

CASCADING HAZARDS

This report primarily addresses the risks that existing and future flood hazards may pose to local infrastructure. An increase in flooding, however, is just one of many potential climate change threats. The frequency and severity of drought, extreme heat, wildfire, and other related natural hazards are also expected to increase over the coming decades. Much like the wide variety of flooding-related challenges, the long-term impacts of these hazards can also take a substantial toll on public infrastructure.

Additionally, hazards such as drought and flood can be deeply interrelated. The feast-and-famine cycle of prolonged drought followed by extreme rainfall can lead to a cascade of localized hazards such as flash flood, landslides, failing or overflowing water and sewer lines, and water supply contamination. These events can have a pronounced impact upon local infrastructure, public health, and community well-being.

While this report primarily addresses flooding and other water-related challenges as direct impacts to local infrastructure, the principles described throughout are broadly transferrable to other natural hazard and long-term climate risks.

precipitation in the Northeast, Midwest, and Great Plains has exceeded the national average over this period of time, while annual averages have declined in the Southwest. Heavy precipitation events, which are defined as "episodes of abnormally high rain or snow" in the 2018 National Climate Assessment, have outpaced annual average increases (USGCRP 2018). Even in areas experiencing drier years on average, heavier and more destructive rainstorms are still occurring more frequently. These trends are expected to continue and strengthen (Figure 1.3).

More frequent heavy precipitation events are a leading indicator of climate change, along with changes in temperature, sea level rise, drought, and wildfire. Heavy precipitation events are projected to continue to increase as global temperatures warm (USGCRP 2018).

Increases in both average precipitation and the frequency and intensity of heavy precipitation events may lead

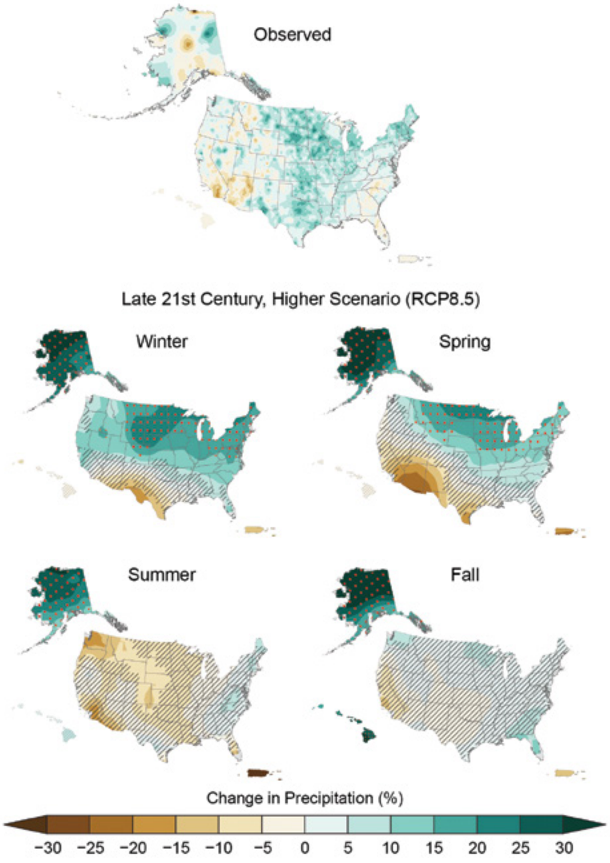


Figure 1.3. Climate change projections point to greater levels of precipitation across the United States (USGCRP 2018)

to increasing extreme flood events (such as riverine flooding), though local variables such as land use have made clear trends difficult to assess (USGCRP 2018). Given projected increases in heavy precipitation events, localized flooding, stormwater flooding, and nuisance flooding are likely to increase in frequency and intensity, especially in communities where these events are already common.

Closed-basin lake regions, in which water drains in but does not flow out, are also being slowly inundated by rising water levels from increased precipitation caused by climate change. One such area, the Devils Lake basin in northeastern North Dakota, has lost 600 square miles of dry land since the early 1990s (Wirtz 2012).

Compound Extreme Events

Compound extreme events are the "combination of two or more hazard events or climate variables over space and/or time that lead to an extreme impact [and] have a multiplying effect on the risk to society, the environment, and built infrastructure" (USGCRP 2018). These events can be common during hurricanes and tropical storms.

Hurricanes Isaac (2012) and Matthew (2016) coupled storm surge with extreme precipitation that brought extreme riverine flooding to inland communities and significant storm surge impacts to communities along the coast. When storm surge is combined with extreme precipitation and high tides, as in the case of Hurricane Sandy (2012), flooding impacts are multiplied even further (USGCRP 2018).

FUTURE FLOOD RISKS AND PUBLIC INFRASTRUCTURE VULNERABILITY

Uncertainty surrounding the severity of climate changes, the age and complexity of local infrastructure systems, and how each may influence the other makes assessing the scale of future flood risk particularly difficult.

Increasing levels of precipitation, sea level rise, and more frequent and powerful coastal storms will result in discrete impacts to local infrastructure. While infrastructure sectors such as coastal protection and stormwater/wastewater management are expected to experience direct impacts, sectors such as health and emergency management services, transportation, public facilities, energy, and community open space and recreation facilities are also expected to suffer.

Table 1.2 lists the infrastructure sectors and types that are considered in this report. The age, condition, location, and role the infrastructure plays locally are crucial factors in determining just how these sectors will be impacted by more intense and frequent flood events.

As noted above, in 2017, the American Society of Civil Engineers (ASCE) gave a cumulative D+ grade to infrastructure across the United States (ASCE 2017). The individual categories of energy, hazardous waste, wastewater, schools, and public parks were given a D+ grade, while aviation, dams, drinking water, inland waterways, levees, and roads were given a grade of D. Transit was the lone category assessed at D-.

The ASCE defines D-graded infrastructure as "mostly below standard, with many elements approaching the end of their service life" and "large portion[s] of the system exhibit[ing] significant deterioration" (ASCE 2017). These grades are based on a wide variety of factors, including infrastructure capacity, condition, future needs, and resilience to long-term hazard impacts such as climate change.

Aging and deteriorating coastal protection and water infrastructure are especially notable concerns, with estimates in the trillions of dollars for reconstruction and maintenance costs of wastewater, sewer, aqueduct, dam, and levee systems across the United States. Hundreds of billions of dollars are likely needed to address aging and deteriorating drinking water, stormwater, and combined sewer systems (USGCRP 2018).

TABLE 1.2. INFRASTRUCTURE SECTORS AND TYPES

Infrastructure Sector	Infrastructure Type
Water, wastewater, and stormwater	Water and wastewater treatment plants, distribution systems, drainage, retention
Transportation	Roads, bridges, public transit, airports, ports
Public facilities	Community centers, schools
Energy	Electric grid of municipal utility
Parks and open space	Public parks, bike paths
Health and emergency management services	Fire and police stations, emergency operations centers
Coastal protection	Groins, jetties, seawalls, dams

Rising sea levels and increasingly frequent and powerful coastal storms are major threats to existing energy and transportation infrastructure at the local, regional, and national scales. Disruptions to road and transit networks could have implications for local economies, emergency services, and quality of life. Given our reliance on coastal shipping, airports, and energy resources, coastal flooding and extreme weather impacts to ports and energy facilities may have repercussions for the national economy.

Extreme precipitation and associated flooding are also likely to impact municipal infrastructure throughout the United States. Direct flood impacts will likely include frequent flooding that exceeds the capacity of stormwater systems and local drainage networks; overtopping and erosion of roads, bridges, and other transportation infrastructure due to higher river levels and faster streamflows; and more combined sewer overflow events that can contaminate drinking water and local ecosystems (USGCRP 2018). Secondary impacts due to more frequent and extreme flooding can include disruptions to the mobility of local citizens and emergency services, the provision of public services and access to public buildings, and water quality and public health.

Compound events can cause large-scale systemic failures for complex systems such as energy, water, and transportation infrastructure. Infrastructure that is designed to account for natural hazards such as storm surge, extreme precipitation, or coastal storms tends to consider impacts in isolation, contributing to the possibility of cascading failure during compound events.

Direct investments by communities in adapting infrastructure have not kept pace with the scale of expected future climate challenges and impacts (USGCRP 2018). Generally, the costs of replacing, repairing, or adapting infrastructure must compete with other more imminent concerns. Providing services and maintaining existing infrastructure are likely to be high priorities for many municipalities, and longer-term adaptation of already expensive infrastructure, especially given the uncertainty of the scale of flood impacts, may be of secondary concern in a city's annual budget. Especially in marginalized or underresourced communities already struggling to provide services and maintain infrastructure, implementing climate adaptation through larger-scale infrastructure interventions may simply be out of reach. As climate impacts continue and worsen, these communities, many of which are already more susceptible to climate change and its impacts, will be further disadvantaged.

The existing processes through which infrastructure needs are identified and infrastructure is planned, designed, and constructed also have not kept pace with future climate and flood risks. When considering natural hazard impacts, infrastructure planning and design generally relies upon static historical data, usually from within the last century. As the climate continues to change, the standards by which infrastructure design and risk assessment are based will grow increasingly out of date. Given the long expected lifespan of infrastructure and capital projects, a piece of infrastructure expected to function to the year 2100, but designed based on storm surge risk from the year 2000, will likely be far more vulnerable to flooding (and require far more maintenance and perhaps early replacement) than one designed according to projected sea level rise.

Unfortunately, while integrating future flood risk projections into infrastructure planning and design processes is possible (and frequently done in communities with access to expertise and funding), there is no agreed-upon standardized method for considering these risks in existing design codes and guidelines (USGCRP 2018). This can threaten smaller, marginalized, or underresourced communities that do not have access to up-to-date climate expertise, the capacity to change or evaluate infrastructure design processes, or the funding to hire staff to do either.

OPPORTUNITIES FOR INFRASTRUCTURE RESILIENCE

There is a clear leadership role for planners to play in ensuring that communities and local infrastructure are resilient and adaptable to climate and flood impacts. This role includes:

- Assessing long-term infrastructure needs and understanding future risks to infrastructure assets;
- Ensuring the integration of long-term climate and flood risks and infrastructure considerations into local plans and policies;
- Advising and guiding the local capital improvements planning process and ensuring alignment with long-term resilience goals;
- Ensuring standards, guidelines, and regulations for both public and private infrastructure are aligned with plans and local codes; and
- Working with municipal leadership and local finance officials to identify sources of funding that can be used to realize resilient infrastructure and long-term community adaptation.

Communities across the United States are increasingly moving beyond awareness of climate adaptation needs and into the vital stages of vulnerability assessment and planning (Figure 1.4). However, on-the-ground implementation through local infrastructure adaptation and development has been limited, and there are few if any efforts underway focused on long-term monitoring of resilient infrastructure performance. Planners can help their communities continue to learn more about climate change impacts and assess the risks, plan for mitigation and adaptation, and implement and evaluate strategies and actions.

Figure 1.4. Planners can help their communities move beyond awareness of climate adaptation needs and into the vital stages of vulnerability assessment and planning (USGCRP 2018)

Infrastructure Risk and Vulnerability Assessments

While many localities may lack the capacity to gather or apply local data or undertake rigorous climate impact projections, there are many publicly available data sources and decision- support tools to help planners evaluate the susceptibility of infrastructure to future flood inundation and related climate change impacts.

Planners should take note that fine-scale, local climate models may not be necessary to improve flood resilience. Local knowledge informed by larger, regional, or national scale data can be successful in enhancing positive outcomes. Taking action based on existing hazards and climate data resources and specialized local knowledge should be central to the approach of planners without access to highly localized and downscaled data on future climate conditions.

Applying these data to a community-wide infrastructure vulnerability assessment process can help a community to:

- Identify long-term climate and flood risks;
- Evaluate how long-term climate and flood risks may impact existing infrastructure assets and planned infrastructure projects;
- Identify long-term infrastructure needs and adaptation measures based on potential impacts;
- Evaluate the potential for integrating resilient infrastructure needs into plans; and
- Evaluate the potential for improving local infrastructure processes to ensure long-term resilience.

Local Plan Integration

Integrating climate risks into local plans is vital to accurately capturing the future conditions to which existing infrastructure and any planned infrastructure projects will be subjected. Therefore, local plans that are broadly aligned on infrastructure and consider future flood risks can play a central coordinating role in subsequent stages of implementation.

Building the foundation for coordinated action through the plan-making process will include:

- Educating and informing a variety of stakeholders with vastly differing levels of understanding about climate change, its impacts, and solutions;
- Engaging in equitable and thorough visioning and public engagement;
- Coordinating local planning with existing or ongoing regional planning efforts, especially if those efforts address climate and infrastructure issues;
- Outlining the role of the local comprehensive plan in guiding infrastructure recommendations;
- Determining the points of intervention for integrating climate and future flood risks into the comprehensive planning process;
- Developing clear recommendations for resilient infrastructure implementation through the determination of actionable goals, objectives, and action items;
- Outlining the potential linkages between hazard mitigation, climate adaptation, and any other functional plans as they relate to infrastructure resilience;
- Ensuring the alignment of functional plans with long-term comprehensive planning efforts; and

KEY TERMINOLOGY

Here are some key terms planners should be familiar with when addressing resiliency issues.

Adaptive capacity is the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change (IPCC 2014). As it relates to infrastructure planning, adaptive capacity refers to the inherent ability of a piece of infrastructure or an infrastructure system to adapt to the impacts of climate change without needing larger-scale modifications. A bridge or structure that is designed to be easily elevated or requires no elevation to accommodate sea level rise can be said to have adaptive capacity (San Francisco 2015).

Climate change adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities (IPCC 2014). Climate adaptation therefore refers to the actual process of adapting to the impacts of climate change. A community that decides to plan for and design a stormwater system based on future precipitation projections is practicing climate adaptation.

Climate change mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC 2014). Mitigation of climate change therefore refers to actions that seek to reduce or store greenhouse gas emissions and to limit future warming. Investing in zero- or low-emission energy sources such as wind turbines is an example of climate change mitigation.

Hazard is any real or potential condition that can cause damage, loss, or harm to people, infrastructure, equipment, natural resources, or property (Thompson et al. 2016). Flood hazard refers to the combination of the overall likelihood of flooding and the intensity of the flood.

Risk is a measure of the probability and consequence of uncertain future events (Thompson et al. 2016). Flood risk refers to the combination of the flood hazard with other factors that contribute to a community's, asset's, or system's vulnerability to flooding.

Resilience is the ability to prepare and plan for, absorb, respond, recover from, and more successfully adapt to adverse events (NRC 2012a).

Vulnerability is the propensity or predisposition to be adversely affected (IPCC 2014). The concept of vulnerability as it relates to climate change has evolved to include larger societal issues such as inequality and poverty (Bharwani 2019). The vulnerability of an infrastructure system to future flooding can be measured by assessing the system's exposure, sensitivity, and adaptive capacity (San Francisco 2015).

- Determining how to bridge functional plans that address infrastructure and flood resilience with local infrastructure implementation processes.

Capital Improvement Plans and Planning

Making connections between regional, comprehensive, or functional plans and the local capital improvement plan (CIP) can help communities meet long-term resilience goals. Planners can ensure the local CIP is informed by existing plans and effectively integrates future climate and flood information into project prioritization and selection processes.

Specifically, planners can:

- Seek to expand the participation of staff, agencies, and departments in the CIP process when scoping, prioritizing, and recommending projects for funding;
- Work to integrate climate vulnerability assessments into the CIP process to better understand the potential long-term impacts of more frequent and severe flooding on proposed infrastructure projects and existing infrastructure assets;
- Identify clear linkages between the goals, objectives, and actions cited in local plans and the various stages of the CIP;
- Improve project prioritization and selection processes by assessing the long-term value of infrastructure in light of more frequent or severe flood impacts over a project's useful lifespan; and
- Clearly document climate and hazards information sources and the rationale for project prioritization, selection, and decision making to improve stakeholder, elected official, and local staff understanding of the overall CIP process and the methods by which future flood impacts were considered.

Standards, Guidelines, and Regulations for Infrastructure Resilience

Infrastructure siting and design standards and guidelines, in conjunction with a variety of zoning, land-use, and associated regulatory mechanisms, can improve the resilience of infrastructure to more frequent and severe flooding due to climate change.

Planners can:

- Help local staff to contextualize and overcome long-term climate uncertainty when developing local infrastructure siting and design standards;
- Ensure that findings, recommendations, goals, and objectives from local plans are consulted in project siting and design phases;
- Identify potential changes to zoning and subdivision codes to ensure the resilience of privately developed or maintained infrastructure to more frequent and severe flooding;
- Help to develop a regulatory framework to reduce the need for stationary gray infrastructure in especially exposed parts of the community and bolster the ability of natural green infrastructure to compensate in lieu of gray infrastructure; and
- Outline the regulatory mechanisms to support community buyouts and retreat from highly vulnerable and exposed areas.

Resilient Infrastructure Finance

Infrastructure tends to be a significant and expensive investment on the part of municipalities. However, planners have not traditionally played a major role in the infrastructure finance process.

The potential impacts of more frequent and severe flooding due to climate change on local infrastructure, along with the extensive planning process preceding project selection and funding, offer opportunities for planners to become more involved in local infrastructure finance processes.

Working with local finance officials, planners can:

- Develop a stronger understanding of the infrastructure funding and finance process in order to inform goals, objectives, and recommendations related to infrastructure resilience and adaptation in local plans;
- Identify potential funding sources and inform requests for proposals on grant opportunities through existing federal and state hazard mitigation grant opportunities; and
- Develop a strong working knowledge of emerging resilient infrastructure finance tools such as resilience bonds, catastrophe bonds, and green bonds.

ABOUT THIS REPORT

This PAS Report is intended for an audience that includes planners and floodplain managers in coastal and inland communities across the United States. This report is primarily concerned with the intersection between local infrastructure and future flood risk and assumes only basic knowledge on the part of readers about flood hazards, climate data and information, and the infrastructure planning and development process.

In some communities, the planning, design, and maintenance of infrastructure, public facilities, and other public investments can occur in isolation from planning departments and planners. Similarly, climate adaptation, climate risk assessment, and hazard mitigation may also be isolated from the work of community planning. In contrast, other communities may have processes that seek to integrate long-term planning with infrastructure development and climate adaptation goals. This report is intended to support planners, floodplain managers, and other local practitioners across this wide spectrum with guidance suited to addressing the real challenges of planning for long-term resilience of infrastructure.

The first three chapters of this report following this introduction focus on preparation and planning: data and tools to interpret future flood risk due to climate change, the processes of infrastructure and community vulnerability assessment, and the integration of climate and flood risk with planning for infrastructure. The rest of the report focuses on resilient infrastructure implementation through the capital improvement planning process; standards, guidelines, and regulations; and public investment. The following roadmap details the contents of this report.

Chapter 2, Understanding Flood Risk With Data and Tools, introduces the types of flood hazards that impact communities, discusses how these flood hazards are likely to be impacted by climate change in the present and future, and provides an overview of the types of data and tools available to practitioners for understanding and assessing flood hazards.

Chapter 3, Assessing Infrastructure Vulnerability, defines what a vulnerability assessment is, explains how it can be useful in the context of both community-wide and infrastructure planning, and outlines how a local practitioner can conduct a vulnerability assessment in advance of or concurrent with local planning efforts. This chapter bridges the gap between the availability of flood-related climate data and tools and their use by local practitioners in planning for long-term infrastructure resilience.

Chapter 4, Planning Tools for Infrastructure Resilience, discusses the intersection between long-term climate resilience and infrastructure in the context of the local planning process. This chapter offers specific recommendations on how infrastructure resilience can be better integrated into comprehensive, area, and functional plans. This chapter also describes the various implementation processes that communities use to put plans into action, as a transition to the discussion of implementation strategies in the following chapters.

Chapter 5, Resilient Infrastructure and the Capital Improvements Plan, reviews the CIP process and outlines its relationship with local plans and planning. This chapter specifically addresses climate-related flood hazard risks and the role that climate-informed planning should play in infrastructure project review, ranking, and prioritization.

Chapter 6, Standards, Guidelines, and Regulations for Resilient Infrastructure Development, describes the ongoing challenge of establishing climate-informed standards and guidelines for the design, siting, and construction of public infrastructure, and outlines potential strategies for local practitioners to develop standards and guidelines. This chapter also acknowledges the role played by privately constructed or managed infrastructure in communities throughout the United States, and the types of regulations that may be necessary to ensure resilience to flood hazards.

Chapter 7, Infrastructure Finance and Resilience, is a deep dive into how communities can pay for infrastructure that is resilient to current and future flood risk. This chapter outlines the existing tools communities have at their disposal to finance infrastructure and describes emerging financial instruments geared toward resilient infrastructure.

Finally, Chapter 8, Looking Ahead, summarizes the roles that planners can play in building a culture of infrastructure resilience and discusses the challenge of deep uncertainty as an emerging issue when planning for local climate change impacts.

The appendix to this report offers an example of how one jurisdiction is already integrating climate-related flood hazard considerations into local planning: a checklist for assessing the vulnerability of proposed infrastructure projects to sea level rise developed by the City and County of San Francisco's Office of Resilience and Capital Planning.

CHAPTER 2

UNDERSTANDING FUTURE FLOOD RISK WITH DATA AND TOOLS

Understanding the existing and potential future flooding situations in a municipality is one of the most important first steps a planner can take at the outset of a planning process, or when considering potential changes to local codes and regulations. But for many planners and the communities they serve, this may be unknown territory.

The combined effects of future flood impacts due to climate change are difficult to predict with certainty, but they are likely to strain available resources in communities across the country. Communities that have relied upon historical flood data and information for planning, siting, and designing infrastructure are now faced with more severe but also more uncertain future conditions.

However, in recent years, the quality and availability of climate information that can be used to assess future flood risk has improved. There is now a wide variety of tools available that can help communities plan for more intense and frequent future flooding.

Planners must proactively prepare for flooding based not only on historical data, but also on projected trends for the years to come. Knowledge of future environmental conditions can inform long-term planning. This information is essential to making educated decisions about the planning, design, and location of infrastructure projects and systems. As this awareness grows, the number of tools and data sources related to climate change and flood hazards continues to expand. The purpose of this chapter is to highlight a small number of select tools to demonstrate the options available for practitioners.

This chapter outlines for planners a general approach to understanding climate data and how it can be used to improve the public infrastructure planning process. It describes the types of data that exist relevant to flood hazards and lists critical climate data sources. Finally, it provides guidance for planners in finding and analyzing local data on future climate impacts, as well as options for partnering with academia, the government, and industry that may provide vital assistance to this effort.

CLIMATE AND FLOOD HAZARD DATA TYPES

While many localities may lack the capacity to gather data, there are numerous data sources publicly available to evaluate general susceptibility to flood inundation. Finely scaled local climate models may not be necessary to improve flood resilience. Local knowledge informed by larger regional- or national-scale datasets can be successful in enhancing positive outcomes.

For short-term planning (e.g., a five- to 10-year timeline), historical data can be extrapolated and used as a reasonable proxy to estimate future conditions. Many historical datasets can be used in this context, including documented landslides, shoreline change over time, and river water levels. However, planning that extends beyond this time frame should rely on more sophisticated methods.

Because current climate trends are inconsistent with those observed in the past, there is an increasing reliance on complex modeling and projections that result in improved insight into future conditions. Modeling future climate is essential to planning projects with timelines greater than 10 years into the future. It is important to note that projections are not intended to be precise predictions of what is to come; rather, they provide a range of possible outcomes that may or may not come to pass. The sidebar on p. 24 provides some additional background on climate modeling.

The primary aspects of climate that are relevant to flooding, and those that require data gathering for planning purposes, include sea level rise or lake level fluctuation, coastal erosion, extreme precipitation events, and subsidence. All of these factors contribute to increased inundation areas on both our coasts and inland areas, reducing the amount of developable land, shrinking coastal habitat, threatening structures and infrastructure, and endangering people and property.

GLOBAL CLIMATE MODELS

The four climate scenarios used by the Intergovernmental Panel on Climate Change (IPCC) are called *representative concentration pathways*, or RCPs (Figure 2.1). These are based on the amount of *radiative forcing* (the amount of solar energy absorbed by the earth after some of it is reflected back into space) that could be expected in the future according to assumptions about population growth, continued reliance on fossil fuels, and other socioeconomic determinants (IPCC n.d.).

The names RCP2.6, RCP4.4, RCP6.0, and RCP8.5 refer to the amount of additional radiative forcing that can be anticipated in 2100 as compared to pre-industrial levels. RCP2.6 refers to a scenario in which strict mitigation efforts have been enacted and greenhouse gas emissions have been curbed in a substantial way, while RCP8.5 is the highest amount of radiative forcing—the scenario in which current trends continue and either no or minimal efforts are made to reduce emissions (IPCC n.d.).

Many data sources and web tools use the RCP scenarios to inform their outputs. Others may simply refer to scenarios as "high," "medium," or "low."

Global climate information can also be "downscaled" to be more appropriate for small areas. This is done by either *dynamical downscaling* or *statistical downscaling* (Carbon Brief 2018). Dynamical downscaling uses regional climate models (RCMs), which are similar to global models but cover a smaller geographic extent and can therefore be run more quickly. Statistical downscaling involves using observed data to determine a statistical relationship between global and local data and extrapolating from that.

The validity of models, both global and regional, can be evaluated by using them to simulate past climate or weather events and determining how accurately they represent patterns that we know have existed previously. Such comparisons with the past are often called *hindcasts* (Carbon Brief 2018).

More information on climate modeling may be found at "Climate Models" (www.climate.gov/maps-data/primer/climate-models), a National Oceanic and Atmospheric Agency (NOAA) primer on climate modeling.

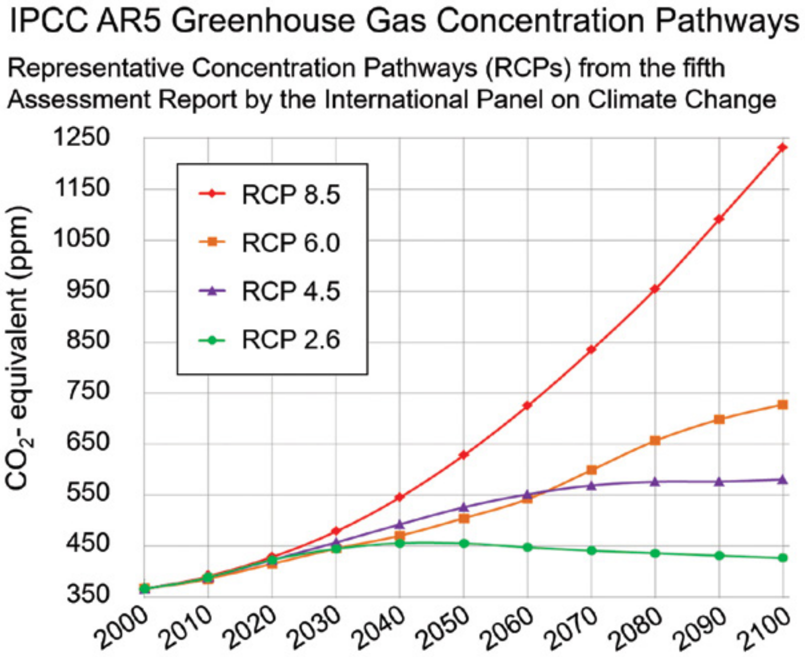


Figure 2.1. The four RCP scenarios used by the IPCC (Wikimedia/Ilinri (CC0 1.0))

In coastal areas, more land may become intermittently or permanently underwater due to increased precipitation in conjunction with rising sea levels and the sinking of the land surface itself. Inland, flooding is also increasing in many places as a result of more intense and frequent storm events. Urbanization and the increase of impervious surfaces such as concrete has also been shown to exacerbate flooding in developed areas.

The following sections describe the flood-relevant climate aspects listed above and explain what types of data are available for each.

Sea Level Rise

Many sea level rise mapping projects utilize the "bathtub model" when spatially modeling sea level rise inundation for coastal areas. In the bathtub model, the ocean is treated as a static pool in which water levels increase uniformly. In this case, modelers add the anticipated sea level rise to the existing mean higher high water (MHHW) for the region of interest. MHHW refers to the average highest daily tide water level observed during the 19-year period (1960–1978) established as the National Tidal Datum Epoch (NOAA 2016b).

However, there are some obvious concerns with this process. In some communities, a 19-year interval might not be frequent enough to keep up with trends. NOAA uses a "modified tidal datum epoch" procedure that is appropriate for areas with more extreme observed changes (Szabados 2008). Southeast Alaska and the Louisiana/Mississippi Delta area, for example, use this metric because they are witnessing sea level changes of about 7–8 millimeters a year—several times greater than the worldwide average of 1.7 millimeters.

Sea level rise visualization and planning tools that employ the worldwide average of sea level rise may not account for variability seen on a local scale. For example, although sea level is rising in most places, in much of Alaska sea level is falling due to post-glacial rebound (the rise of land due to the melting of glaciers). There may also be seasonal variability due to atmospheric and oceanic circulation patterns. Some signals, like astronomical tide, can be accounted for. However, other signals such as storm surge or wind-driven circulation may be more difficult to factor into these models.

One of the best ways to contextualize local trends in relative sea level is through tidal gauge station data. Tidal stations are valuable because they include continuous data over a long duration (Figure 2.2). Dozens of these stations exist in nearly all coastal states and territories of the United States. Note that because tidal stations measure relative sea level rise, it may be unclear whether trends are due to land subsidence or water level itself rising. By consulting existing historical tidal station data, planners and practitioners can better contextualize, ground-truth, and inform the findings of tools that project potential sea level rise.

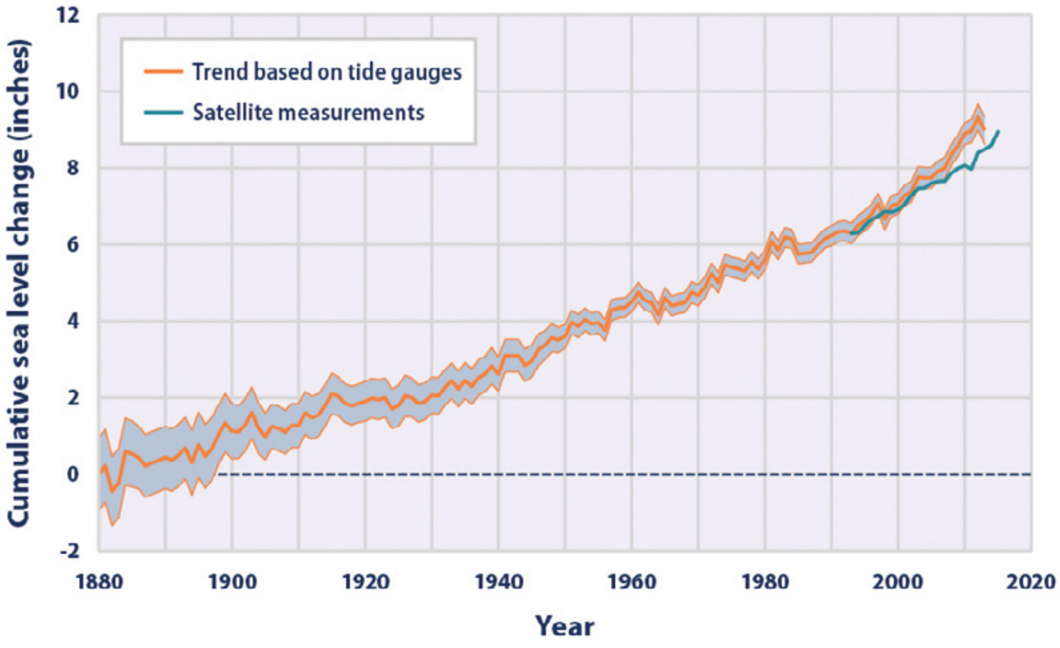


Figure 2.2. Global average sea level rise from 1880 to the present, based on tide gauges and satellite measurements (U.S. EPA 2016)

Data from all U.S. and international tidal gauge stations can be found on NOAA's "Tides and Currents" website (https://tidesandcurrents.noaa.gov/sltrends/index.shtml).

Planners should also consider subsidence of the land surface in conjunction with sea level rise. Subsidence is the gradual settling or sudden sinking of the Earth's surface due to subsurface movement of earth materials. It can confound sea level rise projections, as noted above in the Alaska example.

According to the U.S. Geological Survey (USGS), more than 17,000 square miles and 45 states experience subsidence to some degree. A majority of land subsidence in the United States can be attributed to human activity, namely groundwater extraction (USGS 2017). If sea level rises as the surface of the Earth itself simultaneously falls, this exacerbates flooding impacts.

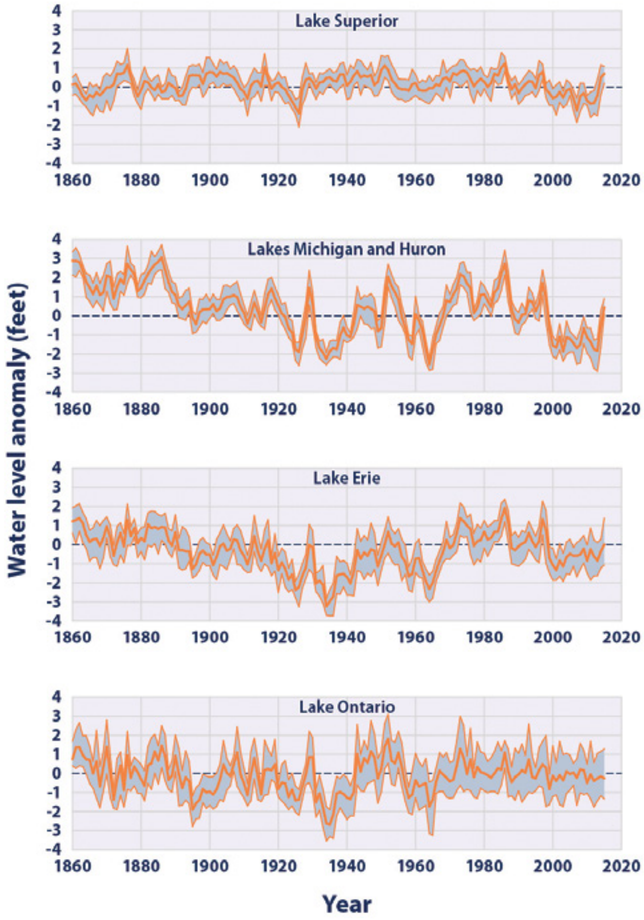


Figure 2.3. Lake level fluctuations from 1860 to 2015 on the Great Lakes (NOAA 2016a)

Lake Levels

Lakes are also subject to changes in water levels that can be detrimental to nearby communities. Unlike sea levels, lake levels can be far more variable over short time frames, with levels in the Great Lakes rising and falling regularly since record keeping began in 1860 (Figure 2.3).

Temperatures in the Great Lakes have seen a modest increase since the 1990s. This contributes to increasing rates of evaporation and may be one of several causes for observed declines in lake levels. However, many highly interconnected variables such as seasonal temperature swings, precipitation rates, and ice cover also play major roles in determining Great Lakes water levels.

While early climate projections initially pointed to a long-term trend of lower lake levels over the coming decades, newer science indicates comparatively minor declines, though there are large margins of error in these projections (Environmental Law and Policy Center 2019). Additionally, this describes a long-term average. Periods of highly variable lake levels are expected, with the potential for rapid swings between high and low extremes.

The unpredictability of lake levels over the coming decades due to climate change poses significant challenges to the effective use of lake level data in local planning. The highly contextual and interconnected nature of lake levels with uncertain weather patterns, precipitation rates, and changes in temperature contribute to this challenge. Planners should take special care when working with lake level data to factor these significant degrees of uncertainty into their assessments of infrastructure vulnerability and long-term plans.

Coastal Erosion

The shape of our coastlines, as well as the shorelines of the Great Lakes and all the lakes and rivers in the United States, is constantly changing as land both accretes (grows) and erodes due to wave action. Knowledge of which coastlines or shorelines are likely to degrade due to high-intensity storm events or other processes—and at what rate these changes are likely to happen—can be extremely valuable to coastal planners and developers as they site facilities near the shore.

Creating projections of future shoreline erosion is challenging and unreliable. Therefore, most erosion data is based on historic photographs supplemented by modern sources such as Lidar and satellite imagery. By comparing past shoreline extent with today, general rates of erosion or accretion can be estimated for a given time period. However, the fine-scale nature of coastal features will likely necessitate site-level analysis rather than use of a national data source.

Extreme Precipitation Events

High-intensity precipitation events are one of the most direct causes of flooding. While large volumes of rainwater over a long period of time can often be managed via absorption into soil or through engineered systems, capacity is severely limited when this volume arrives suddenly. If this excess water cannot infiltrate into the ground or exceeds sewer system capacities, it pools at the surface and floods businesses, facilities, and homes.

Unfortunately, events of this nature are becoming more and more common across nearly all of the United States (Figure 2.4). As the atmosphere warms, it can hold more water vapor; in turn, the amount of precipitation falling in very heavy events (the heaviest one percent of all daily events) increases. In 2017, Hurricane Harvey unleashed over 50 inches of rain in a matter of days in the Houston area, dramatically exceeding that region's average August rainfall of 3.54 inches.

The occurrence of high-intensity precipitation events is more difficult to project than other climate variables such as temperature and sea level rise. Precipitation on a national scale is measured at weather stations throughout the United States and abroad. These stations measure precipitation as well as temperature, wind speed and direction, humidity, and other important climatic variables.

Data from these stations is managed by NOAA's National Centers for Environmental Information (NCEI). Station locations, as well as information about how long they have been in operation, can be found on NOAA's "Land-Based Station Data" website (www.ncdc.noaa.gov/data-access/land-based-station-data). This raw data can be downloaded for free. However, other tools exist that may be more intuitive to the end user, as described later in this chapter.

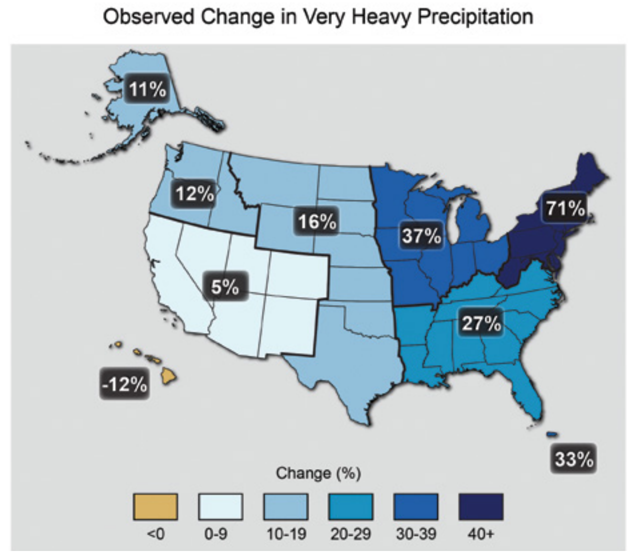


Figure 2.4. Observed changes in very heavy precipitation events (the heaviest one percent of all daily events) from 1958 to 2012 (USGCRP 2014)

Storm Surge

Storm surge refers to the abnormal rise of water generated by a storm (Figure 2.5, p. 28). Storm surge is created by water being pushed to shore by strong winds related to hurricanes or other coastal storms, and it can be exacerbated when it coincides with high tide.

Seiches are a form of storm surge that occur in enclosed or partially enclosed bodies of water (e.g., lakes, harbors, or bays). They can be a result of changes in pressure or sustained high winds, in addition to offshore storms.

Storm surge is measured and recorded by three means: tide stations, Federal Emergency Management Agency (FEMA)/USGS High Water Marks (HWMs), and pressure sensors. There are 175 tide stations throughout the United States that continually operate and provide data for storm surge estimates. HWMs are marks on trees and other structures that display the highest extent of previous floods. Flood extent can be observed due to mud or other debris that leaves behind a mark after the flood waters recede. HWMs are visually striking and helpful for both awareness and data collection but may be subjective and can be destroyed. Pressure sensors are temporary water level and barometric sensors that can provide information about storm surge duration, times of arrival and retreat, and maximum depths (National Hurricane Center n.d.a.). These are the newest means of storm surge data gathering.

Storm surge flooding poses a serious threat to coastal communities and their infrastructure. The relative unpredictability of coastal storms and the relationship between sea level rise and storm surge impacts are a major challenge to overcome for planners. However, a thorough understanding of what storm surge is and how it is measured and assessed is critical to effectively considering its impacts for the purposes of vulnerability assessment, long-term infrastructure planning, and infrastructure siting and development.

FINDING TOOLS AND DATA

While many types of climate data are helpful for local infrastructure planning, finding them can be a real challenge

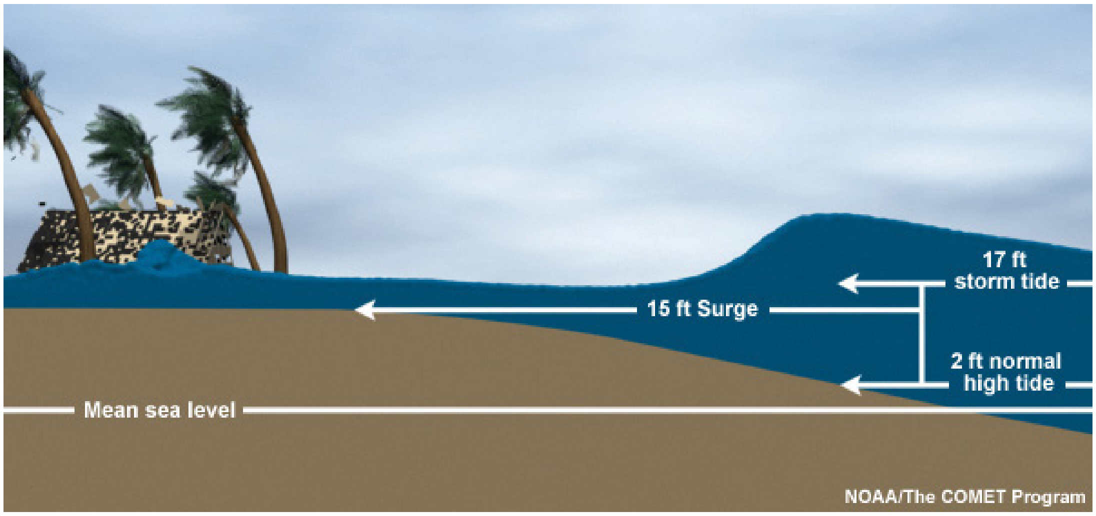


Figure 2.5. Storm surge heights are cumulatively based on the mean sea level, the height of the tide, and the high volume of water pushed toward the shore by coastal storms (National Hurricane Center n.d.b.)

for local planners and allied professionals. From intuitive, public-friendly mapping interfaces to sources of raw data that can be exported into Excel or ArcGIS, there are many options from which to choose.

For planners balancing many responsibilities, navigating these potential sources of information can be overwhelming and confusing. However, thinking critically about how this information will be used for the purposes of planning for more resilient infrastructure can help to make this search a bit more manageable.

Before choosing a tool or data resource, planners should consider (1) their own ability to interpret and understand this information, (2) the audience with which this information will be shared, and (3) the ultimate product that they hope to create.

If this information will be used to justify infrastructure planning decisions to a broad audience or will be presented to the public, tools that will produce clear and easy-to-interpret maps may be the best option. Alternatively, if engineering staff require data on increasing precipitation for use in assessing future stormwater system capacity, then an emphasis on the precision and utility of the dataset, rather than mapping functionality, would be the priority.

This section presents a series of decision-support tools and data resources that vary in ease of use, geographic extent, and intended purpose. Many of the sources described are nationally produced and can be used in most parts of the country. Established resources (such as FEMA's Flood Insurance Rate Maps) are included alongside more dynamic tools focusing on future projections (such as NOAA's Sea Level Rise Viewer) in order to capture as complete a picture as possible for both present and historic conditions and future scenarios.

Regional-scale tools available for assessing future climate are even more numerous than those at the national level, with new data resources emerging annually. The sidebar on pp. 34–35 highlights two examples of local- and regional-scale tools from the Northeast that may be helpful to planners in those areas.

Additionally, a growing body of guidance exists to help planners and other practitioners better understand and use the data and decision-support tools available to assess climate-related flood risks. One such resource is the report *Future Conditions Risk Assessment and Modeling*, developed for FEMA by the federal Technical Mapping Advisory Council. This resource is further described in the sidebar on p. 36.

FEMA Map Service Center

The information conveyed by FEMA's Flood Insurance Rate Maps (FIRMs) are a useful starting point for establishing the baseline of local flood risk.

FEMA's Map Service Center should be the first stop for planners in finding information about flood vulnerability in any community. Here, the most up-to-date flood maps created through the National Flood Insurance Program (NFIP) can be found by searching addresses, places, or latitude and longitude coordinates. An interactive version of this information can be accessed through the National Flood Hazard Layer (NFHL) dataset (www.fema.gov/national-flood-hazard-layer-nfhl), which is a regularly updated compilation of effective FIRMs.

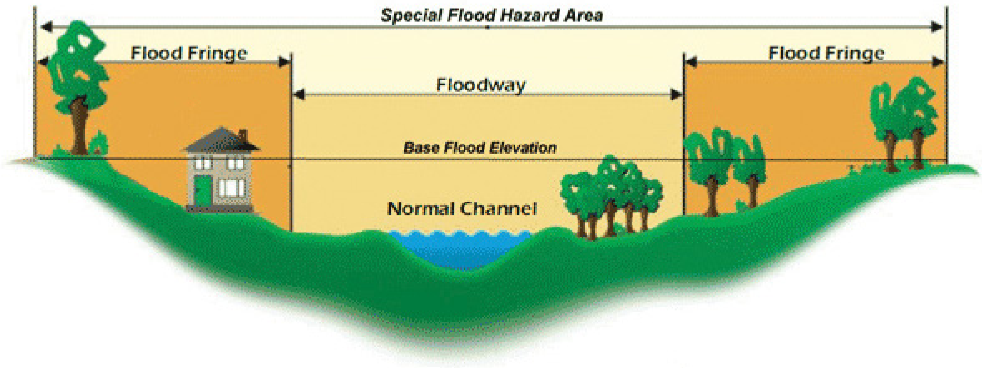


Figure 2.6. Cross-section view of the special flood hazard area (FEMA)

Flood zones in the NFHL are color-coded to represent the probability of inundation from various flooding events. Interpreting this information requires an understanding of a few foundational terms regularly used in flood hazard mitigation planning (FEMA 2019a) and basic knowledge of the types of flood zones that FEMA uses to delineate flood risk (Table 2.1):

- BFE stands for “base flood elevation,” the height to which floodwater is expected to rise during a base flood (the 100-year or one percent annual chance flood) and the regulatory requirement for the elevation or floodproofing of structures.
- SFHA stands for “special flood hazard area,” the area inundated by floodwaters in a base flood that is subject to FEMA’s regulatory requirements (Figure 2.6).

TABLE 2.1. FEMA’S NATIONAL FLOOD INSURANCE PROGRAM FLOOD HAZARD ZONES

Zone A	The 100-year or base floodplain. There are six types of A Zones: **A:** The base floodplain mapped by approximate methods; BFEs are not determined. This is often called an unnumbered A Zone or an approximate A Zone. **A1–A30:** These are known as numbered A Zones (e.g., A7 or A14). This is the base floodplain where the FIRM shows a BFE (old format). **AE:** The base floodplain where base flood elevations are provided. AE Zones are now used on new format FIRMs instead of A1–A30 Zones. **AH:** Shallow flooding base floodplain. BFEs are provided. **A99:** Area to be protected from base flood by levees or Federal Flood Protection Systems under construction. BFEs are not determined. **AR:** The base floodplain that results from the decertification of a previously accredited flood protection system that is in the process of being restored to provide a 100-year or greater level of flood protection.
Zone V and VE	**V:** The coastal area subject to a velocity hazard (wave action) where BFEs are not determined on the FIRM. **VE:** The coastal area subject to a velocity hazard (wave action) where BFEs are provided on the FIRM.
Zone B and Zone X (shaded)	Area of moderate flood hazard, usually the area between the limits of the 100-year and 500-year floods. B Zones are also used to designate base floodplains of lesser hazards, such as areas protected by levees from the 100-year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than one square mile.
Zone C and Zone X (unshaded)	Area of minimal flood hazard, usually depicted on FIRMs as above the 500-year flood level. Zone C may have ponding and local drainage problems that do not warrant a detailed study or designation as base floodplain. Zone X is the area determined to be outside the 500-year flood and protected by levee from 100-year flood.
Zone D	Area of undetermined but possible flood hazards.

Source: FEMA 2005

It is extremely important for planners to understand that FIRMs do not depict future areas of concern based on projections; they only describe current conditions. FIRMs do not consider sea level rise, changes in shoreline characteristics, or more frequent extreme precipitation events. To plan for infrastructure that will be resilient to more severe flooding requires the use of data and tools that consider future conditions. These future-oriented tools and data resources are presented below.

U.S. Climate Resilience Toolkit

The U.S. Climate Resilience Toolkit (https://toolkit.climate.gov) is an effort by NOAA to share case studies, tools, and information resources to help communities develop workable solutions to reduce climate-related risks. It also allows individuals to access training courses or local climate science centers for more individualized information. The intended audience for the interface is broad, from city officials to the general public.

The Climate Resilience Toolkit is a good first step for local planners to gain a general understanding of the concept of resilience and how to better integrate it into local planning and implementation. The Toolkit provides direct access to a curated series of decision-support tools and data resources that can be filtered by topic, function, and region. Several of these tools are listed below.

Sea Level Rise and Coastal Flood Web Tools Comparison Matrix

There are dozens of tools, web interfaces, and mapping programs available to a planner interested in climate change adaptation. However, it may be overwhelming to determine which are most appropriate for the region, scale, and user's skill level. The Sea Level Rise and Coastal Flood Web Tools Comparison Matrix (http://sealevel.climatecentral.org/matrix), developed in a partnership between NOAA, The Nature Conservancy, and the nonprofit environmental news organization Climate Central, can help users easily compare and contrast this plethora of tools.

With this matrix, a planner can compare web-based sea level rise and coastal flood risk tools available for any given state (Figure 2.7, p. 31). The matrix describes the features of each tool, including the level of skill required, how recently it was updated, and the geographic scope. It also lists the top three strengths and limitations of that approach and provides quick links and contact information for all included tools.

The Sea Level Rise and Coastal Flood Web Tools Comparison Matrix is a good first step for navigating the multitude of available tools for a particular state. Planners can review the matrix and decide for themselves which tool suits their needs best. Two of the tools included in the matrix, the Sea Level Rise Viewer and the Surging Seas Risk Zone Map, are explored in detail below.

The matrix only applies to the coastal states and Hawaii; it is not adapted for Puerto Rico, the Virgin Islands, or the U.S. Territories, including Guam. Moreover, if a dataset is newer than the most recent update of the matrix, it may not be found here.

Sea Level Rise Viewer

NOAA's Office for Coastal Management developed the Sea Level Rise Viewer (https://coast.noaa.gov/slr) to provide visual and geospatial information on community-scale impacts related to sea level rise and coastal flooding. The viewer is particularly useful for planners and other allied professionals who are developing plans and assessing vulnerability to long-term flooding associated with sea level rise.

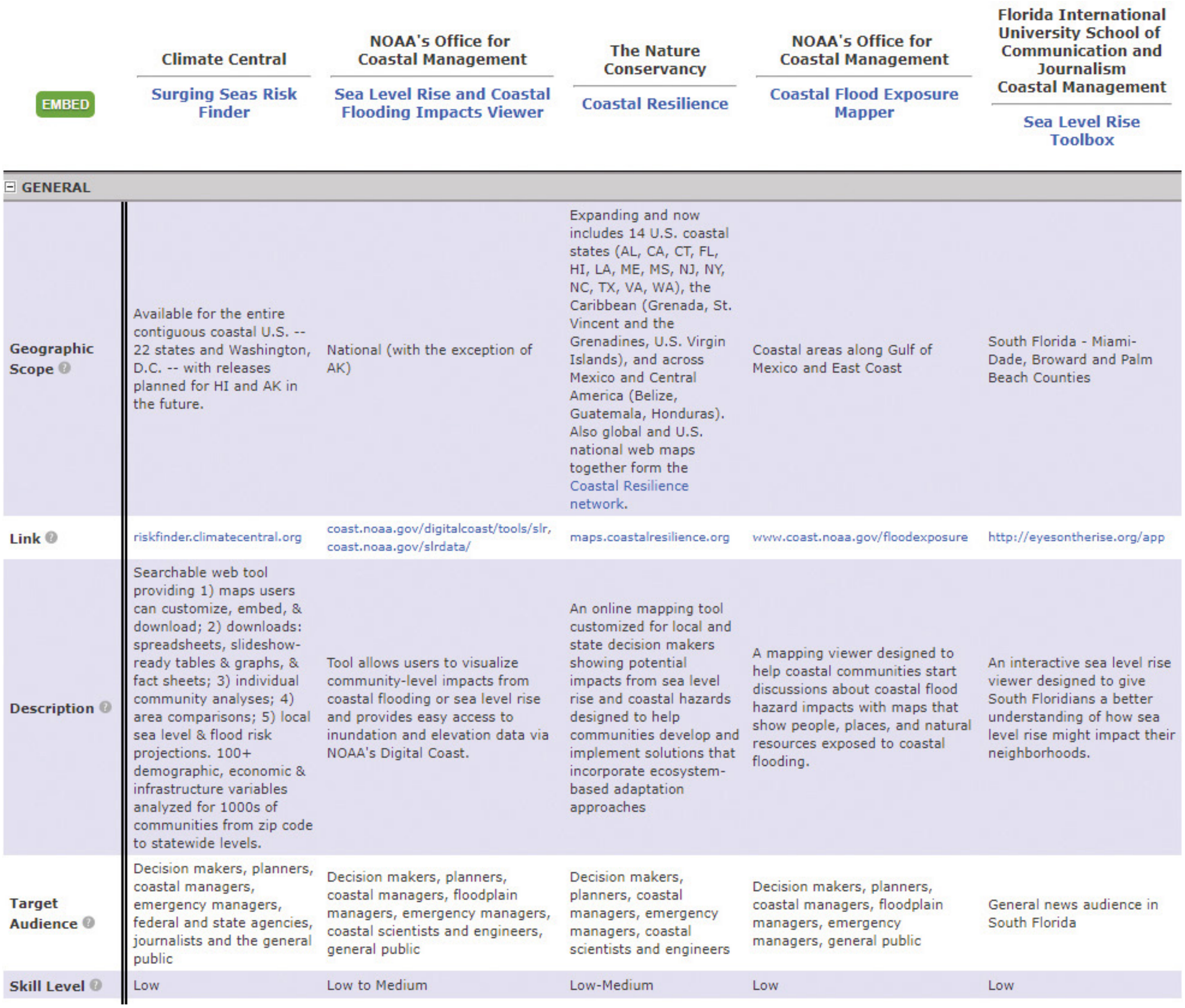
The Sea Level Rise Viewer covers all coastal states and U.S. territories and uses the "bathtub" model, which makes inferences about flood inundation based on the available elevation data. It allows for mapping of coastal flooding due to sea level rise at one foot increments up to 10 feet above average high tides. These dynamic and interactive capabilities are especially useful for planners seeking to spatially assess community vulnerability to sea level rise across a wide array of scenarios.

The related local scenario function allows users to select and compare flooding across five distinct scenarios of sea level rise, ranging from intermediate-low to extreme (see Table 3.2, p. 44). Additionally, the Sea Level Rise Viewer directly integrates contextual information on social vulnerability and impacts to the natural environment (especially on the migration of critical marsh habitat). The viewer also provides needed context on mapping confidence, which is indicated on the maps as a color-coded range from high confidence of inundation to high confidence of dry land.

In addition to the visual and geospatial capabilities of the tool itself, users can also download data on sea level rise extent, sea level rise depth, mapping confidence, flood frequency, and the local Digital Elevation Model, which includes detailed information on mapped elevations. This raw data is available at the county level for all coastal states and territories. Users can then integrate this data into GIS analyses for the purposes of assessing impacts and vulnerability across a wide variety of sectors for which local GIS data is also available. This analysis may include overlaying mapped sea level rise under various scenarios with local geospatial information on the location and condition of infrastructure assets and systems. This is explored in more depth in Chapter 3 as part of the vulnerability assessment process.

It is important to note that the Sea Level Rise Viewer is primarily intended as a planning tool at the community scale. Therefore, while it is extremely useful in assessing potential inundation broadly across coastal geographies, it should only be a starting point for more detailed local analysis when used at the site or building scale.

Given these capabilities, the Sea Level Rise Viewer and the underlying data that it makes available for download is an effective first step for communities looking to assess their vulnerability to sea level rise. It can be directly integrated into local plans to understand and contextualize potential future conditions or consulted on an as-needed basis when making decisions about infrastructure siting or long term exposure, and it can form the basis for local and highly contextual analyses when fed into GIS software. It is a versatile and useful



EMBED	Climate Central **Surging Seas Risk Finder**	NOAA's Office for Coastal Management **Sea Level Rise and Coastal Flooding Impacts Viewer**	The Nature Conservancy **Coastal Resilience**	NOAA's Office for Coastal Management **Coastal Flood Exposure Mapper**	Florida International University School of Communication and Journalism Coastal Management **Sea Level Rise Toolbox**
⊟ **GENERAL**					
Geographic Scope	Available for the entire contiguous coastal U.S. -- 22 states and Washington, D.C. -- with releases planned for HI and AK in the future.	National (with the exception of AK)	Expanding and now includes 14 U.S. coastal states (AL, CA, CT, FL, HI, LA, ME, MS, NJ, NY, NC, TX, VA, WA), the Caribbean (Grenada, St. Vincent and the Grenadines, U.S. Virgin Islands), and across Mexico and Central America (Belize, Guatemala, Honduras). Also global and U.S. national web maps together form the Coastal Resilience network.	Coastal areas along Gulf of Mexico and East Coast	South Florida - Miami-Dade, Broward and Palm Beach Counties
Link	riskfinder.climatecentral.org	coast.noaa.gov/digitalcoast/tools/slr, coast.noaa.gov/slrdata/	maps.coastalresilience.org	www.coast.noaa.gov/floodexposure	http://eyesontherise.org/app
Description	Searchable web tool providing 1) maps users can customize, embed, & download; 2) downloads: spreadsheets, slideshow-ready tables & graphs, & fact sheets; 3) individual community analyses; 4) area comparisons; 5) local sea level & flood risk projections. 100+ demographic, economic & infrastructure variables analyzed for 1000s of communities from zip code to statewide levels.	Tool allows users to visualize community-level impacts from coastal flooding or sea level rise and provides easy access to inundation and elevation data via NOAA's Digital Coast.	An online mapping tool customized for local and state decision makers showing potential impacts from sea level rise and coastal hazards designed to help communities develop and implement solutions that incorporate ecosystem-based adaptation approaches	A mapping viewer designed to help coastal communities start discussions about coastal flood hazard impacts with maps that show people, places, and natural resources exposed to coastal flooding.	An interactive sea level rise viewer designed to give South Floridians a better understanding of how sea level rise might impact their neighborhoods.
Target Audience	Decision makers, planners, coastal managers, emergency managers, federal and state agencies, journalists and the general public	Decision makers, planners, coastal managers, floodplain managers, emergency managers, coastal scientists and engineers, general public	Decision makers, planners, coastal managers, emergency managers, coastal scientists and engineers	Decision makers, planners, coastal managers, floodplain managers, emergency managers, general public	General news audience in South Florida
Skill Level	Low	Low to Medium	Low-Medium	Low	Low

Figure 2.7. Screenshot of a portion of the output for the Sea Level Rise and Coastal Flood Web Tools Comparison Matrix for Florida (The Nature Conservancy, NOAA's Office for Coastal Management, and Climate Central)

tool, and—in the absence of highly specific (and expensive) locally developed models—can be the foundation for a community's infrastructure adaptation and resilience strategy.

Surging Seas Risk Zone Map

The Surging Seas Risk Zone Map (https://ss2.climatecentral.org) is a global sea level and flood visualizer created by Climate Central. With this tool, a user can explore inundation risk worldwide based on data gathered by more than 1,000 tide gauges. Each of the 1,000 gauges marked on this interactive map has downloadable sea level rise projections through the year 2200 for three scenarios: extreme carbon cuts, moderate carbon cuts, or unchecked carbon emissions (Figure 2.8).

The Surging Seas Risk Zone Map is a versatile tool that incorporates social vulnerability, demographics (including ethnicity, income, and population), property values, and landmarks such as critical infrastructure facilities. It also provides the anticipated date when each level of inundation can be expected given different emissions scenarios.

While the Surging Seas Risk Zone Map is easy to use, it does have limitations. It assumes no changes in the patterns of coastal storms, which is unlikely based on existing climate models. It also assumes that conditions in nearby communities can be extrapolated to others when data is missing for some communities, which may not always be the case. However, these limitations are common across tools that map sea level rise inundation and impacts and should not preclude their use at the community-wide scale.

The Surging Seas Risk Zone Map can be used at much the same scale as NOAA's Sea Level Rise Viewer. It can be an effective tool for assessing community-wide vulnerability under multiple inundation scenarios and can be an effective way of guiding planning and decision making about coastal infrastructure siting.

Great Lakes Lake Level Viewer

NOAA's Great Lakes Lake Level Viewer (https://coast.noaa.gov/llv) is an accessible and versatile tool for assessing the impacts associated with changes in lake level for communities along the Great Lakes. It offers similar functionality as NOAA's Sea Level Rise Viewer and allows for dynamic and interactive mapping and visualization of lake level changes across a 12-foot range from six feet below to six feet above the long-term average lake level. The viewer also incorporates visualization of social vulnerability factors, economic data, and mapping confidence.

Raw data pertaining to water depths, mapping confidence, social vulnerability, and the Digital Elevation Model are available at the county scale for all Great Lakes states. As with the Sea Level Rise Viewer, users can then conduct analy-

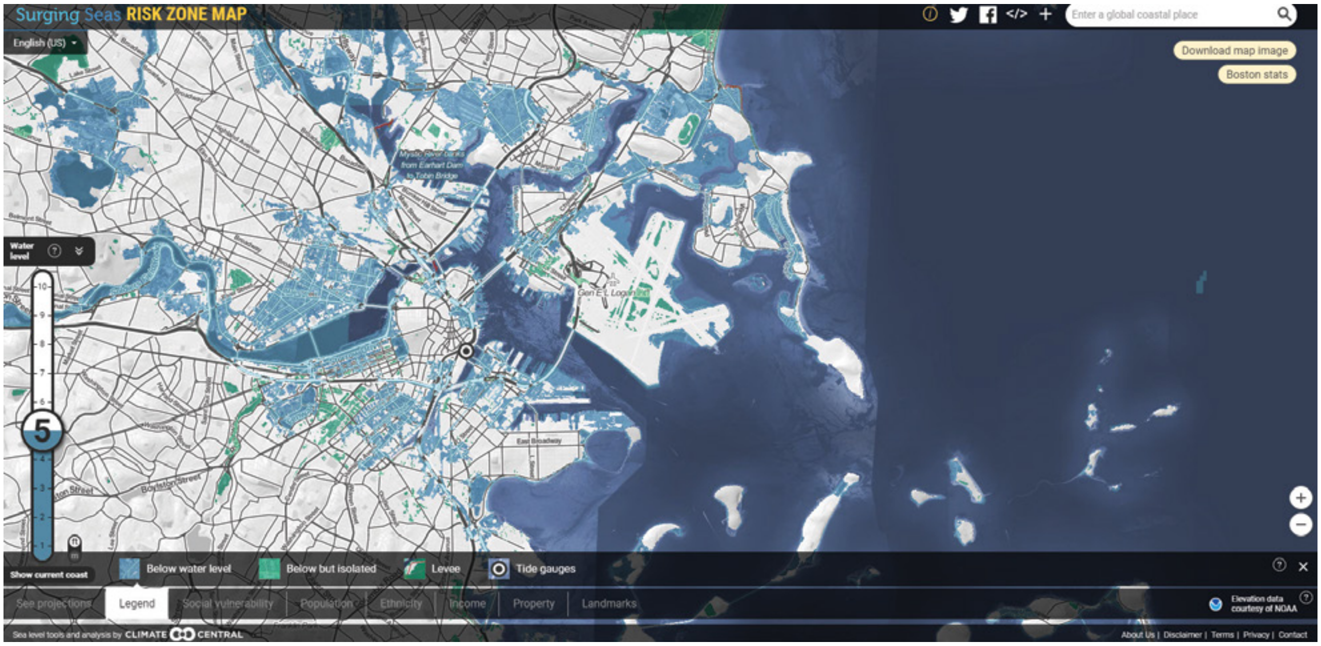


Figure 2.8. Screenshot of Surging Seas Risk Zone Map for Boston with five feet of sea level rise (Climate Central)

ses by downloading and overlaying this data with local geospatial data in GIS software. This basic analysis carries significant benefits for assessing the vulnerability and exposure of existing and planned infrastructure assets. Planners should be aware that this tool and data is best suited for community-level analyses and planning, or as a starting point for decision making at the site or project scale.

Additional Sources for Data, Tools, and Guidance

Data sources and tools available through FEMA, NOAA, and other organizations have expanded in geography and functionality over time, with coastal communities and sea level rise modeling included in a variety of potential resources. However, communities may require more specific information, locally developed or contextual models, or technical assistance in interpreting available data. Below are a series of sources for building technical capacity, developing or discovering new sources of contextually appropriate local data, or interpreting and putting flood hazard data to use.

NOAA Digital Coast. NOAA's Digital Coast is a highly comprehensive clearinghouse of raw data resources, decision-support tools, technical guidance, and education on data interpretation and use in local practice for coastal flooding and coastal natural resources across the United States. Many of the tools available on the Digital Coast website are developed for use in specific regions and may offer a more contextually appropriate scale for local infrastructure planning and decision making than national-level tools. The technical guidance available from the Digital Coast can be extremely beneficial for communities and practitioners looking to build capacity to use climate data and associated decision-support resources as part of their planning efforts. More information on the Digital Coast is available at https://coast.noaa.gov/digitalcoast.

NOAA Regional Climate Centers (RCCs). Managed by NOAA's National Centers for Environmental Information (NCEI), RCCs provide climate data services to six regions in the United States, including Puerto Rico (Figure 2.9). The key roles of RCCs are to develop and host climate data resources and assist in integrating non-NOAA climate data with traditional NOAA data sources. RCCs can be helpful in contextualizing climate data for use at the local level, and they can also help to build capacity through technical education resources. More information on the products and services offered by RCCs is available at www.ncdc.noaa.gov/customer-support/partnerships/regional-climate-centers.

NOAA Regional Integrated Sciences and Assessments (RISA). The RISA program exists to support both public and private research teams in producing data and advising local, regional, state, and tribal governments. RISA staff work directly with climate scientists but can also help communi-

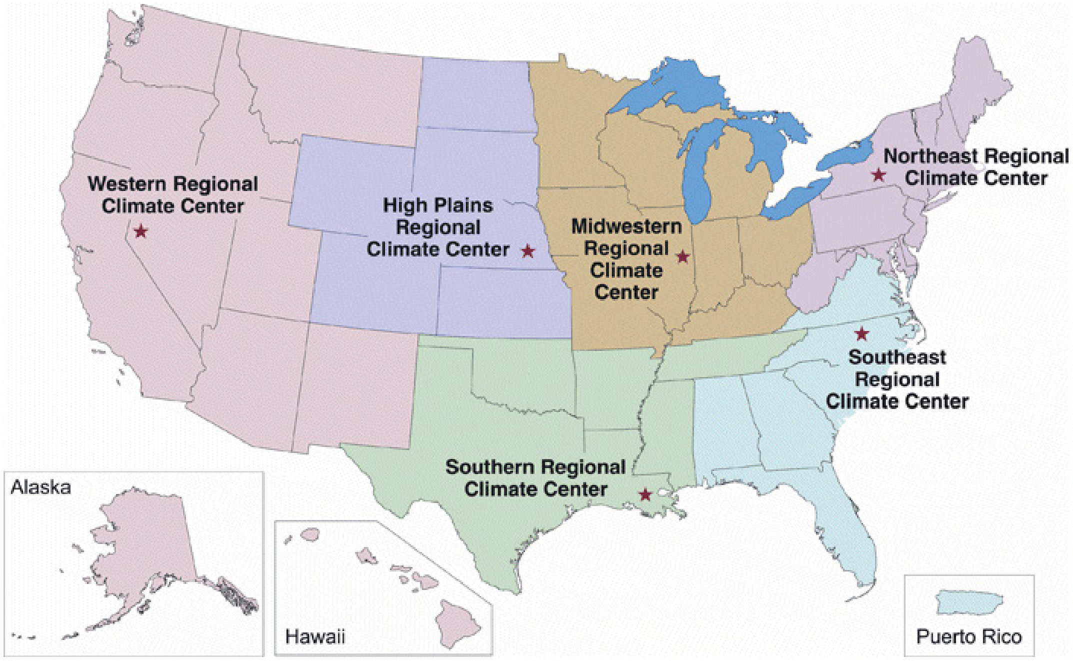


Figure 2.9. NOAA's Regional Climate Center program regions (NOAA NCEI)

LOCAL AND REGIONAL TOOLS: TWO OPTIONS IN THE NORTHEAST

The Hudson River Flood Impact Decision Support System (Version 2) is an interactive mapping application produced by Columbia University (Figure 2.10). With this tool, residents of the Hudson River watershed in New York State can see, on a city block scale, the anticipated impacts of several sea level rise scenarios and flooding on critical infrastructure, natural features, and social vulnerability.

Sea level rise scenarios are available from zero to six feet above the base mean sea level from 1983 through 2001. The application also includes flood event scenarios with different return periods (the average amount of time between events of this size). The output "impact summary" includes an estimation of financial losses, which can generate more support or stronger rationales for better floodproofing.

The application has many built in "help" options, including a yellow "i" button next to each part of the scenario builder that guides the user to the scenario best for them. This tool is quite comprehensive and can be a one-stop shop to evaluate several potential impacts of flooding.

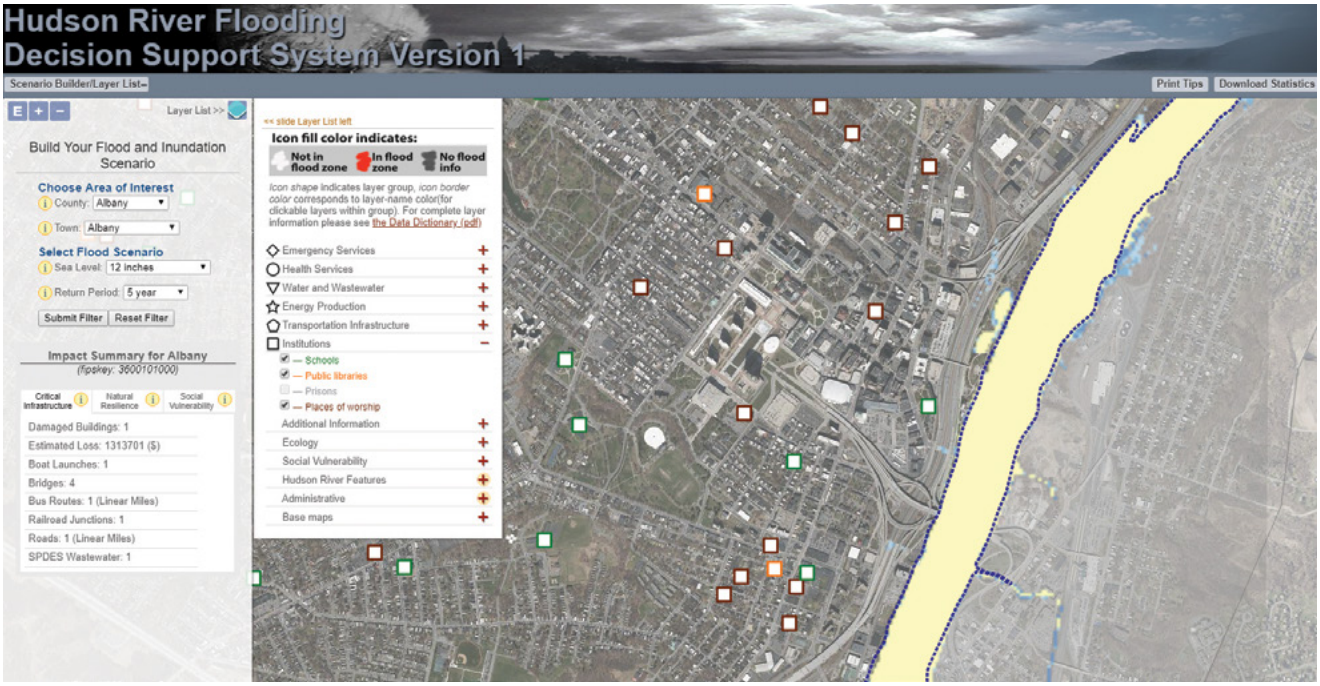
The Hudson River Flood Impact Decision Support System may be accessed at www.ciesin.columbia.edu/hudson-river-flood-map/index_new.html. A similar tool for the Boston area, Coastal Flood Impacts for the City of Boston, may be found at http://ciesin.columbia.edu/fib.

Another potentially useful tool for New York State is the Intensity Duration Frequency Curves created by the Northeast Regional Climate Center at Cornell University (http://ny-idf-projections.nrcc.cornell.edu). Here, planners can choose a high or low emissions scenario and, with relative ease, produce downscaled projections of extreme rainfall within the state to the year 2099 (Figure 2.11, p. 35).

This tool provides the total volume of rain associated with different events. The planner or engineer is responsible for layering that additional water on existing topography to determine the resulting inundation. Intensity, duration, and frequency of precipitation are all considered.

While perhaps less valuable for capital infrastructure planning, another interesting feature for raising awareness is a grid map of the entire state with projected changes of precipitation showing how different parts of the state compare to one another.

Raw data for this site comes from 157 National Weather Service Coop-



Build Your Flood and Inundation Scenario

Choose Area of Interest
County: Albany
Town: Albany

Select Flood Scenario
Sea Level: 12 inches
Return Period: 5 year

Icon shape indicates layer group, icon border color corresponds to layer-name color(for clickable layers within group). For complete layer information please see the Data Dictionary (pdf)

☑ — Schools
☑ — Public libraries
☐ — Prisons
☑ — Places of worship

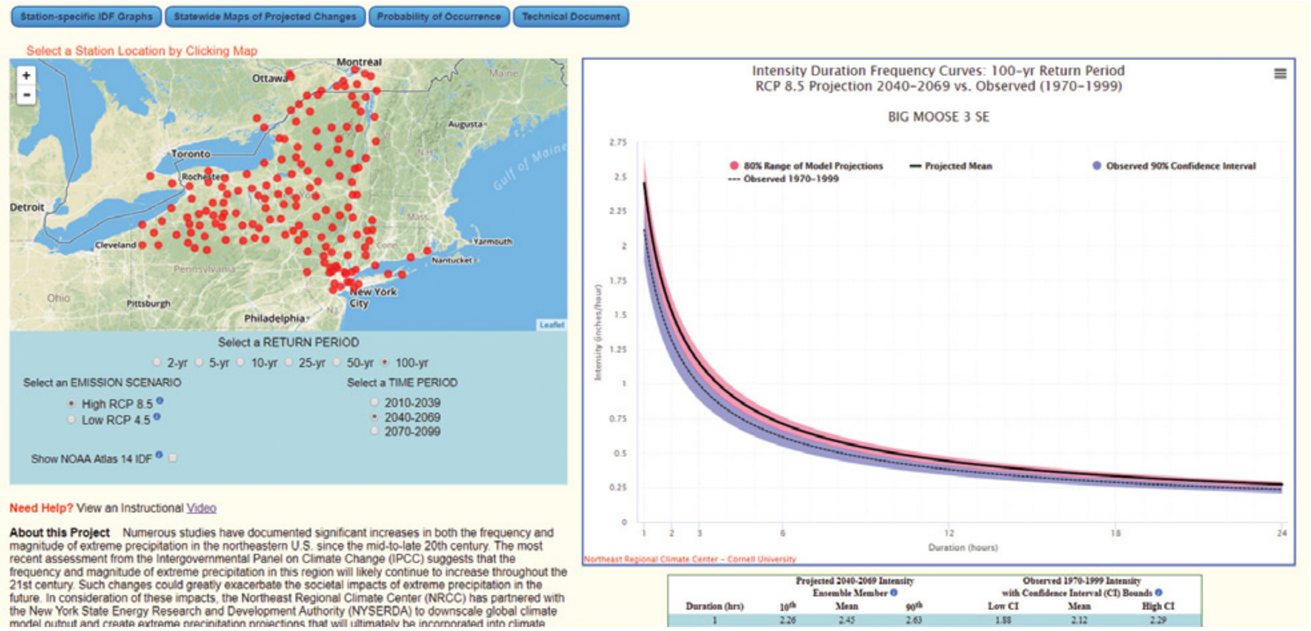
Impact Summary for Albany
(fipskey: 3600101000)

Damaged Buildings: 1
Estimated Loss: 1313701 ($)
Boat Launches: 1
Bridges: 4
Bus Routes: 1 (Linear Miles)
Railroad Junctions: 1
Roads: 1 (Linear Miles)
SPDES Wastewater: 1

Figure 2.10. Screenshot of expected inundation in Albany, New York, given 12 inches of sea level rise and a flood event return period of five years (Center for International Earth Science Information Network, Columbia University, with New York State Energy Research and Development Authority support)

erative Observer Program stations with long-term precipitation data covering the years 1961–2010. Modeling was used for both historical and future trends; historical trends were calculated to ensure that the values found for the future were valid.

The required skill level for this tool is greater than previously described tools. It may require a user with engineering background to translate these precipitation curves to spatial inundation.



Select a RETURN PERIOD

○ 2-yr ○ 5-yr ○ 10-yr ○ 25-yr ○ 50-yr ● 100-yr

Select an EMISSION SCENARIO

● High RCP 8.5
○ Low RCP 4.5

Select a TIME PERIOD

○ 2010-2039
● 2040-2069
○ 2070-2099

Show NOAA Atlas 14 IDF ☐

Need Help? View an Instructional Video

About this Project Numerous studies have documented significant increases in both the frequency and magnitude of extreme precipitation in the northeastern U.S. since the mid-to-late 20th century. The most recent assessment from the Intergovernmental Panel on Climate Change (IPCC) suggests that the frequency and magnitude of extreme precipitation in this region will likely continue to increase throughout the 21st century. Such changes could greatly exacerbate the societal impacts of extreme precipitation in the future. In consideration of these impacts, the Northeast Regional Climate Center (NRCC) has partnered with the New York State Energy Research and Development Authority (NYSERDA) to downscale global climate model output and create extreme precipitation projections that will ultimately be incorporated into climate

	Projected 2040-2069 Intensity Ensemble Member			Observed 1970-1999 Intensity with Confidence Interval (CI) Bounds		
Duration (hrs)	10th	Mean	90th	Low CI	Mean	High CI
1	2.26	2.45	2.63	1.88	2.12	2.29

Figure 2.11. Screenshot of intensity duration frequency curve for Big Moose station, using a 100-year return period and high emissions scenario (Northeast Regional Climate Center, Cornell University)

A FRAMEWORK FOR INTEGRATING CLIMATE SCIENCE AND FUTURE FLOOD RISK

In 2013, Congress chartered the Technical Mapping Advisory Council (TMAC), a group made up of national experts in risk modeling, flood science, and climate science, to develop detailed guidance for FEMA on integrating climate science and advanced future risk modeling into flood risk assessments. Two years later, TMAC issued its report, titled *Future Conditions Risk Assessment and Modeling*. Planners and other local practitioners can use this report to better understand climate information, data, and decision-support tools.

The report offers a series of recommendations for coastal and riverine flood risk assessment. Recommendations 3 and 4 comprehensively describe the variables of future flood risks; list data needs and authoritative sources on topic areas such as topography, shoreline and riverine erosion, coastal and riverine water levels, demographics, and land use; and explain how practitioners can use this information to assess community-wide risk.

The report also outlines approaches for dealing with uncertainty and the challenges of estimating future flooding. Perhaps most critically, Recommendation 5 defines a philosophy of flood risk management that offers local practitioners a framework for using climate science in the local planning context. This approach is based on the need for future conditions to be directly integrated into the "standard methods" for local flood risk assessment, with special considerations for quantifying and accounting for the uncertainty of not only climate-related flood hazards such as sea level rise or extreme precipitation, but also changes in demographics and the built environment.

The full report can be found at https://tinyurl.com/s3t2qn7.

ties appropriately communicate the science to the public and officials. Currently, RISA supports over 100 projects, which are described on its website, https://cpo.noaa.gov/Meet-the-Divisions/Climate-and-Societal-Interactions/RISA.

State Hazard Mitigation Officers (SHMOs). State hazard mitigation officers are responsible for coordinating state hazard mitigation policy, overseeing completion of the state hazard mitigation plan for FEMA, and working with local governments. As a result, they can be good sources of important data and policy information. The Association of State Floodplain Managers maintains a directory of SHMOs, which may be accessed at www.floods.org/index.asp?menuID=767.

Regional planning organizations. Regional planning organizations coordinate planning efforts of multiple localities in matters that are regional-scale concerns, sometimes including climate and hazards. Often, their capacity exceeds that of local planning departments. They may be able to provide technical assistance or partner in finding or developing new data. For example, the Chicago Metropolitan Agency for Planning recently worked with several partners, including NOAA and the American Planning Association, to develop climate vulnerability assessments for four pilot communities in the region and created guidance to help Great Lakes communities use climate information in local planning processes (APA 2019).

Local universities. Often, local universities have professors, staff, and graduate students studying climate-relevant phenomena. These individuals and departments may have data archives and may also be gathering new data. Potential departments of interest include environmental sciences, civil or environmental engineering, and atmospheric and oceanic sciences. Colleges and universities involved in NOAA's National Sea Grant College Program (https://seagrant.noaa.gov) are especially notable as potential sources of information and guidance on issues related to natural resources, climate change, conservation, and flooding on the coasts. Local universities may also have dedicated science libraries and librarians to provide additional guidance.

Data from neighboring communities. If one community has robust climate data and is willing to advise, it is possible that its measurements, data, and projections would also be appropriate for other nearby communities. Communities with similar conditions and goals may decide to pool resources and support future data gathering.

Anecdotal evidence from community members. Oftentimes, community members who have been in the area for many years can remember the extent of past flooding that they experienced on their own properties. Some may have even documented high water marks on the sides of their homes or businesses. Gathering this anecdotal evidence can be useful in planning for future events.

CONCLUSION

Climate data can be intimidating for professionals who lack a robust science background. Developing a basic understanding of the various types and sources of climate data and the many tools available to support decision making is crucial to both establishing existing vulnerability and planning for infrastructure that is resilient to more frequent and severe flooding. Planners' efforts to learn how climate data resources are created, who maintains them, and how they can be appropriately used is time well spent toward securing the safety of their communities.

But gathering information is just the first step. A wealth of climate data may be functionally useless if it is not applied to the planning process. The application of available information about future flood risk is especially important for making decisions about long-term infrastructure investments, adapting existing infrastructure assets, and siting and designing new infrastructure.

Once planners are armed with relevant climate data and appropriate decision-support tools, they can begin assessing the vulnerability of existing and proposed infrastructure in their communities. Chapter 3 discusses the vulnerability assessment process in detail, outlines specific use cases for climate information, and provides a framework for future planning and decision making that advances long-term infrastructure resilience.

CHAPTER 3

ASSESSING INFRASTRUCTURE VULNERABILITY

The previous chapter outlined how planners and allied professionals might go about finding data sources and using tools to better understand the potential local impacts of climate change. With this foundation in place, communities can use this information to more deeply assess the vulnerability of existing local infrastructure to more frequent and severe flooding, and to also make informed decisions about placing new infrastructure out of harm's way.

An infrastructure vulnerability assessment is a powerful and versatile tool for improving local resilience to climate change. These assessments can be used to

1. Define the baseline conditions of local infrastructure,
2. Establish the impacts of future flooding on this infrastructure,
3. Outline community needs for new infrastructure, and
4. Establish a process for ensuring that any new infrastructure is resilient to long-term climate impacts.

Assessing infrastructure vulnerability is less a defined stage within a rigid process of planning and implementation and more a tool that can be used, referred to, and built upon throughout the development of a plan; during selection of infrastructure projects for funding; and in the siting, design, construction, and maintenance of those projects.

Assessing infrastructure vulnerability to future flood impacts can also contribute to and be informed by social vulnerability factors. This can help improve environmental justice outcomes related to flood risk, project siting, and the delivery of services for underresourced communities. A holistic understanding of infrastructure vulnerability to climate change that integrates social vulnerability can help to safeguard those most at risk of impacts due to sea level rise, coastal storms, and extreme precipitation.

This chapter explains the process for assessing infrastructure vulnerability to more frequent and severe flooding due to climate change. First, it outlines the utility of infrastructure vulnerability assessments to the overall infrastructure planning and implementation process. This section defines the process by which planners and allied professionals can assess the vulnerability of infrastructure across a community through an inventory of existing assets, an evaluation of asset exposure and sensitivity to future flooding, and the outlining of an adaptation action plan. This process includes considerations for assessing existing assets that may require replacement or adaptive actions to increase long-term resilience to flood impacts. It also addresses assessing the vulnerability of new or proposed infrastructure in advance of project selection, siting, design, and funding.

This chapter also discusses the role of planners in integrating social vulnerability factors into the infrastructure vulnerability assessment process and outlines the importance of equity and environmental justice considerations to infrastructure planning and decision making. Finally, case study examples discuss how San Francisco and Toledo, Ohio, have approached assessing infrastructure and community vulnerability to flood impacts due to climate change.

INFRASTRUCTURE VULNERABILITY ASSESSMENT

For local practitioners, a vulnerability assessment is useful as a primary reference throughout the planning and implementation process. In the visioning stage, understanding infrastructure conditions and vulnerability to future flooding can help to inform long-term goal setting and build awareness around infrastructure deficiencies and climate threats among local stakeholders.

As part of the planning process, an infrastructure vulnerability assessment is critical to understanding existing infrastructure conditions, developing recommendations, and building specific goals, objectives, and action steps regarding the adaptation of existing infrastructure and the planning of new infrastructure assets. As part of the capital improvements planning (CIP) process, infrastructure vulnerability assessments can inform efforts to inventory and prioritize infrastructure projects for funding and development.

Finally, as a reference for the development of resilient infrastructure standards and guidelines, vulnerability assessments can be used to understand how factors such as sea level rise, coastal storms, and extreme precipitation can be factored into the siting and design of new infrastructure projects to ensure long-term resilience.

An infrastructure vulnerability assessment evaluates the exposure, sensitivity, and adaptive capacity of existing and planned infrastructure to climate impacts, allowing practitioners to create plans for adaptation (Figure 3.1). By considering both existing infrastructure assets and any planned or proposed projects, planners and the communities they serve can develop a strong understanding of infrastructure needs, community-wide risk, and the particular actions needed for specific infrastructure assets or systems.

Step 1: Inventory Existing Infrastructure Assets and Systems

Conducting an inventory of existing infrastructure assets and systems across the community is a critical first step toward assessing overall infrastructure vulnerability to more frequent and severe flooding due to climate change.

Generally, an infrastructure inventory lists and categorizes all infrastructure assets and systems for which a municipality is responsible. Table 1.2 in Chapter 1 (p. 16) can be helpful in understanding what infrastructure types to consider for inclusion. Age, condition, location, and any other pertinent or available information should be included in the inventory. Additionally, it is vital for local staff to identify in their initial inventory those assets that are a part of critical infrastructure systems. The inventory should be geocoded to allow for mapping and overlaying assets and systems with flood risk information.

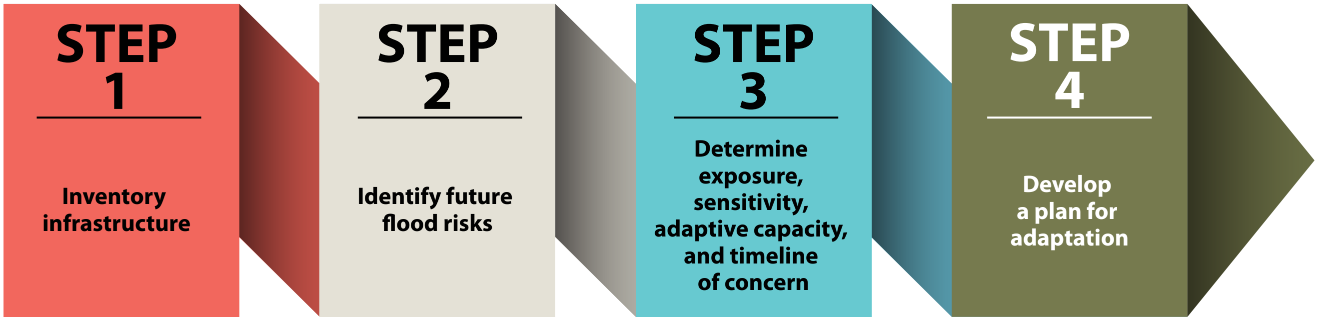
An infrastructure inventory likely will not need to be created from scratch. Planners can consult a recent capital improvements plan (if one exists); appendices and any documentation that was used to develop the CIP; and public works or infrastructure agency documents, databases, spreadsheets, and staff to obtain infrastructure lists, maps, and condition information.

An infrastructure inventory should also identify big-picture infrastructure needs, funded projects that have not yet been implemented, unfunded but planned projects, and potential infrastructure improvements that have been identified in local plans. By including these projects in an inventory, communities can gain a holistic understanding of not just what exists, but what may also exist in the near future. This information should also be geocoded, mapped, and categorized according to its status as planned but not yet constructed infrastructure.

Planners should consider working to standardize the inventory process for use across local agencies and departments. Aside from the foundation it provides for the vulnerability assessment process, a comprehensive and regularly updated infrastructure inventory can be a useful process improvement for a future CIP and a vital reference for any local planning efforts. It can also improve interagency coordination by ensuring all staff are working from the same master list of infrastructure assets.

Step 2: Identify and Assess Future Flood Risks

With an infrastructure inventory in hand, communities should outline and map any existing and future flood risks. The types of information that communities may seek out are



STEP 1

Inventory infrastructure

STEP 2

Identify future flood risks

STEP 3

Determine exposure, sensitivity, adaptive capacity, and timeline of concern

STEP 4

Develop a plan for adaptation

Figure 3.1. The process for conducting an infrastructure vulnerability assessment (Joseph DeAngelis)

outlined in more detail in Chapter 2 of this report, but generally, communities should identify and collect any data related to:

- Existing floodplains and floodways
- Floods of record
- Wetlands
- Ground elevation, especially areas of low elevation
- Storm surge inundation
- Sea level rise based on low, medium, and high scenarios
- Tidal flooding
- Stormwater and nuisance flooding

In conjunction with establishing general areas of vulnerability to existing and future flooding, communities should also work at this stage to establish a formal timeline of concern. In the case of infrastructure vulnerability assessment, this timeline should span several decades to account for the lifespan of local infrastructure assets and systems. Outlining areas of vulnerability based on a five-year projection may help establish near-term flood vulnerability, but a 30- to 60-year assessment of sea level rise inundation will be more helpful for understanding the cumulative risks posed to infrastructure over a more significant period of its useful life.

Organizing any collected information on both existing and future flood vulnerability can be a challenge. However, resources of the sort outlined in Chapter 2 can help to fill capacity gaps. Even if FEMA flood maps are the only available options, then some basic analysis and mapping can go a long way toward establishing the potential vulnerability of certain areas to future flood impacts. In this case, relying on the 500-year (or 0.02 percent annual chance) floodplain to delineate an area of vulnerability that is beyond the historic 100-year extent and may be susceptible to more intense and frequent flooding in the future can be a useful shorthand for a more in-depth analysis of sea level rise, ground elevation, or increasing precipitation. Similarly, for coastal communities, use of the National Oceanic and Atmospheric Administration's (NOAA) Sea Level Rise Viewer can outline potential areas of inundation due to sea level rise at a variety of potential timeframes and intensities. While a more in-depth analysis would be preferable, communities can still take these basic actions to outline areas of vulnerability.

The delineation of vulnerable areas based on the collected and mapped information should be overlaid with the mapped inventory of existing and proposed assets and infrastructure systems. This is a crucial element in understanding the exposure, sensitivity, and adaptive capacity of infrastructure that is outlined in the next step.

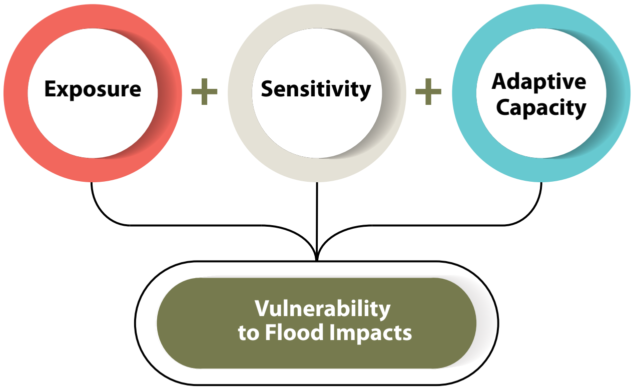


Figure 3.2. A project or asset's vulnerability to flood impacts is a product of its exposure, sensitivity, and adaptive capacity (Joseph DeAngelis)

Step 3: Identify Asset Exposure, Sensitivity, and Adaptive Capacity

To formally assess the vulnerability of infrastructure to increasingly frequent and severe flooding, communities must analyze the exposure, sensitivity, and adaptive capacity of infrastructure (Figure 3.2).

Exposure

Assessing the exposure of infrastructure to future flooding is a crucial component of establishing its overall vulnerability. *Exposure* refers to the degree to which an infrastructure asset or system is potentially endangered by hazards.

Exposure can be established by mapping the existing or planned infrastructure (identified and geocoded in the inventory) and overlaying this information with the locally appropriate existing and future flood hazards. Assets are then rated based on the degree of exposure to these flood hazards. An asset may be considered to have high exposure if it is anticipated to experience flooding based on historic flood extents or the likeliest near-term future flood scenarios due to sea level rise or heavy precipitation. Alternatively, the asset would be considered to have low exposure if impacts are not expected, even with extreme projections.

Planners should keep in mind that for specific assets that are part of a larger infrastructure system (such as wastewater facilities that collectively make up a local wastewater network), the high exposure of a single asset may compromise the integrity of the rest of the network.

In the case of new planned or proposed infrastructure projects, the process for evaluating exposure is similar to that of existing assets. Planned projects can be added to the overall inventory as needed, geocoded according to their planned locations, and evaluated for exposure to the selected future flood hazards.

Sensitivity

Next, infrastructure sensitivity should be evaluated. *Sensitivity* refers to how significantly an asset or system would be affected by flooding and the degree to which disruptions to services may impact the community.

Some pieces of infrastructure may easily return to full operation after flood waters recede, others may struggle to cope with repeated inundation (as may be the case with sea level rise and increasing rates of tidal flooding), and some may require extensive repairs following a single flood. A project with low sensitivity can easily recover after an event, whereas a project with high sensitivity may be costly or time-consuming to return to full capacity.

Compared with exposure, assessing sensitivity will likely require a more qualitative judgment. In this case, reliance on the inventory assessment can be helpful in parsing out an asset or system's age, its function, and its value to the community, especially as it relates to community safety and public health.

An example of a low-sensitivity facility may be an outdoor soccer field, which may not be considered a critical local asset, and for which flood waters may come and go with minimal damage. Higher-sensitivity assets may include wastewater treatment or emergency services facilities.

Given the likely critical role that these assets play in the overall health, safety, and welfare of a community, higher-sensitivity assets that are also significantly exposed to existing and projected future flood impacts must be extensively evaluated for their adaptive capacity, the final step in the vulnerability assessment process.

Adaptive Capacity

Finally, for existing or proposed assets that exhibit either moderate or high exposure or sensitivity, adaptive capacity should be assessed. *Adaptive capacity* is an infrastructure asset's ability to adjust to potential future flood impacts without the need for significant retrofitting. For example, a critical facility that is built on a floating dock will have more adaptive capacity to accommodate sea level rise than a ground-based structure.

In the case of a piece of planned but unconstructed infrastructure, design modifications that account for increasing flood risks can improve its adaptive capacity. However, in order to best account for future flood impacts over the project's life, the project planners, engineers, and other involved local staff must also identify the particular climate scenario to which the project will be sited and designed.

In the case of existing infrastructure that is expected to function well into the future, staff may have to develop an asset- or system-specific adaptation plan. These options are explored in the following step. For proposed projects or existing assets that already have a high adaptive capacity, more in-depth adaptation plans likely are not necessary.

To summarize, the process of assessing exposure, sensitivity, and adaptive capacity can be distilled into this series of questions:

TABLE 3.1. EXPOSURE, SENSITIVITY, AND ADAPTIVE CAPACITY ASSESSMENTS FOR COMMUNITY INFRASTRUCTURE ASSETS

Asset	Exposure	Sensitivity	Adaptive Capacity
Fire station	**High** (located in floodplain)	**High** (disruption could pose a danger to the community)	**Low** (structure is not elevated and would be difficult to retrofit for elevation)
Soccer field	**Low** (located in area not likely to flood now or in the future)	**Low** (disruption could be accommodated)	**N/A** (assessment not required given low levels of exposure and low levels of sensitivity)
School	**Medium** (located in area forecast to be vulnerable to sea level rise in 15 years)	**Medium** (valuable piece of built infrastructure, disruptions to which could impact residents over the medium to long term)	**High** (structure was designed and constructed at an elevation capable of accommodating the flooding from a 500-year storm event)

- **Exposure:** Where is the asset or project located? Is it likely to be inundated or impacted based on the available future flood impact data? If so, how soon?
- **Sensitivity:** How detrimental would the consequences of a flood event at this site be? How long would the disruption be if the asset or proposed project were to flood? Would that disruption threaten public health and safety? What would it cost to replace or repair the structure?
- **Adaptive Capacity:** Is it possible to design the structure so that costly adaptation at a later date would not be necessary, or so that small changes could be made over time when money becomes available and flooding becomes more extreme?

Table 3.1 (p. 42) provides sample outcomes for exposure, sensitivity, and adaptive capacity assessments for three hypothetical community assets.

A helpful complement to the process of assessing the exposure, sensitivity, and adaptive capacity is the addition of numerical scores. For exposure and sensitivity, these would be 1 for low, 2 for medium, and 3 for high assessments; for adaptive capacity, which is a positive feature, the scores would be reversed (i.e., 1 for high, 2 for medium, and 3 for low). This allows communities to quantitatively assess the overall vulnerability of a project or asset based on its score from 1 (not vulnerable) to 9 (most vulnerable). The city of San Francisco uses this ranking system as part of its capital infrastructure planning process. A deeper dive into San Francisco's process can be found in the case study beginning on p. 49.

Step 4: Developing Project Adaptation Plans

Once the slate of vulnerable infrastructure assets is identified, project-specific adaptation plans should be developed. It is important to note that plans to adapt specific assets or projects based on future climate scenarios are related to, but mostly distinct from, wider and more comprehensive community adaptation plans.

Project adaptation plans can be closely aligned with or developed as part of a community's CIP program. More detailed information on how project or system-wide adaptation can be incorporated into the CIP can be found in Chapter 5.

To develop project adaptation plans, communities should:

1. Create a list of the most vulnerable infrastructure assets and proposed projects.
2. Determine the lifespan of each asset or project.
3. Determine the adaptation strategies necessary for each at-risk asset or project over its lifespan.
4. Determine the budget for adaptation actions.
5. Determine responsible staff.
6. Outline a timeline for design and construction.

Developing infrastructure adaptation plans can be complex undertakings that will require the weighing of variables such as:

- The importance of a project or asset to health and safety
- The lifespan of the project or asset, including considerations regarding its design life versus its functional lifespan
- The particular climate scenario to which the project will be sited, designed, or in the case of existing infrastructure, retrofitted
- The timeline for completing the project or retrofitting the asset
- The budget for taking adaptation actions

Considerations surrounding the lifespan of the asset or project and the particular climate scenarios that will be used to inform siting and design are steeped in complex uncertainties. However, even communities without the capacity to develop complex site-specific climate projections can still develop project and asset adaptation plans that account for more severe and frequent future flooding.

Assessing the Lifespan of an Infrastructure Asset

The *design life* of a project is the period of time during which the asset is expected by its designers to work within its specified parameters. However, a project's design life likely assumes the community can afford a full replacement after the design life has ended. Often, projects must continue in operation long after they were intended to be replaced.

Rather than strictly focusing on the ideal design life of a project, it may be better to think in terms of *functional lifespan*. A project's functional lifespan is the realistic time frame in which the asset will be operational in a community. This is a more pragmatic assessment of how long a project or asset will be in service that anticipates challenging budgetary conditions and other future uncertainties.

Given the highly variable lifespans of different types of local infrastructure, cities should determine general benchmarks for how long local infrastructure is expected to remain functional. As an example, for the purposes of choosing the most accurate sea level rise scenarios, the city of Santa Monica, California, identifies "Anticipated Lifespan of Development" standards in the most recent coastal update to its local land-use plan. These benchmarks range from five years for temporary structures, to 25 to 75 years for roadways and bridges, to up to 100 years for water mains, storm drains, and electrical and gas infrastructure (Santa Monica 2018). While these are broad ranges, and more well-defined timeframes will need to be established in the project scoping and design phases, they provide a window of time for local staff to account for sea level rise early in the planning phase.

Gaining a sense of a project or asset's functional lifespan in one community will involve consulting the infrastructure inventory or local CIP that contains information on how long certain types of assets remain in service. With this information in mind, planners, engineers, and other local staff can begin to make some reasonable assumptions about how long new projects will be expected to remain in service, or how much longer existing assets and systems will be expected to be operational. By honestly assessing a project's realistic functional lifespan, local staff can then determine the time frame in which climate impacts may be expected. This information will be helpful in determining the climate scenarios to be planned for.

Establishing Climate Scenarios

Step 2 of the vulnerability assessment process outlines the types of flood hazard data that should be mapped in order to assess the overall exposure of the infrastructure assets identified in the inventory. This general assessment is intended to screen out those projects that are not likely to be exposed to existing and future flood impacts.

However, developing an adaptation plan for a project or asset requires more specific information that is based not only on its overall exposure to flooding but also on how critical it is to local health and safety, the scale of the investment, and its overall value to the community. For example, a community that is planning to adapt a wastewater treatment plant will likely want to consider planning for a higher sea level rise or more extreme scenario. This assessment may be based on the importance of the facility to public health; the time frame in which it is expected to operate; and the overall cost of the investment, which is likely to be significant. By planning for more significant impacts, communities can help to ensure enough leeway for critical investments if these less likely but more impactful scenarios play out.

The types of scenarios for which communities can plan for vary considerably between climate hazard types. NOAA has established defined sea level rise scenarios ranging from low to extreme based on the rate of greenhouse gas emissions through 2100 (Table 3.2). These figures are global averages, meaning they will vary at the regional and local scales. Additionally, they do not account for variables such as the frequency of coastal storms or intermittent tidal inundation. However, they are an extremely useful shorthand for coastal communities seeking to make project-specific decisions based on a wide range of potential impacts.

If used in conjunction with available mapping tools such as NOAA's Sea Level Rise Viewer (see Chapter 2) and reasonable assumptions about coastal storm impacts, high tide inundation, or any other identified local variables, this information can help coastal communities make decisions about how to site, design, and adapt their infrastructure to minimize risks associated with sea level rise.

TABLE 3.2. SEA LEVEL RISE SCENARIOS (IN INCHES) THROUGH 2100

Scenario Name	2020	2040	2060	2080	2100
Low	2.4	5.1	7.5	9.8	11.8
Intermediate-Low	3.1	7.1	11.4	15.7	19.7
Intermediate	3.9	9.8	17.7	28.0	39.4
Intermediate-High	3.9	11.8	23.6	39.4	59.1
High	4.3	14.2	30.3	51.2	78.7
Extreme	4.3	16.1	35.4	63.0	98.4

Source: NOAA 2017

For inland communities not at risk of sea level rise, future precipitation scenarios are more complicated to work with. As discussed in Chapter 1, observed trends in heavier and more frequent precipitation events across the country resulting in higher annual rainfall totals in the Northeast, Midwest, and Great Plains are likely to continue and worsen. However, the degree of these changes and the impacts they will have at the local scale are far more uncertain than those outlined in the sea level rise scenarios. This is primarily due to the influence that unpredictable atmospheric conditions such as storm tracks and circulation have on the location, intensity, and timing of precipitation events (USGCRP 2017).

Data for precipitation changes due to climate are largely available at the regional scale and generally based on either a lower (RCP4.5) or higher (RCP8.5) scenario, as seen in Figure 3.3. This is in contrast to the more fine-grained scenarios available for sea level rise.

Generally, communities choosing a precipitation scenario will have to make assumptions about the averages, rate, and frequency of precipitation over the functional life of a project. In making these assumptions, communities should refer to any existing data on regional or local average rainfall, local information on stormwater flooding, and the regional projections referred to in Figure 3.3 and available through the 2018 National Climate Assessment.

If the budget permits, it is often best practice to plan for a climate scenario more severe than anticipated, especially for projects considered critical to health and safety. Costs to retrofit an existing asset or adapt a new project may be greater given these considerations, but the longevity of the project is enhanced and overall risk is reduced. Projects could also be designed or retrofitted based on a lower or more moderate scenario, with the option to make more significant changes based on performance and climate impacts over time.

The formal process of developing a project adaptation plan is likely to occur in conjunction with an established infrastructure planning and implementation process, such as a CIP. More information on integrating infrastructure adaptation planning into CIPs can be found in Chapter 5 of this report. Generally, however, a project adaptation plan will be most useful in the project prioritization and funding recommendation stages of local capital improvements planning.

A similar process of vulnerability assessment and adaptation plan development is described in the NOAA publication *Adapting to Climate Change: A Planning Guide for State Coastal Managers* (NOAA 2010). Though that guide is written for state coastal managers and thus for a scale much larger than a single community or project, the overall process and considerations provided in that report should still help inform assessment and adaptation efforts at the local level.

SOCIAL VULNERABILITY ASSESSMENT: MOVING BEYOND INFRASTRUCTURE

Beyond its direct impacts on physical infrastructure assets, more severe and frequent flooding due to climate change can also expose a community's underlying inequalities. Existing issues of poverty; access to housing, transportation, and health resources; and a variety of other factors are likely to worsen as flooding due to sea level rise, more severe coastal storms, and extreme precipitation take their toll over the coming decades.

There are clear intersections between these factors, often referred to as a community's *social vulnerability*, and the vulnerability of physical infrastructure assets. The disproportionate provision of infrastructure, the failure to adequately maintain vital infrastructure, and the siting of industrial uses and polluting facilities in already at-risk and underresourced parts of a community all highlight the troubling history of environmental injustice that has contributed to underlying issues of poverty and inequality across the country.

As the impacts of climate change continue, and communities begin to assess the vulnerability of existing physi-

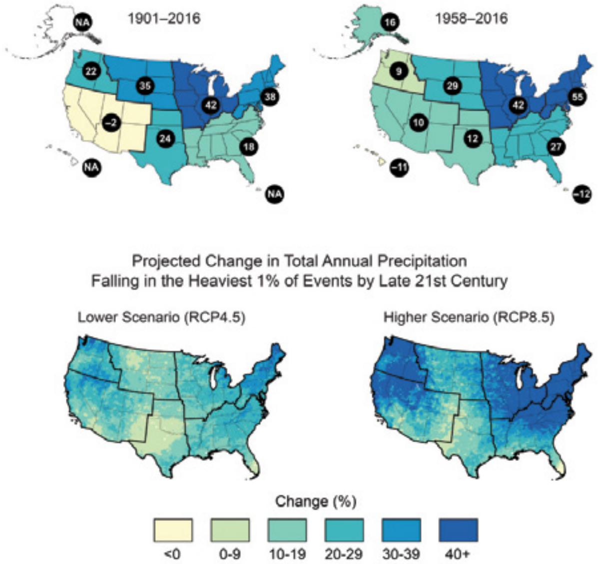


Figure 3.3. Observed (above) and projected (below) changes for total annual precipitation at the regional scale in the United States (USGCRP 2017)

cal assets and propose new infrastructure projects, they must also ensure that these projects are correcting legacy infrastructure inequities and are actively building the resilience of those parts of the community that are most at risk of climate change impacts. A social vulnerability assessment can be a critical first step in this process.

This section outlines the role of environmental justice in highlighting existing and long-standing infrastructure inequities, and it explores how assessing the social vulnerability of a community can advance local infrastructure resilience.

Environmental Justice and Social Vulnerability

Environmental justice is defined by the U.S. Environmental Protection Agency (EPA) as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations, and policies" (U.S. EPA n.d.b.).

Though the National Environmental Policy Act requires the consideration of environmental justice in the activities of all federal agencies, the movement for environmental justice goes well beyond just addressing federal actions. In the 1970s and 1980s, the environmental justice movement developed around the need to correct existing and deeply embedded disparities related to the effects of pollution and the siting of dangerous and noxious uses in or near impoverished communities and communities of color (Taylor n.d.).

Environmental justice as it relates to infrastructure refers to the need to correct this discriminatory legacy of infrastructure siting and service provision, and to reverse the exclusion of people of color, the poor, and underresourced portions of the community from the decision-making process. Additionally, environmental justice seeks to reverse the outsized and disproportionate burden of environmental hazards (which can include climate change) that is often borne by the people and communities that are least responsible for causing them.

Existing social vulnerabilities, such as poverty or inadequate access to transportation and housing, can be a legacy of environmental injustice. This legacy in turn relates to underlying vulnerabilities related to long-term climate change impacts. Impoverished neighborhoods, communities, and populations will be forced to endure more persistent flooding and will likely face ever-increasing timelines and costs for recovery. As the rate and severity of flooding increases, populations may decline, further isolating those residents with the least capacity to relocate. Over time, the provision of services, the maintenance of infrastructure, and the resilience of that infrastructure to more frequent climate impacts may become even less of a priority than before. Therefore, understanding how the social vulnerability of a community intersects with the vulnerability of its infrastructure is crucial to not only addressing the resilience of a community as a whole, but also demonstrating that planners and decision makers hold equity as a community value.

By assessing social vulnerability, planners can help to identify how the lack of infrastructure (or the siting of actively harmful infrastructure) has contributed to persistent inequalities, and to identify the parts of a community that are most at risk of more frequent and severe flooding. In concert with the assessment of long-term infrastructure needs and vulnerabilities, an assessment of social vulnerability can help communities to make more educated decisions about local infrastructure needs and adaptation measures that can serve those stakeholders most at risk of future flood impacts.

Integrating Social and Infrastructure Vulnerability Assessments

Planners can play a critical role in assessing local social vulnerability to more frequent and intense flood events due to climate change. They can also help to ensure essential linkages to the infrastructure vulnerability assessment process.

A full explanation of the social vulnerability assessment process is beyond the scope of this report, but the steps outlined below provide a basic overview of this process. The sidebar on p. 48 provides some additional resources for planners to learn more about this approach. An outline of the process provided below explains how planners can spatially assess social vulnerability and how they can then integrate this information with infrastructure vulnerability assessments.

Identify categories. A social vulnerability assessment should be inclusive of a wide variety of potential factors. It may be helpful, however, for planners to conduct the initial analysis based on four general categories and consider the roles that these factors may play in the ability of the community to adjust to climate-related flood impacts. These factors are:

- *Socioeconomic status*: Are there members of the community who, due to lack of essential resources, will be unable to recover or will experience prolonged hardships in the post-flood recovery phase? Are they unable to afford flood insurance, or do they live in residences that are not covered by flood insurance? Will they struggle to relocate because they cannot afford new housing?
- *Household composition, age, and disability*: Are there members of the community who, due to age or disabilities,

cannot access vital services before, during, and after flood events? Are they at risk of more severe impacts due to their potential inability to evacuate or adequately prepare for major flooding?

- *Race/ethnicity/language:* Are there members of the community without access to vital services before, during, and after a flood event due to entrenched racial, ethnic, or language barriers? Are there areas of the community, due to legacies of segregation and inequitable access to housing, that are especially vulnerable to major flooding, sea level rise, and related environmental risks?
- *Housing and transportation*: Are there areas of the community in which the condition or location of housing is especially vulnerable to major flooding, sea level rise, and related environmental risks? Are there areas of the community without robust access to the transportation network that may be necessary in the event of flood-related evacuation or the provision of emergency services? Would the existing transportation network that serves these areas be subject to more impactful flooding that may preclude evacuation or access by emergency services?

These categories are identified in the Center for Disease Control's Social Vulnerability Index tool (see sidebar on p. 48), the use of which may be helpful to simplify later stages in this process. These categories should be tailored to fit local conditions and account for individual community context.

Identify social vulnerability data sources and map the data. Following the identification of categories for the assessment, planners should identify sources of data. The most recent U.S. Census and American Community Survey (ACS) data is a reliable primary source of information on socioeconomic status, household composition, disability, race, age, ethnicity, language, housing status, and transportation. Other local data sources maintained by the municipality, data collected by local universities, or data and tools developed by regional organizations or state agencies related to the identified categories may also be helpful.

Census and ACS data should be mapped at the census block or tract level. This will require the use of GIS software. To the extent that it is possible, any other data sources should be geocoded and mapped as well. Ultimately, the goal of this stage is a spatial evaluation of where the most vulnerable populations are currently located within a jurisdiction.

Overlay social vulnerability data with identified areas of risk and infrastructure inventory data. The mapped social vulnerability data should be overlaid with the mapped hazards and future risk data that was used in the infrastructure vulnerability assessment. This may include existing FEMA flood maps, areas of storm surge inundation, areas at risk of sea level rise, local data on stormwater and nuisance flooding, and any other flood-related hazards considerations.

More detail on the types of hazards and the potential data sources for these hazard types can be found both in Chapter 2 and in this chapter's section on conducting an infrastructure vulnerability assessment. This information is critical to conducting an analysis of the relationship between social vulnerability, infrastructure access, and future flood impacts.

Analyze social vulnerability in the context of infrastructure needs and future flood risks. This stage in the assessment concerns how to integrate the social vulnerability and infrastructure vulnerability assessment processes. Generally, this analysis should focus on the impacts of more severe and frequent flooding on a community's most vulnerable populations. Additionally, communities should identify the primary infrastructure gaps in areas of social vulnerability, including information on infrastructure age and condition, and any planned infrastructure projects, especially those addressing current and future flood risk.

Integrate the social vulnerability assessment into existing infrastructure planning processes. Much like the infrastructure vulnerability assessment, findings from the social vulnerability assessment should be used to inform the infrastructure planning and decision-making process. Integrating vulnerability assessments into the local CIP process is discussed in Chapter 5 of this report. Communities should consider social vulnerability in the process of infrastructure project prioritization and selection, and planners can and should lead the way in identifying and implementing ways to do so.

INFRASTRUCTURE VULNERABILITY ASSESSMENTS IN ACTION

Infrastructure vulnerability assessments are becoming increasingly common across the United States. San Francisco has developed a process deeply integrated into the city's capital planning program that empowers agencies and project managers to assess the vulnerability of proposed infrastructure projects to sea level rise impacts. In seeking to increase its use of green infrastructure across the city, Toledo, Ohio, used risk and vulnerability assessments to improve the siting of natural infrastructure, reduce long-term maintenance needs, and improve outcomes for the community. This city

COMMUNITY VULNERABILITY ASSESSMENT TOOLS

Several organizations and researchers have developed community vulnerability assessment tools to help identify vulnerable populations. Planners can use these tools to better assess risk to these populations and allocate appropriate support and resources to them in times of need. Below are three examples of these tools.

The Social Vulnerability Index

Since its inception, the Social Vulnerability Index (SoVI) has been considered a standard for social vulnerability assessment for both academics and professionals. Currently in its third edition, the SoVI was developed by Susan Cutter, PHD, at the University of South Carolina's Hazards and Vulnerability Research Institute. It is intended to measure social vulnerability to environmental hazards at the county level.

This index synthesizes 29 socioeconomic variables identified in the research as relevant to hazards, including family structure, housing status, and access to medical services. Much of the data comes from the U.S. Census Bureau. The numeric score that results from this analysis is a relative score when compared with other counties, which may be a limitation of this tool. The index outputs statewide maps that display relative vulnerabilities of each county compared with others within that state and nationally.

The sensitive nature of much of the data most relevant to social vulnerability makes measuring such vulnerability extremely challenging. Some metrics, especially those pertaining to health, are protected by patient confidentiality agreements. Therefore, many social vulnerability evaluations are unable to assess at a more granular level than county or census block. The SoVI may be most useful to a community because it has vetted many variables with robust academic research and found those that are most valuable and associated with available existing datasets. Local planners may choose to use those variables to conduct their own analyses.

The SoVI may be accessed at http://artsandsciences.sc.edu/geog/hvri/sovi%C2%AE-0.

Centers for Disease Control and Prevention's Social Vulnerability Index

In many cases, the public health field has taken the lead on social vulnerability to shed light on the needs of populations suffering the most due to climate-related hazards. The Centers for Disease Control and Prevention (CDC) has been a leader in this effort and maintains an interactive web map illustrating county-level vulnerability.

The CDC's Social Vulnerability Index (SVI) has four themes: socioeconomic status, household composition, race/ethnicity/language, and housing/transportation. For disaster events, this database can be used to estimate amounts of needed supplies, such as food, water, medicine, and bedding; help decide how many emergency personnel are required to assist people; identify areas in need of emergency shelters; plan the best way to evacuate people, accounting for those who have special needs, such as people without vehicles, the elderly, or people who do not understand English well; and identify communities that will need continued support to recover following an emergency or natural disaster (ATSDR 2018).

The SVI may be accessed at https://svi.cdc.gov.

Community Based Vulnerability Assessment Guidebook

The *Community Based Vulnerability Assessment Guidebook* was developed by the University of North Carolina's Institute for the Environment with support from a FEMA grant. The greatest strength of this tool is that it lays out, in a step-by-step fashion, a process through which planners can engage their communities and complete a comprehensive assessment of environmental vulnerability.

This guidebook is especially useful in that it offers a community-based approach that assesses both physical and social vulnerability in one document. It also provides thoughtful advice about how to meaningfully engage those community members who often suffer the most after a disaster but are never brought to the table to develop policy.

The guidebook breaks tasks into discrete actions in a logical, easy-to-follow progression. However, because it is a static document, it may not be as interactive as other web-based tools, and because it was developed in 2009 some portions may be outdated. Regardless, it stands as a well-developed and thoughtful tool that urban planners should consider.

The guidebook may be accessed at www.mdcinc.org/wp-content/uploads/2017/11/Community-Based-Vulnerability-Assessment.pdf.

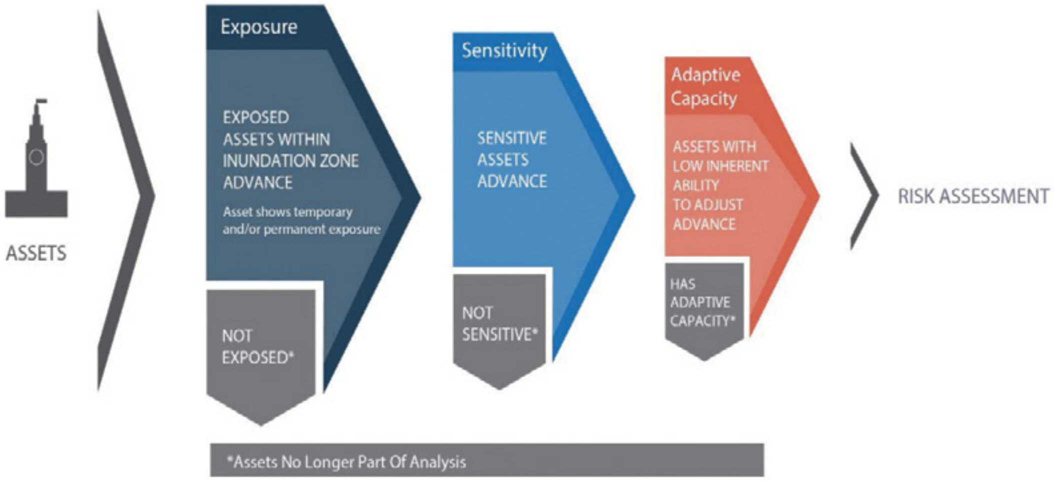


Figure 3.4. San Francisco's asset vulnerability assessment process (City and County of San Francisco Sea Level Rise Committee)

has also delved into social vulnerability assessment to better quantify flood impact risks within the community.

These cases outline the methods and processes each community developed to better assess the risks posed by future flooding to local infrastructure as well as residents.

Assessing Sea Level Rise Impacts: San Francisco

As San Francisco is a city surrounded on three sides by the Pacific Ocean and San Francisco Bay, planning for sea level rise is a necessity. In 2014, the Capital Planning Committee (CPC) for the City and County of San Francisco adopted a document, *Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco: Assessing Vulnerability and Risk to Support Adaptation* (San Francisco 2015), to rationalize standards and processes for public investments potentially affected by sea level rise and storm surge. This guidance primarily seeks to clearly assess the risks posed by sea level rise and storm surge to coastal infrastructure and integrate these considerations into the capital planning process.

To simplify the assessment process, the city first selected regional sea level rise estimates that would be used as an authoritative reference for any involved agencies, staff, and project managers. These estimates were drawn from the National Research Council report, *Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present and Future* (NRC 2012b).

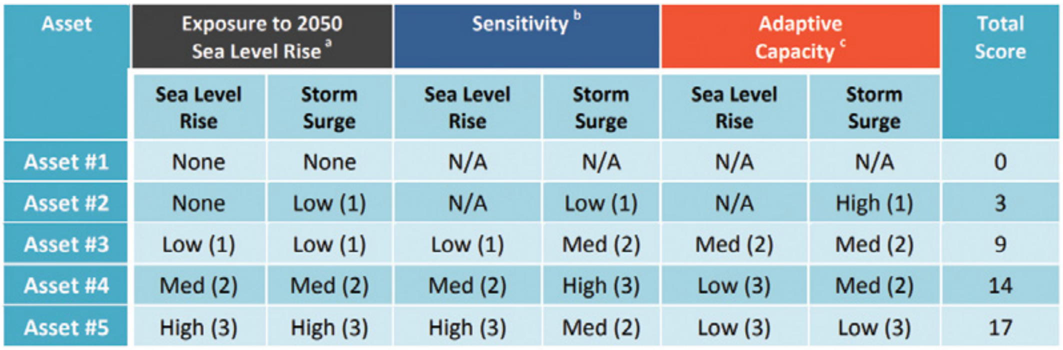
After choosing a reliable data source, the city determined which projected scenarios should be applied to its capital infrastructure projects. The CPC's Sea Level Rise (SLR) Committee recommended using the upper end of the estimates in the NRC report, as it found lower global GHG emission scenario estimates to be unrealistically optimistic. The SLR Committee also elected to account for storm surge and waves in their selected scenarios.

For specific location information, the committee selected inundation maps created by the San Francisco Public Utilities Commission that included highly accurate assessments of ground elevations along the coast. With these data sources identified and mapped, projects can be assessed for vulnerability to sea level rise and storm surge impacts.

Assets, either existing or proposed, are subjected to a three-stage analysis to determine (1) whether they are exposed to flooding from sea level rise and storm surge, (2) whether they are sensitive to such threats, and (3) whether they contain adaptive capacity that will allow them to withstand or ameliorate that threat (Figure 3.4).

If an asset is not exposed or sensitive to sea level rise or storm surge impacts, or if it contains the adaptive capacity to withstand these impacts, it drops out of the ranking process as not needing further attention. For each asset that remains, exposure, sensitivity, and adaptive capacity are each rated on a scale of one to three. It is important to note that low scores in exposure and sensitivity are considered to be favorable and preferred, while low scores in adaptive capacity are unfavorable. Likewise, high scores in exposure and sensitivity are unfavorable, while a high adaptive capacity score is favorable and preferred. Total scores for each asset allow for the ranking of projects based on their overall vulnerability to sea level rise and storm surge impacts (Figure 3.5, p. 50).

Following the assessment of exposure, sensitivity, and adaptive capacity, project life cycles are analyzed during the development of project-specific adaptation plans. The project



Asset	Exposure to 2050 Sea Level Rise [a]		Sensitivity [b]		Adaptive Capacity [c]		Total Score
	Sea Level Rise	Storm Surge	Sea Level Rise	Storm Surge	Sea Level Rise	Storm Surge	
Asset #1	None	None	N/A	N/A	N/A	N/A	0
Asset #2	None	Low (1)	N/A	Low (1)	N/A	High (1)	3
Asset #3	Low (1)	Low (1)	Low (1)	Med (2)	Med (2)	Med (2)	9
Asset #4	Med (2)	Med (2)	Med (2)	High (3)	Low (3)	Med (2)	14
Asset #5	High (3)	High (3)	High (3)	Med (2)	Low (3)	Low (3)	17

Figure 3.5. Sample exposure, sensitivity, and adaptive capacity assessments and scores based on both sea level rise projections and potential storm surge inundation (City and County of San Francisco Sea Level Rise Committee)

or asset's expected service life is compared with the available climate projections to determine the degree of adaptation that will be necessary. The longer a project is expected to remain operational, the longer is the range of sea level rise projections used.

With this information in hand, project managers are expected to outline a series of adaptation actions. These actions could include changing the location of a project, elevating the project, or hardening the project to flood impacts. The vulnerability assessment and the adaptation plans are organized by each responsible agency and then submitted to the CPC for review and potential inclusion in the city's overall capital expenditures package.

San Francisco's process is notable for attempting to standardize the overall process of vulnerability assessment and to integrate it more deeply into existing capital planning procedures. Most of the work of assessment falls to individual project managers tasked with overseeing the operations of particular infrastructure systems and assets. The process of standardization is intended to remove the guesswork and complexity of dealing with climate science, allow project managers to make decisions about the infrastructure systems and assets they know best, and reduce the process of assessment to a series of standardized forms. The city's focus on making vulnerability assessment a standard part of the job has aided its overall adoption and success.

The infrastructure vulnerability assessment process outlined at the beginning of this chapter is drawn from San Francisco's approach as a comprehensive and scalable way of determining the vulnerability of infrastructure assets and sectors to more frequent and severe flooding due to climate change.

More information on San Francisco's vulnerability assessment process is available at http://onesanfrancisco.org/node/148. An associated document, the city's Sea Level Rise Checklist, is provided as an appendix to this report.

Stormwater Flooding and Green Infrastructure: Toledo, Ohio

While Toledo is not subject to sea level rise, flooding is no less a concern for this Great Lakes city. Toledo is vulnerable to riverine flooding due to its proximity to the mouth of the Maumee River where it meets Lake Erie, along with the more typical stormwater and nuisance flooding experienced in cities across the United States. Flooding in Toledo is also closely linked with Great Lakes water levels, as well as its location at the very tip of a large hydrologically altered watershed.

With increasingly heavy and more frequent rain events, basement flooding, decreased water quality, and standing water have become commonplace in the city. To address these concerns sustainably, affordably, and with minimal adverse impact, Toledo officials chose to assess the viability of nature-based solutions for stormwater flooding. Such solutions are often referred to as *green infrastructure*, and include elements such as bioswales, rain gardens, and green roofs. These vegetative landscapes allow deeply rooted plants to absorb and filter water, reducing flooding as well as the need for excessive chemical water treatment procedures.

However, green infrastructure projects must be sited appropriately to maximize their utility, and plans need to be made for their long-term maintenance. Neglecting green infrastructure projects can significantly limit their stormwater holding capacity. Poorly maintained green infrastructure can also be aesthetically displeasing, which can reduce public support for these projects.

Toledo's process of evaluating the potential for green infrastructure began with a partnership between the city, the Association of State Floodplain Managers, NOAA's Office for Coastal Management, the U.S. Army Corps of Engineers, and the Eastern Research Group, Inc., funded by a Great Lakes Restoration Initiative grant through NOAA's Office for Coastal Management. The intention of this partnership was

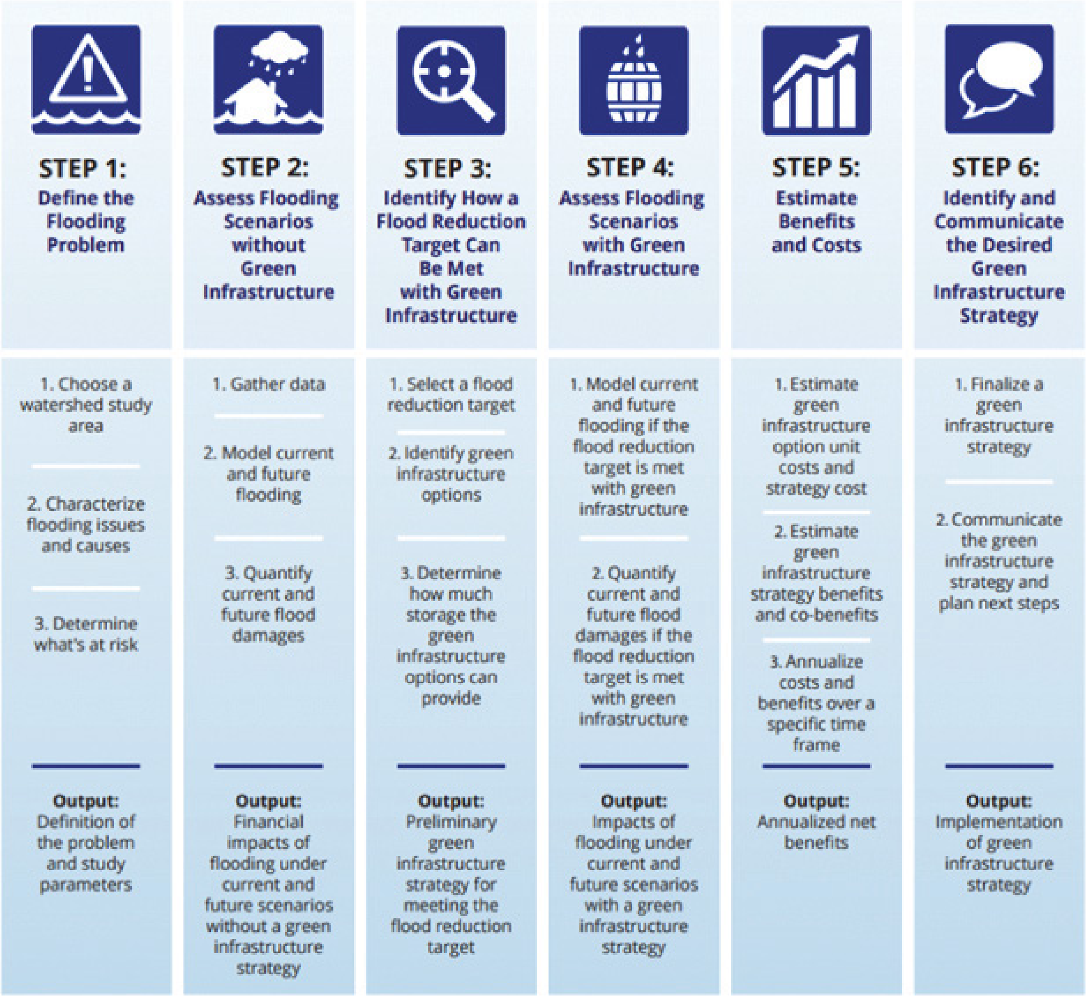


Figure 3.6. The six-step process for evaluating how green infrastructure can help communities reduce flooding and estimate the costs and co-benefits of green infrastructure (NOAA 2015)

to develop a guide to identify flood issues and evaluate potential costs and benefits of nature-based solutions.

In order to quantify projected changes in precipitation in Toledo, which would inform the extent to which green infrastructure solutions could reduce flood impacts, the team used the U.S. EPA's Climate Resilience Evaluation and Assessment Tool (CREAT) (U.S. EPA n.d.a.). CREAT guides users through five modules to review historic climate conditions for an area, evaluate how those conditions may change, identify critical community assets (such as water bodies, buildings, and communications infrastructure), and compare different adaptation strategies to find those that are most effective and affordable. CREAT is particularly useful as an awareness-building tool that can provide rationales and build support for adaptation planning for specific utilities. It guides the user through each step, offering directions and links for more information, but may be most effective if completed by an informed user such as an engineer or public works official.

The five modules of the CREAT tool are Climate Awareness, Scenario Development, Consequences & Assets, Adaptation Planning, and Risk Assessment. The user begins by creating a summary report of historic climate statistics and how they are anticipated to change for a particular region. The user identifies key assets within the community and estimates the time period for which each asset will be relevant (for example, the design life of the structure).

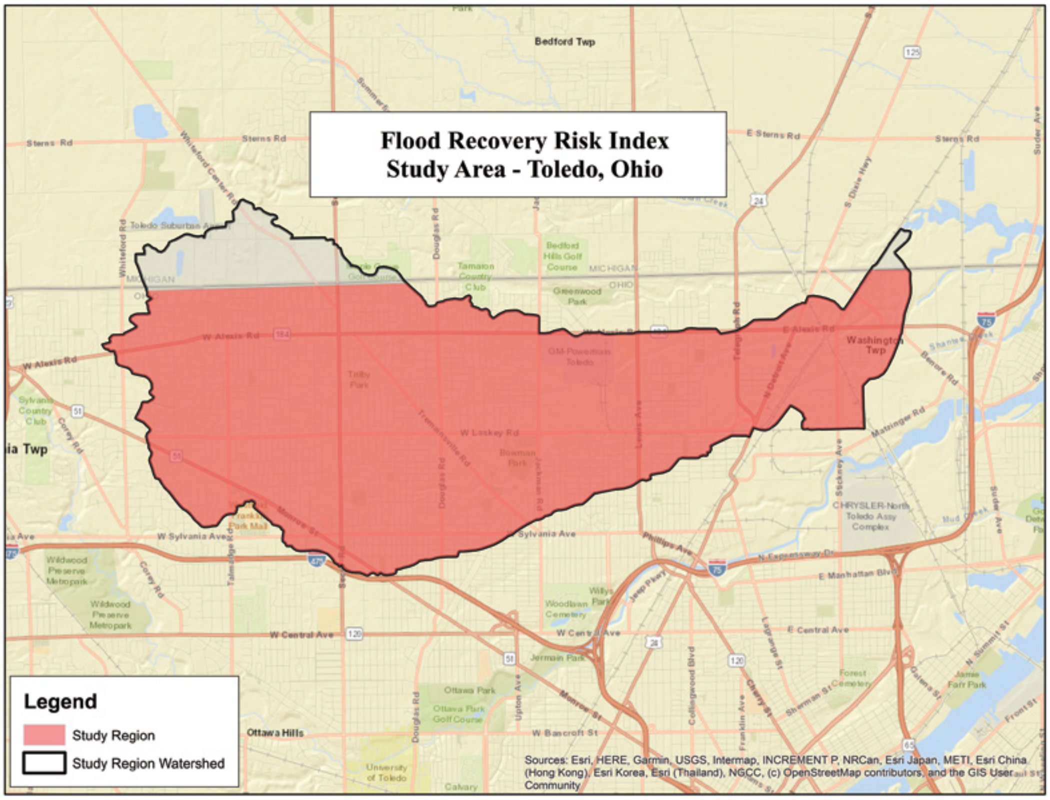
Users also describe current adaptation strategies being implemented in the community as well as potential strategies that could be explored in the future. Ultimately, users may download intuitive tables and charts related to their community's infrastructure that may be used to convince stakeholders or officials of the value in climate adaptation planning.

The city used CREAT to create a table of projected changes in annual precipitation to gain a sense of the extent of potential negative scenarios. Planning for the most extreme scenario of precipitation increase ensures that all other more moderate scenarios will also be accounted for.

Toledo followed a six-step process for evaluating the potential of green infrastructure solutions (Figure 3.6, p. 51), along with two other communities, which ultimately led to the development of NOAA's *Guide for Assessing Green Infrastructure Costs and Benefits for Flood Reduction* (NOAA 2015). While the specifics of this process differ somewhat from the vulnerability assessment process outlined in this chapter, there are similar principles underlying both approaches. For example, the need to define the scope of the geography, the scale and expected severity of flood hazards, and the risks these hazards pose to the community lie at the core of both the NOAA process and the process recommended in this chapter.

An important aspect of this process is choosing a manageable scope for analysis. Toledo chose to explore only one of its watersheds—the highly urbanized Silver Creek watershed, which drains into Lake Erie. Next, the city quantified flood damage under current conditions and extrapolated CREAT data to estimate future damage. Keeping good records of current flooding is very helpful as baseline data in conducting such an analysis. Then it chose quantifiable and specific goals for flood reduction—in this case, a 10 percent flood reduction target. Finally, it identified all potential green infrastructure options and estimated the costs and benefits of such a strategy.

Being able to argue for a strategy's financial benefit is very powerful. In many cases, green infrastructure and other nature-based infrastructure solutions may be better suited to withstanding dynamic flood conditions than fixed gray infrastructure. If a green infrastructure strategy can be shown to minimize damage to such a degree that it outweighs the costs of installing and maintaining the green infrastructure, it is a viable option. The co-benefits of green infrastructure beyond flood resilience, such as improvements to air and wa-



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 3.7. Study area, Silver Creek Watershed, Toledo, Ohio (Association of State Floodplain Managers)

ter quality, can help to build the case further for nature-based infrastructure over traditional gray infrastructure.

As a result of this analysis, Toledo applied for funding through the U.S. EPA to develop several bioswales in the Silver Creek watershed, and it also was able to increase outreach about green infrastructure and its associated benefits.

More information on the U.S. EPA's CREAT tool can be found at www.epa.gov/crwu/creat-risk-assessment-application-water-utilities.

More information on NOAA's *Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction* can be found at https://coast.noaa.gov/digitalcoast/training/gi-cost-benefit.html.

Flood Recovery and Social Vulnerability: Silver Creek Watershed, Toledo, Ohio

The issue of social vulnerability and its accurate assessment at the neighborhood scale is gaining interest among both academics and hazard mitigation professionals. In 2019, the Association of State Floodplain Managers, the Polis Center at Indiana University–Purdue University Indianapolis, and the University of Wisconsin Space Science and Engineering Center conducted a study that sought to address this issue within the Silver Creek watershed in Toledo.

The purpose of this study was to use detailed economic and infrastructure data to determine neighborhoods within the Silver Creek watershed that are more likely to experience long recovery times following a flood event. Researchers focused specifically on residential structures (single family homes, mobile homes, duplexes, and triplexes) within FEMA's National Flood Insurance Program's one-percent flood boundary (Figure 3.7, p. 52). Using these criteria, 719 structures were identified for evaluation.

The study approach assumed that recovery is primarily tied to the economic vitality of the impacted person, rather than age or other social characteristics. The specific metrics examined were structure-specific data (including value of property, height of first floor, and mortgage status), household economic vitality, flood insurance status, and property equity of homeowners.

Household economic vitality was approximated using debt-to-income ratio at the census block level. "Cost-burdened" households—those in which more than 35 percent of monthly income is required to pay for monthly owner costs—were households considered at risk. Monthly owner costs included mortgage, real estate taxes, insurance, utilities, and similar expenses.

Flood insurance status is highly relevant to a homeowner's ability to recover after a flood. Access to individual locations of National Flood Insurance Program or privately held insurance policies is restricted, however, so for the purposes of the study, researchers made the assumption that if homeowners had a mortgage and were located in the one percent annual chance floodplain, they had flood insurance. Property equity of homeowners was evaluated by considering the distribution of market values in the study area, assuming that if a home is valued higher, the owner has increased ability to sell their property and recover some costs.

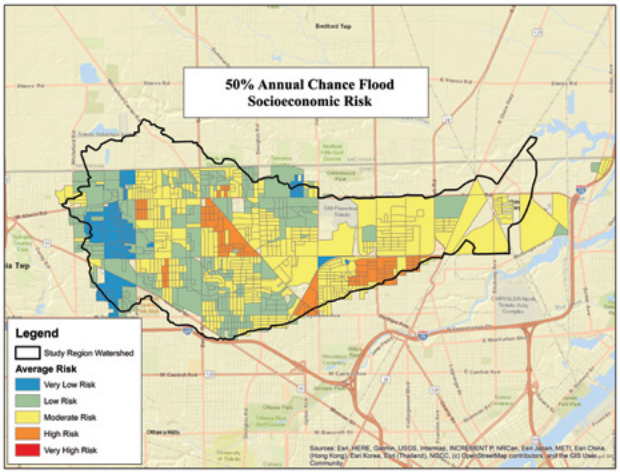


Figure 3.8. Model output for 50 percent annual chance flood, indicating five key vulnerable areas (Association of State Floodplain Managers)

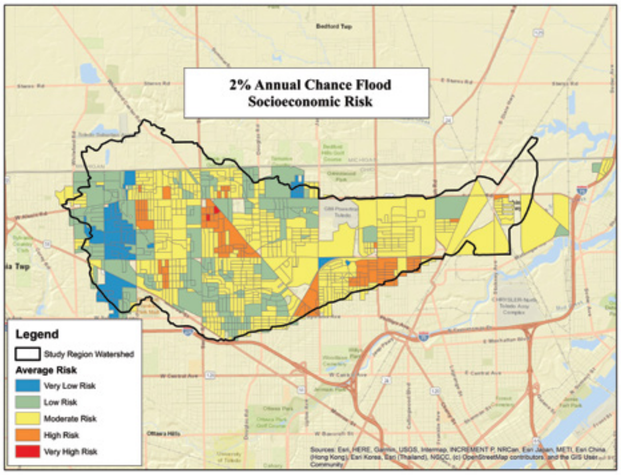


Figure 3.9. Model output for two percent annual chance flood, indicating five key vulnerable areas (Association of State Floodplain Managers)

Both of the above assumptions illustrate the limitations of available datasets and represent potential approaches for communities to consider if undertaking a similar assessment for which specific data sources are unavailable. Communities should clearly describe their methods and approach in any documents or graphics and ensure that the public, elected officials, and other local staff are aware of how these assumptions factored into the overall assessment.

Mental health is also an important aspect of an individual's ability to recover from flood events, but it is one of the most difficult metrics to measure accurately. Many factors contribute to or take away from an individual's personal mental resilience. This study initially attempted to address mental health by using physical proximity to mental health facilities, a variable that has been found helpful in rural settings. However, due to the urban nature of the study area, there was an abundance of mental health facilities nearby, and this metric was eliminated from the final study. For similar studies in other locations it may be worthwhile to consider this metric.

All of these described variables were spatially represented within the study area, assigned a standardized risk value, and combined with flood depth grids for six flood scenarios: the 50 percent, 20 percent, 10 percent, four percent, two percent, and one percent annual chance floods. Two of the resulting maps are shown in Figures 3.8 and 3.9 (p. 53).

In both cases, five distinct areas were identified as having the greatest risk, based on these chosen metrics. Researchers determined that the areas with the highest likelihood of long recovery times following a flood event do not change significantly with differently sized storms. This suggests that the variables in this model are most strongly correlated with underlying features of vulnerable households, rather than the intensity or scale of the storm or flood itself. Therefore, by better understanding both household-level vulnerability and those areas with higher concentrations of vulnerable households, planners can pursue strategies that offer resiliency benefits across the widest possible array of storm and flood events.

While this is a preliminary attempt to quantify risk, there are many potential variables to be considered regarding hazard vulnerability. Furthermore, the accuracy of models such as the one employed in this study is heavily dependent on the quality of data inputs. As granular data sources become more widely available, it is expected that studies such as this will become more reliable and useful for communities to use in planning for hazards and reducing risk for vulnerable populations.

CONCLUSION

Assessing the vulnerability of infrastructure to future climate risks can be a complex and somewhat daunting process. However, understanding how these risks may impact existing infrastructure assets, planned infrastructure projects, and the people that infrastructure is intended to serve is vital to long-term community health and well-being.

Rather than getting lost in the potential uncertainty of climate change impacts, planners can bring to bear the available data on existing flood hazards and potential future flood risks with an eye toward holistically assessing the vulnerability of existing infrastructure assets and planned infrastructure projects. Together with a thorough assessment of the social vulnerability of a community, with particular attention paid to the legacies of environmental injustice and persistent inequities related to the provision of and access to critical infrastructure and services, planners can then turn toward a wider integration of local vulnerability into local planning and plan-making processes.

CHAPTER 4

PLANNING TOOLS FOR INFRASTRUCTURE RESILIENCE

Communities tend to organize themselves around different plans of widely varying topics and time frames. Comprehensive plans, open space and recreation plans, hazard mitigation plans, climate adaptation plans, neighborhood or area plans, and plans for specific infrastructure systems (such as stormwater or transportation) are all potentially part of the local universe of plan types that communities might develop. Communities may also participate in larger regional planning exercises with other municipalities to coordinate on issues such as transportation, housing, and natural resources and the environment.

Planning for infrastructure that is resilient to more frequent and intense flooding will require the use of all planning tools at a community's disposal. However, this can be a complex and challenging exercise. Levels of staff expertise, capacity, and funding can limit a community's ability to substantively consider long-term infrastructure needs. Adding climate change, sea level rise, extreme weather, and natural hazards (and the inherent uncertainties of impact and time frame) to the equation further complicates efforts to align and integrate planning procedures.

This chapter will guide planners through the strategies and tactics that they can use to effectively plan for infrastructure that is resilient to more frequent and intense flooding. First, this chapter will discuss community visioning and engagement in the context of infrastructure resilience, equity, and inclusion. It will then outline the role of regional planning for infrastructure and future climate impacts, and guide planners through the strategies for getting involved in regional planning processes and in using regional plans at the local level.

Next, this chapter will take an in-depth look at the ways in which the comprehensive plan can be used as an essential tool in determining infrastructure needs and risks across communities and outlining an actionable framework for long-term infrastructure resilience and adaptation. The chapter concludes with a discussion of how functional plans such as hazard mitigation plans, climate adaptation plans, open space plans, and infrastructure plans can bridge planning and implementation by integrating future flood risks and impacts into specific plans for infrastructure systems.

COMMUNITY VISIONING AND ENGAGEMENT

A community visioning exercise is often used at the beginning of a planning process to establish a shared understanding of a community's desired future. In conjunction with active community engagement, a visioning process tends to conclude in a statement or series of statements that summarizes where a community wants to be within a specific timeframe, generally 20 to 25 years.

Visioning can also function as a stand-alone exercise addressing a specific set of issues or concerns about the future. For example, a visioning process could be organized around a more specific set of challenges related to the impacts of climate change upon a community.

The following strategies outline how planners can approach a visioning and engagement process on long-term infrastructure resilience.

Engage the broadest possible set of local stakeholders. Visioning should engage as broad an array of community stakeholders as possible and should include special efforts to amplify the voices of traditionally underrepresented residents, stakeholders, and organizations. Visioning should engage elected officials and should include the participation of other city agencies that will be vital to later stages of the planning and implementation process.

While involving a broad base of participants is a best practice in any visioning process, ensuring the inclusion of underrepresented groups, stakeholders, elected officials, and local staff when discussing infrastructure needs in light of future climate risks is vital to guiding subsequent planning processes. This can help to establish a strong foundation for a community's later plans and ensure that local action on infrastructure is grounded in the lived experiences of stakeholders and informed by local needs and future climate risks.

Understand the audience. Effective public engagement, particularly in the context of a far-ranging visioning exercise, requires a thorough understanding of one's audience. Residents, stakeholder organizations, and interest groups are rarely homogenous in their opinions and thoughts on a community's future, the causes or risks of climate change, or the long-term needs of infrastructure in light of more frequent and severe flood impacts. Planners must be prepared to understand the perspectives offered by a wide variety of participants and to discuss infrastructure resilience in the context of these perspectives.

With a strong understanding of stakeholder perspectives and viewpoints, planners can begin to chart a path toward consensus based on shared values that is critical to the ultimate development of a community-wide vision for infrastructure resilience.

Communicate climate science, information, and impacts as clearly as possible. Planners should be prepared to communicate the risks posed to infrastructure by more frequent and severe flooding as clearly as possible. Communicating climate risks and potential impacts can be a difficult task, especially in communities where planners themselves struggle to identify or interpret complex climate projections and data sources. However, this perspective may ultimately be helpful in working to reduce complex concepts surrounding infrastructure and climate to plainer language.

Harnessing local knowledge about existing hazards can be crucial in this stage, particularly in communities that are already at risk of flooding due to coastal storms and extreme precipitation. To the extent possible, planners should seek to discuss future flood risk in the context of existing flooding, outline the ways in which climate change is likely to exacerbate historical hazards, and discuss the potential impacts this may have on infrastructure and communities as a whole.

Translating complex and technical information in meaningful ways is a key responsibility of the planner. It is important to customize presentations to the audience by using language that is understandable, defining new concepts, and using local examples of climate impacts.

Integrate the findings of vulnerability assessments. The vulnerability assessment process discussed in Chapter 3 is an effective complement to a visioning and engagement exercise. The information gathered in the vulnerability assessment can be used to highlight long-term flood risks to existing community infrastructure such as schools, healthcare services, open space, and emergency services facilities. It can also illustrate long-term needs for infrastructure sectors that will bear the brunt of more frequent and intense flooding, such as stormwater and wastewater systems and coastal protection infrastructure.

Additionally, by integrating the findings of a social vulnerability assessment into visioning and engagement exercises, planners can begin to build a foundation for plans that consider the wider context of climate impacts upon people and the environment. Including those communities and stakeholders identified as part of a social vulnerability assessment in the visioning and engagement stages can help to ensure that plan-making and implementation are informed not just by future climate conditions, but also by how those conditions affect the most vulnerable populations.

Community engagement, while critical to creating a successful vision, should not end with the crafting of a statement for the future. Rather, community engagement is vital at all stages of the planning process. Natural hazards such as flooding can have broad and deep impacts on communities and can both reveal and worsen underlying community challenges. Public infrastructure can also be an emotional flashpoint for community stakeholders, particularly on the topics of infrastructure deficiencies, maintenance needs, and long-term costs. Ensuring continual, meaningful, and substantive engagement with the community on these issues is critical to an equitable and successful planning process.

REGIONAL PLANNING

Regional planning is a collaborative process to plan for common issues across a shared geographical area. Regional plans cross existing municipal boundaries and involve jurisdictions and entities within common ecological, political, or economic boundaries (Piro and Leiter 2017).

Infrastructure sectors such as transportation, energy, and water are deeply integrated systems that serve subregional, regional, and supraregional geographic areas, and they can be the focus of elements in regional plans. The federal government requires the creation of metropolitan planning organizations for regions with a population greater than 50,000 to coordinate transportation planning as a condition of federal funding. Sustainability and climate change adaptation are increasingly common components of regional plans. Additionally, natural systems such as watersheds, coastlines, riverways, and wetlands largely ignore municipal boundaries and require large-scale coordination at the regional scale.

In some cases, local coordination and comprehensive plan consistency with regional plans is required by state law. Even in cases where consistency with a regional plan is not required, regional plans can play a critical role in providing a framework for local comprehensive planning. Regional plans, therefore, can be a vital resource for communities seeking to plan for infrastructure that is resilient to more intense and frequent flooding due to climate change. One region that is incorporating infrastructure resilience as a focal point of regional planning is Chicago and its surrounding counties, as described in the sidebar on pp. 60–61.

The following strategies can help planners make the most of regional planning efforts to support climate-resilient infrastructure development.

Rely upon regional plans as sources of data and information on climate change impacts. Regional plans can be critical sources of information on the regional impacts of climate change and flooding upon communities and their infrastructure. While extreme precipitation, storm surge, coastal storms, and sea level rise will vary somewhat based on local factors such as land use and geography, regions are an effective and reliable scale at which to assess how climate change and future flood hazards will generally affect communities and public infrastructure. Although the plan may discuss these impacts generally, more specific information on existing and future flood hazard risks to infrastructure sectors can likely be found in regional plan elements dealing with transportation, energy, water, and natural resources and the environment.

Get involved in regional planning to aid your local planning efforts. Regional planning tends to involve a wide variety of governmental, quasi-governmental, and nongovernmental organizations. These efforts will likely include special districts and authorities that are responsible for infrastructure sectors such as water resources management, flood control, and energy. The infrastructure managed by these agencies and organizations are critical to the long-term welfare of communities.

Regional planning exercises are an opportunity for planners and local jurisdictions to create meaningful connections with regional infrastructure agencies that can pay dividends during a local comprehensive or adaptation planning effort. By developing relationships with partners who manage vital infrastructure sectors, planners and their communities can increase their access to technical expertise on topics such as natural hazards, climate change, and flood impacts on integrated infrastructure systems.

COMPREHENSIVE PLANNING

The comprehensive plan can function as a community's guiding document, statement of purpose, vision of the future, framework for action, and reference manual for policies, maps, and data. The comprehensive plan also occupies a central place in the education and practice of the community planner. Given its role as both formally adopted legal and policy document and guiding vision of the future, the comprehensive plan can be critical in creating linkages between and among other local plans, policies, and programs.

Planners should play a central role in holistically considering infrastructure resilience in the comprehensive plan. In some cases, planners may be the only people in the room able to connect infrastructure development with long-term flood risk while also ensuring connections with the overall health and welfare of a community across a wide variety of plan elements.

As a document intended to direct investment and development, the comprehensive plan is an ideal place for determining how existing infrastructure assets can adapt to more intense and frequent flooding, and how new infrastructure can aid overall community resilience.

Infrastructure Resilience in the Comprehensive Plan

Climate considerations are suitable for all plan elements within a comprehensive plan but are most frequently found in sections such as sustainability and the environment, transportation, water and air quality, hazard mitigation and disaster recovery, and parks and open space. These sections are frequently home to infrastructure recommendations as well, enabling communities to link the adaptability of infrastructure to future flood risk, as well as identify ways for new infrastructure to increase overall community resilience.

The following steps outline a process for planners and communities to integrate infrastructure resilience into comprehensive plans.

Gather background information. Chapters 2 and 3 of this report outline ways in which communities can identify data sources on future flood risk and how they can use this information to assess overall community and infrastructure vulnerability. This assessment should:

- Outline and identify the primary climate risks (such as extreme precipitation, sea level rise, more intense and frequent coastal storms, tidal flooding) to the community.
- Identify the location, age, and condition of infrastructure assets (both gray and green) that mitigate flood hazards.

ON TO 2050: THE CHICAGO METROPOLITAN AGENCY FOR PLANNING AND INFRASTRUCTURE RESILIENCE

The Chicago Metropolitan Agency for Planning (CMAP) is a regional planning agency for the counties of Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will in northeastern Illinois. Created in 2005, CMAP is empowered by Illinois state law to coordinate long-range planning within the region and is a major source of technical assistance to communities and planners within its jurisdiction.

CMAP also provides a critical leadership role on climate resilience, adaptation, sustainability, and how infrastructure can meet current and future climate challenges. These efforts are reflected in its *Go To 2040* regional comprehensive plan, and most recently in its draft plan update *On To 2050* (Figure 4.1).

CMAP has identified extreme weather, heavy precipitation, drought, and extreme heat as the most likely and impactful climate risks to communities within the region, with flooding due to more frequent and intense rainfall expected to stress already aging infrastructure across this heavily urbanized region.

On To 2050 provides a six-point framework for how CMAP intends to meet these challenges (CMAP 2018).

1. **Incorporate climate resilience and adaptation measures into planning and development.** Integrating climate change adaptation into plans and ensuring plans within the region are aligned with goals are critical to CMAP's efforts. Integrating resilience and adaptation into capital improvements and infrastructure plans can help to ensure that new infrastructure is ready to meet future climate challenges. CMAP's Local Technical Assistance program, which provides technical, data analysis, planning, public engagement, and other forms of capacity-building support to municipalities, is critical to this effort, particularly when local expertise on climate and infrastructure is limited. More information on the Local Technical Assistance program can be found at www.cmap.illinois.gov/programs/lta.
2. **Strengthen gray and green infrastructure to withstand climate change.** CMAP is focusing on an infrastructure strategy for the region that integrates both green and gray infrastructure for overall community resilience. This approach highlights the many co-benefits of green infrastructure for open space, air and water quality, ecological restoration, and stormwater management, while also recognizing the need for gray infrastructure to adapt to changing climate conditions. CMAP's strategy centers on ensuring that gray infrastructure is planned, designed, and constructed based on future climate projections.
3. **Improve the operational response to weather events to ensure mobility.** More intense and frequent precipitation will impact transportation infrastructure and regional mobility. CMAP's strategy for ensuring adequate mobility includes upgrading traffic control systems, developing a regional flood reporting system to help plan for more frequent flood events, and conducting more extensive analysis on road performance and pavement flooding during heavy precipitation events.
4. **Create a more flexible and decentralized electric grid.** A more decentralized electrical grid that places electrical generation closer to the communities it serves is less susceptible to natural hazards and future climate stresses. In the event of broader disruptions to services following a major storm or flood, microgrids that operate independently from the main grid can help to compensate and maintain power to communities, emergency services, and other

Figure 4.1. CMAP's On To 2050 plan update process continued a regional focus on infrastructure resilience introduced in its 2040 plan (Jackson Morsey, AICP, UIC Great Cities Institute)

critical infrastructure. CMAP's strategy highlights this approach as one that communities, electrical utilities, the state, and federal partners should continue to invest in.

5. **Diversify agricultural systems to promote resilience.** CMAP has identified alignments between agricultural resilience and extreme weather and climate change, food distribution, and infrastructure systems. CMAP's strategy for long-term resilience of regional agriculture includes coordinating with municipalities, counties, and regional partners to invest in infrastructure that enables more efficient use of water and natural resources in farming and food distribution.
6. **Explore a regional climate resilience platform to coordinate initiatives and provide data and resources.** Given the role that access to accurate climate data plays in planning for infrastructure resilience, CMAP is exploring a regional partnership with the Midwestern Regional Climate Center, the Illinois State Water Survey, and the Illinois State Climatologist to coordinate the release and use of climate data across the region. Additionally, CMAP hopes to work with these partners to identify ways to downscale climate data so that it can be better used by municipalities for planning and infrastructure development purposes.

More information about CMAP and *On To 2050* is available at www.cmap.illinois.gov/2050/environment/climate-resilience.

- Identify and assess risks to neighborhoods and populations that are vulnerable to future flood impacts.
- Identify and assess risks to critical infrastructure, public buildings, and other city assets that are vulnerable to future flood impacts.

Whether conducted as an independent exercise, addressed as part of the visioning process, or developed in the course of information gathering, a community-wide climate vulnerability assessment can be extremely useful in informing later planning and implementation stages. Additionally, spatially mapping this information can be extremely useful in the course of writing the plan, for materials that will be distributed to the public, and as a resource that can be updated for years to come.

Communities and planning departments that lack the capacity, funding, staff expertise, or time for an in-depth analysis of community vulnerability can seek out some of the information sources identified in Chapter 2 that are intended to simplify and streamline climate risks. These communities may also want to consider identifying other communities within their region or regional planning organizations that may have already developed vulnerability assessments, climate adaptation plans, or have discussed climate adaptation within their comprehensive plans. Similarly, both the Regional Climate Centers and the National Oceanic and Atmospheric Administration (NOAA) Regional Integrated Sciences and Assessments teams described in Chapter 2 have large amounts of easily understandable data and information on how climate change is likely to impacts regions across the country. These resources will not be able to identify the risks posed to local infrastructure, but they can function as a useful shorthand for the first stages of assessing vulnerability and outlining climate risks.

Planners and communities should also gather existing plans, documents, policies, codes, and regulations that will be helpful to informing risks posed to infrastructure and in identifying infrastructure needs. Hazard mitigation plans, especially the sections on hazard identification and risk assessment, can be a useful way of assessing current risks based on historical weather and climatological patterns. Hazard mitigation plans are not required to incorporate climate change into these risk assessments, though this is becoming increasingly common.

Flood Insurance Rate Maps (FIRMs) are an extremely useful and popular means of spatially assessing flood risk. Planners should understand, however, that these maps are not based on future changes in sea level or precipitation patterns. And if these maps are many years old, they might not reflect changes in land use or the addition and degradation of infrastructure.

Planners and communities may also want to consider using the 0.2 percent annual chance floodplain (often called the 500-year floodplain) as a useful illustration of extreme flood risk. This approach is not scientific, but it can help to illustrate parts of the community and infrastructure assets that may be at risk in the event of more severe flooding events.

Engage the public equitably and extensively. Engaging the public extensively, early, and often in the comprehensive planning process can allow planners to educate residents and stakeholders on climate issues and impacts and receive extensive feedback on infrastructure needs and priorities. This can include assessing the public appetite for infrastructure repair, maintenance, adaptation, and replacement.

Extensive public engagement can also be a useful way of identifying areas that are underserved by existing infrastructure, areas of growth that will require new infrastructure, and areas that are at higher risk of flooding. Speaking and interacting with the public is also an effective way of gathering anecdotal and historical information on how flooding and its impacts may have changed or worsened over time. Given the influence that changes in land use and development can have on local flood impacts, this can be a useful way of groundtruthing climate change effects and changing weather patterns in the lived experience of residents.

Communicating future flood risks and potential impacts to infrastructure can be difficult, especially given the jargon and complex technical information that is often used in the planning process. Planners should communicate in plain language whenever possible and make extensive use of imagery and storytelling to effectively illustrate potential risks and interventions to as wide an audience as possible.

When engaging with the public during a comprehensive planning process on the topic of infrastructure resilience, planners should be mindful of underlying issues of environmental injustice, inequitable distribution of services, and disproportionate climate and infrastructure development impacts on underrepresented residents, stakeholders, and organizations. By practicing deference to local knowledge and collaborative problem solving in the context of planning for infrastructure resilience, planners can help to create more equitable plans that advance positive environmental and economic outcomes. For more information on equitable public engagement that is informed by the principles of environmental justice, refer to the American Planning Association's Planning for Equity Policy Guide (APA 2019b).

Draft information on future flood risks and infrastructure vulnerability. Distill the background information gathered earlier in the process based on what those reading and relying on the plan will need to understand about climate change, future flood risk, and infrastructure vulnerability. If there is already a climate vulnerability assessment to refer to, consider adapting it for the comprehensive plan document. If the full climate vulnerability assessment is a large document, consider including it as an appendix to the report, and identify the most critical sections and content needed for the comprehensive plan. Content related to future flood hazard risk; infrastructure exposure, age, and condition; and social vulnerability will be helpful in illustrating big-picture climate risk factors.

Complement this information with information on existing flood control infrastructure, such as coastal flood protection, stormwater infrastructure (e.g., retention basins and sewers), and dams. Also helpful in illustrating existing conditions are any available flood maps of the community and information derived from the hazard mitigation plan.

Among the most important concepts to convey to readers of the plan are the dynamic and unpredictable impacts of more frequent and intense flooding on infrastructure. Most existing infrastructure, from stormwater systems to road networks to critical public facilities, are planned and designed based on broadly predictable climate and weather patterns. Climate change introduces new uncertainties into the rate and degree of precipitation, sea level rise, and coastal storm intensity. Conveying the concept of infrastructure that can withstand these conditions, and that in turn increases the overall resilience of communities, is critical to effectively embedding infrastructure resilience into the comprehensive plan.

Develop goals, objectives, and implementation strategies. Most comprehensive plans are organized around a set of broadly defined areas of community concern and interest called elements. Goals, objectives, and implementation strategies (such as policy making, public investments, and regulatory tools) derived from analysis of existing conditions, future needs, and engagement with the public are organized within these plan elements.

When developing goals, objectives, and strategies it is important to identify how infrastructure resilience may intersect with the various plan elements. Some communities opt to isolate hazards and climate adaptation-related content in only those elements. Other communities pursue a more integrated approach and consider climate adaptation needs throughout the plan. Given the complex and interconnected nature of public infrastructure, and the similarly complex and wide-ranging risks that more severe and frequent flood events pose to that infrastructure, planners should think critically about where and how to best integrate infrastructure resilience within plan elements.

The following are a selection of plan elements and questions to consider regarding infrastructure resilience in the comprehensive plan:

- **Economic development:** What sort of impacts will more frequent and intense flooding have on the mobility of residents and visitors on transit and road networks? Is coastal and stormwater protection infrastructure able to reduce the exposure of business districts, downtowns, and major local employers and industries?
- **Community facilities:** Are any new critical facilities such as fire and police stations planned for areas at risk of sea level rise, storm surge, regular tidal inundation, riverine flooding, or stormwater flooding resulting from extreme precipitation? Do community facilities have adaptive capacity, or can they be adapted at a later date? On what sea level rise and extreme precipitation projections is the community basing its siting and design guidelines for community facilities?
- **Environment and natural resources:** What are the flood control and water resources management co-benefits of existing environmental and natural resources? Do wetlands, dunes, berms, breakwaters, and plant and animal habitats provide a buffer between populated areas and potential flood hazards? Are there plans, regulations, and policies to preserve these resources as natural flood infrastructure? Is green infrastructure identified as a functional alternative to gray infrastructure in managing future flood events?
- **Housing:** What critical infrastructure exists to protect residents and housing from natural hazards? Is this infrastructure equipped for dealing with more regular and severe flooding? Are decisions regarding new development informed by existing and future infrastructure capacity to deal with more severe flooding?
- **Natural hazards, hazard mitigation, and disaster recovery:** What have been the impacts of recent flood events on the community? Was this a flood event of record, or have there been a series of recent major flood events in the recent past? Have these events highlighted any major infrastructure deficiencies, or led to any new infrastructure investments? Has this infrastructure been planned, sited, and designed based on more severe and frequent flooding? If it is a coastal community, what sort of coastal infrastructure such as floodwalls exist, and is this infrastructure based on historic tidal and surge rates? Does this infrastructure consider sea level rise over its expected useful life?
- **Public health:** Are there any plans for hospitals or critical health facilities in areas already subject to flooding, or that might be vulnerable to more intense and frequent flooding? What types of infrastructure serve these critical facilities, and is this infrastructure resilient or adaptable to future flood impacts? Do the roads and transportation networks that provide access to hospitals and health facilities have adaptive capacity to weather more intense and frequent flooding, storm surge, and sea level rise? Is there secondary infrastructure in place to ensure adequate power and access to critical health facilities in the event of large-scale flood events?
- **Recreation and open space:** Do any recreational facilities or community open spaces such as parks also function as flood storage infrastructure or buffers to homes, businesses, or critical facilities? Are recreational facilities or community open space expected to also function in a post-flood event for the purposes of emergency services staging? How will more intense or frequent flooding in the future impact the ability of this infrastructure to continue to function as flood storage, buffers, or as post-disaster staging areas? Are there plans for any new recreational facilities or open spaces, and will they be expected to serve as flood-resilient infrastructure?
- **Emergency services:** What types of infrastructure do safety and emergency services rely upon? In future scenarios with more frequent and intense flood events, will road and transportation networks be blocked or inaccessible? Are emergency service facilities in areas already at risk of flooding or that could be at future risk of flooding? What about the location of assets such as fire, police, and EMS vehicles? Are emergency services served by energy infrastructure that is resilient to flood impacts? In the event of power failure, are backups resilient to flood impacts? Are response protocols integrated into the county and local hazard mitigation plans?
- **Sustainability and climate change**: Does this plan element only consider climate change mitigation—that is, policies, programs, and regulations intended to reduce greenhouse gas emissions? Are there any opportunities to think about how the community may need to adapt to the impacts of climate change? Does this element summarize the community's overall adaptation strategy? Are there opportunities to integrate the adaptation strategy throughout the plan, especially where the plan discusses infrastructure?

PLAN INTEGRATION FOR RESILIENCE SCORECARD

Infrastructure is expensive and is usually expected to serve communities for decades, if not longer. Therefore, if communities want to make the best of their investments, local practitioners must be aware of how existing infrastructure assets and future infrastructure plans align with long-term goals, actions, and policies, especially regarding flood resilience.

Developing a strong spatial understanding of the interaction between various plan elements, policies, and actions, and the impacts of more frequent and severe flooding, is crucial to the success of resiliency planning efforts. *Plan integration* requires communities to critically assess the existing framework through which they make and implement plans, and then work to ensure that plans and implementation techniques are aligned to effectively realize community goals and objectives (FEMA 2015b).

Plan Integration for Resilience Scorecard Guidebook, developed by Texas A&M's Institute for Sustainable Communities and funded by the U.S. Department of Homeland Security Coastal Resilience Center, identifies three challenges to integrating and aligning plans to realize long-term hazard mitigation, climate adaptation, and infrastructure and community resilience goals (Hicks Masterson et al. 2017):

- Cities often have far too many plans to properly ensure that they are aligned and coordinated.
- There tends to be no process for understanding how policies, often developed at different times and in different departments, interact with each other.
- The spatial dimension of policy impacts is poorly understood, particularly regarding hazards and climate change.

The *Guidebook* outlines the following process through which communities can spatially assess how well their existing plans, processes, policies, infrastructure projects, and regulatory frameworks are aligned for community resilience (Figure 4.2).

1. **Map and define neighborhoods, planning districts, and existing hazard zones**. Hazard zones can include flood zones, storm surge inundation areas, areas subject to tidal flooding, areas under threat of sea level rise, and others. By mapping and delineat-

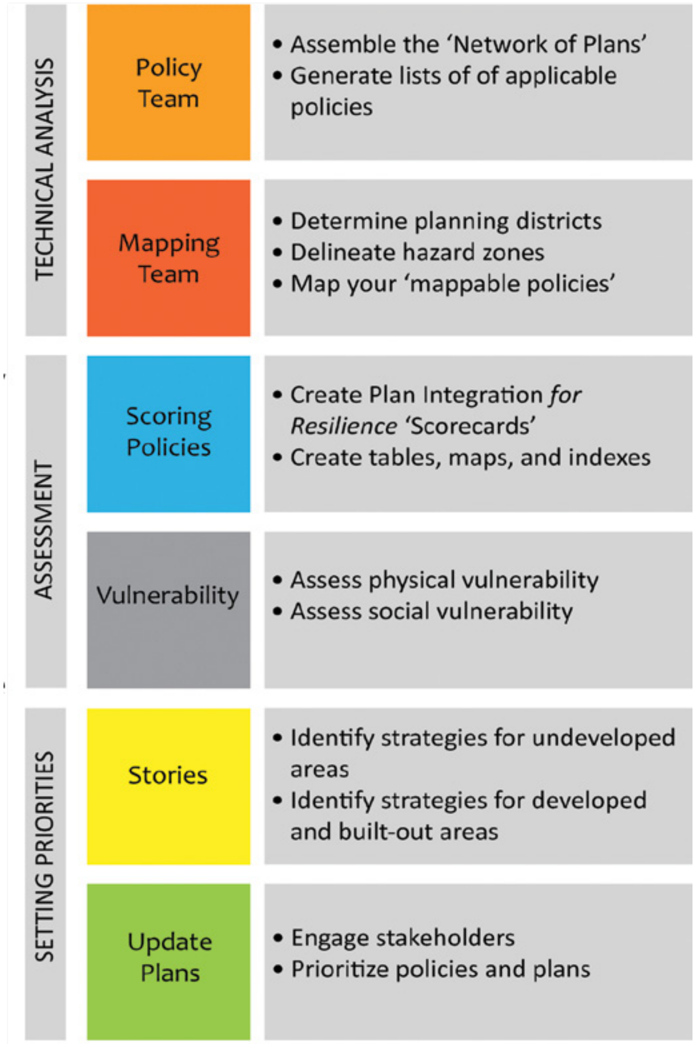


Figure 4.2. The Plan Integration for Resiliency Scorecard outlines a general framework for conducting technical analyses, assessing overall vulnerability, and setting priorities across many types of plans to advance local resiliency goals (Texas A&M University)

ing these areas, neighborhood-scale units can be created to visualize impacts across smaller geographies.

2. **Score local plans and planning documents** based on how their recommendations influence land use and affect vulnerability, as well as whether they can be assigned to a particular geography. Cumulative high scores show a greater policy focus on reducing hazard vulnerability. Lower scores point toward policies that increase vulnerability.
3. **Map physical and social vulnerability to each district and overlay with the policy scores** to determine how well local plans and policies target those neighborhoods and planning districts that are the most vulnerable (Figure 4.3).

Ultimately, the goal of the scorecard exercise is to illuminate for planners how well they understand local plans and policies, and to spur action toward changing local plans and policies that do not reduce vulnerability to natural hazards.

With its focus on how plans and policies are reflected spatially in particular neighborhoods or planning districts, the scorecard can be an effective means of understanding the impacts of existing or proposed infrastructure on community vulnerability, and in turn assessing how natural hazards, plans, and policies might impact local infrastructure. Additionally, by considering social vulnerability, the scorecard can be a helpful tool in assessing the vulnerability of underserved communities to natural hazards and determining if existing plans, programs, policies, and infrastructure projects are serving the neighborhoods and populations in most need.

The *Plan Integration for Resilience Scorecard Guidebook* is available at https://tinyurl.com/yxkwf27d.

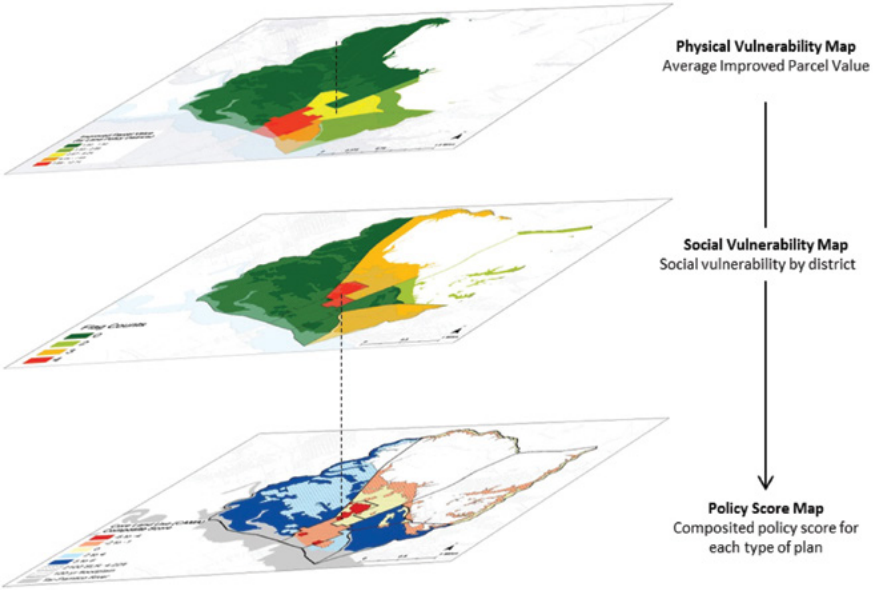


Figure 4.3. Assessing the spatial dimensions of physical vulnerability and social vulnerability for each plan is a major component of the Plan Integration for Resilience process (Texas A&M University)

- **Transportation:** How vulnerable is the existing transportation network to more intense and frequent flooding? Do roads, bridges, and public transit assets have adaptive capacity to withstand future flooding and sea level rise? Are there any plans to adapt the transportation network to future flood hazards such as extreme precipitation, sea level rise, or regular tidal inundation? Are maintenance facilities for major transportation assets such as bus, train, or light-rail fleets located in areas subject to future flood risk?
- **Zoning and land use:** Are there existing policies, standards, rules, or code regulations for privately developed or maintained flood infrastructure such as dams or stormwater retention? Are these policies, standards, or regulations based on historic rates of flooding or do they also incorporate future rates of precipitation, sea level rise, and other potential climate impacts? In what other ways is local zoning used to drive land development to appropriate areas and discourage development in sensitive or flood-prone areas? Are areas outside of flood-prone areas appropriately zoned for higher density?

Align goals, objectives, policies, and programs. Given the potentially unpredictable impacts that climate change can have on local infrastructure, it is important for communities to align goals, objectives, policies, and programs across plan elements. This is crucial to ensuring that plans for infrastructure, design standards, siting, and performance do not work at cross-purposes.

The resilience of single infrastructure projects or systems (such as a stormwater network or emergency services facility) is a worthy goal. Infrastructure, however, should not just be physically resilient to more severe or frequent flood events in isolation; it should increase the overall resilience of the community it serves. By critically assessing the plan's goals, objectives, policies, programs, and regulations for the impacts they have on community resilience, planners and communities can make smarter decisions on how to prioritize actions and allocate funding.

The California Governor's Office of Planning and Research, through its Adaptation Clearinghouse toolkit, has collected a series of resources offering guidance to planners in the state of California on plan alignment and integration. These resources highlight the critical areas of statewide policy for local practitioners to be aware of, such as the California Coastal Commission's Sea Level Rise Policy Guidance and the state's General Plan Guidelines, along with an array of local guides, policy briefs, and web-based tools centered on coastal adaptation and plan alignment (California Governor's Office of Planning and Research 2019).

Another tool, Texas A&M's *Plan Integration for Resilience Scorecard*, offers a process to help better align plans, policies, and implementation. This tool, which can have major benefits for aligning comprehensive plan goals and actions with long-term infrastructure planning and implementation policies, is described in more detail in the sidebar on pp. 64–65.

Move toward implementation. Public investment in infrastructure development, adaptation, and maintenance is one of the primary tools that communities have to realize and implement comprehensive plans.

Given the extensive process a typical comprehensive plan goes through, and its status as a formally approved policy document, the comprehensive plan is well suited to serve as a nexus for hazard risk, climate adaptation, and infrastructure planning and development. Ensuring that the comprehensive plan remains a primary linkage between plans, policies, and action over a 15- or 20-year period is complex and requires active management in daily practice.

Individual infrastructure plans, area plans, or functional plans (such as a climate adaptation plan) may follow a comprehensive planning effort. The capital improvements plan (discussed in detail in Chapter 5) can be a powerful tool for advancing comprehensive plan implementation. In conjunction with plan goals and objectives, communities can develop siting and design standards for new infrastructure development that accounts for future flood hazards risk.

To enable comprehensive plan implementation, communities should be clear about the agencies or departments that are leading implementation efforts and the time frames for the expected completion of those efforts. Even when not leading implementation efforts, planners should have major roles in teams, committees, and work groups that are tasked with implementation efforts.

Monroe County, Florida, is one community that has established clear policies calling for specific actions to increase infrastructure resilience in the face of sea level rise and storm surge; see the sidebar on pp. 68–69 for specific examples from its comprehensive plan.

FUNCTIONAL PLANS

Functional plans are intended to address specific topics of interest or areas of local concern. These plans may build upon key areas or elements identified in the comprehensive plan, which tends to be the case for climate adaptation plans, or they may be independently developed plans that apply to some functional area in a community, as is the case with the hazard mitigation plan.

Infrastructure resilience to long-term climate and flood hazard impacts can be a part of a wide array of local functional plans. The following sections take a deeper look at some of the functional plan types that most clearly align with infrastructure resilience and discuss the roles that planners should play in the planning process.

Hazard Mitigation Plans

The local hazard mitigation plan is a community's primary avenue for considering how hazards of all types impact the community and how they can best be mitigated. The Disaster Mitigation Act of 2000 requires state, local, and tribal governments to develop hazard mitigation plans and update them every five years to qualify for non-emergency disaster assistance funds through the Hazard Mitigation Grant program. The Federal Emergency Management Agency (FEMA) envisions the local hazard mitigation plan as a living document intended to integrate hazard mitigation into the daily process of planning (FEMA n.d.).

Hazard mitigation plans are adopted by counties and other local jurisdictions to describe existing natural and man-made hazards and their impacts on the community, and to establish mitigation actions intended to reduce or mitigate these impacts. Flooding and flood-related hazards, particularly in coastal communities, are a critical part of hazard mitigation plans.

The involvement of planners and comprehensive plans in the hazard mitigation planning process varies by jurisdiction. Planners' involvement in the hazard mitigation planning process, and how hazard mitigation plans can be integrated with comprehensive and other local plans, are explored in PAS Report 560, *Hazard Mitigation: Integrating Best Practices into Planning* (Schwab 2010).

Hazard Mitigation Plans and Infrastructure Resilience

Integrating climate change into local plans is an emerging practice for hazard mitigation that more comprehensively considers how existing natural hazards will be shaped by changes in climate. Though climate change risks and impacts are not required to be a part of hazard mitigation plans, planners can play a critical role in ensuring that more severe and frequent flood events are integrated into both risk assessment and mitigation actions such as infrastructure planning and development.

The following are recommended practices to address hazard mitigation in the context of infrastructure resilience:

Engage in the hazard mitigation planning process. Even if they are not leading the process, planners still bring a unique and necessary perspective to the development of hazard mitigation plans. Planners tend to have a strong understanding of long-term, secondary, and cascading impacts on people and the built and natural environments. How flood hazards may impact critical local infrastructure, and, by extension, the people and places served by that infrastructure is a crucial element that planners can bring to this process.

Engagement in the hazard mitigation planning process can strengthen a planner's knowledge of critical natural hazards, data sources, agencies, departments, and staff with expertise. This information can be useful during other local planning processes, and especially in the context of comprehensive planning.

Integrate existing local plans with the hazard mitigation plan. By engaging in the hazard mitigation planning process, planners have the opportunity to share critical information on community context that exists in local comprehensive, area, and other functional plans. This information might include areas that have been identified by the community as particularly susceptible to sea level rise but are not currently within a flood hazard area, or planned improvements to a stormwater network based on future precipitation projections. Integrating infrastructure assets and planned infrastructure improvements from comprehensive or other planning efforts into the hazard mitigation planning process lays the foundation for aligning those efforts with mitigation actions.

Align mitigation actions. Mitigation actions are projects, processes, and activities that a community undertakes to reduce long-term hazard risks (Institute for Sustainable Community Design n.d.). Infrastructure projects, improvements to natural systems, and new regulations, standards, and guidelines all are considered mitigation actions.

Planners who are involved in the hazard mitigation planning process should work to inform and align the mitigation actions included in the hazard mitigation plan with goals, objectives, and implementation actions in the comprehensive plan, especially if the actions outlined in the comprehensive plan consider climate change and its impacts. This can help to expand the discussion on historic hazard impacts to include the increasing risks of more frequent and severe flood events due to climate change.

Aligning mitigation actions can also benefit existing plans and processes within the planner's community. For mitigation actions that may be of benefit to long-term community and infrastructure resilience, planners should work to include these in local processes and plans.

IMPLEMENTING INFRASTRUCTURE RESILIENCE IN COMPREHENSIVE PLANS: MONROE COUNTY, FLORIDA

Monroe County is a coastal community in South Florida that includes the islands of the Florida Keys. While most of the county's land area is located on the mainland, nearly all 77,000 residents live in the Florida Keys.

In its recent comprehensive plan update, the county developed a number of policies tied to goals and objectives to improve the use of information related to future flood risk and climate change when implementing infrastructure projects. The following are a selection of policies outlined in the plan that deal with infrastructure resilience and adaptation to long-term threats such as sea level rise.

Policy 1502.1.1. *Prior to incorporating a new project to the Capital Improvements Element, Monroe County shall assure that it is reviewed for recommendations to increase resiliency and account for the impacts from climate change, including but not limited to, sea level rise and storm surge. Monroe County shall evaluate financial expenditures to fund repairs, reconditioning of deteriorating infrastructure and new infrastructure improvements within or proximate to vulnerable areas to manage public investments appropriately. Monroe County shall focus on level of service standards, as one of the points of analysis, to assure that infrastructure useful life and service expectations can be met in the face of climate change impacts.*

Policy 1502.1.4. *Within five (5) years after the adoption of the 2030 Comprehensive Plan, Monroe County shall identify criteria to define adaptation action areas (AAA), or a similar concept to be defined by the County, which may include infrastructure. Within five (5) years after the adoption of the 2030 Comprehensive Plan, Monroe County Monroe County shall identify proposed adaptation action areas (AAA), or a similar concept to be defined by the County. Pursuant to Chapter 163, F.S., AAA are those areas that experience coastal flooding due to extreme high tides and storm surge, and that are vulnerable to the related impacts of rising sea levels for the purpose of prioritizing funding for infrastructure needs and adaptation planning. In the AAAs, strategies will be developed to address vulnerabilities from these effects as well as the rate of impact and available adaptation options. In conjunction with later updates to the 2030 Comprehensive Plan, Monroe County shall update existing, or map new, potential impacts of sea level rise for consideration in long-term planning decisions.*

Policy 1502.1.5. *Within five (5) years after the adoption of the 2030 Comprehensive Plan, Monroe County shall initiate an inventory of existing and planned infrastructure up to the 2030 horizon, based upon the vulnerability mapping identified in Policy 1502.1.4, for capacity to accommodate projected sea level rise over the life expectancy of that infrastructure. Monroe County shall identify the infrastructure within those areas, its useful life and any retrofits or capital projects necessary to address the impacts of sea level rise. These strategies may include defense, accommodation, or and retreat projects, or not building planned infrastructure in vulnerable locations, to address the impacts of sea level rise. Monroe County will consider developing design criteria, in conjunction with a broader asset management planning process.*

Policy 1502.1.6. *Within five (5) years after the adoption of the 2030 Comprehensive Plan, Monroe County shall consider incorporating a planning, design and permitting standard for infrastructure and public facilities that may include a sea level rise assumption of 3″–7″ by 2030 as developed by the Southeast Regional Climate Compact. The County shall review and update sea level rise projections when new and pertinent data is available. (The 3″–7″ by 2030 is based on a 2010 baseline—if adjusted to a 1992 baseline it would result in 6″ to 10″ by 2030 above the 1992 mean sea level.)*

Policy 1502.1.7. *Monroe County shall ensure that new, renovated and replacement public facilities and infrastructure, such as streets and bridges, water and wastewater treatment plants, police stations and fire stations, and any other public facilities that the County has authority over, are designed in a manner which considers the useful life of public facilities and infrastructure. The County shall also consider the potential impacts from climate change, including rising sea levels and shoreline stabilization needs, on its infrastructure and public facilities.*

Policy 1502.1.8. *Monroe County shall exchange data regarding locally-specific vulnerable areas and land use strategies/policies with the Florida Department of Transportation, the U.S. Department of Transportation and the Federal Highway Administration relative to ferry, airport, transit, bridges and transportation systems.*

Policy 1502.1.9. *Monroe County shall coordinate with appropriate agencies to monitor changes to minimum road elevation standards which may be specific to Monroe County due to its unique exposure to climate change and sea level rise impacts. This could also include enhanced stormwater management requirements and resurfacing requirements for certain transportation segments.*

Policy 1502.1.10. *Within five (5) years after the adoption of the 2030 Comprehensive Plan, Monroe County shall review land development regulations that address stormwater management considerations for sea level rise impacts. To the* *extent practicable, Monroe County shall incorporate green infrastructure or passive alternatives that maximize land preservation over impervious or "active" infrastructure. Such alternatives could include the reconditioning and reuse of septic tanks, increased use of rainwater harvesting techniques, such as cisterns and other water storage techniques. Monroe County shall determine if land development regulation amendments are needed to address increased retention requirements and other topographic or infiltration considerations which may influence stormwater management requirements. Monroe County shall also consider the ability to meet water quality requirements related to stormwater management regulations and if there are any impacts from climate change that may jeopardize the County's ability to meet those requirements.*

For more information on Monroe County's comprehensive plan, visit www.monroecounty-fl.gov/180/Comprehensive-Planning.

Review based on plan updates. As hazard mitigation plans are updated every five years, planners and their communities should remain engaged in the process to identify changes, coordinate actions, and ensure integration with other local plans and processes. This is especially important as new infrastructure needs are identified in light of ongoing climate change impacts. As comprehensive and other local plans change to accommodate revisions to climate models and any emerging observed impacts on planned or existing infrastructure, hazard mitigation plans and any identified mitigation actions should be revised to reflect this new reality.

Climate Adaptation Plans

Communities develop climate adaptation plans to understand how they will be impacted by climate change, and to determine the actions that need to be taken to adapt to those impacts. Climate adaptation plans (sometimes called climate resilience plans, especially when integrated with climate mitigation planning) may assess and recommend actions across a community; others may focus on specific areas, such as housing or transportation.

Climate adaptation plans tend to extensively survey the state of local infrastructure, and they often result in recommended actions to adapt existing infrastructure, establish new standards and guidelines for infrastructure development, and identify areas in which new infrastructure will be needed to cope with climate change impacts.

Planners can play a major leadership and coordinating role in the development of climate adaptation plans, especially when considering long-term infrastructure resilience to flood hazards. One example of how hazard mitigation and climate adaptation can be comprehensively integrated to better assess risk and plan for the future is Baltimore's Disaster Preparedness and Planning Project (DP3), described in the sidebar on p. 71.

The following are recommended practices for planners engaged in climate adaptation planning:

Define the scope. Planners should ensure that the scope of climate adaptation plans is well defined. Climate change and more frequent and severe flooding can have wide-ranging and unpredictable impacts. This can lead to plans with overly broad recommendations that do not outline and define clear objectives and actions for dealing with these impacts. By clearly defining the scope around a time frame for action or area of focus (such as a specific infrastructure system), a community will be better equipped to make specific recommendations.

Practice equitable and extensive public engagement. Given the complexity of future climate impacts and the importance of local infrastructure to the safety and well-being of the lives of residents, planners should engage the community as extensively as possible. Climate change and more severe flooding are expected to have considerable and disproportionate impacts on underrepresented communities. Relying on local expertise and engaging thoughtfully with these communities can help to ensure that those bearing the burdens of climate change have a voice in adaptation planning and implementation.

Create links to the comprehensive and other local plans. Climate adaptation plans can function as documents independent of comprehensive plans, they can be components of comprehensive plans, or they can be reference documents used in comprehensive and other local planning processes. Planners should work to develop strong linkages between climate adaptation plans and other local plans, especially for goals, objectives, and recommended actions. Where actions concern infrastructure adaptation and the development of standards and guidelines, planners should ensure that time frames and responsible agencies are well defined and in agreement with the comprehensive plan.

Update regularly. Climate adaptation plans should be updated regularly, preferably along with and in between comprehensive plan updates. A regular update schedule will allow planners and their communities to monitor progress toward infrastructure adaptation and upgrades; regularly incorporate emerging information on how local flood events are impacting existing infrastructure; and integrate new climate science, projections, and information into the plan and any resulting policies, regulations, standards, and guidelines.

Parks, Open Space, and Natural Systems Plans

Parks, open space networks, and natural systems have a wide variety of co-benefits for long-term climate resilience and community adaptation to future flood hazards. These plans can feature frameworks for the protection of existing ecological systems such as dunes or wetlands, include strategies calling for the use of green infrastructure features, or outline the flood storage benefits of existing park assets such as sports fields. The sidebar on pp. 72–73 describes how Norfolk, Virginia, integrated resilience and sea level rise considerations into its green infrastructure plan.

The following are a series of strategies that planners should consider when developing parks, open space, and natural systems plans for long-term community resilience.

Consider the co-benefits. Parks, open spaces, and natural systems can be a major part of a community's overall flood resilience strategy. When crafting a parks and open space plan, identify how parks, open space, and ecological systems could be used as flood storage for storm surge or riverine flooding. Consider also how existing natural systems like wetlands absorb floodwaters and provide buffers to inhabited areas. Identify strategies to preserve and expand on these benefits by developing regulations that protect the integrity of wetlands, habitats, and riparian areas that are under threat of future development. Explore, consider, and include future purchases of important natural areas by the municipality, conservation groups, or others to include in the public park system.

Ensure adaptive capacity. Consider how existing and future parks and natural systems may be impacted by more frequent and severe flooding. If these resources are already serving as flood storage or buffers, analyze how more frequent and severe flooding in the future may impact their ability to function effectively. Try to minimize the interventions and costs of future adaptation by planning for systems that can cope with a variety of future flood, surge, and precipitation scenarios.

Align with community goals and objectives. Identify primary and secondary roles for parks, open space, and natural systems that are aligned with community goals. Planned recreational facilities should serve community recreational needs and goals first and act as flood infrastructure second. For open space networks and natural features with clearer flood resilience benefits, identify and plan for ways to improve upon those functions without damaging existing ecological functions.

Infrastructure Plans and Programs

Generally, infrastructure plans are highly technical documents that originate in engineering and public works departments. These plans can be unfamiliar to or disconnected from the daily work of planners and planning departments. Nonetheless, infrastructure plans are essential resources for implementing comprehensive plans. In order to increase the likelihood of comprehensive plan implementation and to influence the degree to which these plans consider future flood impacts, planners should be involved in the development of infrastructure plans and knowledgeable about how they interact with other local implementation techniques.

In contrast to a community's capital improvements plan (which is explored in detail in Chapter 5), most infrastructure plans are organized around a single type of infrastructure system. The most complete infrastructure plans and programs at the municipal level are generally related to water, wastewater, and transportation infrastructure (Elmer

INTEGRATING HAZARD MITIGATION, CLIMATE ADAPTATION, AND INFRASTRUCTURE PLANNING IN BALTIMORE

The well-established connection between an event (a high tide, storm surge, or coastal storm) and its precipitating factor (climate change) means that similar connections between hazard mitigation and climate adaptation are essential for coastal communities. Creating this linkage can help to establish a base profile of coastal hazards vulnerability that considers both long-term concerns and short-term impacts.

Along these lines, the City of Baltimore through its Disaster Preparedness and Planning Project (DP3) has worked to comprehensively integrate hazard mitigation and climate adaptation planning to better assess future risk and plan for the future.

Completed in 2013 and updated in 2018, DP3 analysis and recommendations centered on four strategy areas:

- **Infrastructure:** maintaining quality and capacity to meet future existing needs
- **Buildings:** improving building design and codes to protect against existing and future hazards and improve the conservation of natural resources
- **Natural systems:** preserving natural systems as community resources and as natural infrastructure
- **Public services:** coordinating public services to ensure safety and improve outreach and education on hazards and climate impacts

Early phases of the plan focused on extensive risk and vulnerability assessment based on both current and future natural hazard risks. This process included:

- Hazard identification
- Infrastructure and asset inventory, including hospitals, schools, and other facilities
- Risk modeling based on future climate projections
- Assessment of the exposure, sensitivity, and adaptive capacity of infrastructure, assets, and critical facilities

The resulting actions are heavily oriented toward infrastructure resilience and adaptation to future flood hazards and coastal storms. They include:

- Evaluating and improving the resilience of communication systems to more frequent and severe weather events
- Adapting stormwater systems with green infrastructure based on future rainfall projections
- Adapting road materials and evaluating maintenance schedules based on future hazard projections
- Protecting the wastewater system from future flood impacts to improve water quality and the health of important local ecosystems
- Requiring integration of hazard mitigation and climate adaptation into the capital improvement program
- Extending and enhancing wetland and riparian buffers throughout the city as natural flood infrastructure
- Creating and enhancing coastal buffers for flood storage and protection and ecosystem preservation
- Conducting ongoing analysis and regular revisions based on emerging climate science and information that will be used to inform future policies

More information on Baltimore's Disaster Preparedness and Planning Project is available at www.baltimoresustainability.org/plans/disaster-preparedness-plan.

A GREEN INFRASTRUCTURE PLAN FOR NORFOLK

As part of its participation in the Rockefeller Foundation's 100 Resilient Cities initiative and its own *plaNorfolk2030* comprehensive planning efforts, in 2018 the city of Norfolk, Virginia, developed a green infrastructure plan (Figure 4.4) intended to advance environmental outcomes, improve community health, and protect vital infrastructure systems.

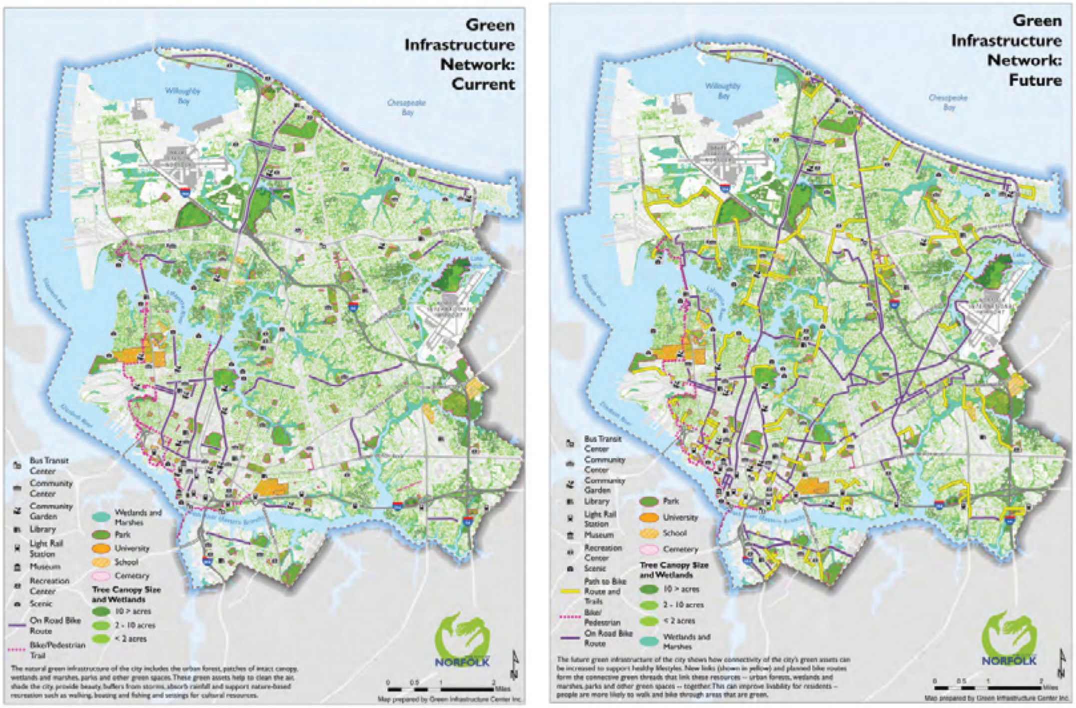
The plan is designed around expanding the city's existing network of green infrastructure to provide a wide variety of co-benefits such as improving air and water quality, reducing the impacts of stormwater flooding, and increasing recreational opportunities for residents.

Following an extensive public outreach process and analysis of existing conditions, the city developed a series of strategies centered on the themes of "Land" and "Water."

- *Land Goal 1: Increase and maintain natural green infrastructure—urban forest, shrub and meadow habitats—to support wildlife, infiltrate and clean water, improve air quality, reduce high temperatures, and provide scenic beauty.*
- *Land Goal 2: Install and maintain constructed green infrastructure to detain and retain stormwater and beautify areas where natural green infrastructure practices are less suitable.*
- *Land Goal 3: Provide adequate open space access to ensure a healthful city for residents and visitors.*
- *Water Goal 1: Protect and restore natural shorelines to support healthy aquatic life, storm buffering, and water filtration.*
- *Water Goal 2: Expand water access for boaters, fishermen, birders and walkers of all abilities.*

The city developed criteria for green infrastructure based on how it will be impacted by sea level rise over its expected useful life. Given the reduced financial outlay and the lower life expectancy of vegetation and other forms of green infrastructure when compared with gray infrastructure, the city was more lenient in assessing the viability of potential green infrastructure in the face of sea level rise impacts—if planting projects will not be underwater by the year 2040, then they are considered viable. The flexibility offered by green infrastructure as a lower-cost option capable of offering benefits even in areas at significant risk of sea level rise is significant.

The city plans to actively update the plan on an annual basis as a way to monitor progress on plan goals and objectives. Actions not underway ac-



The natural green infrastructure of the city includes the urban forest, patches of intact canopy, wetlands and marshes, parks and other green spaces. These green assets help to clean the air, shade the city, provide beauty, buffers from storms, absorb rainfall and support nature-based recreation such as walking, boating and fishing and settings for cultural resources.

Map prepared by Green Infrastructure Center Inc.

The future green infrastructure of the city shows how connectivity of the city's green assets can be increased to support healthy lifestyles. New links (shown in yellow) and planned bike routes form the connective green threads that link these resources -- urban forests, wetlands and marshes, parks and other green spaces -- together. This can improve livability for residents -- people are more likely to walk and bike through areas that are green.

Map prepared by Green Infrastructure Center Inc.

Figure 4.4. Norfolk's 2018 green infrastructure plan outlines an ambitious strategy for the expansion of the city's existing green infrastructure network (Green Infrastructure Center, Inc.)

cording to the proper time frame will be assessed by the city to decide whether changes need to be made or additional resources are necessary. Additionally, all city departments involved in implementation will be required to assess their current and future workplans for areas in which the green infrastructure strategy can be included.

More information on *A Green Infrastructure Plan for Norfolk* is available at www.gicinc.org/virginia.htm.

and Leigland 2014)—all of which have significant potential to be negatively affected by more severe and frequent flooding. Ensuring that the planning, siting, and design of these and other related systems are based on future flood risk factors is essential to advancing overall community resilience.

In general, there are six steps in the preparation of an infrastructure plan. Planners can play a crucial role at each step in the process by creating the linkages between future flood risk due to climate change and long-term community resilience. The following are recommended practices to help planners better engage in the process of infrastructure planning (Elmer and Leigland 2014).

Organize the planning process. The first stage of the infrastructure planning process generally involves building the team that will develop the plan and preparing the public engagement process. Planners should also play a major role in crafting the public engagement plan to ensure that it is equitable and engages traditionally underrepresented stakeholders.

Analyze existing conditions. While this is likely to be a relatively technical exercise of infrastructure condition assessment and inventory, planners should ensure that discussions around the determination of service areas and capacity are consistent with existing conditions analyses and climate risk and vulnerability assessments that may be a part of comprehensive, hazard mitigation, and climate adaptation plans.

Determine the goals and objectives for the system. Engagement by planning staff in the infrastructure planning process can help to ensure links with the comprehensive plan and other local plans and alignment with climate resilience goals and objectives. For example, if the climate adaptation plan identifies a need to increase the capacity of the stormwater system to accommodate extreme precipitation rates by 2030, then the stormwater plan should reflect those goals and develop more specific objectives to meet them within that time frame.

Project future demand and needs. Traditional demand assessment for an infrastructure system may revolve around population projections and changes in land-use and development patterns. Planners can be crucial to this stage of the process by integrating information from other existing plans and introducing future considerations that may not already be a part of the analysis. If information exists on future precipitation rates, rates of sea level rise, and the scale of damage associated with coastal storms within a climate vulnerability assessment, a comprehensive plan, a climate adaptation plan, or a hazard mitigation plan, then it should be integrated into any analysis of future needs or system capacity.

Identify and evaluate alternatives. Identifying and evaluating alternatives in infrastructure plans can include scenario modeling and spatial simulations. This is also the stage at which costs, potential financing alternatives, and secondary impacts should also be considered. Planners should play a role in identifying and evaluating future scenarios based on potential secondary impacts of future flood hazards. This can include analyses of population shifts due to extreme flooding in certain areas, changing community needs based on heightened flood risk, and impacts to the local economy, public health, emergency services, and natural systems.

Adopt an alternative and implement the plan. The final step in an infrastructure planning process involves implementing the selected alternative. Planners should ensure that the selected alternative is both resilient to future flooding and helps to advance overall community resilience. The adopted plan should be consistent with the comprehensive plan and any other local plans.

Communities may want to consider adding the adopted infrastructure plan as an appendix to the comprehensive or climate adaptation plan. When the comprehensive plan is amended, the adopted infrastructure plan should be included as documentation in the early stages of the planning process to improve coordination and alignment between plans.

CONCLUSION

The plan-making process is among the most crucial steps to ensuring long-term community and infrastructure resilience to future flood hazards. By developing plans that are informed by climate risk, planners establish a foundation that can be built upon by future plans, policies, and actions.

Plans informed by climate risks should not sit on a shelf. By developing clear linkages between plans and implementation through infrastructure, planners can help to realize long-term adaptation goals. Managing the transition to implementation, however, is crucial. As communities develop their capital improvements program, which is explored in depth in the next chapter, planners should continue to be at the front lines of ensuring alignment and consistency.

CHAPTER 5

RESILIENT INFRASTRUCTURE AND THE CAPITAL IMPROVEMENTS PLAN

Infrastructure planning is undergoing a dramatic transformation, particularly for communities that are facing the challenges of sea level rise, more severe storms, and flooding due to more intense and frequent precipitation. Communities that continue to plan based on past trends in the face of climate change uncertainties threaten their future viability.

No person or place is immune from disasters or disaster-related losses. Increasing the resilience of local infrastructure through better planning and implementation will reduce disaster losses, improve the safety and well-being of communities, and create a wide variety of local co-benefits.

The first four chapters of this report have outlined how communities can understand their vulnerability to future climate impacts and how they can plan for infrastructure that is adaptable to future flood risk and increases overall community resilience. This chapter shifts the focus to implementation. Public investment in local infrastructure is one of the most powerful and direct means through which communities can both address their vulnerability to future climate risks and implement their plans.

The capital improvements plan (CIP) is critical to realizing the goals, objectives, and actions identified in these plans through on-the-ground implementation. Making connections between regional, comprehensive, or functional plans and the local CIP can empower communities to ensure that infrastructure is meeting long-term resilience goals.

This chapter documents how planners and communities can use capital improvements planning to improve the resilience of local infrastructure to future flood hazards. It outlines the primary components of capital improvements planning and discusses the overall process and role of planners in the context of long-term infrastructure resilience, and it highlights how planners can improve CIP policies, increase engagement and alignment with other city departments and agencies, and create strong links between the CIP and other local plans.

AN OVERVIEW OF CAPITAL IMPROVEMENTS PLANNING

CIPs document the ongoing process of providing and maintaining the infrastructure to support a specific quality of life in a community. These plans are used to assess infrastructure needs within a jurisdiction over a defined timeframe (five to seven years is considered a best practice), weigh these needs against overall goals and objectives, and then evaluate specific infrastructure projects that should be prioritized for funding (Elmer and Leigland 2014).

Ideally, a CIP should be linked to both a capital needs study that evaluates infrastructure systems (e.g., stormwater, energy, transportation) and the fiscal realities of a jurisdiction (Elmer and Leigland 2014). As a critical tool for implementation, the CIP should also be strongly linked to the local comprehensive and functional plans within a community.

A formal CIP document should include:

- The process and plans to achieve local infrastructure and service goals over the CIP's timeframe
- Assessments of short- and long-term capital needs, or references to separate facility master plans that outline these needs
- A discussion of the intradepartmental and interagency infrastructure coordination process
- An annual schedule for nonrecurring infrastructure investments
- Short-term and long-term funding needs and sources

While different jurisdictions may focus on a different mix of infrastructure improvements based on local and statutory assignments of responsibility, generally the mix of sectors and types will include those listed in Table 1.2, p. 15.

DECLINING REVENUE BASES AND FUNDING FOR INFRASTRUCTURE RESILIENCE

In some areas, the impacts of climate change are already causing declining revenue bases for communities. From 2005 to 2017, rising sea levels, associated flood impacts, and consequent market fears of the vulnerability of coastal property reduced coastal property values by $7.4 billion in five states (First Street Foundation 2018). Florida lost $5.4 billion of this total, with $465 million lost in the Miami-Dade area alone (Figure 5.1).

The local tax bases, revenue streams, and debt capacities of counties and municipalities are directly threatened by climate change. This means increased competition for external funding from state, federal, or private sources, which are likely to increase matching requirements to make the most of limited funds.

For communities that refuse to adapt—or cannot afford to adapt—to climate change, tax and utility revenues are likely to decrease as the value of vulnerable coastal property decreases, as lost coastal property loses all its value, and as the population decreases due to outmigration of displaced or risk-averse residents. But for communities that can protect their infrastructure and development from rising waters, there may be temporary gains in value. Post-Katrina New Orleans foreshadows this, as neighborhoods on relatively higher ground have experienced increased investment and surges in property values while more vulnerable areas have declined.

Questions of social equity will take on increasing importance, as much of the more affordable coastal property is in the most vulnerable areas. Southeast Florida provides a good example of this, as properties along the coastal ridge are some of the most valuable real estate and more affordable communities are located on lower ground to the south and west. While wealthier areas of Miami may have the resources to fund critical infrastructure, its lower-income suburbs to the west, such as Sweetwater, lack the tax base and household incomes required to make essential improvements.

Funding for infrastructure resilience is discussed in more depth in Chapter 7 of this report.

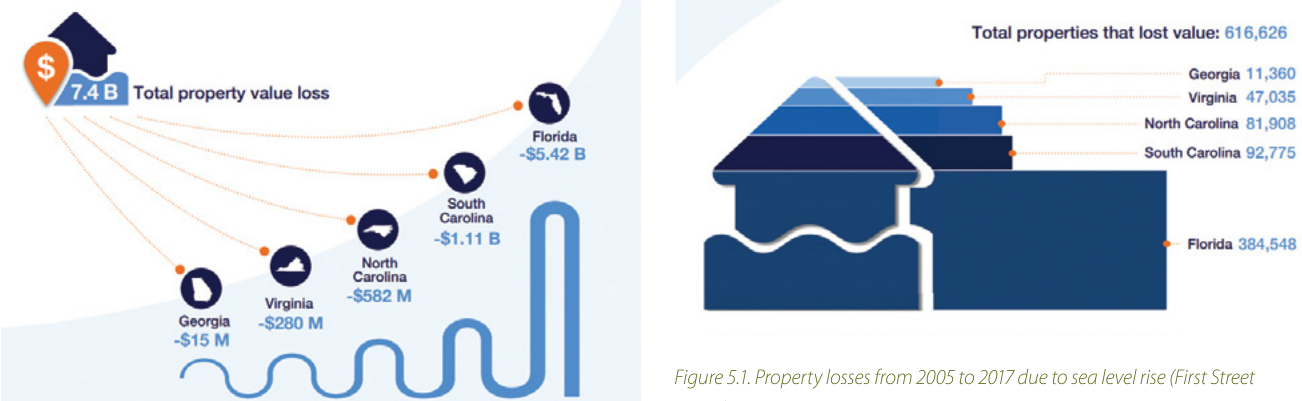


Figure 5.1. Property losses from 2005 to 2017 due to sea level rise (First Street Foundation)

The capital improvement planning process requires communities to have a strong understanding of their priorities. In the context of developing a CIP, communities must consider how they will target investments to achieve community objectives for growth, preservation, conservation, revitalization, health, resilience, and a host of other factors. The local comprehensive plan, if up to date, is a valuable resource for weighing these priorities against one another.

Communities must also consider how they wish to maintain levels of services to provide certainty for residents and businesses. To realize long-term goals and maintain expected levels of service, communities must make efficient use of limited funding. Therefore, spending on infrastructure that achieves local goals, maintains quality of life, and reduces risks to life, property, and the natural environment must be balanced against a community's ability to pay for it.

ADDRESSING CLIMATE AND FLOOD RISK IN THE CIP

Climate change impacts pose a wide variety of challenges to communities, their infrastructure, and their capital infrastructure coordination processes.

Communities that are already struggling to prioritize and fund projects based on a variety of community needs must now consider the risks posed by future hazards that are not grounded in historic precedent. For infrastructure that deals directly with flooding or water resources management, such as stormwater drainage and retention, wastewater treatment, and coastal protection, staff must develop new procedures to rank and prioritize projects based on uncertain rainfall or sea level rise projections. Other local infrastructure and capital projects are no less at risk and will face similar prioritization challenges related to the increasing costs of maintaining, repairing, or adapting infrastructure. At the same time, climate change may be affecting local revenues and tightening local budgets, as explained in the sidebar on p. 78.

This section walks readers through the capital improvement planning process, focusing on the role of planners and the identification of interventions in this process to better integrate infrastructure resilience.

The Capital Improvement Planning Process

The local commitment to a formalized CIP process varies widely across jurisdictions. Some communities may simply ask project managers and infrastructure departments or agencies to assemble wish lists and propose an allocation of resources based on perceived need, existing funding sources, and various political considerations.

This relatively informal approach skips critical parts of the capital planning process that are designed to integrate a wider variety of considerations and viewpoints. While needs and potential projects are identified, the process is largely internal and neglects many internal and external stakeholders, in addition to obscuring the basis for the community's critical investment decisions.

This approach can also exclude planners, resulting in an exercise that disregards existing plans and prioritizes projects that do not advance long-term community goals. For communities that are facing more severe and frequent flooding due to climate change and have a strong vision for infrastructure resilience through their comprehensive or climate adaptation plans, overlooking these priorities in the CIP will result in bad investments, exposed infrastructure, and communities that are vulnerable to more severe future flooding.

A complete CIP process should include the following steps:

- Establish scope, process, and participants
- Identify the basis for needs
- Identify projects
- Prioritize and select projects for funding
- Prepare and recommend the CIP
- Adopt and implement

The process should engage a wide variety of internal and external stakeholders and should be based on existing community plans, goals, and objectives. As outlined in Table 5.1 (p. 80) and in the subsequent sections, planners should play a critical role in this process by ensuring that both community and infrastructure resilience are considered at each stage of the process.

Establish Scope, Process, and Participants

This first stage in the process should identify all relevant stakeholders within and outside the organization and provide meaningful opportunities to identify needs and opportunities. Establishing the scope and identifying needs can draw from existing planning documents and processes, such as comprehensive, hazard mitigation, or climate adaptation planning efforts.

While department heads can be expected to advance and protect their own silos, planners and planning departments can be crucial to fostering interdepartmental collaboration and coordination. Planners and planning departments tend

TABLE 5.1. INTEGRATING INFRASTRUCTURE RESILIENCY INTO THE CIP PROCESS

Stages of the CIP Process	Integrating Future Flood Considerations
Establish scope, process, and participants	Engage a wide variety of potential participants, including departmental representatives from outside the traditional infrastructure agencies in the CIP committee to ensure a wider variety of factors are considered throughout the process
Identify needs	Integrate findings from vulnerability assessments and local plans on the potential impacts of future flooding on infrastructure levels of service and the exposure of neighborhoods and populations into existing processes for analyzing existing conditions and long-term infrastructure needs
Identify projects	Ensure that the projects identified for potential inclusion in the CIP are aligned with long-term infrastructure goals and needs identified in local plans, and that future climate risks to both the infrastructure itself and the communities that infrastructure is intended to serve are identified in a vulnerability assessment
Prioritize and select projects for funding	Assess the long-term value and costs of infrastructure projects in light of the future flood risks posed to those projects, the maintenance and adaptation measures that might be necessary to ensure the continued operation of infrastructure, the overall vulnerability of the areas and populations that infrastructure is intended to serve, and the potential resiliency benefits that the project might bring
Prepare and recommend the CIP	Establish a clear rationale for project selection that is consistent with comprehensive (or functional) plan recommendations, a sound understanding of the flood vulnerability of the selected projects, and clear justifications for how the selected projects advance flood resiliency goals
Adoption and implementation	Review the adopted CIP annually and help to define a regular update process to ensure continued integration of flood resilience goals into the CIP and alignment with existing or ongoing planning processes

not to oversee infrastructure assets and so can function as arbiters and coordinators throughout the process. For this reason, and because of the CIP's intended links to comprehensive planning, planning departments are ideal overseers of the CIP process, and in some municipalities' charters or codes they are specifically called on to do so.

In organizing the committee or workgroup tasked with overseeing the development of the CIP, planners should seek to engage departments and agencies that can provide valuable input in scoping, prioritizing, and selecting projects. This list should include participants from departments that oversee infrastructure, such as public works or transportation, but should also include local health officials and floodplain and emergency managers. Even in cases where planners are not overseeing the process or participation from other agencies may be lacking, planners should still argue for strong links to the goals and objectives within the comprehensive and other local plans that have been informed by a wider variety of municipal agencies.

In the scoping process, planners can help to introduce additional factors that public works or engineering staff may not have considered. It is vital to include the economic, environmental, and social equity issues raised by climate change and how it impacts those who live in the most vulnerable neighborhoods. The resilience of local infrastructure, and how well it serves residents and stakeholders who are underprivileged or in neighborhoods that are more exposed to future climate impacts, is an important environmental justice issue. Planners should convey these concerns and perspectives to the committee or workgroup tasked with scoping the CIP.

Identify the Basis for Needs

Identifying the basis for needs helps to establish the foundation for the later prioritization and selection of projects in the CIP. The committee tasked with developing the CIP should consider several critical questions at this stage, ranging from the practical day-to-day concerns of future flooding on infrastructure operations to the visionary and bigger-picture goals identified in the comprehensive plan. Examples include the following:

- What are the levels of service being sought for the infrastructure system? Are these levels of service based on a static population base in a specific neighborhood? What impacts might future flooding have on those population figures?
- How do these considerations align with the community's goals and objectives for that neighborhood?
- What time frames are other service providers planning for? Are these aligned, or are they based on different sources of information? For example, if the street department is planning to resurface roads on a schedule, how does that schedule compare to plans for new stormwater infrastructure under those roads? Will this new stormwater infrastructure have an impact on how those roads are impacted by flooding?
- When dealing with sea level rise or storm intensities, are all departments working with the same assumptions for how high the water will rise, or how impactful storm surges might be?

Planners should seek to structure this conversation by seeking out clear linkages between the goals, objectives, and actions cited in the comprehensive or climate adaptation plan and the basis for needs in the capital improvements plan.

For considerations related to infrastructure resilience, climate vulnerability assessments, comprehensive plans, or adaptation plans can be critical sources of data and information related to future climate impacts. For example, if a climate adaptation plan identifies and designates local areas of risk based on a particular sea level rise projection, then this projection should be considered as a basis for decision making on infrastructure within those areas. Referring to existing plans that have reached informed conclusions about future needs and risk factors can help to address the uncertainty of future impacts and remove one of the more critical impediments to prioritizing infrastructure projects later in the process.

Identify Projects

At this stage, the committee will be tasked with identifying projects for potential inclusion in the formal CIP document. Questions commonly considered at this stage may include:

- What projects are most critical for the coming years, given assumptions for demand?
- How does each of the projects relate to other projects?
- What needs to be in place for each project to occur?
- Are there economies of scale, or concurrence, that can be implemented?
- How much will each project cost to build, operate, and maintain?

Referring to the prior stages in the process is crucial to ensuring that the considerations and risk factors identified in those stages are a major part of identifying which projects will be considered in the CIP. For example, questions of future demand along with factors of future flood risk should be considered when determining critical infrastructure needs. Future impacts from more severe and frequent flooding should factor into determining the costs of construction, operation, and maintenance.

It is important to remember that adaptation actions may increase the up-front costs of projects (through elevation, hardening, or other strategies), but these costs will often more than pay for themselves in the project's overall adaptive capacity and its longer useful life. Projects that do not integrate adaptation early on will likely be subject to higher maintenance costs and potential early replacement. These factors should be considered in the project identification stage.

Prioritize and Select Projects for Funding

Prioritizing and selecting projects for funding should be an iterative process of balancing funding and timing of projects that engages all infrastructure agencies and service providers. Many communities use this process to distinguish funded projects from unfunded projects that typically float until funding can be secured.

The input of agencies and stakeholders should be a major part of this process. Planners should continue to help ensure that those projects that are prioritized for funding are in line with any long-term climate resilience goals established in comprehensive, climate adaptation, or other local plans. As these plans are typically developed with significant community input, they should provide a reliable perspective through which agencies can assess the community's long-term infrastructure goals.

Practical consideration for infrastructure resilience in the prioritization and selection stage should center on the long-term value of investments, particularly in a community's most vulnerable areas. If the community has identified certain areas as especially susceptible to sea level rise within 25 years, does new stormwater infrastructure in those areas have long-term value? Of course, infrastructure resilience is not the only consideration at this stage. Compelling public safety reasons or community goals of continuing to provide high-quality services even in at-risk areas are valid considerations in prioritizing projects. Planners should play a major role in arbitrating and facilitating these conversations.

Prepare and Recommend the CIP

At this stage, the CIP and budget are prepared and then recommended to the local decision-making body for adoption and funding. While the focus of the CIP process up to this point may have been on projects, schedules, prioritization, and funding, documentation of the CIP process and the rationale for the decisions it incorporates is essential to building foundation for future decisions. Planners can be vital to ensuring the success of this stage.

The preparation of the CIP document can be a great opportunity to formally tie the CIP process to the comprehensive or climate adaptation plan. Comprehensive plan goals should be identified or cited in the CIP to highlight how certain projects advance infrastructure and community resilience. While it is expected that the CIP document may feature technical information such as sea level rise projections or charts featuring complex cost-benefit analyses, planners can help to render this information in plain language and with specific linkages to resilience goals, objectives, and actions developed in other local plans.

Describing the process by which the CIP was developed and explaining the rationale for why certain decisions were made can help to guide future infrastructure planning efforts. New participants in subsequent CIP processes may require a reference for understanding how the committee or workgroup is formed, how long the process will take, or what considerations factor into project prioritization. Planners should ensure that this information is clearly outlined and presented in the current CIP to help guide participants in the next cycle.

In the context of infrastructure resilience, it will be helpful for readers to understand the rationale for why certain decisions regarding a bridge elevation or stormwater drainage capacity may have been made, and what future scenarios informed those decisions. This context could be important if new data sources on future sea level rise or precipitation rates become available.

Formally recommending the CIP involves presenting the document and its budget to the local body of elected officials. The clarity of a CIP, how well it meets the goals and objectives identified in the comprehensive plan, and the degree to which the projects identified for funding provide long-term value to the community are vital at this stage. Especially in communities that are susceptible to long-term flood impacts due to sea level rise, the resilience of infrastructure to these impacts may be high on the list of local priorities. Ensuring that adaptation goals are clearly defined and that associated costs carry substantial resilience benefits are likely to be helpful at this stage.

Adoption and Implementation

Municipalities do not formally adopt capital improvements plans as they would a comprehensive plan. Rather, the community will adopt the first year of funding for the projects identified in the CIP through its capital or operating budget.

Adoption by the body of local elected officials is a step toward implementation, but communities must be nimble in the CIP's implementation to account for infrastructure coordination issues and changing conditions. The projects ultimately funded are subject to political adjustments to address citizen complaints or legislative desires. A severe flood can unsettle existing infrastructure plans and require the community to reallocate limited resources toward repairing critical systems. Rising water and increasingly severe flooding may increase demands on infrastructure while complicating the process by which communities can move toward implementation.

Nevertheless, planners should work to ensure that future climate risk factors such as more severe and frequent flooding are integrated into the capital improvements planning process. By rooting the infrastructure projects identified in a CIP in inclusive and expansive planning processes (particularly comprehensive planning processes), planners can help to build a strong case for adoption by the local decision-making body. A regular commitment to this integration as part of the regular CIP cycle can help to ensure that infrastructure resilience remains a community priority. One such example is described in the sidebar on p. 83, which reviews how San Francisco integrates sea level rise into its capital planning process.

CONCLUSION

Capital improvements planning is a crucial tool for realizing the long-term resilience of communities and their infrastructure to future climate change risks such as sea level rise, severe coastal storms, and more frequent periods of heavy and extreme precipitation. The involvement of planners in crafting the CIP is vital to ensuring a crucial link between the goals and objectives identified in existing local plans and the actual process of designing and constructing infrastructure.

INFRASTRUCTURE RESILIENCE AND THE CAPITAL PLANNING PROCESS IN SAN FRANCISCO

The San Francisco case study in Chapter 3 of this report describes how the city assesses the vulnerability of infrastructure to sea level rise. In addition to this formal vulnerability assessment process, the process by which the city organizes and prepares its capital plans is similarly vital in ensuring that projects are effectively identified, vetted, prioritized, and selected for funding based on the consideration of sea level rise impacts over the life of a project.

The city's general plan and planning code, its Capital Planning Committee (CPC), the San Francisco Bay Conservation and Development Commission, and the California Coastal Commission all play roles in both planning and implementing coastal infrastructure in San Francisco. The overall process for developing the city's capital plan is overseen by the CPC. The CPC is chaired by the city administrator and includes the president of the San Francisco Board of Supervisors, the mayor's budget director, the controller, the planning director, and the departmental heads of all city agencies that plan for and operate infrastructure assets.

The CPC provides city departments with overall guidance for evaluating capital planning and maintenance. These departments also need to consider relevant state regulations and guidance such as the California Environmental Quality Act (CEQA), which requires coordination on many levels but may be advantageous. For example, CEQA requires the city to consider whether projects would expose people or structures to a "significant risk" of loss, injury, or death due to flooding. The planning department has adopted this standard and determined that it also applies to sea level rise.

The CPC provides each agency and their project managers with a standardized checklist assessing exposure, sensitivity, and adaptive capacity, as described in the case study in Chapter 3. This information is then compiled by each agency into its own distinct capital plan. The CPC reviews each agency's plan for consistency, alignment with other local plans, and the degree to which it reduces long-term vulnerabilities to sea level rise. A combined plan is then submitted to the mayor and board of supervisors for approval and funding.

The city's capital plan is intended as a framework that can be used to realize long-term infrastructure resilience while also addressing the day-to-day issues of safety and accessibility. This deeply integrated approach relies upon strong guidance from the CPC, significant buy-in from agency and department heads, and a culture of resilience among individual project managers. Such an approach is obviously scaled to the needs of a large city, but the principles of alignment, integration, and process standardization for implementing infrastructure resilience are applicable to municipalities of all sizes across the country.

More information on San Francisco's approach is available at http://onesanfrancisco.org.

Chapter 7 of this report will dig deeper into the challenges of developing standards and guidelines for resilient infrastructure and outline the role of planners in advancing community resilience goals through implementation.

CHAPTER 6

STANDARDS, GUIDELINES, AND REGULATIONS FOR RESILIENT INFRASTRUCTURE DEVELOPMENT

The previous chapters of this report have discussed how communities can assess their vulnerability to climate change and associated flooding impacts, how they can develop plans to increase overall community and infrastructure resilience, and how these plans can be linked with implementation through the capital improvements plan.

A critical next step for implementation includes developing and using standards and guidelines for the design, siting, and development of infrastructure that is resilient and adaptable to more intense and frequent flooding. These standards and guidelines can be used in conjunction with a variety of zoning, land-use, and associated regulatory mechanisms that can reduce the need for stationary gray infrastructure and ensure the resilience of privately constructed or maintained infrastructure that may be at risk due to future climate and flood hazards.

This chapter will discuss the challenges surrounding infrastructure resiliency standards and the major barriers preventing their use. Uncertainties regarding the scale of climate change risks and the many potential impacts to communities and their infrastructure have made developing predictable and broadly useful standards for resilient infrastructure design especially difficult, and much work remains to be done in this area. This section will also explore how planners can help to develop local standards and guidelines for infrastructure that advance local resiliency.

Regulatory approaches through zoning and land-use tools can complement infrastructure guidelines and improve long-term community resilience. The chapter next offers a series of considerations to help planners ensure that privately developed or maintained infrastructure is resilient to more frequent and severe flooding.

Finally, this chapter will conclude with overarching strategies for planners to hasten the adoption of local guidelines and regulations that advance community and infrastructure resilience.

STANDARDS AND GUIDELINES TO SUPPORT RESILIENT INFRASTRUCTURE

To date, there are no national standards for resilient infrastructure that have been widely accepted by engineering and public works professionals. While efforts are underway through such recent publications as *Climate-Resilient Infrastructure: Adaptive Design and Risk Management* from the American Society of Civil Engineers (ASCE 2018), formal and predictable resiliency standards that can be used across the country by local staff involved in infrastructure planning and design are still a few years away.

In the absence of broadly accepted standards, communities can still develop contextual standards and guidelines for the siting and design of public infrastructure that is resilient to future climate change impacts. Planners can play a critical role in ensuring that these standards and guidelines advance long-term community resilience and are aligned with the visions outlined in comprehensive, climate adaptation, and other local plans.

The Challenge of Infrastructure Resiliency Standards

Public infrastructure is expected to maximize benefits to public safety, health, and well-being over the long term. In many cases, the useful life of public infrastructure is several decades long. There is considerable agreement among climate scientists that a wide variety of impacts due to sea level rise, coastal storms, and more severe and intense precipitation events are likely within that time frame. However, significant uncertainties exist regarding the scale and timing of these impacts.

While global climate models continue to improve, downscaling climate change to the regional, subregional, and local scales introduces additional uncertainties. At the sub-local and site scales, where most community infrastructure is constructed, these uncertainties pose significant challenges to local engineering and public works staff who are tasked with siting and design (Olsen 2015). Standard approaches exist for measuring and integrating levels of service for variables such as future population in the design of local infrastructure, but there are no formally established approaches to systematizing and standardizing climate change uncertainties.

Current design practices do address natural hazards risk, but only to a certain extent. *Climate stationarity* refers to the assumption that the future climate and potential extremes will be much like the past. This creates a general sense of predictability surrounding climate and natural hazards that infrastructure can be designed to accommodate. In designing for a natural hazard like storm surge, for example, practices such as integrating freeboard (additional elevation above the base flood elevation) into the design of a public building or bridge to account for floods beyond the magnitude of one percent annual chance events are common and standardized both across the profession and within local practice.

Engineers are also familiar with common statistical methods such as confidence intervals, sampling error, and probability distributions to define the realm of what is possible and what can be designed for (Olsen 2015). These assumptions inform the development of standards governing where infrastructure should be built and what kinds of stresses it should be built to accommodate.

Climate change, however, introduces complexities that pose a significant challenge to these existing methods for accounting for future uncertainties in infrastructure design. Climate change does not just act upon the piece of infrastructure itself, it also introduces many new variables that undermine standard assumptions about the future. For example, these deeper uncertainties may include changes in demand that can result from how climate change impacts a city or region, population change due to migration resulting from climate impacts, the state of the local economy in especially exposed and vulnerable areas, and stresses on the natural environment that can impact broadly relied-upon natural resources.

Atop these many variables are climate models that themselves are highly variable and dependent on assumptions about future greenhouse gas emissions (Olsen 2015). These models can outline future scenarios, but they are not predictions. They can be downscaled to regions and cities, but they lose precision as the scale becomes smaller.

The sheer number of variables that must be accounted for can paralyze the ability of staff to meaningfully factor future uncertainties into their calculations. Without broadly accepted methods and standards adopted by the profession, local staff are largely on their own in determining how to consider these factors in local project siting and design. But while such national standards do not yet exist, there is an increasing amount of guidance available for planners, engineers, and other local staff involved in infrastructure planning that point a way forward for developing local standards and guidelines to support infrastructure resilience.

Developing Local Standards and Guidelines to Support Infrastructure Resilience

Locally developed standards and guidelines for infrastructure siting and design that are informed by climate vulnerability assessments and any applicable local plans and processes can help to remove the guesswork for staff involved in infrastructure implementation.

Local standards and guidelines can help staff cope with future uncertainties by focusing particularly on the local context. This can be especially helpful to engineering staff, public works staff, and infrastructure project managers who ordinarily rely upon standard design manuals and historic hazards data. While planners may not be involved in the formal design of infrastructure, they can play a crucial role in advising and overseeing the development of standards and guidelines. Therefore, planners should at least be aware of emerging methods in engineering and infrastructure design practice to account for more frequent and severe flooding.

This guidance is drawn from the "observational method," which is well established in geotechnical engineering and has been studied for its use in infrastructure adaptation practice (Olsen 2015). It is designed for establishing a process of initial design and adjustment over time based on observed changes in climate. The strategies described below are useful for the development of both standards, which are an established level of quality that must be adhered to, and guidelines, which are not necessarily required but outline a predictable approach.

Design and site infrastructure based on the most probable climate scenario. The most probable climate scenario should be identified as the primary standard to which infrastructure will be sited and designed. Less probable and more unfavorable scenarios should also be identified.

While the identification of scenarios can be challenging, prior stages in the vulnerability assessment and planning processes should guide the scenario identification process. Maps identifying areas of risk and projected flood hazard impacts within those areas will be especially useful at this stage.

Planning staff should work with and advise project managers on how these scenarios were selected.

Design infrastructure to accommodate any unfavorable deviations from the most probable scenario. Unfavorable scenarios should factor into project siting and design. While the most probable scenario should drive the decision-making process on siting, project capacity, and similar factors, more extreme flood impact scenarios should also be considered. Projects should be designed to accommodate these changes over time based on monitoring and observation.

For example, a stormwater drainage project should be designed according to the most probable future changes in precipitation rates, but redundancies should be built into the system to allow it to be expanded at a later date based on more extreme scenarios. The actual modifications to be undertaken in the event of more extreme impacts should be outlined in the initial design stage to enable later modifications.

Develop standard processes for observing changes over time. Processes should be identified at the time of project design for monitoring and observation over the project's design life. It is vital during the project design stage to identify the most critical changes to be measured.

Considerations at this stage may include the integration of monitoring systems that measure water levels over time, the identification of departments or staff responsible for collecting condition data at regular intervals, and the data sources that will be relied upon to assess the severity of climate impacts. This information will be crucial to future comprehensive, adaptation, and capital improvements planning processes.

The information obtained through active and regular monitoring can inform infrastructure vulnerability and help a community assess future infrastructure needs and potential modifications based on existing infrastructure performance. For this reason, planners should be made aware of any climate impact monitoring processes identified at the design stage and become familiar with the practice of monitoring performance.

Design and construct modifications in response to changes. If monitoring points to more extreme climate impacts, then local staff should refer to existing plans for project modifications. This stage relies on considerable buy-in from local decision makers to undertake the necessary modifications.

Funding will likely be required, in addition to the dedication of time and resources from local staff. However, if alternative scenarios were originally anticipated, considered, and adequately monitored, these investments are likely to be far less demanding, disruptive, and expensive than if the project was not designed for adaptation over time. If local plans are diligently updated at regular intervals, these modifications could be factored into existing plan-making processes.

In the absence of formal criteria for designing infrastructure that is resilient to more frequent and severe flooding due to climate change, communities should consider developing their own standards and guidelines. Following the general process outlined above helps to address some of more complex difficulties of dealing with uncertainty by integrating a wide variety of future scenarios into the infrastructure design process. By building the capacity to adapt into initial project design, establishing systems for monitoring impacts, and formalizing the processes for making modifications based on infrastructure performance, communities can improve their ability to adapt promptly and economically in the face of emerging but as yet uncertain future flood hazards.

REGULATORY APPROACHES TO PRIVATELY DEVELOPED OR MAINTAINED INFRASTRUCTURE

This report primarily discusses the ways in which a community can ensure that its public infrastructure is resilient to the impacts of more frequent and severe flooding due to climate change.

However, in many communities, infrastructure can be developed by private entities as a condition for the construction of subdivisions or new residences. In some cases, long-term maintenance responsibilities are assigned to homeowners associations. Ensuring that this infrastructure is resilient to future flooding can be a challenge, especially in the case of homeowner association-managed flood detention infrastructure requiring regular maintenance and upkeep.

The following are regulatory strategies planners should consider for privately developed or maintained infrastructure. These recommendations are largely drawn from PAS Report 584, *Subdivision Design and Flood Hazard Areas* (Schwab et al. 2016), with additional considerations for more severe and frequent flood impacts due to climate change.

Require privately developed or managed local road systems to account for existing flood hazards and future vulnerability. Planners should ensure that privately developed or managed road systems consider the potential impacts of more frequent and severe flooding in their siting, design, and construction. The primary consideration for road networks in the event of flooding is ensuring adequate mobility, ingress, and egress for residents and emergency services.

NEW YORK CITY'S CLIMATE RESILIENCY DESIGN GUIDELINES

New York City is an outlier with regard to the climate change and sea level rise challenges it faces. The city's recently revised Federal Emergency Management Agency (FEMA) flood zones are home to approximately 400,000 residents, tens of thousands of buildings, and thousands of infrastructure assets and systems. Accounting for sea level rise increases the total exposure of residents, buildings, and infrastructure significantly.

The surge from Hurricane Sandy, which far exceeded the boundaries of the city's previous flood zones and caused widespread loss of life and billions of dollars in property loss, illustrates the emerging risks posed by not only sea level rise (nearly one foot since 1900) but also more powerful and frequent coastal storms. Even before Hurricane Sandy, the city has aggressively sought to develop a strategy for dealing with risks posed by climate change.

In 2008, then-Mayor Michael Bloomberg convened the New York City Panel on Climate Change (NPCC) as part of *PlaNYC*, the city's long-term strategic planning and visioning effort intended to guide future decision making. That panel has produced a series of reports aimed at updating its original findings, the most recent of which appeared in the Annals of the New York Academy of Sciences (NPCC 2019).

The 2015 NPCC report included recommendations for a climate resiliency indicators and monitoring system for the New York metropolitan area. It used information from global climate models and regional sources to generate projections of changes in annual average temperatures and sea level rise through 2100.

The 2015 report provides considerable detail—and cause for concern—related to growing areas of the city subject to potential flooding. It noted an expansion from 33 square miles to 50 square miles of the one percent annual chance floodplain from the 1983 Flood Insurance Rate Map (FIRM) to the 2013 FIRM. The report outlined even larger vulnerable areas projected by the middle and end of the 21st century. By 2100, the FEMA one percent annual chance flood map was projected to cover 91 square miles, and the 0.2 percent annual chance map 99 square miles.

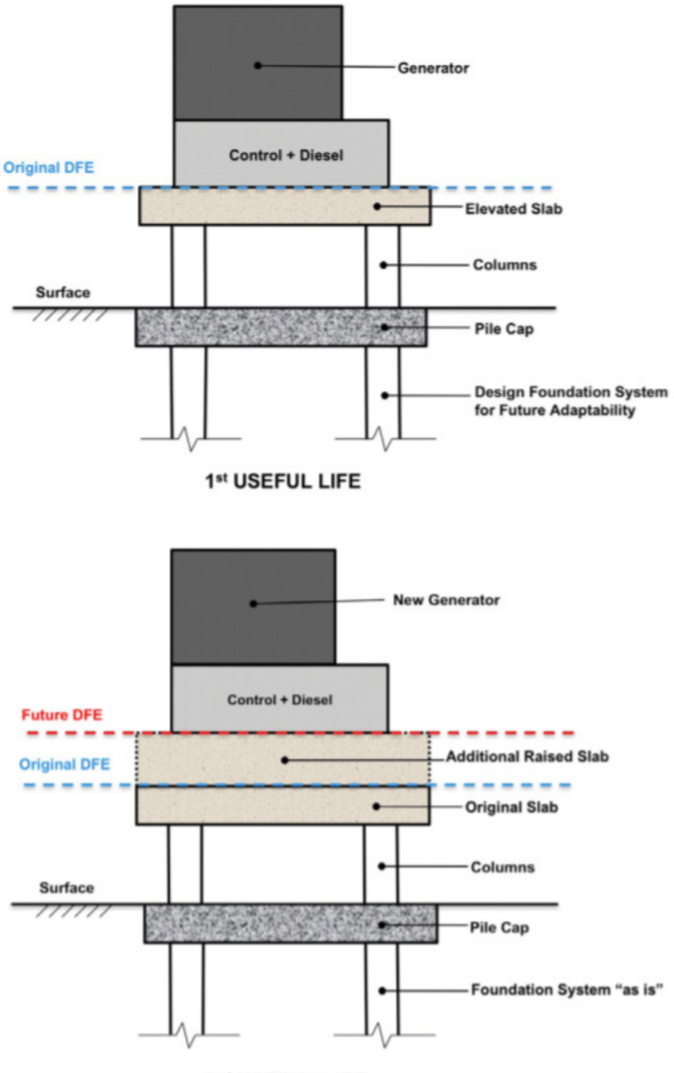


Figure 6.1. This hypothetical generator project is designed to the existing design flood elevation and has the potential to be elevated even higher in the future (NYC Mayor's Office of Recovery and Resiliency)

With much of New York's public infrastructure either on the waterfront or within these flood-prone areas, design guidelines for climate resiliency take on a distinct urgency. The city and other public entities control substantial elements of infrastructure, including transportation, water, and wastewater systems, as well as public schools and colleges. All 14 of the city's wastewater treatment plants, for example, are within the 100-year flood zone.

The city's infrastructure design guidelines, updated in March 2019, outline resiliency guidelines for critical infrastructure systems to extreme heat, more severe and frequent precipitation, and sea level rise. The guidelines are based on an "adaptation pathways" model to manage uncertainty in the design process. This model is similar to the observational method discussed in this chapter, which selects a single climate scenario baseline for project design but allows for modification based on observed impacts.

The selection below from the city's design guidelines for sea level rise follows an earlier risk assessment stage that includes identifying impacts due to tidal inundation, existing flood hazards, and future hazards due to rises in sea level.

> *For all projects at risk of current or future flooding, select design interventions that meet the project's sea level rise adjusted DFE [design flood elevation]. Consider project-specific factors, including the site location, criticality, operational requirements, existing continuity planning, and cost. A Design Strategies Checklist in Appendix 4 is available for use as a resource to track possible design approaches. Some examples of design alternatives are:*
>
> - *For site relocations, conduct alternative site analysis where feasible.*
> - *Permanent barriers at a site (e.g., flood walls).*
> - *Deployable flood barriers (e.g., stop logs, flood doors/gates, inflatable barriers).*
> - *Natural systems-based approaches (e.g., living shorelines, restored wetlands).*
> - *Prioritized protection of electrical, mechanical, and other critical or costly-to-replace equipment above the DFE (e.g., motors and controller, boilers and furnaces, fuel storage tanks, duct work, alarm systems, suppression equipment, electrical panels, electrical distribution, switching areas, gas and electric meters, telecommunications equipment, chemical feed equipment, HVAC units, and emergency generators).*
> - *For dry floodproofing, design a facility to prevent water from entering.*
> - *For wet floodproofing, design a facility to permit floodwaters to flow in and out of the structure without causing significant damage (e.g., elevate or protect critical equipment, use water-resistant building materials below the design flood elevation, include flood vents and pumps).*
> - *Design redundant telecommunications conduit entrances for multiple carrier entry. Telecom conduit should run to diverse manholes when possible.*
> - *Install backup power for telecom equipment with resilient design considerations (e.g., installation above the DFE).*
> - *Install outdoor-rated disconnect switch for telecommunications equipment on the roof.*
> - *Explore interventions to protect underground utilities and other telecommunications facilities from water damage.*
> - *Install backflow preventers, backwater valves, and sump pumps for all buildings and infrastructure in the floodplain, as well as behind flood barriers.*
> - *Shoreline improvements that reduce the height of waves or attenuate waves where feasible.*

New York City's *Climate Resiliency Design Guidelines* are available at www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_Guidelines_v3-0.pdf.

Bridges and culverts are generally required by state departments of transportation to be designed to account for 10- or 50-year storms. Roadway standards in subdivisions often allow for up to six inches of flood water (Schwab et al. 2016).

Given the likelihood of more severe and frequent flooding due to climate change, planners should take steps to significantly strengthen private road design standards. This may include updating bridge and culvert standards to account for flooding in excess of 100-year storm events and requiring roads to be elevated above the base flood elevation. Municipalities should ensure that private developers have access to the necessary data or maps used by the municipality to determine future flood risk.

Require developers to identify stormwater and flood protection infrastructure maintenance needs and costs and to account for more severe or frequent flooding. As a condition for approval of development plans, developers should be required to submit information on stormwater and flood protection infrastructure maintenance needs and long-term costs accounting for more frequent and severe flood impacts. Municipalities should ensure that developers have access to data and maps on potential flood heights and impacts in order to make informed determinations.

Require local government maintenance of stormwater and flood protection infrastructure. Many homeowners associations struggle to maintain locally managed stormwater or flood protection infrastructure (Schwab et al. 2016). Communities should consider requiring developers to turn over to local government the ownership or maintenance responsibilities of critical stormwater or flood protection infrastructure.

In the event that full ownership is not transferred to the local government, long-term maintenance costs established as a condition for approval of the development plan should be factored into any maintenance agreements between the homeowners association and the municipality. These agreements should be updated over time to account for more frequent maintenance needs due to flood impacts.

Create incentives for conservation easements in flood-prone areas to preserve or bolster natural infrastructure. Planners should consider density bonuses or related incentives in exchange for conservation easements to preserve critical natural flood protection infrastructure. Planners should work with developers through the plan review process to preserve natural drainage features and to reallocate density in less vulnerable areas within a subdivision.

STRATEGIES FOR ADOPTING INFRASTRUCTURE RESILIENCY GUIDELINES AND REGULATIONS

Pursuing the adoption of infrastructure resiliency standards and guidelines and realizing a regulatory framework for natural and private infrastructure will require the collaboration of local partners, agencies, and staff across local government. It will also require buy-in from stakeholders and residents and clear connections to the goals and objectives outlined in local plans.

The following are some strategies planners and allied professionals can pursue to hasten the adoption of infrastructure resiliency standards, guidelines, and regulations.

Engage with other local agencies. The need for collaboration with other local agencies on issues related to infrastructure is a recurring theme of this report. Developing standards and guidelines for infrastructure resilience will require the active participation of agencies that own, manage, or maintain infrastructure; input from local policy and decision makers; and clear connections with the goals and objectives identified in local plans.

As no broadly accepted standards or guidelines exist outlining siting and design considerations for infrastructure at risk of more frequent and severe flooding due to climate change, communities must rely upon local knowledge and expertise. This will require significant cross-departmental collaboration. As generalists, planners can play a crucial coordinating role by working across local silos, organizing and facilitating interdepartmental meetings and committees, and working to ensure that resiliency standards are aligned with long-term local goals and objectives.

Communicate with the public. Effective and equitable communication with the public is crucial to the adoption of infrastructure standards, guidelines, and regulations. Planners should perform due diligence to attract a variety of stakeholders to provide input on proposed actions, improve the potential for public buy-in, and enhance the public's understanding of the role of infrastructure resiliency standards, guidelines, and regulations in long-term community well-being.

Planners should consider a variety of methods to solicit input, including social media, traditional media, direct mail, public hearings, open houses, design charrettes, and community workshops. Ensure that public events include those involved in designing infrastructure (planners, engineers, developers) and those who use services provided by infrastructure (residents, visitors, businesses). In communicating with the public, planners should be transparent, use direct language, and be willing to follow up if information is not available.

Ensure that standards, guidelines, and regulations do not pose insurmountable burdens. Planners should aim to provide opportunities for communities to evaluate proposals and outline barriers to adopting, administering, or enforcing regulatory measures at the local level. They should try to address concerns or limitations to successful implementation early in the process, and work to remove any systematic barriers that exist by providing technical assistance whenever possible.

Planners should be transparent about how any standards, regulations, or guidelines impact initial investment costs, maintenance costs, and function over time. Many stricter standards increase upfront investment costs but decrease other costs across a project's useful life. Helping explain the cost effectiveness, potential savings, payback, or ability to withstand greater future impacts can pay significant dividends on gaining approval for new standards, guidelines, and regulations.

Ensure proper regulatory authority. Depending on state, county, or local government structure, local decision makers must determine the appropriate statutory or regulatory authority to enact regulations, standards, and guidelines. While infrastructure standards or guidelines may be implemented at the departmental level, regulatory approaches will require passage by the city council or other relevant body of elected officials. Further, not all approaches can be enacted locally. Therefore, planners should play a major role in advocating for action at the state and federal levels.

The lack of well-established infrastructure resiliency standards and the burdens of relying entirely on local regulations strain the capacity of communities to plan for climate change impacts. Planners should advocate for state and federal agencies and elected officials to provide clear guidance on establishing local standards, guidelines, and regulations.

CONCLUSION

Infrastructure resiliency standards are still an emerging area of study. The resources available for communities wishing to establish standards and guidelines for local infrastructure that account for future flood impacts due to climate change are limited. Nevertheless, planners are crucial to advancing the development of local standards, guidelines, and regulations.

By building on the critical steps of vulnerability assessment, planning, project prioritization, and project selection through the capital improvement plan, planners can establish a strong foundation for developing local standards and guidelines that account for future flood risk factors. This foundation will be critical as communities seek to fund infrastructure projects that are resilient to future flood impacts.

CHAPTER 7

INFRASTRUCTURE FINANCE AND RESILIENCE

Infrastructure and capital needs already strain municipal budgets. Adapting infrastructure to be more resilient through elevation, hardening, relocation, or other means can add to these upfront costs, but is also likely to pay dividends over the long term.

While taking the long view is a worthy goal, it is understandably a hard sell for communities struggling to pay for more immediate infrastructure needs. Planners, therefore, can play a crucial role in ensuring that local finance officials, elected officials, and the communities they serve are considering long-term flood risk and climate change impacts when seeking to invest in infrastructure.

Planners provide a critical linkage between visioning, plan development, and ultimately plan and project implementation. Given their potential relationships with funding agencies and their on-the-ground knowledge of flood hazards and how future flood risk may impact local infrastructure and the community, planners can help to identify funding sources, inform funding requests, and help build support for long-term infrastructure resilience and adaptation. However, basic understanding of local municipal finance as it relates to capital and infrastructure planning is crucial.

This chapter takes a comprehensive view of financing infrastructure that is resilient to future flood hazards and climate risks. It begins with an evaluation of the state of infrastructure finance as currently practiced in communities today. This includes discussions of how infrastructure planning interacts with the capital budget and the various mechanisms that communities use to fund and finance local capital projects and infrastructure.

The next section will discuss the existing funding streams that are typically dedicated to flood hazard mitigation in communities, with a particular focus on both post-disaster congressional appropriations and Federal Emergency Management Agency (FEMA) pre- and post-disaster flood mitigation funding. This section will also discuss emerging financial tools that are specifically tailored to the long-term resilience of local infrastructure to climate change and its impacts.

Finally, the chapter explains why planners should be knowledgeable about infrastructure finance, the benefits of involving finance officials in the planning process, and how both can contribute to the implementation of infrastructure that is resilient to flood impacts and future climate risks.

CAPITAL BUDGETING AND INFRASTRUCTURE FINANCE

Whether a municipality uses a capital improvement plan (CIP) or a more distributed method of infrastructure planning, both relate directly to the capital budgeting process. Unlike the CIP, the capital budget is a legal document, adopted and approved by local elected officials on an annual basis.

The capital budget links the multiyear nature of a CIP or infrastructure development plan with the annual budgeting process of a municipality. In practice, this means that the capital budget tends to contain a description of the project, a summary narrative, funding sources, charts or relevant graphics, and most importantly the approved revenues and expenditures for one year of a funded project. As this budget must be approved by the local elected body, the capital budget is the official local authorization of a given infrastructure project (Elmer and Leigland 2014).

While the broad strokes of the capital budgeting process apply to communities across the country, there is a wide spectrum of complexity (Elmer and Leigland 2014). This spectrum, from least to most complex, includes the following:

- Low-debt, project-specific capital financing
- Basic debt and multiyear capital project planning

- Strategic capital planning and special budget procedures
- Interjurisdictional coordination for capital facilities planning

Generally, these various types of capital budgeting procedures vary according to jurisdictional size and capacity. Many smaller, understaffed, or underresourced communities tend to lack more robust means of infrastructure prioritization, long-term asset management, and access to larger sources of financing. This has important implications for resilient infrastructure planning and financing. For those communities that already struggle to coordinate land-use and comprehensive planning with their infrastructure development processes, planning for flood resilient and adaptive infrastructure will add an additional layer of complexity.

Communities further along the spectrum may have access to more sophisticated means for prioritizing and monitoring infrastructure projects and maintenance needs. They may also have the additional staff capacity and expertise to manage and plan for capital assets. Further, they may enjoy more access to project financing mechanisms. However, these communities may also face greater complexities of infrastructure planning within more dynamic and interrelated environments, along with substantial burdens of aging infrastructure and ongoing maintenance. In short, the complex nature of capital budgeting and infrastructure finance is a challenge across the spectrum of community types and municipal governance.

The following sections outline the primary means by which local governments currently pay for infrastructure.

Bonds

Capital infrastructure is expensive, and cities are often unable to pay for new infrastructure or significant upgrades out of pocket. Instead, most local infrastructure is paid for through the issuance of bonds (Elmer and Leigland 2014).

Bonds are loans between a borrower, who needs money, and a lender, who has money. If a city decides to upgrade its aging stormwater system but does not have the cash to pay for it, it may decide to issue a bond. An investor (a bank, mutual fund, insurance fund, individual, or some combination of these groups) provides the money for the stormwater upgrade project, and the issuer/borrower (the city) pays the investor back over time with interest. The money to pay off the bond tends to come from tax revenue or, increasingly, special assessments and user fees.

Municipal bonds are attractive to investors for two primary reasons. First, the interest earned is exempt from federal (and sometimes state and local) income taxes. Second, since the Great Depression, local governments have had a very good track record of paying back their loans (Elmer and Leigland 2014). The low risk of default makes municipal bonds a secure and reliable investment for lenders. Bonds are likewise attractive to cities, special districts, and authorities that manage and maintain infrastructure because they allow for predictable budgeting and the ability to pay for necessary capital and infrastructure projects or improvements over a period of years or decades.

As cities began to implement spending caps to limit local tax increases, new methods for paying off municipal bonds emerged in the form of user fees and special assessments. Today, the market is dominated by these two general categories: general obligation (GO) bonds, which are backed by local taxes, and revenue bonds, which are backed by fees.

GO bonds are backed by the established credit and taxing authority of the local government. Therefore, they have relatively low interest rates and are highly secure (Elmer and Leigland 2014). However, a variety of limitations on the ability of local governments to issue GO bonds (restrictions on GO bond debt or interest rates) has reduced their popularity in recent years. Voter referenda, sometimes requiring the approval of two-thirds of local voters, have also taken a toll on GO bond issuance and the willingness of local governments to pursue them.

Revenue bonds have emerged as one of the primary financial instruments for local governments, special districts, and other local taxing authorities to finance infrastructure. Revenue bonds rely upon nontax revenue, often in the form of user fees or special assessments, to pay down loans. As with GO bonds, interest on revenue bonds is tax exempt. However, since repayment is based upon more limited (and potentially more variable) sources of funding, interest rates are often higher (Elmer and Leigland 2014). Nonetheless, revenue bonds have grown in popularity. As a mainstay of local infrastructure finance, revenue bonds are of particular value for those sectors in coastal communities where adaptation to flood hazards and long-term climate change may be a particular priority.

Two subcategories of revenue bonds have proven to be popular for infrastructure that will primarily serve a specific geography within a municipality.

Special assessment districts are predefined areas inside which property owners pay an additional fee to finance some local improvement. Approval is generally required by a majority of property owners within this area. Special assessments are a popular means to finance local stormwater improvements (Elmer and Leigland 2014).

Tax increment finance (TIF) is a popular tool for municipalities who wish to incentivize local redevelopment. Within a TIF district, a developer pays traditional real estate taxes only on the predevelopment value of the property. The difference (or increment) between the predevelopment value and the postdevelopment value is a dedicated funding stream, paid by the developer or owner, to pay down the bond debt (Provus 2004).

These tools are well established in local planning and finance, and they have the potential to be leaned upon as more flexible alternatives to traditional general obligation bond-financed infrastructure. Special assessment and TIF districts tend to feature heavily in local plans as finance tools of choice, especially as communities increasingly seek alternative means to incentivize development and target specific infrastructure needs in specific areas without increasing the overall burden of taxation across the entire community.

Development Impact Fees

Along with the trend toward user fees, assessments, and special districts, development impact fees have also emerged as a popular means of paying for and maintaining local capital infrastructure.

When new development is built, new infrastructure is often needed to serve it. Previously, the burden of paying for that new infrastructure fell upon the whole of the municipality. Over the last several decades, that burden has instead shifted to the new development itself and the developers who build it. Agreement to pay impact fees is generally a condition of approval for the project by the city.

There are four types of development impact fees:

- *In-lieu fees* are direct payments by the developer to the municipality or district to pay for some infrastructure improvement. These payments are “in lieu” of land dedication that would otherwise have been used to site the necessary infrastructure.
- *Linkage fees* are often used in the case of commercial or industrial development to accommodate secondary impacts. These are primarily used to ensure adequate housing, child care, or other related services accessible in the area in which people are expected to work.
- *Mitigation fees* are used to pay for the cost of mitigating environmental impacts under the National Environmental Policy Act and other environmental regulations.
- *Connection fees* are paid by the developer and are expressly dedicated to the cost of necessary utility upgrades that will allow new buildings to connect to the larger network of water, sewer, and related utility services (Elmer and Leigland 2014).

In communities experiencing significant growth through new subdivision development, development impact fees can help to defray, reduce, or eliminate the direct costs to the municipality of constructing and maintaining necessary infrastructure. In-lieu, mitigation, and connection fees can be especially useful in the case of reducing long-term flood risk. Infrastructure such as on-site flood retention, connections to stormwater and wastewater networks, riparian and floodplain buffers, and natural infrastructure all can be funded through these development impact fee types.

Pay As You Go

Pay as you go refers to relying on existing funding sources to finance capital infrastructure (Marlowe 2013). This method does not depend upon the issuance of debt that will be paid back, but instead requires communities to pay out of pocket to fund local infrastructure.

Local property taxes represent the largest source of revenue that local governments use to directly fund local infrastructure through pay as you go. Similar to their use as methods for paying down bond debt, user fees and special assessments are also a popular and growing source of funding.

Pay as you go can be contentious for municipalities, as the money to pay outright for new infrastructure needs to be saved over time. Absent tax increases, this will need to be pulled from unspent budget lines and often from agencies conditioned to using their entire budget annually.

Privatization and Infrastructure Finance

The influence of the private sector in infrastructure finance, development, and maintenance has grown over the last four decades. This trend has been especially pronounced in areas experiencing rapid growth (Elmer and Leigland 2014). Local governments, faced with growing populations, booming housing markets, and increasing demand, are turning to the private sector to build and operate new infrastructure. Budget deficits and labor costs have also driven many communities to consider full or partial infrastructure privatization.

The core of the appeal lies in both initial and long-term costs and responsibility. While the ultimate cost of new infrastructure development lies with the municipality, the potential for faster construction at an overall lower price tag has proven to be attractive.

FINANCING RESILIENCE: CURRENT PRACTICE AND EMERGING TRENDS

Federal funding for hazards-related infrastructure development has generally (though not exclusively) been limited to the post-disaster context. Initially, this funding is made available by the federal government through a congressional act and allotted to a variety of federal agencies, departments, and administrations.

This money can be dedicated to a wide array of purposes and streams. Initial direct response actions by a variety of agencies, local relief to impacted residents and businesses, structural repair of federal assets, repair of waterways under U.S. Army Corps of Engineers jurisdiction, and funding for Community Development Block Grants are among the many pathways for post-disaster federal funding.

Only a portion of the total funding outlay is eventually made available to states and localities via grants. Of that pool, a still smaller subset may concern grants to pay for (or to help defray the cost of) infrastructure repair, development, and maintenance. However, these congressional outlays are not the only source of federal mitigation grants and infrastructure funding. There are a variety of new funding mechanisms, both through the federal government and from the private sector, that are specifically intended for both near-term flood mitigation and long-term resilience to future flood hazards.

FEMA Pre- and Post-Disaster Hazard Mitigation Assistance

FEMA's Hazard Mitigation Assistance (HMA) grant programs are major sources of federal grants for funding local mitigation projects, plans, and activities. The three programs are the Hazard Mitigation Grant Program, the Pre-Disaster Mitigation Grant Program, and the Flood Mitigation Assistance Grant Program (Figure 7.1).

Hazard Mitigation Grant Program

Since it began in 1989, the Hazard Mitigation Grant Program (HMGP) has made available nearly $14 billion in grants to states, federally recognized tribes, U.S. territories, local governments, residents, nonprofits, and businesses (FEMA 2019c).

The HMGP is a post-disaster funding mechanism and requires a Presidential Major Disaster Declaration (FEMA 2019c). Funding for local governments, residents, businesses, and nonprofits is routed through the states, which are responsible for selecting local mitigation projects from the pools of applicants and administering the programs locally (Figure 7.2, p. 99). Only states, territories, and federally recognized tribes can apply directly to FEMA for funding through the HMGP. Local governments, which must have or be included within an adopted, FEMA-approved local hazard mitigation plan, must apply through their state, tribe, or territory.

Figure 7.1. FEMA's Hazard Mitigation Assistance comprises the Hazard Mitigation Grant Program, Pre-Disaster Mitigation, and Flood Mitigation Assistance (FEMA)

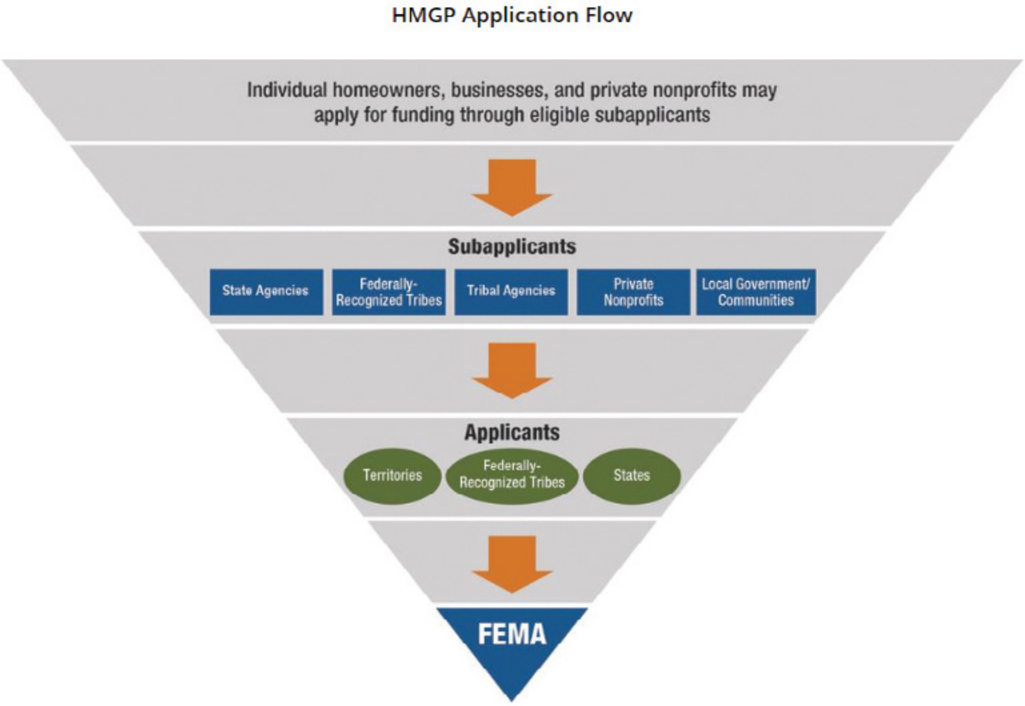


Figure 7.2. FEMA's Hazard Mitigation Grant Program process (FEMA)

FEMA outlines six general standards for HMGP-funded projects (FEMA 2019c):

- Supports risk reduction activities
- Improves resiliency
- Eliminates the impacts of future events
- Provides a long-term solution to a problem
- Offers a cost-effective solution
- Helps avoid repetitive damage from disasters

Many of the potential mitigation projects covered under this program are related to residential natural hazards mitigation. This includes acquisition, demolition, relocation, reconstruction, or elevation of homes; wind, wildfire, or earthquake-related structural retrofits of residences; and the dry-floodproofing of historic buildings. However, the HMGP can also fund local mitigation of flood and drought conditions via infrastructure development and adaptation. Qualifying projects include flood storage, green infrastructure, floodplain restoration, and similar infrastructure projects. HMGP funds for these projects can provide up to 75 percent of the total cost. For local infrastructure projects that receive HMGP funding, the municipality or local entity is required to make up the remaining amount through cash payments, loans, or other grants.

After the initial shock and disruption of a natural disaster fades, municipal governments with well-established and clear infrastructure priorities may be positioned to seek HMGP funds. Similarly, HMGP funding can be vital to help realize resilience-oriented wish-list infrastructure projects that had been too expensive to previously consider.

However, while the intent of the HGMP is to fund projects and actions that reduce long-term risk (and cost), these funds are only available after the declaration of a natural disaster. FEMA's Pre-Disaster Mitigation Grant Program can help to fill the gap and allow communities to preemptively address mitigation and adaptation needs.

Pre-Disaster Mitigation

The stated goal of the FEMA Pre-Disaster Mitigation Grant Program (PDM) is to "reduce overall risk to the population and structures from future hazard events, while also reducing reliance on Federal funding in future natural disasters" (FEMA 2019d).

Much like the other HMA programs, states, tribal governments, and territories apply for the funding, with local governments contributing as subapplicants. Local governments must have or be included within an approved local hazard mitigation plan and must ensure their proposed projects are consistent with state and local mitigation goals.

Availability of funding has increased considerably since the program began in 2015 with an initial outlay of $25 million. In fiscal year 2018, $235 million was made available through the program, which more than doubled the amount available in 2017 and 2016 (FEMA 2018b).

In 2018, for the first time in the program's history, FEMA established a dedicated funding line for "resilient infrastructure." The program is funding capital infrastructure projects that "reduce risks, prevent loss of life, and lead to significant savings by reducing damage from natural disasters and lowering NFIP [National Flood Insurance Program] premiums" by providing up to $10 million per project, with a maximum federal cost share of 75 percent (FEMA 2018b). This is far in excess of the $4 million available for mitigation projects through the PDM and is intended to supplement the funding already available for those projects in the post-disaster-focused HMGP (FEMA 2015a).

Flood Mitigation Assistance

The Flood Mitigation Assistance Grant Program (FMA) is the third element in FEMA's Hazard Mitigation Assistance program series. The FMA is intended to provide funding for projects and planning that mitigate (and eliminate) long-term flood risk to structures insured by the National Flood Insurance Program (NFIP) (FEMA 2019b). As with the HMGP and the PDM, adoption of an approved local hazard mitigation plan is a condition of receiving funding under the FMA.

In 2018, Congress appropriated $160 million for the FMA. While the bulk of this funding is intended for direct mitigation of flood risk for structures (primarily homes) covered by the NFIP, $70 million is also allocated for "projects addressing flooding on a community level" (FEMA 2018a).

Many homes with long histories of NFIP claims and severe flood-related structural damage are often dealt with on an individual basis. This results in a cycle of flood damage, NFIP claims, and structural repair, which reoccurs with the next flood event when the home is again impacted. This new approach, first utilized by FEMA as part of the 2017 FMA program, is primarily due to increasing demand on the part of municipalities for infrastructure-based methods to adapt to flood conditions and mitigate risk comprehensively, rather than at the scale of individual structures. It is intended to better address the problem of areas with substantial numbers of these repetitive loss properties (FEMA 2018a).

This approach is further split into two general focus areas: Advance Assistance and Community Flood Mitigation Projects (FEMA 2019b). Advance Assistance is meant to fund local strategies and data gathering to prioritize and develop community-wide flood mitigation projects. This assistance can be vital to improving both the processes and methods by which communities select and rate potential flood-mitigating infrastructure projects for funding as well as the quality and quantity of data that can be used as part of these prioritization efforts. It can also be vital in securing funding for the second focus area, Community Flood Mitigation Projects, which funds flood mitigation projects directly.

Other Federal Programs for Infrastructure Funding and Technical Assistance

While FEMA may be the most obvious source of federal funding for infrastructure projects related to flood hazard mitigation, there are other federal sources that offer grant funding and technical assistance. Some of these include the following:

- Department of Housing and Urban Development funding through the Community Development Block Grant program can be a significant source of funding for flood resilient infrastructure development or adaptation, though this can be somewhat limited to post-disaster Congressional appropriations.
- The National Oceanic and Atmospheric Administration's (NOAA) Regional Coastal Resilience Grants Program provides funding for coastal infrastructure and ecosystem adaptation and technical assistance (NOAA 2019).
- The U.S. Environmental Protection Agency's (EPA) Water Infrastructure and Resiliency Finance Center provides technical assistance and guidance for communities on seeking out funding for drinking water, wastewater, and green infrastructure (U.S. EPA 2019). This program offers webinars, fact sheets, networking resources, and guidance on available funding sources and strategies for developing requests for proposals or grant applications for water infrastructure.

These are far from the only sources of federal funding and technical assistance for flood-resilient infrastructure. Planners should play an active role in partnering with local finance officials to search for and catalog potential federal funding sources, and they can actively assist in the development of grant applications to meet local infrastructure resilience needs.

Private-Sector Approaches for Financing Flood-Resilient Infrastructure

While FEMA has increasingly sought to incentivize predisaster community-wide infrastructure interventions that reduce long-term flood risk in coastal communities, the vast majority of federal funding for infrastructure adaptation and long-term mitigation only becomes available after a disaster. Absent local means to pay for adapting infrastructure to the twin threats of near-term flooding and long-term climate change, municipalities would ordinarily have to either compete for limited (though increasing) pre-disaster funds or wait for a damaging flood, the subsequent congressional funding appropriations, and the availability of grants through myriad federal and state agencies.

However, the private sector is attempting to fill this funding gap through a variety of new financing mechanisms intended for both near- and long-term infrastructure adaptation to flood risk and climate change. These mechanisms—green bonds, catastrophe bonds, resilience bonds, and environmental impact bonds—build upon existing structures of municipal finance, but differ in their utility to local governments, focus areas, and overall maturity and acceptance in both the private and public sectors. However, all can be considered emerging means through which communities can bridge infrastructure finance, flood hazards, and climate adaptation.

Green Bonds

Green bonds are a category of bond that is intended to tap the private market to finance projects and infrastructure (either public or private) with positive environmental benefits. Green bonds are expected to have a positive monetary return for investors and to achieve positive environmental outcomes according to a predetermined set of standards (ICMA 2018).

Between 2015 and 2018 the size of the green bond market more than quadrupled, from $42 billion to $180 billion (Panerai and Guidice 2016; BusinessGreen 2018). Issuers of green bonds are primarily nations and large corporations, though the share of cities and other forms of municipal government is increasing. Green bonds issued by a municipality are similar to other types of municipal bonds and require repayment via dedicated tax revenues or special fees and assessments (Colgan, Beck, and Narayan 2017).

Historically, projects focused more generally on sustainability, renewable energy, pollution reduction, and transportation innovations have dominated the green bond market. The climate-related outcomes of these projects are broadly aligned with (though not exclusive to) reducing greenhouse gas emissions, rather than adapting to ongoing and future impacts of a changing climate. However, climate adaptation, especially where adaptation overlaps with conservation and the development of natural and green infrastructure, is also an acceptable "green project" (ICMA 2018).

Since 2016, there have also been some significant shifts toward better integrating climate adaptation infrastructure projects into the larger green bond market. The Climate Bonds Initiative, an organization that helps to certify green bonds, is working to develop a set of standards for green bonds dedicated to water infrastructure specifically, and adaptation and resilience generally. Water infrastructure projects that consider mitigation, adaptation, and long-term resilience are eligible for these bonds (Climate Bonds Initiative Water Consortium 2018). As of April 2018, five green bonds adhering to the criteria had been issued. Of these, four bonds totaling over $1 billion were issued by the San Francisco Public Utilities Commission to fund stormwater and wastewater management infrastructure projects (Climate Bonds Initiative n.d.b).

Similar to the water climate bonds initiative, in November 2018 the Climate Bond Initiative launched a working group to begin developing criteria for bonds focused specifically on long-term adaptation and resilience, though initial draft findings have not yet been released (Climate Bond Initiative n.d.a).

Environmental Impact Bonds

Environmental impact bonds (EIBs) are an emerging type of bond that seeks to tie positive environmental and flood resilience outcomes to greater financial returns for investors. Developed by Quantified Ventures in 2016 and first piloted with the District of Columbia Water and Sewer Authority (DC Water) as a private bond offering, EIBs are broadly similar to most other types of bonds that cities, agencies, or public authorities may use to finance infrastructure (Curley 2019). Cities issue a bond, investors provide the capital, and the city pays back the investors over time plus interest. EIBs differ, however, in both the types of infrastructure that they are intended to finance and how risk is shared between investors and the city or issuing agency.

EIBs are primarily intended to finance water infrastructure, green infrastructure, and natural infrastructure with some connection to flood resilience, climate adaptation, or water quality. Metrics tied to some positive outcome (e.g., reductions in flooding, improvements in water quality, quantity of runoff captured) are established at the outset of the agreement. Infrastructure projects that meet or exceed these

THE NEW YORK METROPOLITAN TRANSPORTATION AUTHORITY'S $200 MILLION CATASTROPHE BOND

In 2013, the New York State's Metropolitan Transportation Authority (MTA) secured a $200 million catastrophe bond to provide for repair and replacement of infrastructure in the event of a major flooding event similar to that of Hurricane Sandy. The bond covered the three-year period from August 2013 to August 2016. Twenty investors financed the bond, which sat in an independent trust for the three-year term (Adaptation Clearinghouse 2013).

The terms specified that payout of the bond to the MTA could only be triggered by a storm surge event reaching or exceeding the surge experienced during Hurricane Sandy (2012) and Hurricane Donna (1960). To avoid confusion and conflict in determining whether a trigger event had taken place, the bond terms specified reliance upon NOAA and USGS tidal gauges in specific locations. In assessing the risk factors and establishing these terms, the MTA worked with an independent risk management organization to analyze flood models and outline the probabilities of such an event taking place (Adaptation Clearinghouse 2013).

Ultimately, no storm surge event meeting the trigger took place. The investors were refunded their initial $200 million contribution, along with an additional $27 million in profit from MTA's premiums collected over the three-year term (Adaptation Clearinghouse 2013).

targets pay out a higher interest rate as a bonus to investors. Projects that fail to meet these targets pay a lower interest rate (Curley 2019).

At first, this structure may seem counterintuitive. Projects that are successful require the municipality to pay more to investors, and projects that don't meet their targets pay less. However, this incentivizes investors to finance projects that have clear metrics and positive environmental and flood resilience benefits. For cities, these incentives can make EIBs and the infrastructure they finance more attractive to investors. Though meeting or exceeding the targets comes with a higher price tag, it also likely provides long-term cost savings in the form of avoiding flood losses or reducing or eliminating the need for future adaptation actions.

Since 2016, Atlanta, Washington, D.C., Baltimore, and Lafourche Parish, Louisiana, have each issued EIBs for a variety of projects related to long-term flood resilience, coastal sea level rise adaptation, and green and natural infrastructure (Curley 2019; Quantified Ventures 2019). While DC Water's initial pilot of EIBs was structured as a privately issued municipal bond, Atlanta has helped to pilot the use of EIBs as a public offering at competitive rates (Kopelman Sitton Law Group 2019). This standardization of EIBs within the existing publicly offered municipal bond market could help to improve access to funding for flood resilience, adaptation, and green infrastructure projects across the United States.

Catastrophe Bonds

Catastrophe bonds are complex financial instruments intended to insure municipalities, national and state governments, and private organizations against the losses and impacts of disasters. They can be described as an "instant insurance company created for one particular situation facing a well-defined set of risks over a specific period" (Colgan, Beck, and Narayan 2017).

A catastrophe bond might be issued by a municipality (though more regularly, an insurance company) to hedge against the impacts of a specific natural disaster that results in a particular scale of damage or volume of losses—for example, a coastal flood causing $50 million in structural damage. Funds from the investors who purchase the bond are held in an escrow account. Interest payments from the issuer (the municipality) are also held in escrow and function as an insurance premium. Should a disaster occur within the bond term that meets the established standards of disaster impact, the escrow account is liquidated, the municipality receives the money to recover from their losses, and the investors lose their investment. Should no disaster meeting the standard

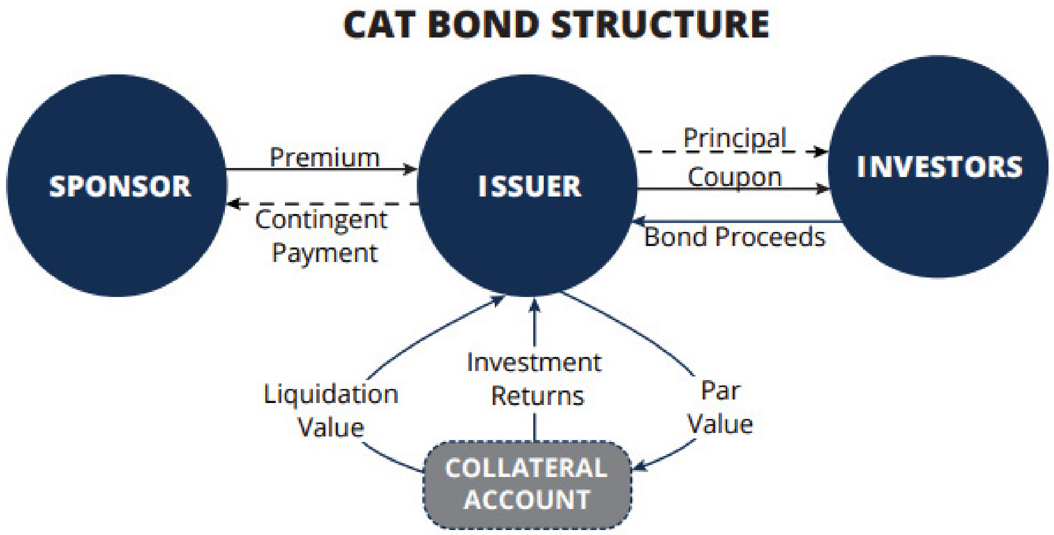


Figure 7.3. Catastrophe bond structure (re:focus)

occur within the bond term, the investors receive their money back plus interest (Spector 2015) (Figure 7.3).

Catastrophe bonds are a rapidly growing market, with total issuance since 1997 growing from $785 million to nearly $14 billion in 2018. FEMA recently issued a $500 million catastrophe bond through the NFIP to cover losses to the NFIP from named coastal storms (Artemis n.d.). This transaction helps to highlight how catastrophe bonds have helped to open significant pools of private capital for both disaster recovery and resilient infrastructure development. The sidebar on p. 102 describes an example of catastrophe bond use from New York.

While catastrophe bonds are a way for communities and insurers to hedge against natural hazard risk by tapping private capital to cover losses and enable redevelopment, they lack clear incentives for preventing, avoiding, or adapting to hazard and climate impacts in the first place. The post-disaster context of catastrophe bonds is inherently reactive to disruptions that kill and displace people, damage and destroy homes and businesses, and strain local, state, and national resources. While helping to minimize financial impacts to a municipality or its insurer, these bonds can resemble a gamble.

Technically, it is in the best interest of investors in catastrophe bonds to incentivize resilience in the municipality. This can reduce the upfront cost of the bond and reduce potential impacts below the preestablished standards. More resilient cities mean fewer impacts from natural hazards, and investors recoup their investment rather than losing it to payouts.

However, there are few established mechanisms within the structure of catastrophe bonds to formalize the relationship between resilient local improvements and the reduced potential for payouts. Resilience bonds (discussed below) are an unproven but emerging financial instrument that could formalize this connection and help fill the gap between the reactive nature of catastrophe bonds and pre-disaster adaptation finance.

Resilience Bonds

Resilient infrastructure design firm re:focus, together with partners in the financial industry and with support from the Rockefeller Foundation, developed the resilience bond model to incentivize risk reduction, climate adaptation, and pre-disaster infrastructure finance. Resilience bonds are envisioned as a variation on catastrophe bonds that links planned resilient infrastructure projects with reduced risk to investors.

According to the resilience bond model, issuers of catastrophe bonds use a financial model to assess the impact of resilient infrastructure on the potential losses to investors. The resulting value is held as a rebate. The rebate is then distributed to the sponsor of the bond (likely the local government, special district, or infrastructure authority) to fund those municipal adaptation and mitigation improvements that would reduce the odds of triggering a full catastrophe bond payout in the event of a disaster (Figure 7.4, p. 104).

Reduced potential for hazard impacts means that investors in the bond are less likely to lose their investment. The benefit for municipalities is in their newly funded infrastructure and the reduced risk of impacts (re:focus 2017). The ul-

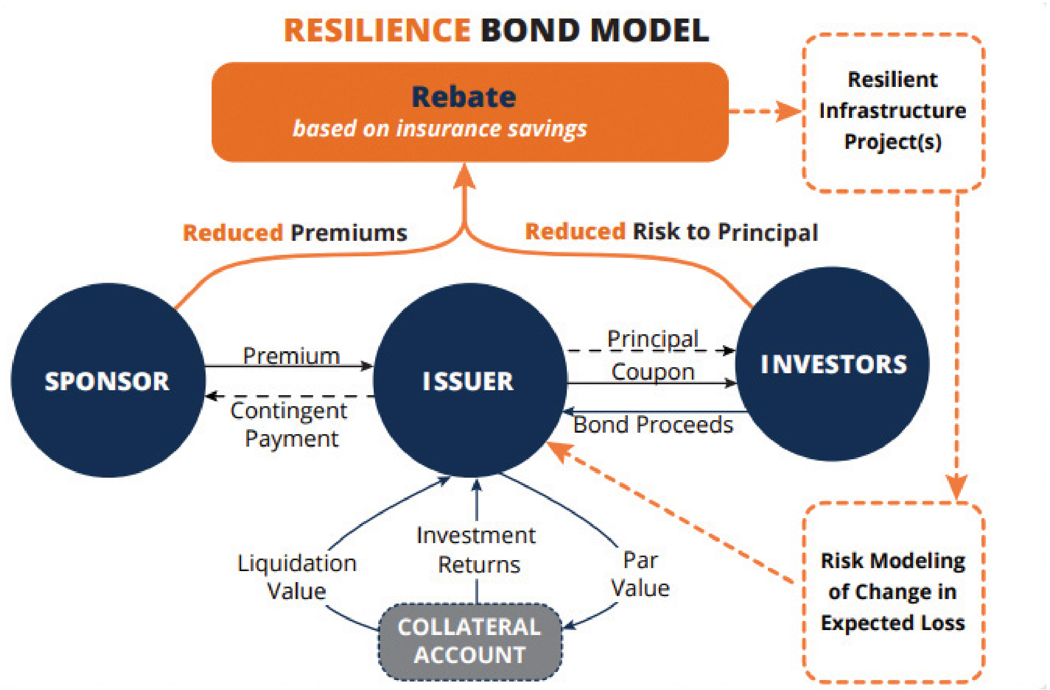


Figure 7.4. The proposed resilience bonds model, a spin on catastrophe bonds (re:focus)

timate goal of the resilience bond model is to translate the as yet unmodeled savings and reduction in risk that a resilient infrastructure project can provide into a monetary value that the private market can fund.

re:focus identified a number of potential use cases for the bond. The use of resilience bonds to finance coastal flood protection is high on the list. The monetary benefits of coastal flood protection are relatively easy to quantify, and engineering models that can assess the degree to which the flood protection will be effective are well established (re:focus 2017).

The resilience bond model is generally more suitable for larger-scale infrastructure projects, for which the cost-benefit analyses already performed can help to inform the cost savings used to finance the project. Smaller-scale projects and projects with diffuse benefit that cannot be translated into a monetary value for investors, such as repairing or adapting a single school or fire station, are not currently well suited for this type of financing. As risk modeling improves, and the private market for funding adaptation and disaster-resilient infrastructure grows, this has the potential to change.

While speculation continues to grow on the potential for resilience bonds and municipal infrastructure adaptation and risk reduction, the model is currently untested.

THE PLANNER'S ROLE IN RESILIENT INFRASTRUCTURE FINANCE

Planning for infrastructure resilience to increasingly intense and frequent flood hazards should not be disconnected from financial considerations. Rather, planners who have a strong understanding of the costs of infrastructure adaptation, the existing local financial context, and potential funding options can help to ensure that implementation is ultimately carried out.

In a post-disaster context, particularly when funding becomes available for infrastructure repair, adaptation, or replacement, the involvement of planners can be critical. Planners and planning departments with a comprehensive understanding of long-term infrastructure needs, future risk factors, and potential federal sources of funding can play a major role in identifying funding opportunities and contributing knowledgeably to an effective proposal. Additionally, relationships that planners and planning departments cultivate with major federal and state infrastructure agencies in the post-disaster response and recovery period can bear fruit later in the process when funding for infrastructure projects might be made available.

Planners can also play a major role in the financing of infrastructure that is adaptable and resilient to future flood hazards by working closely with local finance officials through the visioning, planning, and implementation process. The involvement of local finance officers in this process can help to ground the infrastructure recommendations flowing out of a comprehensive or climate adaptation plan in the realities of municipal finance (GFOA 2009). Additionally, finance officers can be critical in assessing the financial risks that future flood hazards might pose to critical infrastructure, they can help to develop effective cost-benefit analyses, and they can help to convey these long-term financial risks to local elected officials, policy makers, and funding agencies (GFOA 2009).

In 2009, the Government Finance Officers Association (GFOA) released a set of recommendations outlining the importance of local finance officers in the local planning process (GFOA 2009). The four specific recommendations are:

- Master plans should provide a vision for capital project plans and investments.
- Governments should make capital project investment decisions that are aligned to their long-range master plans.
- The finance officer should play an active role in the early planning process.
- Financial factors should be considered as part of the development of master plans.

By involving finance officials early and often in the planning process, planners can aid the integration of long-term local infrastructure needs with the necessary financial tools and considerations to make adaptation to climate change and increasing flood risk a reality.

CONCLUSION

Ultimately, finding and securing funding to adapt or construct infrastructure that is resilient to more frequent and severe flooding is the most consequential action for communities. It represents the culmination of a process that has its roots in the earliest stages of vulnerability assessment and visioning.

Though planners do not control municipal funds, knowledge of the infrastructure finance process can help them to inform comprehensive planning efforts and implementation processes that feed directly into local decisions to fund and develop infrastructure.

While this chapter has reviewed the main forms of financial sources, planners should also be on the lookout for other opportunities to integrate resilience into funding decisions, including requiring the incorporation of resilience considerations in grant proposals. Planners may not have direct control over grant applications or requests for proposals at the local level, but they can advocate for the inclusion of resiliency standards in these documents.

By bringing to bear climate information, federal funding opportunities, and knowledge of emerging private-sector tools for infrastructure adaptation, planners can play a major advisory role in helping to finance resilient infrastructure and fully realize local resiliency goals.

CHAPTER 8

LOOKING AHEAD

Climate trends clearly point to flooding of increasing severity and frequency over the coming decades. For coastal communities, more powerful storms combined with the inevitability of sea level rise may constitute a threat to not just infrastructure, but to the existence of the community itself. Gradual inundation over several years in the form of encroaching higher tides, punctuated by storm surge impacts due to coastal storms, highlight these existential risks.

For communities not on the coasts, the impacts may be no less significant, especially in communities already at risk of severe riverine or lake flooding. Across the United States, more frequent and intense flooding will tax the ability of infrastructure to serve local needs and strain the ability of municipalities to pay for maintenance, adaptation, and replacement.

Beyond the direct impacts posed by future flooding to the long-term well-being of communities, climate change comes with a host of even greater uncertainties. Communities are more than just bordered municipal entities. They are part of dynamic and deeply interrelated political, economic, social, and environmental systems. Climate change will impact these systems in unpredictable ways. Factors such as where people choose to live, the viability of businesses, the strength of local and regional economies, the health of environments and ecosystems, and a host of other variables will be impacted by more intense and frequent flooding due to climate change. How infrastructure responds to or influences these variables is similarly uncertain, especially in light of direct climate stresses on infrastructure itself.

Planners, however, are particularly well suited for dealing with these uncertainties. Planners' strengths lie in understanding issues holistically, dealing with many potential long-term variables, building consensus, and working across disciplines and interest groups. This final chapter summarizes the principal roles that planners can play in building a culture of infrastructure resilience and discusses the challenges that climate change uncertainty poses to the practice of local planning.

THE PLANNER'S ROLE IN INFRASTRUCTURE RESILIENCE

The items below summarize the roles of planners in planning for infrastructure that is resilient to the impacts of more frequent and intense flooding due to climate change. These items have been drawn from the many techniques, tactics, and strategies described throughout this report.

Planners can:

- Identify future flood risk data sources and tools and identify ways to integrate these tools into existing planning processes
- Work with local staff to assess the vulnerability of existing or proposed infrastructure to more severe and frequent flood impacts
- Use climate and flood risk data to identify the capacity for infrastructure adaptation and to reduce exposure and vulnerability to more frequent and intense flood events
- Engage in robust public outreach to understand local needs, better assess community vulnerability, and identify infrastructure and noninfrastructure solutions that equitably reduce risk while also meeting existing and future needs
- Facilitate inclusive community visioning processes that clearly identify long-term climate, flood, and infrastructure-related challenges, and outline a vision for the future that can guide subsequent comprehensive, climate adaptation, and other local plans
- Build strong links among comprehensive, climate adaptation, hazard mitigation, and any other plans that address local infrastructure to ensure the consistency of

data sources and recommendations and reduce potential areas of conflict
- Clearly link plan-identified goals, objectives, and next steps concerning local infrastructure with responsible staff and local agencies to ease the transition between plan development and infrastructure implementation
- Establish consistent timelines for plan updates to allow for the revision of climate and flood-related data and projections, monitor infrastructure implementation, and revise strategies for achieving long-term infrastructure resilience goals
- Guide, inform, or contribute to the local capital improvements planning process to build strong connections between climate vulnerability, long-term community goals, plan-identified recommendations, and infrastructure project prioritization
- Work closely with public works departments and any other local infrastructure agencies to develop standards and guidelines for local infrastructure siting and design that are based on project exposure and vulnerability to future flood impacts, improve the adaptive capacity of projects, and reduce the need for costly maintenance, mitigation, or early replacement
- Develop an understanding of the local infrastructure finance process and work with local finance officials to identify traditional and emerging funding sources

While planners are somewhat limited in the roles they can play in directly influencing the maintenance, design, and construction of infrastructure, they can play a crucial role in coordinating and aligning actions that may be occurring on disparate time frames, at a variety of scales, and across several different local agencies. Planners can not only help to break down silos in local government, but they can also work to ensure that impacts due to sea level rise, coastal storms, and extreme precipitation are considered in local planning and implementation processes.

CLIMATE CHANGE AND DEEP UNCERTAINTY

There are many emerging issues at the intersection of climate change and infrastructure planning. How local planners, allied professionals, and other decision makers can overcome the deep uncertainties surrounding the intensity and time frame of climate change impacts is of critical importance.

Given the significant costs of constructing, adapting, and maintaining infrastructure, and the time frames in which infrastructure is expected to operate, contextualizing or overcoming climate change uncertainties in infrastructure planning and design is vital to the long-term health and well-being of communities.

Climate change uncertainty can be particularly paralyzing for planners. While the causes of climate change are settled science, and the broad, primary impacts of climate change in the form of various extremes are acknowledged by climate scientists and experts, there are still significant questions at the micro and macro scales on critical issues such as time frame and intensity.

The rate of greenhouse gas emissions over the coming decades will drive the degree to which the planet will continue to warm. The Paris Agreement, a United Nations-mediated international accord that establishes global and national emissions reduction targets, is intended to limit the degree of warming and slow the rate of climate change. However, there is still uncertainty surrounding the ability of the agreement to lead to a decline in greenhouse gas emissions, especially on a time frame necessary to avert significant social, economic, and environmental impacts across the globe (Dennis and Mooney 2018). Therefore, climate models continue to lay out a variety of pathways that point to a range of potential futures, and this can greatly complicate the decision-making process at the local scale.

The future conditions illustrated by climate models also feed into complex social and environmental systems. How these systems are impacted by and react to climate change is itself unpredictable and extremely complex. For example, emerging research on the potential instability of the Antarctic ice shelf has led climate scientists to revise sea level rise projections to include more extreme scenarios (NASA 2018). Though such an event becomes more likely as emissions rise, the wide-ranging ramifications for communities due to a rapid significant increase in sea levels are unclear. How more extreme sea level rise may impact global, regional, and local environmental, economic, and social systems is dependent on the interplay of many potential variables. While some big-picture conclusions can be drawn at the global and regional scales from this scenario, local impacts beyond the potential for much more water in a much shorter period of time may be extremely difficult to discern.

Climate data, while useful for assessing potential changes globally, is difficult to downscale for use at the local level. In order to refine this data so that it can be useful for planners and other practitioners, researchers must make an ever-increasing number of assumptions about future local conditions. These assumptions may include determinations on topics such as the particularities of local weather systems at some point in the future, or how future land-use conditions may mitigate or exacerbate local flooding.

These complex but interrelated uncertainties constitute an environment known as *deep uncertainty* (Marchau et al. 2019). Planning for a future that is deeply uncertain can be overwhelming for local practitioners. Making decisions about infrastructure—which represents significant investments of a community's time and money—based on such complex future scenarios can be an intimidating prospect.

Linking deep uncertainty with the practice of local planning is an emerging issue that over the past decade has become a major area of study for environmental researchers. More time will be needed, however, for strategies on dealing with climate uncertainties to filter into local planning practice.

For planners and allied professionals interested in learning more on the topic of deep uncertainty, the Society for Decision Making Under Deep Uncertainty (DMDU) is an organization affiliated with the RAND Corporation that conducts research exclusively on the topic of uncertainty. In 2019, DMDU released the open-access book, *Decision Making Under Deep Uncertainty: From Theory to Practice*, which goes into depth on how practitioners can begin to approach planning and long-term decision making in a deeply uncertain environment. This publication is available at www.rand.org/pubs/external_publications/EP67833.html.

Additionally, researchers working as part of the Great Lakes Integrated Sciences and Assessments team (GLISA), a group affiliated with NOAA and the University of Michigan, have published extensively on the challenges of local decision making in the context of climate change uncertainty. This research includes a wide body of case studies from across the Great Lakes region on bridging the gap between climate scientists and local practitioners to improve local decision making. More information on GLISA and these publications, many of which are freely available, is available at http://glisa.umich.edu.

CONCLUSION

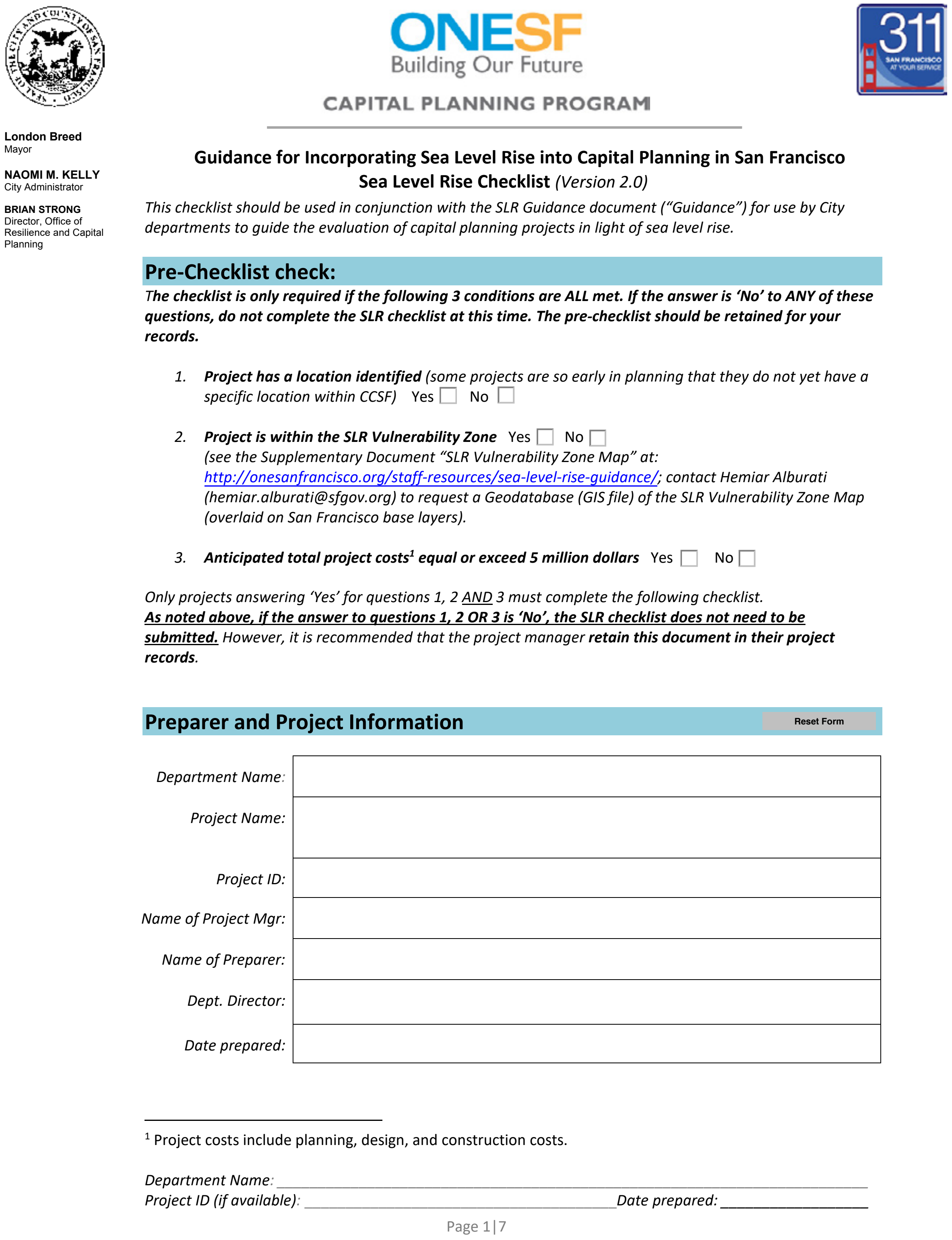
For communities across the United States, increasing the resilience of infrastructure to the impacts of climate change is not yet a priority. Understandably, concerns surrounding increasing costs, declining tax revenue, and the maintenance needs of rapidly aging and degrading infrastructure all tend to dominate the infrastructure conversation. The chronic issues of funding, time, and local capacity are high on the list of challenges for planners, public works officials, city managers, and other local staff to resolve. However, climate change is expected to have a multiplier effect on these already daunting concerns.

As climate impacts such as sea level rise, increasingly frequent and severe coastal storms, and extreme precipitation continue over the coming years and decades, communities will be forced to grapple with how these impacts exacerbate the underlying problems of funding, maintenance, and capacity. This report is an attempt to make the case for planners and the communities they serve to begin the process of integrating long-term climate and flood resilience into the plans and processes that are essential to making infrastructure happen.

Planning is a deeply iterative process. Planners recognize that there is no one simple solution or definitive process for doing the hard work of building safer, healthier, and more resilient communities. Planning can be messy, confusing, and filled with fits and starts, especially when attempting to address emerging and unfamiliar issues. Communities must embrace the complexities that lie at the heart of the intersections between climate change impacts and long-term infrastructure resilience. By committing to taking action, whether in the form of a single vulnerability assessment, a new plan element, or a set of basic design standards, planners can begin to take the first steps toward building a culture that is committed to not just the resilience of infrastructure assets, but the resilience of the community as whole.

APPENDIX

As part of its *Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco*, which is explored in Chapters 3 and 5 of this report, the City and County of San Francisco has developed the following highly detailed checklist for infrastructure agencies and project managers to assess sea level rise and storm surge impacts to planned infrastructure assets. The checklist is intended as a tool for mainstreaming and formalizing the process of factoring sea level rise and storm surge impacts into infrastructure project planning, site selection, and design.



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London Breed
Mayor

NAOMI M. KELLY
City Administrator

BRIAN STRONG
Director, Office of Resilience and Capital Planning

Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco

Sea Level Rise Checklist *(Version 2.0)*

This checklist should be used in conjunction with the SLR Guidance document ("Guidance") for use by City departments to guide the evaluation of capital planning projects in light of sea level rise.

Pre-Checklist check:

The checklist is only required if the following 3 conditions are ALL met. If the answer is 'No' to ANY of these questions, do not complete the SLR checklist at this time. The pre-checklist should be retained for your records.

1. ***Project has a location identified*** *(some projects are so early in planning that they do not yet have a specific location within CCSF)* Yes ☐ No ☐
2. ***Project is within the SLR Vulnerability Zone*** Yes ☐ No ☐
   (see the Supplementary Document "SLR Vulnerability Zone Map" at: http://onesanfrancisco.org/staff-resources/sea-level-rise-guidance/; contact Hemiar Alburati (hemiar.alburati@sfgov.org) to request a Geodatabase (GIS file) of the SLR Vulnerability Zone Map (overlaid on San Francisco base layers).
3. ***Anticipated total project costs[1] equal or exceed 5 million dollars*** Yes ☐ No ☐

Only projects answering 'Yes' for questions 1, 2 AND 3 must complete the following checklist.
As noted above, if the answer to questions 1, 2 OR 3 is 'No', the SLR checklist does not need to be submitted. *However, it is recommended that the project manager **retain this document in their project records**.*

Preparer and Project Information

Reset Form

Department Name:	
Project Name:	
Project ID:	
Name of Project Mgr:	
Name of Preparer:	
Dept. Director:	
Date prepared:	

---

[1] Project costs include planning, design, and construction costs.

Department Name: ____
Project ID (if available): ______________________*Date prepared:* __________

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Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco
Sea Level Rise Checklist

SLR checklist – only for projects meeting all 3 pre-checklist conditions above:

Project Information

1. **What is the project location?** *(Please provide the street address or GIS coordinates):*

2. **What type of asset or project is being proposed?** *(e.g., new construction, rehabilitation or modification of existing structure, building(s), roadway structure, utility structure, park, etc.):*

3. **What is the remaining or potential future functional lifespan of the project?** *(The functional lifespan is the period for which a structure can still meet the purposes for which it was constructed. It refers to the time the asset may realistically be in use at this location, including routine repair and maintenance cycles. (See Guidance for more information).*
Construction completion year (past or planned): ___________
Remaining or potential functional lifespan in years:__________
Please provide a brief explanation of how this number was derived:

4. **What is the planning horizon?** *(The construction completion year + functional life span = planning horizon year; e.g., 2017 construction completion year + 60 year functional life span = 2077.)*
Planning horizon year: ___0___

Site Information

Past/Current

5. **Has the site historically been flooded due to high tides/and or storms?**
(If yes, please describe conditions: e.g., King tide, storm surge, rainstorm event)
☐ **Yes** ☐ **No** ____

6. **What is the lowest ground elevation at your project location (in feet)?**
(Please select the elevation baseline used for all calculations (NAVD88 or City Datum).
This assessment is based on:
☐ a) existing grade
☐ b) proposed grade (e.g., with fill)
☐ c) other*? (*If "other", please add explanation under Question 22.)
_________**ft** ☐**NAVD88** ☐**City Datum**

7. **What map/ modeling is used for this assessment?**
☐ SFPUC 2014 Maps and the Supplementary Document "Sea Level Rise Scenario Selection and Design Calculation" found at http://onesanfrancisco.org/staff-resources/sea-level-rise-guidance/
☐ Site Specific Modeling (*please provide date and source of information*):
____

8. **What is the Mean Higher High Water (MHHW) elevation closest to your project location?**
(Use the data source in question 7; e.g., from Figure 1 in Supplementary Document cited in Question 7) or site-specific modeling).
MHHW Elevation (year 2000):__________**ft** ☐**NAVD88** ☐**City Datum**

Department Name: ____
Project ID (if available): ______________________________ *Date prepared:* _______________

9. What is the 100-year extreme tide elevation (in feet) closest to your project location?
(Use the Supplementary Document cited in Question 7 or site-specific modeling.)

100-year extreme tide elevation (in feet):_________ft ☐ NAVD88 ☐ City Datum

10. Is the project located within 100 ft of the shoreline?
(If the project is located directly along the shoreline, the 100-year total water level -- which includes wave hazards at the shoreline -- must be considered.)

☐ **Yes** (Go to Question 11). ☐ **No** (Go to Question 12).

11. If the project is within 100 ft of the shoreline, what is your 100-year total water level elevation?
(Use the Supplementary Document cited in Question 7 or site-specific modeling.)

100-year total water level elevation (in feet): _________ft ☐ NAVD88 ☐ City Datum

SECTION I - Vulnerability Assessment for Potential Projects in the SLR Vulnerability Zone

A. Exposure (see SLR Guidance for additional information):
Assess if the project site or asset could be subjected to sea level rise inundation, temporary coastal flooding, or wave hazards. Some fields below will auto-calculate based on the information entered.

Future Sea Level Rise Calculations

12. Calculate projected sea level rise at the end of the planning horizon year __0__ (from Question 4.)
(If your project is within 500 feet of the shoreline, or if it provides a critical service for the City, please select RCP 8.5 for all following calculations. If RCP 4.5 is selected, please provide justification for this selection below.)

☐ RCP 4.5
a) __0__ in inches and __0.0__ in feet -- likely value
b) __0__ in inches and __0.0__ in feet -- 1-in-200 chance value

☐ RCP 8.5
c) __0__ in inches and __0.0__ in feet -- likely value
d) __0__ in inches and __0.0__ in feet -- 1-in-200 chance value

Assess Project Vulnerability to *Permanent Inundation* from Sea Level Rise

13. Subtract MHHW (8) from the Project elevation (6)

Difference in feet: __0.0__ft
(If the answer is negative, the project is below MHHW and could be vulnerable today.)

a) Is the project vulnerable to permanent inundation during the functional lifespan using the likely SLR scenario? *(Is the answer to Question 12a greater than the answer to Question 13?).*

☒ **Yes**: The project could be inundated by likely sea level rise and will require adaptation strategies.
☐ **No**: Not vulnerable.

b) Is the project vulnerable to permanent inundation during the functional lifespan using the 1-in-200 chance SLR scenario? *(Is the answer to Question 12b is greater than the answer to Question 13).*

☒ **Yes**: The project could be inundated by 1-in-200 chance sea level rise and adaptation strategies are recommended.
☐ **No**: Not vulnerable.

Department Name: ____
Project ID (if available): ________________________ *Date prepared:* ____________

Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco
Sea Level Rise Checklist

Assess Project Vulnerability to *Temporary Flooding* from 100-year Coastal Flood

14. Subtract 100-year extreme tide elevation (9) from the Project elevation (6):

Difference in feet: 0.0 ft
(If the answer is negative, the project could be vulnerable to temporary flooding by the 100-year extreme tide event today.)

a) Is the project vulnerable to temporary coastal flooding coupled with likely sea level rise during the functional lifespan? *(Is the answer to Question 14 less than the answer to Question 12a?)*

☒ **Yes**: The project could be inundated by a 100-year extreme tide coupled with likely sea level rise. Flood-proofing adaptation strategies may be required.
☐ **No**: Not vulnerable.

b) Is the project vulnerable to temporary coastal flooding coupled with 1-in-200 chance sea level rise? *(Is the answer to Question 14 less than the answer to Question 12b?)*

☒ **Yes:** The project could be inundated by a 100-year extreme tide coupled with 1-in-200 chance sea level rise. Flood-proofing adaptation strategies are recomended.
☐ **No:** Not vulnerable.

15. For projects within 100 ft of the shoreline *(If project is not within 100 ft of the shoreline, go to Question 16.)*
Subtract 100-year total water elevation (11) from the Project elevation (6):
Difference in feet: __________ft
(If the answer is negative, the project could be vulnerable to wave inundation if the 100-year total water level can overtop the adjacent shoreline under existing conditions.)

a) Is the project vulnerable to potential wave inundation with likely sea level rise during the functional functional lifespan? *(Is the answer to Question 15 less than the answer to Question 12a?)*

Yes: The project could be inundated by wave hazards with likely sea level rise. Adaptation strategies may be required.
No: Not vulnerable.

b) Is the project vulnerable to potential wave inundation with 1-in-200 chance sea level rise? *(Is the answer to Question 15 less than the answer to Question 12b?)*

Yes: The project could be inundated by wave hazards with 1-in-200 chance sea level rise. Adaptation strategies are recommended.
No: Not vulnerable.

Department Name: ______________________________
Project ID (if available): ______________________ *Date prepared:* __________

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B. Sensitivity (see SLR Guidance for definition):

16. Is the project/asset(s) sensitive to inundation (i.e., is it physically or functionally impaired if it gets wet?)

☐ **Low Sensitivity**: sea level rise and temporary flooding would have little or impact on the project asset(s) physically or functionally.

☐ **Moderate Sensitivity:** sea level rise and temporary flooding would have an impact on the project/assets(s) physically or functionally, but the project would recover quickly one floodwaters subside. The project would retain partial function while inundated.

☐ **High Sensitivity:** sea level rise and storm surge inundation have a significant influence on the project/asset(s) physically or functionally, and the project would not recover quickly once floodwaters subside. The project would lose major function while inundated.

Please explain briefly*:

**(If more space is required, please provide on separate page)*

C. Adaptive Capacity (see SLR Guidance for definition):

17. Does the project/asset(s) have adaptive capacity (i.e., can it easily be adapted to mitigate potential damage or functional impairment, or does it have redundancy to minimize potential consequences?)

☐ **High Adaptive Capacity:** Project/asset(s) has little inherent capacity to adapt to future inundation or flooding without additional capital investments.

☐ **Moderate Adaptive Capacity:** Project/asset(s) has some inherent capacity to adapt to inundation or flooding without additional capital investments (e.g., the project includes redundancy, or a reasonable alternate route is available).

☐ **High Adaptive Capacity:** Project/asset(s) has substantial capacity to adapt to inundation or flooding without additional capital investments (e.g., the ability to adapt to higher sea level rise has been designed into the project, such as automatic flood barriers on doorways).

Please explain briefly*:

**(If more space is required, please provide on separate page).*

Department Name: ____
Project ID (if available): ______________________________ *Date prepared:* ______________

Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco
Sea Level Rise Checklist

SECTION 2 – Risk Assessment for Projects identified as vulnerable to sea level rise or temporary coastal flooding.

18. What is the anticipated level of **DAMAGE** to the project/ asset(s)?

- ☐ **Low Damage**: Asset(s) could be repaired/ partially replaced
- ☐ **Moderate Damage**: Asset(s) would require complete replacement or very costly repairs
- ☐ **High Damage**: Asset(s) would not repairable or replaceable in the existing location
- ☐ Unknown

Please explain briefly*:

19. What is the level of **DISRUPTION**?

- ☐ **Low**: no or little disruption in service or function
- ☐ **Moderate**: disruption in service or function that doesn't threaten public health & safety (non-critical)
- ☐ **High**: disruption of service and/or function that threatens public health & safety (critical)
- ☐ Unknown

Please explain briefly*:

20. What are the **COSTS** (to replace/repair or for health & safety)?

- ☐ **Low**: no or little cost to return asset(s) or minor secondary service disruption costs
- ☐ **Moderate**: moderate costs to repair/ replace asset(s)
- ☐ **High**: high costs to fully replace asset(s) in new location and/ or high secondary costs attributed to asset being out of service
- ☐ Unknown

Please explain briefly*:

If all answers to Section 2, Questions 18, 19, and 20 are Low, project likely has sufficient adaptation planning. If any answers are Medium, additional adaptation planning may be required. If any answers are High, alternatives should be considered.

21. Please briefly summarize sea level rise adaptation measures associated with this project or program*:

22. Additional Comments*:

(If more space is required, please provide on separate page)

Department Name: ______________________________
Project ID (if available): ____________________ *Date prepared:* ____________

Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco
Sea Level Rise Checklist

SECTION 3 – Department Certification Submittal

(This section is for the Dept's Director and Deputy Director level only. Please submit signed copy to the Capital Planning Program for processing.)

____ (Dept Name) certifies that the information provided herein is complete and is consistent with CCSF Sea Level Rise Guidance.

Dept. Director: ____

Signature[2]**:**_____________________________________ Date: ___________

SECTION 4 – Capital Planning Committee

(This section is for City Engineer, Capital Planning Committee, or Designee completion only.)

This project is certified as consistent with the CCSF Sea Level Rise Guidance and

☐ will not be exposed to expected sea level rise and related flooding impacts during its functional lifespan
☐ is exposed but is not vulnerable due to low sensitivity or high adaptive capacity
☐ is exposed, is vulnerable, but includes sufficient adaptation planning to address sea level rise
☐ will require additional adaptation planning

Comments: ____

City Engineer Name (please type/print): ____

Signature[2] **:** _______________________________ Date:___________

Capital Planning Committee Chair Name (please type/print):____

Signature[2]**:** _______________________________ Date:___________

---

[2] *(Digital Signatures are preferred; if this file needs to be printed and scanned for signatures, please ensure high resolution document print and scan for legibility. Thank you.)*

Department Name: ____
Project ID (if available): ____________________________ *Date prepared:* ____________

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