ADAPTATION FOR ALL:
HOW TO BUILD FLOOD RESILIENCE FOR COMMUNITIES OF EVERY SIZE

AMERICAN FLOOD COALITION

NL Netherlands

ARCADIS

FloodCoalition.org

Image source: Getty

Foreword

As the Ambassador of the Kingdom of the Netherlands to the United States, I proudly present this guide. It is the result of an American-Dutch collaboration to help U.S. communities of all sizes by highlighting actions they can take to adapt and become more resilient in the face of increased flooding, sea level rise, and other environmental changes that threaten to fundamentally impact their way of living.

To develop this guide, we partnered with the American Flood Coalition (AFC), a national nonprofit organization and coalition of flood-impacted communities in the U.S., and Arcadis, the largest Dutch design and engineering firm active in the U.S. The guide incorporates AFC's firsthand knowledge of flood challenges and innovations in American communities of all sizes and Arcadis's international design and engineering expertise.

Since Hurricane Katrina 15 years ago, Dutch practitioners and leaders, such as engineers, policy experts, and architects, have been collaborating with their American counterparts to make U.S. communities more resilient. Since the lion's share of The Netherlands is structurally prone to flooding, good water management and integrated planning are essential for the existence of our country. In the past 15 years, we have been sharing centuries worth of experience with our U.S. partners in various ways. This collaboration played a role in the development of new coastal defense structures and a coastal master plan in Louisiana; prompted the Rebuild by Design competition in the New York City area after Superstorm Sandy; and led to resilience strategy initiatives in communities such as Norfolk, Virginia, and Charleston, South Carolina.

While these collaborative resilience efforts have thus far primarily focused on large and medium-sized coastal cities where hurricanes or other flood events could lead to large numbers of casualties or massive economic damage, this approach only covers a fraction of the communities impacted by storms and flooding. As sea levels rise and heavy rainfall increases at a quickening pace, many smaller communities and rural counties in coastal and inland areas are deeply impacted, but they often lack the resources or access to the financing and federal funding options needed to develop and implement effective resilience strategies.

By distilling the shared experiences of Dutch and American resilience experts into practical approaches for smaller communities, we hope to include more communities in the discussion about turning flood risks into opportunities to shape their futures as places to call home.

André Haspels

Ambassador of the Kingdom of the Netherlands to the United States
Embassy of the Kingdom of the Netherlands

NL Netherlands

Foreword

Since our founding in 2018, the goal of the American Flood Coalition has been to advance solutions to flooding and sea level rise for communities of all sizes across the country. We present this guide as a starting point for any community looking to determine which approach best suits their circumstances.

We partnered with the Dutch Embassy and Dutch engineering firm Arcadis to bring the lens of centuries of flooding expertise to shape approaches for an American context. The Dutch have shown a strong commitment to supporting American communities looking to build resilience and we were proud to work with Dutch partners in the 2019 Dutch Dialogues in Charleston, South Carolina.

While national news often highlights the projects and solutions underway in large cities like New York City and Miami, we know that smaller communities have a similar need to build resilience to flooding and sea level rise. In fact, the only way our country will be truly resilient is if we can find, scale, and finance solutions that protect small, rural, and poor communities with the same attention we give to well-resourced cities. This is something we know well because over two-thirds of the municipalities in our Coalition's membership have populations of 50,000 or less, and much of the country's population lives in communities of a similar size. We've kept this in mind as we designed this guide, providing examples from communities both large and small and breaking out approaches by cost and complexity so that local leaders can assess what's needed to implement these approaches.

There are learnings that any community can take from the examples outlined in this guide, and we hope that they serve as a jumping-off point for local leaders looking to build a resilient future for their community. There are key elements of the projects highlighted that may go beyond what is typically covered in national headlines, which we hope can serve as useful takeaways and assist local leaders in scoping and implementing these projects. We have focused many of the case studies on the Southeastern region of the United States, keeping in mind that's where much of our Coalition membership is based.

As record-breaking hurricane seasons and spring flooding have shown in recent years, communities of all sizes are in need of new tools and strategies to prepare for future flooding and sea level rise. Through partnership with the Dutch Embassy and Arcadis, this guide covers strategies at work from communities in the United States and the Netherlands that can serve as tools for local leaders ready to build a resilient future.

Melissa Roberts

Executive Director
American Flood Coalition

AMERICAN FLOOD COALITION

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Marcus Aguilar, Ph.D., PE
City of Roanoke, Virginia

Eveline Bronsdijk
City of Rotterdam, Netherlands

Katelyn Cucinotta
Palm Beach County, Florida

Everett Davis
Music City Center, Nashville, Tennessee

Pat Donovan-Brandenburg
City of Jacksonville, North Carolina

Desiree Ducasa
Town of Cutler Bay, Florida

Kelly Eby
City of San Marcos, Texas

Kent Edwards
City of Delray Beach, Florida

Matthew Flynn
Town of Cary, North Carolina

Andrew (Chip) Fontaine, PE
Town of Weymouth, Massachusetts

Daniël Goedbloed
Amsterdam Rainproof

Rebecca Harvey
City of Boynton Beach, Florida

Christine Howe
Town of Weymouth, Massachusetts

George Homewood
City of Norfolk, Virginia

Jordan Hughes, PE
City of New Bern, North Carolina

Kenneth Hughes, AICP
City of St. Marys, Georgia

Emily Woodward Kenworthy
Georgia Sea Grant

Debbie Love, AICP
City of North Miami, Florida

Robert Mace, Ph.D., PG
Texas State University

Katie McKain, AICP
City of Charleston, South Carolina

Matthew Montayne
City of New Bern, North Carolina

Kim Counts Morganello
Clemson University

Amanda Murray
City of North Miami, Florida

Isabel Nabuurs
Resident of Schoonschip, Amsterdam

Lindsey Nieratka
City of Boca Raton, Florida

Alfredo Quintero
Town of Cutler Bay, Florida

Paul Ray, CZO
City of Brevard, North Carolina

Joshua Revord, PE
St. Lucie County, Florida

Alan Robertson
City of Tybee Island, Georgia

David Ryan, PE
Town of Nags Head, North Carolina

Jeff Schulz
Town of Northfield, Vermont

Kelley Tucker
Ausable River Association, New York

Dave Vlasin
RWMWD, Minnesota

Marianne Walch, Ph.D.
Delaware Center for the Inland Bays

Holly White, AICP, CFM
Town of Nags Head, North Carolina

Michael Zehner, AICP
Town of Nags Head, North Carolina

The Adaptation for All project team:

Project Leadership Team

Jan Peelen
Embassy of the Kingdom of the Netherlands

Anne Baker, PLA
American Flood Coalition

Melissa Roberts
American Flood Coalition

Technical Leadership Team

Edgar Westerhof
Arcadis

Trevor Johnson, AICP
Arcadis

Project Development Team

Annabel Cryan
American Flood Coalition

Kevin Burrows
American Flood Coalition

Caroline Resor
American Flood Coalition

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Table of contents

Introduction

The 2020 Atlantic hurricane season was the most active on record. It was also the fifth consecutive above-average season since 2016. In total, this five-year streak of costly major storms and other record-breaking flood events have cost a total of nearly $400 billion.

In the U.S., flooding affects communities of every size. Pictured above is Sampson, North Carolina, just one of the many small inland communities that experienced severe flooding due to Hurricane Florence in 2018.

This introduction highlights how flooding affects communities of different sizes, and how local communities can use this guide to inform the way they plan for flooding.

Image source: U.S. Army National Guard photo by Staff Sgt. Balinda

Fact source: NOAA BIllion Dollar Disasters

How does flooding affect communities of different sizes?

Across the country, communities large and small feel the increasing and devastating impact of flooding, yet each community's ability to recover and plan for the future is different.

For smaller or resource-constrained communities, the process of identifying, prioritizing, funding, and implementing projects to tackle flooding can be especially challenging.

Even in larger communities that have recently implemented actions to reduce flood impacts, there may still be gaps in long-term planning and funding, especially within historically underserved neighborhoods.

Because of rising sea levels, increasing heavy rainfall, and other environmental changes, **large and small communities alike face increasing flood risk** in many regions—making the need for robust planning all the more imperative.

Where does this guide fit in?

Drawing on examples from the U.S. and the Netherlands—a country with a long history of flood challenges and innovations—**this guide is for local communities of every size looking for strategies to address flooding**.

Using simple rather than technical language, the guide is a resource that local leaders, such as mayors or civic leaders, can use and share broadly during community-based planning processes.

The guide pulls together a well-rounded list of often-separated approaches to addressing flooding, including stormwater management, green infrastructure, coastal infrastructure, local policy, and land use planning.

Costs, benefits, and implementation considerations are outlined for each approach, along with real-world case studies, so that readers can envision and evaluate which approaches may work best in their community.

How to use this guide

Head to the concepts for local leaders to review key tips and ideas for developing a local flood action plan (page 10)

Look at the cost and complexity diagram to explore which approaches may best fit local flood challenges, resources, and budgets (page 16)

Review the approaches section for summaries and case studies of each approach. Approaches are listed in order from low- to high-cost, within each of three sections:

- Land use and policy (pages 18–37)
- Stormwater and drainage (pages 38–66)
- Coastal and shoreline (pages 67–87)

Share this guide with key stakeholders and plan community engagement to build a local action plan

Concepts for local leaders

Most communities will always have some risk of flooding, and for many, flooding is worsening—making it vital for local leaders such as elected officials as well as military, business, and civic leaders, to drive new local strategies to prepare for the future.

This section highlights concepts that local leaders should keep in mind when evaluating approaches to address flooding. From looking at past flood losses to prioritizing equity to considering hospitals and other critical facilities, many of these concepts are essential for local leaders when pursuing comprehensive resilience and adaptation strategies.

Image source: Ebyabe, CC BY-SA 3.0, Fernandina Beach, Florida

Build resilience and adaptation

By applying the concepts of resilience and adaptation, local leaders can focus their community's attention on steps to reduce flood impacts and support long-term community health, safety, and well-being.

Resilience is a community's ability to withstand, recover from, and adapt to shocks and stresses. While resilience is a trait of a community, adaptation is a process.

Adaptation is the process by which a community evolves its systems, capacities, and infrastructure to prepare for and manage future flooding or other environmental changes.

The sketch shown below of Johns Island, South Carolina, includes concepts of resilience and adaptation. The sketch was created during a public workshop in this community of 21,000 people.

To plan for resilience and adaptation, communities should consider both past and future flooding in coastal and inland areas. Key actions include:

+ Use past flood costs to prompt investment. By estimating the costs associated with past floods, local leaders can build a business case for investment in actions to reduce future flood impacts.

+ Estimate future flooding to plan wisely. In many communities, rising sea levels, more heavy rainfall, and other environmental and land use changes are expected to increase flood risk over the rest of this century. This means that estimating future flooding is a critical part of planning for the future.

+ Partner with others to understand flood risk. Communities can partner with neighboring municipalities, academic and civic organizations, and public agencies to share data, develop analyses, and coordinate clear and consistent ways of communicating public information about flood risk.

Adapting development patterns: This sketch of Johns Island, South Carolina, proposes concentrating future development on high ground while preserving waterways for drainage as a method for adapting and building resilience. The sketch was created during a public workshop organized through Dutch Dialogues, a forum through which American and Dutch experts collaborate with local communities to develop resilience and adaptation strategies.
(Source: Dutch Dialogues)

Invest in resilience

Using information about past flood losses, future flood hazards, or flood risk, local leaders can work with community members and stakeholders to prioritize pre-disaster investments. Key actions include:

+ **Collaboratively develop criteria.** Actively seek community input to collaboratively develop and apply criteria for prioritizing areas and facilities for investment.

+ **Identify critical facilities.** Assess and prioritize which infrastructure or buildings, such as hospitals, may be most important to life safety during a disaster.

+ **Develop and compare options for action.** Develop a wide range of actions that could reduce the risk or impacts of flooding. To compare these actions, consider factors such as cost effectiveness, co-benefits, feasibility, political and stakeholder support, operations and maintenance, and the role of regional collaboration.

+ **Use a systems approach.** Identify larger elements of the community, such as wastewater, stormwater, healthcare, or transportation systems, and consider how investments in these systems could advance other resilience objectives, such as reduced community recovery time or reduced disruptions of public services for vulnerable populations.

+ **Assess vulnerability.** Use data about local social, environmental, and economic conditions to identify people or locations that may need extra support or investment in preparing for or recovering from floods.

+ **Establish multiple investment pathways.** Consider pathways for near-, medium-, and long-term investment to prepare for flood risk that may increase over time. Periodically compare progress along these pathways to any changes that may occur in future flood hazard estimates as a result of shifting land use, weather patterns, and environmental changes.

Collaboratively develop criteria: Local farmers played a key role in the design and development of a Dutch infrastructure and land use strategy to create more space for river floodwaters. In the photo above, Netherlands Minister of Infrastructure and the Environment Melanie Schultz van Haegen discussed the project at a gathering in the home of a local community member. (Source: Werry Crone/Rijkswaterstaat)

Create positive change

Communities can adapt and become more resilient by assessing risks, developing a roadmap for investment and action, and planning flexibly for future modifications, should conditions change. Local leaders can turn challenges from increasing flood risk and environmental changes into opportunities for positive growth and change with these principles in mind:

+ Engage stakeholders. Establish multi-step planning processes with clear opportunities for public input. As individuals and groups with an interest in resilience decisions and actions, stakeholders can provide key perspectives and knowledge.

+ Prioritize equity. A resilient community should advance economic, social, and environmental equity by shaping and implementing strategies that are responsive to diverse community needs and prioritize the most vulnerable community members.

+ Take a broad hazards approach. Consider flooding alongside other relevant local hazards, such as fire, snow, heat, or wind, and consider how these hazards may interact with one another.

+ Consider setting up a backup plan. Proper maintenance of pumps, pipes, and other infrastructure should be the first step in preparing for extreme weather or sea level rise—but planning for redundant "backup" systems may also be needed, especially if repairs become more costly and less effective over time.

+ Recognize that one size does not fit all. Building resilience and adaptation must be tailored to community circumstances, supported by ongoing dialogue, and driven by all stakeholders.

+ Integrate solutions. The approaches in this guide are not stand-alone solutions that "fix the problem." They are a set of solutions that should be part of a larger planning and implementation strategy.

Integrated solutions: The Dutch city of Scheveningen combined multiple approaches to address sea level rise. Instead of implementing a single large seawall, this community enlarged the beach and integrated a smaller seawall into a boulevard and walkway design, prioritizing not only flood risk reduction but also the beach experience. (Source: Harry van Reeken, Rijkswaterstaat)

Resilience and adaptation approaches

This guide is intended to help local leaders determine the approach or approaches to flooding or sea level rise that work best for their community. For each approach, the guide outlines key considerations, while highlighting one or more successful examples from communities in the United States or the Netherlands. Many of the examples are from the Southeastern United States, a region with severe flood impacts from hurricanes and major storms and where a great number of American Flood Coalition members are located.

Communities should not view any single approach as the sole solution to their flooding challenges—instead, many communities may combine several approaches at various scales to fit into their broader strategy and budget to address flooding. This guide is not an exhaustive list of approaches but rather a starting point for decision makers and readers looking to enhance their communities' resilience to flooding.

Image source: XeresNelro, CC BY-SA 4.0, Jekyll Island, Georgia

Categories and classifications

This guide will cover 26 approaches to addressing flooding and sea level rise. Each approach is placed within one of three categories:

1. Land use and policy: Actions to build resilience by engaging the community, creating land use ordinances and regulations, and planning proactively

2. Stormwater and drainage: Actions to reduce stormwater runoff by incorporating components for absorbing and storing water into infrastructure and buildings through natural and built solutions

3. Coastal and shoreline: Actions to reduce coastal flooding from storm surge and tidal inundation by using natural and built solutions

Each approach is described based on the following characteristics:

Scale

- **Building –** appropriate for incorporation into building design or as a retrofit
- **Site –** appropriate for application to a property parcel or small group of parcels
- **Shoreline segment –** appropriate for application along a segment of coast or river edge
- **Municipal –** appropriate for application to an entire municipality or district
- **State –** appropriate for application statewide
- **Regional –** appropriate for application at a regional level, spanning multiple jurisdictions

Investment types

- **Public –** requires public investment and/or applies to public property or infrastructure
- **Private –** requires private investment and/or applies to private property or infrastructure
- **Public/Private –** can be achieved through combined public and private investment and/or applies to both public and private property or infrastructure

Operations and maintenance*

- **High –** requires high effort to ensure a state of good repair and proper function
- **Medium –** requires medium effort to ensure a state of good repair and proper function
- **Low –** requires low effort to ensure a state of good repair and proper function

Federal assistance and informational sources: For each approach, a selected list of key federal programs that can be used for funding or technical assistance is provided, along with key informational resources about the approach.

Appendices contain additional resources, information, and important considerations

*All approaches require regular maintenance to ensure a state of good repair and proper function. The three levels of operations and maintenance provided in this guide can be used to compare alternatives in instances when multiple approaches may be feasible and effective. Considering operations and maintenance when designing and planning a project can improve future adaptability and reduce costs over the project's useful life. Actual operations and maintenance demands will depend on the scale of the project and the capacity of the entity responsible for undertaking it.

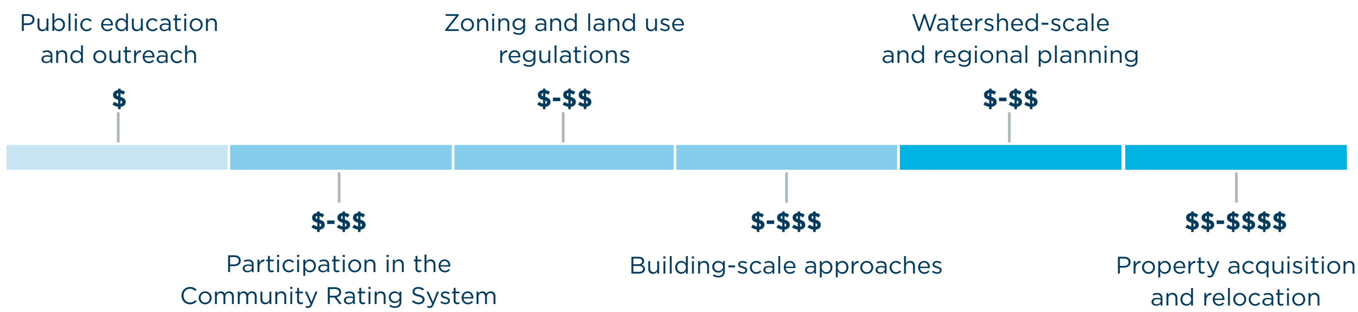
Cost and complexity comparisons

Cost*		
	$	Less than $100,000
	$$	$100,000 – $500,000
	$$$	$500,000 – $1 Million
	$$$$	$1 Million – $5 Million
	$$$$$	$5 Million+

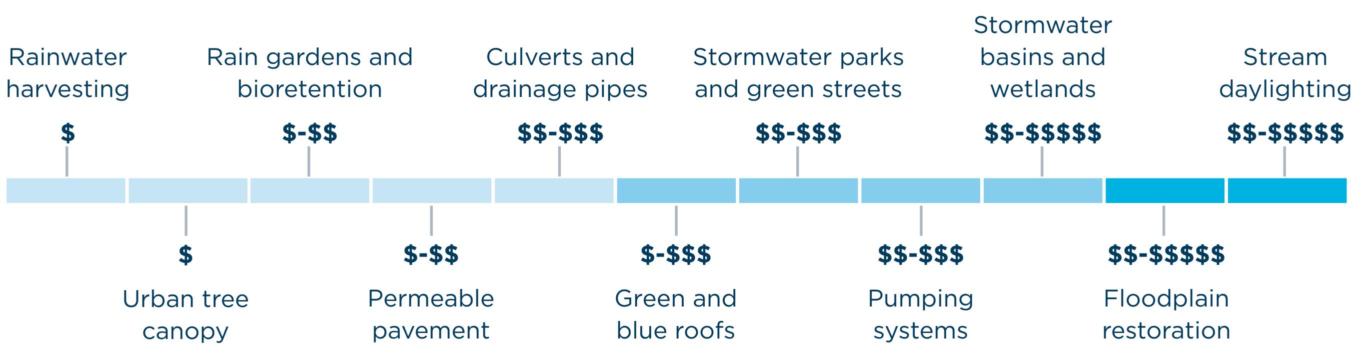
Complexity level

- Low
- Medium
- High

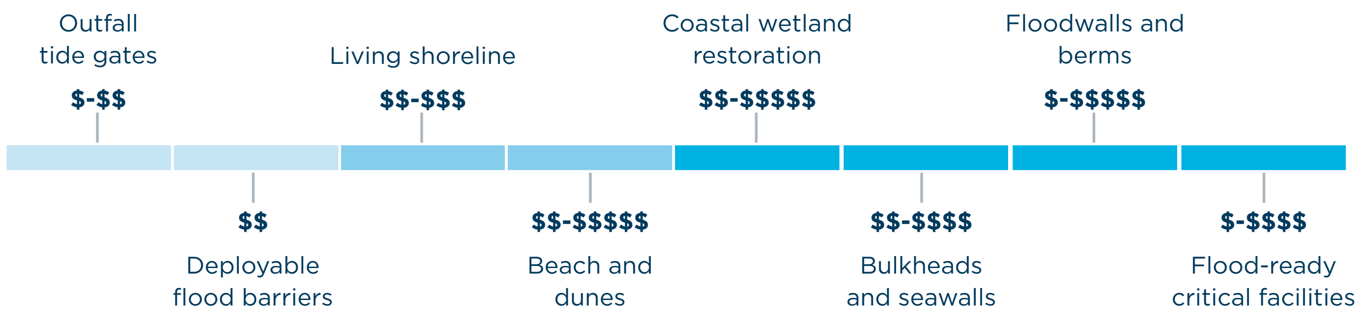
Land use and policy



Stormwater and drainage



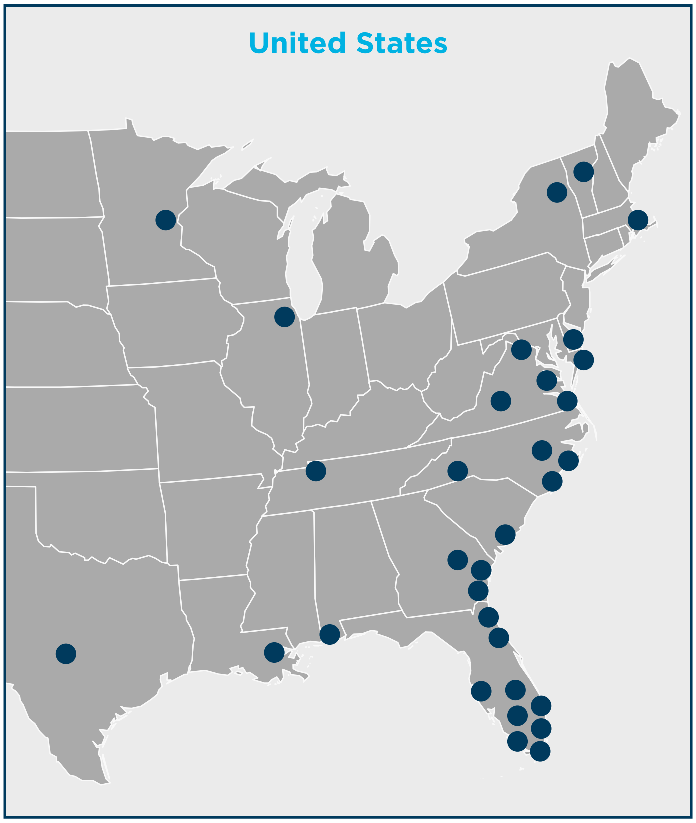
Coastal and shoreline



*These cost and complexity estimates provide generalized order of magnitude guidance. Actual project cost and level of complexity will vary depending on scale, design and technical specifications, location, and community context.

Case study locations

This guide includes examples of resilience and adaptation approaches from both the U.S. and the Netherlands:



Glossary of Acronyms

This guide includes numerous acronyms for departments, agencies, programs, and flood terminology. While each is defined when introduced, the list below provides key acronyms for reference.

ASCE	American Society of Civil Engineers
CRS	Community Rating System
NFIP	National Flood Insurance Program
FEMA	Federal Emergency Management Agency
EPA	Environmental Protection Agency
USACE	United States Army Corps of Engineers
HUD	Department of Housing and Urban Development
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Land use and policy approaches

Land use and policy approaches include a wide range of measures to reduce flood risk and prevent damage to communities. These measures can include providing policy steps for flood-ready construction standards, educating the community on becoming more resilient to flooding, and engaging the community when shaping municipal strategy.

Land use and policy approaches are nonstructural, meaning that while they reduce potential damage from flooding, they do not prevent flooding or influence the natural direction and flow of floodwaters. Nonstructural measures often require little operational, maintenance, repair, rehabilitation, and replacement costs.

When used proactively, these approaches can reduce or prevent development in flood-prone areas, sometimes eliminating the need for building additional protective measures in the future. Land use and policy approaches can and should be considered alongside other types of approaches as part of an integrated plan.

Elevated homes on the Gulf Coast. Navarre Beach, Florida. (Source: Getty)

Public education and outreach

Public education and outreach encompass a broad set of activities to clearly communicate information about flood risk to community members and build consensus to address that risk. Efforts can also facilitate individual actions. Public education and outreach are necessary first steps to pursuing any local strategy to address flooding and a key component of local planning processes.

Scale: Municipal

Cost: < $100,000

Operations and maintenance: N/A

Investment type: Public

Federal assistance sources:

- Funding for education and outreach is built into federal flood-related programs across a wide range of agencies. The NOAA Sea Grant Program is a common source of support in coastal areas.

Informational resources:

- FEMA Flood Risk Communication Toolkit for Community Officials
- Community Resilience Building Workshop Guide

Image above: A public workshop in the Town of Cary, North Carolina. (Source: Town of Cary)

Potential benefits of public education and outreach:

- Increase community engagement and buy-in for strategies and plans to reduce flood risk
- Give local leaders community feedback on areas they should proactively address

In Los Angeles, $10 of direct mail outreach per household resulted in a 10%–50% relative increase in the rate of disaster preparedness activities among families surveyed

Considerations for implementation:

- Local leaders can develop public outreach plans for both community efforts overall and specific projects
- Outreach plans should detail goals, target audiences, and public engagement methods
- Local leaders should consider ways to gain support from elected officials and city leaders, as well as key business and civic leaders for resilience projects
- Digital tools, direct mail campaigns, and door-to-door outreach can help reach more residents

Case Study: Community-based resilience planning St. Marys, Georgia

- In 2013, St. Marys was selected to undergo community resilience and adaptation planning with funding from **NOAA's National Sea Grant Program**
- What became the St. Marys Flood Resiliency Plan was created in part through a **public engagement strategy**
- To document local knowledge about floods, the City hosted a series of **stakeholder interviews, town hall public meetings, and facilitated discussion sessions**

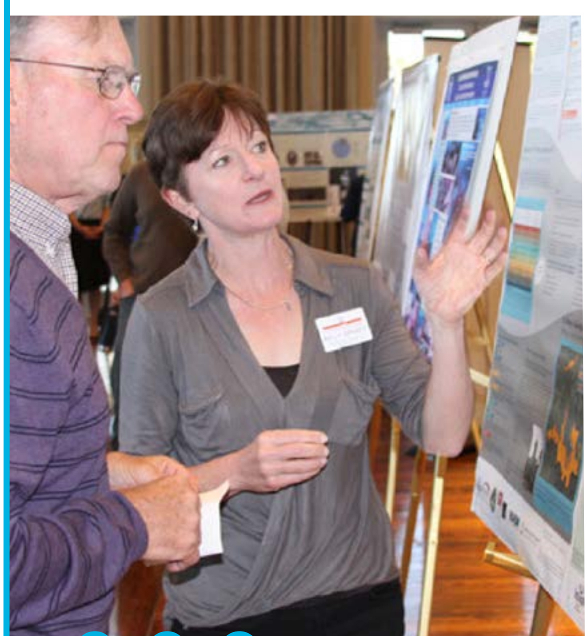
As a low-lying coastal community, the City of St. Marys, Georgia, is vulnerable to flooding from high tides and heavy rains. Over 90% of its historic structures are below the current 100-year floodplain, or the area that has a 1% chance of flooding in any given year.

In 2013, to address its flooding problem, St. Marys received an adaptation planning grant through the National Oceanic and Atmospheric Administration (NOAA) Sea Grant program. To create what eventually became the St. Mary's Flood Resiliency Plan, the City heavily relied on public participation and input.

Through an ambitious public engagement strategy, Georgia Sea Grant collaborated with the City to host a series of open events, such as seminars, discussions, panels, and presentations. In 2014, the City hosted a town hall meeting to collect local knowledge about the community's vulnerabilities. To attract more attendees and emphasize the focus on resilience, the City timed the event in conjunction with the community's annual king tide event.

Throughout the process, the City and its partners created opportunities for the community to play a central role in research and planning, encouraging multidisciplinary and diverse viewpoints. Overall, the strategy to collect the community's insights and experiences was key in creating the St. Marys Flood Resiliency Plan.

Public workshops in St. Marys, Georgia, were a key ingredient in the City's planning for resilience. (Sources: St. Marys Flood Resiliency Project Final Report, left; and Visit St. Marys and Cumberland Island, right)

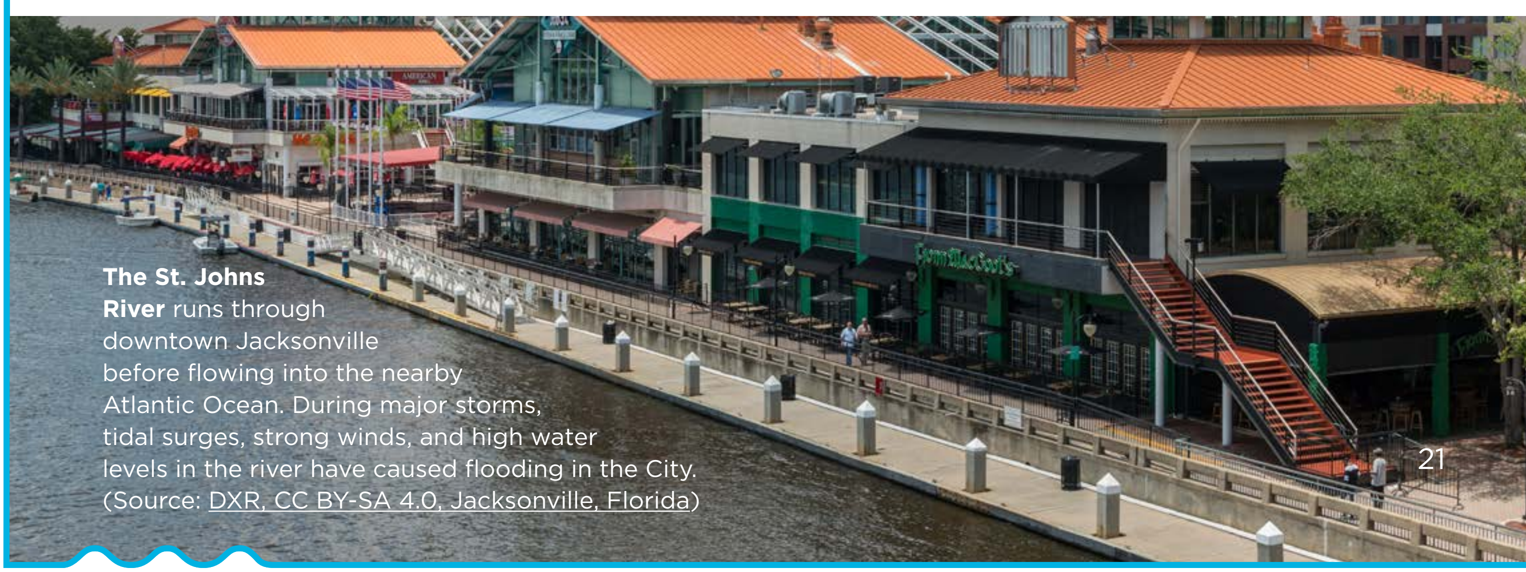


Case Study: Special Committee on Resiliency Jacksonville, Florida

- To address flooding and sea level rise, the City of Jacksonville formed **the Special Committee on Resilience**
- The Committee assesses the resilience of the beaches, coastline, and river systems, as well as reviews the City's environmental, land use, and infrastructure policies
- To increase public participation, the Committee Chair **proposed three subcommittees:**
  - Environmental Planning
  - Infrastructure, and Continuity of Operation for Essential Services
  - Education, Protection of Local Neighborhoods, and Community Outreach
- All three subcommittees are open to volunteers and can have an **unlimited number of voting members**
- These subcommittees submit policy recommendations, document findings, and report back to the full committee

Situated near Florida's Atlantic coastline and the mouth of the St. Johns River, the City of Jacksonville has historically been prone to flooding. To address these problems, in November 2019, the City announced the formation of the Special Committee on Resilience. The City formed the Committee to assess the resilience of the beaches, coastline, and the St. Johns River system, as well as review the City's policies affecting valuable assets and the health and safety of its citizens.

To increase public participation, the committee's first chairman, Councilman Matt Carlucci, proposed three subcommittees, all of which are open to community volunteers. "I think these committees could get pretty big," said Carlucci. "I never put a limit on public participation–never. The one person who may not get to participate may be the one with the best ideas." The subcommittees are a way for community members to participate in resilience planning and for the Committee to draw on the knowledge and talent of a diverse population. The Committee produced a final report with resilience recommendations for Jacksonville in 2021.



The St. Johns River runs through downtown Jacksonville before flowing into the nearby Atlantic Ocean. During major storms, tidal surges, strong winds, and high water levels in the river have caused flooding in the City. (Source: DXR, CC BY-SA 4.0, Jacksonville, Florida)

National Flood Insurance Program Community Rating System

The **Community Rating System (CRS)** is a voluntary incentive program that recognizes and encourages community flood risk management actions by discounting flood insurance premiums for property owners that participate in the National Flood Insurance Program (NFIP). The NFIP is managed by the Federal Emergency Management Agency (FEMA) and provides insurance to reduce the socioeconomic impact of floods.

Scale: Municipal

Cost: < $500,000

Operations and maintenance: Medium

Investment type: Public (but provides benefits to private property owners)

Federal assistance sources:

- Communities can leverage a wide range of federal funding opportunities to support local activities that can improve their CRS rating.

Informational resources:

- CRS program
- floodsmart.org
- NFIP CRS Brochure

Potential benefits of the Community Rating System:

- Incentivizes efforts to reduce flood risk and minimize the cost of flood damages
- Provides discounts ranging from 5% to 45% on NFIP premiums for property owners

As of 2020, over 1500 communities participate in the CRS program

Considerations for implementation:

- To participate in CRS, a community must be part of NFIP
- To join the NFIP, a community must adopt a floodplain ordinance based on FEMA standards
- CRS points are given for actions that exceed minimum NFIP requirements for reducing flood risk
- To gain CRS points, local leaders can take advantage of recent or ongoing local flood risk or stormwater management efforts
- Property owners can reduce flood risk and flood insurance premiums by retrofitting a property

Image source: Town of Cutler Bay

- In 2020, Cutler Bay was one of only 3 Florida communities with a CRS rating of Class 4 or better
- The Town's CRS rating allows many residents and local businesses to **save 30% on flood insurance premiums**
- In Cutler Bay, individual policyholders **save an average of $243 per year**
- Low-cost actions, such as distributing flood educational materials, along with higher-cost efforts, such as updating stormwater infrastructure, have allowed the Town to achieve its good CRS ranking
- Purchasing an 8.4-acre property to buffer against sea level rise shows the community's **commitment to resiliency efforts and the environment**

In 2020, Cutler Bay, Florida was one of only three municipalities in Florida, and one of less than 20 municipalities in the country, at a CRS Class of 4 or better.

Cutler Bay's CRS Class 4 rating allows many residents and local businesses to save 30% on flood insurance premiums, with policyholders saving an average of $243 per year.

The Town achieved this rating through a combination of low-cost actions, such as distributing flood education materials, along with higher-cost efforts, such as updating stormwater infrastructure and purchasing land for flood mitigation.

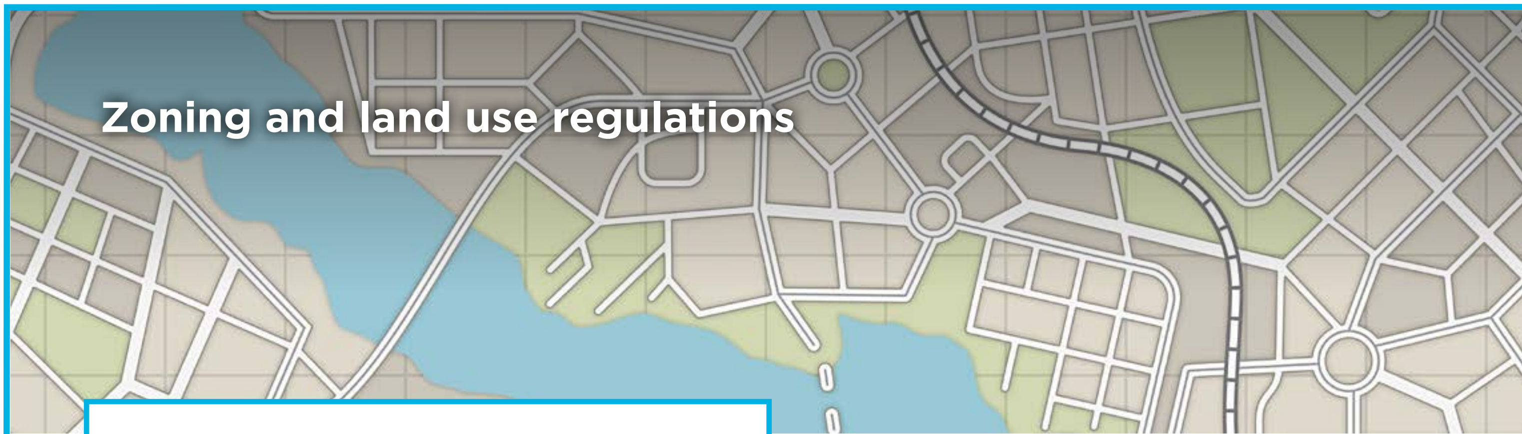
The Town is seeking to further improve its current CRS class rating. One recent higher-cost effort, which will help contribute towards improving the Town's CRS rating, will be the purchase of 8.4 acres of land for use as a natural buffer against sea level rise.

In April 2020, the Town Council voted unanimously to buy the property, which borders the Biscayne Bay Coastal Wetlands project. By preventing development on the property and preserving space for wetlands that can reduce inland flood impacts, the Town has shown its commitment to resilience.

Preventative actions, such as land acquisition have been a recent focus in Cutler Bay to improve the Town's CRS rating. The Town purchased land along Biscayne Bay to serve as a buffer against sea level rise and flooding.

Image source: Town of Cutler Bay

Zoning and land use regulations



Zoning and land use regulations are policy-based approaches to reduce flood risk at the neighborhood and district scale. These approaches include managing the intensity and type of development in flood-prone areas—both by regulating existing development in at-risk areas and by preventing flooding from happening in those areas.

Scale: Municipal, regional, state

Cost: < $500,000

Operations and maintenance: N/A

Investment type: Public

Federal assistance sources:

- FEMA Public Assistance program
- FEMA Hazard Mitigation Grants

Informational resources:

- Naturally Resilient Communities Regulatory and Policy Approaches
- ASFPM Higher Standard for Floodplain Management (ASFPM)

Potential benefits of zoning and land use regulations:

- Reduce the need for major flood infrastructure by concentrating new development on higher ground
- Enhance effectiveness of natural flood barriers such as slopes, forests, and wetlands by redirecting development away from them
- Reduce the burden of chronic flooding by limiting or adapting development in areas that are prone to it
- Preserve open space for flood risk reduction, improving ecosystem and recreational benefits

FEMA estimates the economic value of open space at $45,000 per acre per year. With smart zoning, these areas can help absorb floodwaters

Considerations for implementation:

- Local leaders should engage their community when developing zoning and land use regulations
- Local leaders should assess whether proposed changes might increase segregation by income or adversely affect the community in other ways

Image source: Getty

Case Study: Ordinances to reduce upstream and downstream flooding

Brevard and Cary, North Carolina

- Brevard and Cary both use ordinances to **reduce upstream and downstream flood impacts**
- Brevard requires property owners who propose new construction in the floodplain to first complete a **No Adverse Impact certification** to ensure flooding downstream or upstream is not worsened
- Cary prohibits new lots and new development in the floodplain, and **prevents the creation of new individual lots near streams** (within 50 to 100 feet, depending on lot type and location) to reduce stormwater runoff that could cause downstream flooding
- Cary requires any subdivision with a stream that drains 50 acres or more to perform a **flood study**
- In smaller drainage areas in downtown Cary, **local flood modeling** captures upstream and downstream risks, and is used as the basis for redevelopment and restoration regulations and planning

Following devastating floods in 2004, the **City of Brevard** adopted one of the nation's strongest flood damage reduction ordinances. Adopted in 2009, the ordinance requires a No Adverse Impact certification for all proposed development in the floodplain to ensure new development does not exacerbate upstream or downstream flooding. The city, which has a population of 8,000 people, estimates a cost of $5,000 per year to oversee these requirements.

Perched at the headwaters of multiple streams, the **Town of Cary** adopted ordinance language which includes a focus on preventing downstream flooding from streams. While federal and state requirements focus only on larger waterways, Cary has developed standards such as requiring any subdivision with a stream that drains 50 acres or more to do a flood study. This ensures that buildings in the stream floodplain are flood-ready. Additionally, the Town prohibits new lots and new development in the floodplain, and prevents the creation of new individual lots near streams in order to reduce stormwater runoff that could cause downstream flooding, and has invested in local flood modeling to inform regulations.

The French Broad River (left) runs through the City of Brevard in southeastern North Carolina. In central North Carolina, a stream tributary of **Swift Creek** runs along the Higgins Greenway in the Town of Cary (right).

(Source: Zen Sutherland, CC BY-NC-SA 2.0)

(Source: Town of Cary)

Case Study: Ordinance for flood resilience Norfolk, Virginia

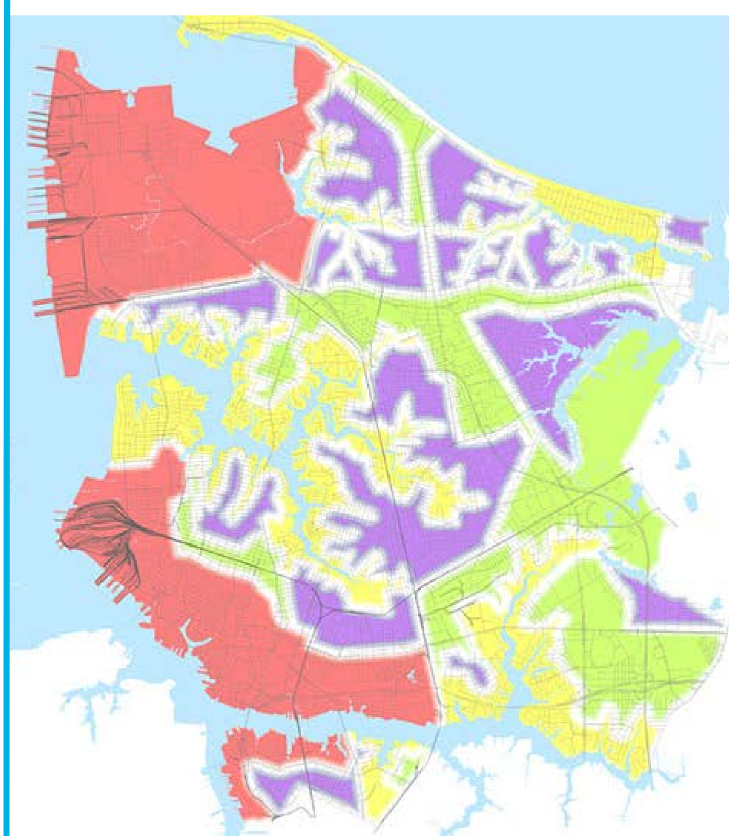
- In 2018, Norfolk adopted a **new zoning ordinance** to reduce flood damages
- The ordinance **directs new construction to higher ground** or to be lifted higher up above the ground, and **developers earn points** for reducing flood risk
- The ordinance **creates several zones with specific requirements**, such as increasing permeable surfaces
- The **process took five years** and was informed by a state-funded report, public input, and two City plans

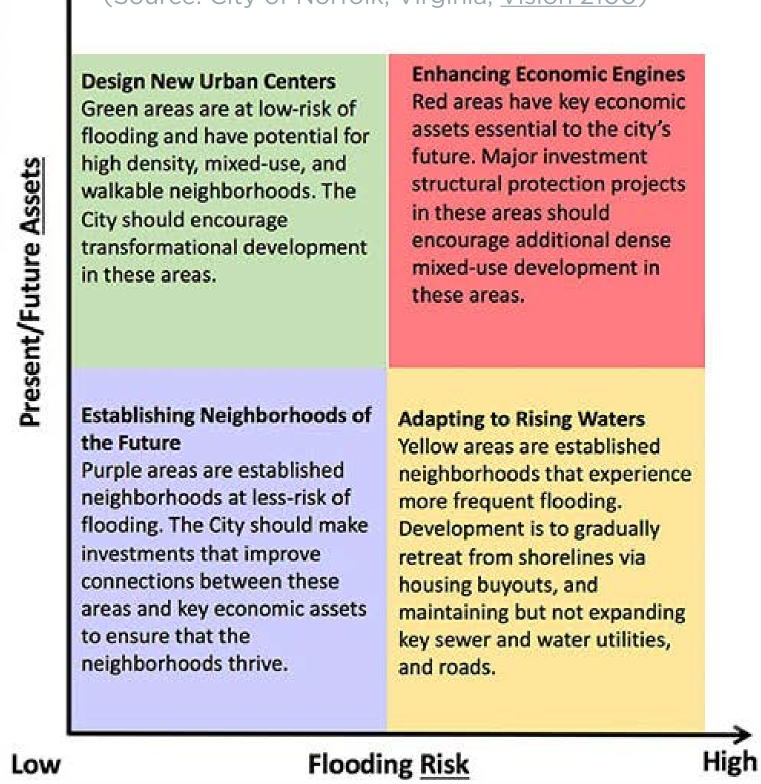
As a low-lying coastal city on land that is slowly sinking, Norfolk has a long history of flooding and one of the fastest rates of sea level rise in the country.

To adapt construction to these conditions, the City created a new zoning ordinance in 2018. Among other mandates, the ordinance directs the most dense development to higher ground and requires all new construction to be raised above the ground by 16 inches to 3 feet, depending on location and level of estimated flood risk. The ordinance also defines several development zones, which have requirements such as increasing permeable surfaces or walkability of neighborhoods. Finally, developers can earn points for actions such as risk reduction or stormwater management through the ordinance's resilience quotient system.

The ordinance grew from the development of a "living with the water" approach (see page 33) towards flooding during the 2015 Dutch Dialogues in Hampton Roads. The ordinance was shaped by public input and from a report funded by the Commonwealth of Virginia and conducted by the Virginia Institute of Marine Science.

Norfolk's forward-looking land use strategies consider how to protect present and future assets within the context of flooding and sea level rise. (Source: City of Norfolk, Virginia, Vision 2100)





Building-scale approaches

Building-scale approaches are actions taken to make buildings more resistant to flood damage. They can be applied to new or existing homes, businesses, or other structures. These approaches include modifying interior or exterior surfaces to be more floodproof, raising buildings above potential flood levels, and protecting equipment.

Scale: Building

Cost: < $1 million
(variable based on approach)

Operations and maintenance:
Variable, but typically low

Investment type: Public/Private

Federal assistance sources:

- FEMA Hazard Mitigation Grants
- FEMA NFIP ICC program
- FEMA Public Assistance
- SBA Mitigation Assistance

Informational resources:

- FEMA Higher Floodplain Standards
- USACE Nonstructural Resources
- FEMA non-residential Floodproofing guide

Potential benefits of building-scale approaches:

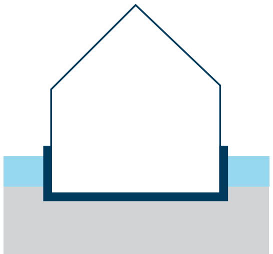
- Make buildings more flood-resistant, reducing the costs of flood damage
- Lower flood insurance premiums and bolster real estate resale values
- Maintain the social fabric of a community by enabling residents to continue living in their homes after a flood

After Hurricane Harvey, flood-damaged homes in Houston, Texas, suffered losses of $56,000 per home

Considerations for implementation:

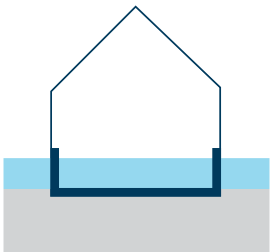
- Local leaders can use building codes and standards to enforce minimum requirements for building-scale approaches, such as freeboard requirements to address increasing flood risk
- To keep up with future sea level rise, local leaders may need to gradually increase requirements to raise buildings above potential flood levels
- Local leaders should educate residents and local construction and development industries about these approaches

Image above: An elevated home after Hurricane Katrina. (Source: Infrogmation, CC-BY-2.5, Chalmette, Louisiana)



Dry floodproofing seals the exterior of a building by making it water tight through treatments to walls, windows, and doors.

- Often applied to commercial or industrial buildings
- May not achieve flood resistance required by residential building codes or standards
- Can be manually deployed or set up to automatically activate
- Requires a medium to high level of operations and maintenance

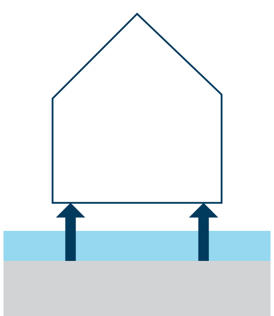


Wet floodproofing allows floodwater to enter a building by making interior materials and equipment more water-resistant.

- Often applied to areas that do not include living spaces, such as garages and storage areas
- Requires a low level of operations and maintenance

Equipment protection or redundancy limits damage and operational disruptions to equipment and manual controls by moving or protecting them from flood impacts. In cases where equipment can't be moved, back-up emergency equipment can be installed away from flood-prone areas to help avoid disruptions.

- Often applied in critical facilities, such as hospitals or industrial sites
- Is more cost-effective when applied to new construction
- Helps quicken recovery after a flood and is typically less expensive than building elevation
- Requires a low level of operations and maintenance



Building elevation lifts the main floor of a building to reduce the risk of flood damage. The height to which it is lifted is often based on local standards or by the National Flood Insurance Program. It is typically performed with piers, posts, piles and columns, or foundation walls.

- Can require additional space for ramps or stairs for building access
- Is expensive to implement (elevating an existing building can cost from $19,000 to $194,000)
- Is more cost-effective when applied to new construction
- Requires a low level of operations and maintenance

Case Study: Elevating historic buildings Mandeville, Louisiana

- In 1993, Mandeville **increased its building elevation standards** to require new construction or significant renovations of existing buildings be one foot above 100-year flood elevation
- Over **300 homes have been elevated** to meet these standards
- The City also developed **guidelines to maintain the historic integrity** of homes when elevating them
- FEMA estimated **$79,000 per home in avoided damages** after Hurricane Isaac, as a result of lifting buildings to Mandeville's standards
- In Mandeville, the **cost of elevating an existing home can exceed $100,000**
- Many homeowners have directly funded these improvements, and some have received FEMA funding

Located on the quiet north shore of Louisiana's Lake Pontchartrain, the City of Mandeville has a reputation as a scenic and popular escape for visitors from nearby New Orleans. Like New Orleans, the City also has a long history of flooding.

To reduce damages caused by floods, in 1993, the City increased its building elevation standards. These standards required newly constructed or significantly renovated buildings to be one foot above the 100-year flood elevation, which is the height that floodwaters have a 1% chance of reaching in a given year. Following Hurricane Katrina in 2005, which led to 437 flood insurance claims totaling $26.6 million for Mandeville, many homeowners renovated their homes to meet these standards.

Elevated buildings are common around Mandeville, with stairs or ramps providing access to the main floor. These elevated lakefront houses in Fontainebleau State Park, near Mandeville, are accessible by ramp. (Source: Louisiana State Parks)

With participation from local residents, the City also developed guidelines for maintaining historic features of buildings when elevating them. To date, Mandeville has elevated over 300 homes, including 70% of the buildings in its historic district.

Many building elevation projects in Mandeville have been largely paid for directly by homeowners. The cost of these projects can sometimes be over $100,000 per home. While this raises affordability concerns, funding from local, state, and federal sources, including FEMA's Hazard Mitigation Grant program, have helped offset some of these costs.

Mandeville also receives credit for its building elevation standards through FEMA's Community Rating System, resulting in reduced flood insurance premiums for some property owners.

After Hurricane Isaac caused severe flooding in Mandeville in 2012, FEMA conducted a Losses Avoided Study in Mandeville and other nearby communities impacted by the storm. The study included an analysis of the storm's flood impacts on 14 Mandeville homes that had been elevated prior to Isaac. Although elevating the buildings initially cost about $1.5 million, FEMA estimated a 74% return on investment after Isaac, with a savings of $79,000 in avoided damages per structure.

With heavier rainfall and rising sea levels expected in the future, Mandeville's building standards are a vital step in the City's long term adaptation.

A Mandeville home before (top) and after (bottom) being elevated. Photos courtesy of Preservation Resource Center of New Orleans (top) and © Charles E. Leche (bottom)

Watershed-scale and regional planning

Watershed-scale and regional planning brings communities together to plan strategies that address flooding and other environmental and land use changes. Watersheds are areas of land that drain to a common outlet and are determined by topography, not jurisdictional boundaries. Planning at the watershed scale focuses on strategies that span across jurisdictional boundaries. Planning can happen through existing regional planning councils or by creating collaborative groups specific to a watershed or multi-community planning area.

Scale: Regional

Cost: < $500,000

Operations and maintenance: Not applicable

Investment type: Public

Federal assistance sources:

- HUD Community Development Block Grant Mitigation Program
- USDA Watershed and Flood Prevention Operations Program

Informational resources:

- Louisiana Watershed Initiative Long-Term Vision
- Handbook for Developing Watershed Plans to Restore and Protect Our Waters (EPA)

Potential benefits of watershed-scale planning:

- Identify projects that reduce the need for costly downstream investments
- Reduce risk at a lower cost per community than if communities acted independently
- Create opportunities that may not be possible for a single community to accomplish alone, leading to broader cross-jurisdictional collaborations

King County, Washington, is nationally recognized for its regional approach to flood resilience, employing 60 staff who collaborate with local communities on these efforts

Considerations for implementation:

- Local leaders can engage upstream and downstream communities to determine cost-sharing
- Planning is typically more effective in areas where inter-jurisdictional collaboration and coordination already exist

Image above: Small communities along the Fall River in King County, Washington, are often impacted by riverine flooding, requiring coordinated planning. (Source: Washington State Department of Transportation,)

Case Study: Multi-community vulnerability assessment Southeast Palm Beach County, Florida

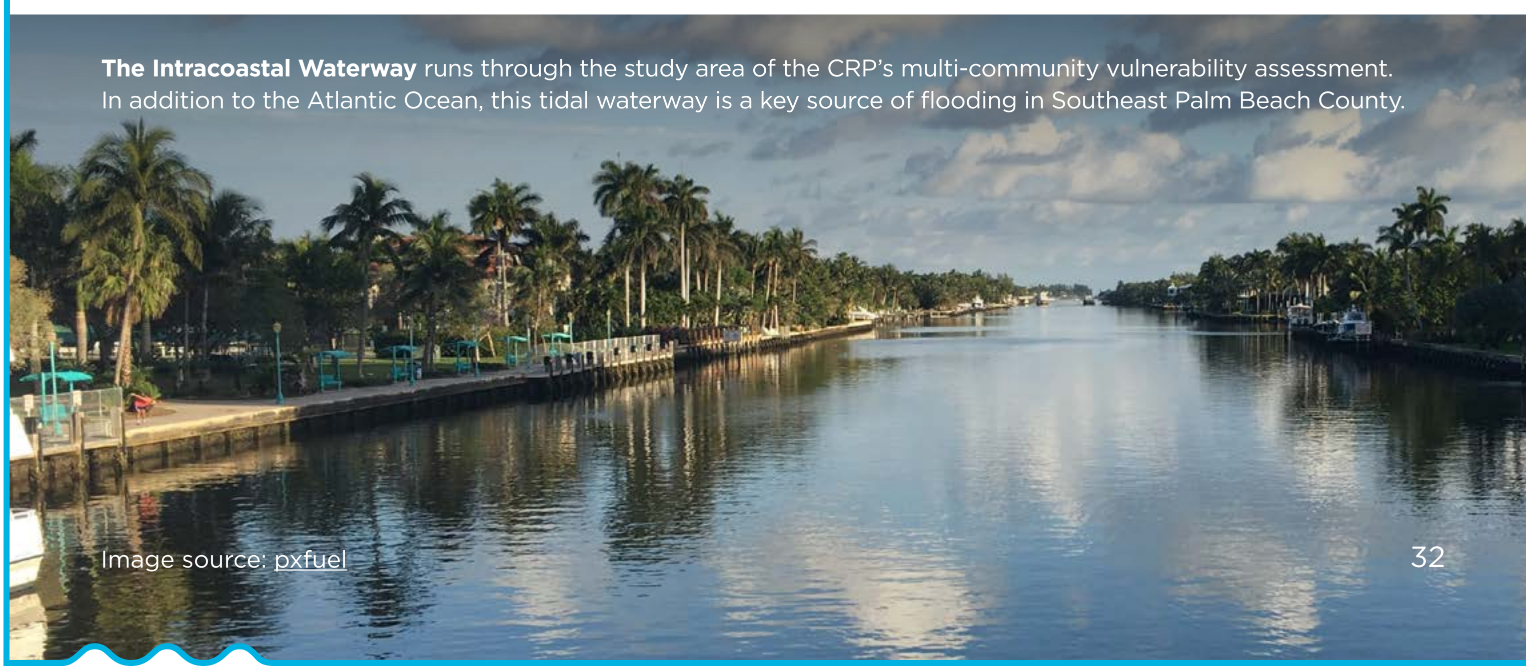
- The Coastal Resilience Partnership of Southeast Palm Beach County (CRP) consists of **Palm Beach County and 7 municipalities**: Boca Raton, Boynton Beach, Delray Beach, Highland Beach, Lake Worth Beach, Lantana, and Ocean Ridge
- The CRP used **innovative legal tools** for the communities to share staff time and funding
- Since 2018, the Florida Department of Environmental Protection has awarded the Partnership two grants, **totalling $147,000**
- The CRP is developing a vulnerability assessment, which will **reduce individual costs, avoid duplication, inform future planning,** and **lead to better investment strategies**

An overwhelming majority of Palm Beach County's 1.5 million residents live along Florida's metropolitan Atlantic shoreline. That proximity to the ocean comes with a cost: tidal flooding, storm surge, and saltwater intrusion.

Rather than tackle these threats alone, in 2019, seven municipalities and the county formed the Coastal Resilience Partnership (CRP) of Southeast Palm Beach County. The CRP encourages collaboration and consistency in research and planning, while reducing the costs of a segmented approach.

With $147,000 in state funding, the CRP worked with Harvard University's law school to establish a legal and cost-sharing framework for the collaboration and is working with local partners, including engineering firms, to develop a climate vulnerability assessment of the region. When completed, the vulnerability assessment will address immediate threats, inform planning, and lead to more resilient investments.

The CRP comprises larger cities like Boca Raton and Boynton Beach, as well as small towns like Ocean Ridge and Highland Beach, each with populations under 5,000. The partners are engaging stakeholders across the region in anticipation of a long-term resilience collaboration.



The Intracoastal Waterway runs through the study area of the CRP's multi-community vulnerability assessment. In addition to the Atlantic Ocean, this tidal waterway is a key source of flooding in Southeast Palm Beach County.

Image source: pxfuel

Living with water

Living with water is a holistic concept that was developed in the Netherlands. It focuses on the question: how can people improve their connection to water while also achieving flood safety along with other environmental and economic outcomes? Applying the concept can result in a range of actions, such as the creation or redesign of waterways to allow more space for floodwaters and public recreation opportunities, retrofitting buildings to be flood-ready, or the design of floating neighborhoods.

Scale: Building, Site, Municipal, Regional

Investment type: Public/Private

Applying the living with water concept can lead to a wide variety of specific projects. The cost, operations and maintenance, and funding sources of this approach vary broadly by project type.

Informational resources:

- The Urban Implications of Living With Water
- Greater New Orleans Urban Water Plan

Potential benefits of applying the living with water concept:

- Prompt input from community members on ways to reduce flood risk while also considering water as a central community feature or amenity
- Broaden the range of flood-reduction actions beyond only "engineered" solutions

Hampton, Virginia, is piloting a living with water approach in the Newmarket Creek watershed, with plans to slow, store and redirect water, adapt nearby development, and redesign the Creek as a central attraction

Considerations for implementation:

- Gathering input and implementing projects can take time, so local leaders should apply this concept early in the planning process
- The concept can be applied broadly, from a single building to an entire region

Image above: Schoonschip floating neighborhood. (Source: Jan Willem Sieburgh, Space&Matter)

Dutch Case Study: Schoonschip floating neighborhood Amsterdam, Netherlands

- Schoonschip, a newly designed floating neighborhood in Amsterdam, is **adaptable to rising river levels** by allowing floating homes and walkways to rise with the river
- The neighborhood includes 46 unique homes that were **built off-site and transported by boat for installation**
- Project designers created a framework for residents to **personalize and tailor each home**
- Collective facilities like a smart grid allow the neighborhood to be nearly energy neutral
- **The construction cost per home was between $350,000 and $950,000**, depending on building type and size, but the design concepts can also be applied elsewhere to create affordable housing

Schoonschip is a unique residential floating neighborhood, initiated by a group of local community members with a shared dream of self-sustaining residences on the water.

While floating neighborhoods may not be feasible in all communities or local permitting contexts, this type of floating neighborhood can serve as inspiration for other communities seeking to embrace the concept of living with water and adapting to sea level rise and increased flooding.

The neighborhood includes 46 homes clustered around five piers. The homes were constructed off-site, then transported by boat for final installation, limiting construction disturbance to the surrounding area. While the construction cost was a minimum of $350,000 per home, the Schoonschip project designers believe the model can also be applied to an affordable housing context.

Homes are designed to rise with the river in the Schoonschip floating neighborhood. (Source: Isabel Nabuurs, Space&Matter)

Dutch Case Study: Schoonschip floating neighborhood Amsterdam, Netherlands

With support from architecture, development, and sustainable technology consultants as well as assistance with permitting from the City of Amsterdam, the community members funded and planned their own neighborhood.

Each family was able to tailor their own floating home within the community's design framework, allowing both personalization and the incorporation of shared public spaces such as gardens, playgrounds, pools, and other elements designed to increase community interaction.

Collective facilities, like solar panels and a smart grid through which the homes efficiently share electricity, allow the neighborhood, which houses over 100 people, to be nearly energy neutral. The canal that the homes float on also contributes to this system: water pumps extract heat from the water in the canal to heat the homes.

Marjolein Smeele, a resident and architect who contributed to the design of the project, describes the community's approach to living with water, in the context of sea level rise. "Water for us is something to live with and enjoy, not to be afraid of," she says.

Homes delivered by boat: Schoonschip homes were constructed off-site, towed by boat to their final location (left), and arranged along piers with common outdoor spaces (below) during final construction. (Source: Isabel Nabuurs, Space&Matter)

Property acquisition and relocation

Property acquisition and relocation involves physically moving or demolishing buildings that have experienced recurrent flood damage. Typically, property owners volunteer to participate, and local municipalities coordinate implementation. Acquired properties are usually deeded as open space and maintained by a municipal government or local land trust.

Scale: State, Municipal

Cost: $100,000 - $1 million per property (variable depending on property size and type)

Operations and maintenance: Medium

Investment type: Private

Federal assistance sources:

- FEMA's Hazard Mitigation Grants
- Communities can earn flood insurance discounts through the CRS program by acquiring or relocating flood-prone properties

Informational resources:

- FEMA Property Acquisition Guidebook for Local Communities
- Naturally Resilient Communities Property Buyouts

Image above: The City of North Miami, Florida, acquired a residential property because of repeated flooding, then converted it into a public park that features stormwater management as a key design element. (Source: Brizaga)

Potential benefits of property acquisition and relocation:

- Reduces future flood damages by removing buildings from flood-prone areas
- Gives flood-impacted property owners an alternative to repeatedly rebuilding
- Reduces the need to maintain infrastructure where clusters of repeatedly flooded properties are acquired

A study of eight Missouri communities found that property acquisitions led to $96 million in avoided flood damages

Considerations for implementation:

- Local leaders should communicate with homeowners about acquisition and relocation in preparation for future flooding
- By offering incentives for property owners to relocate within the same municipality, local leaders can create community cohesion and maintain the local tax base
- Planners can integrate property acquisition strategies into community planning processes

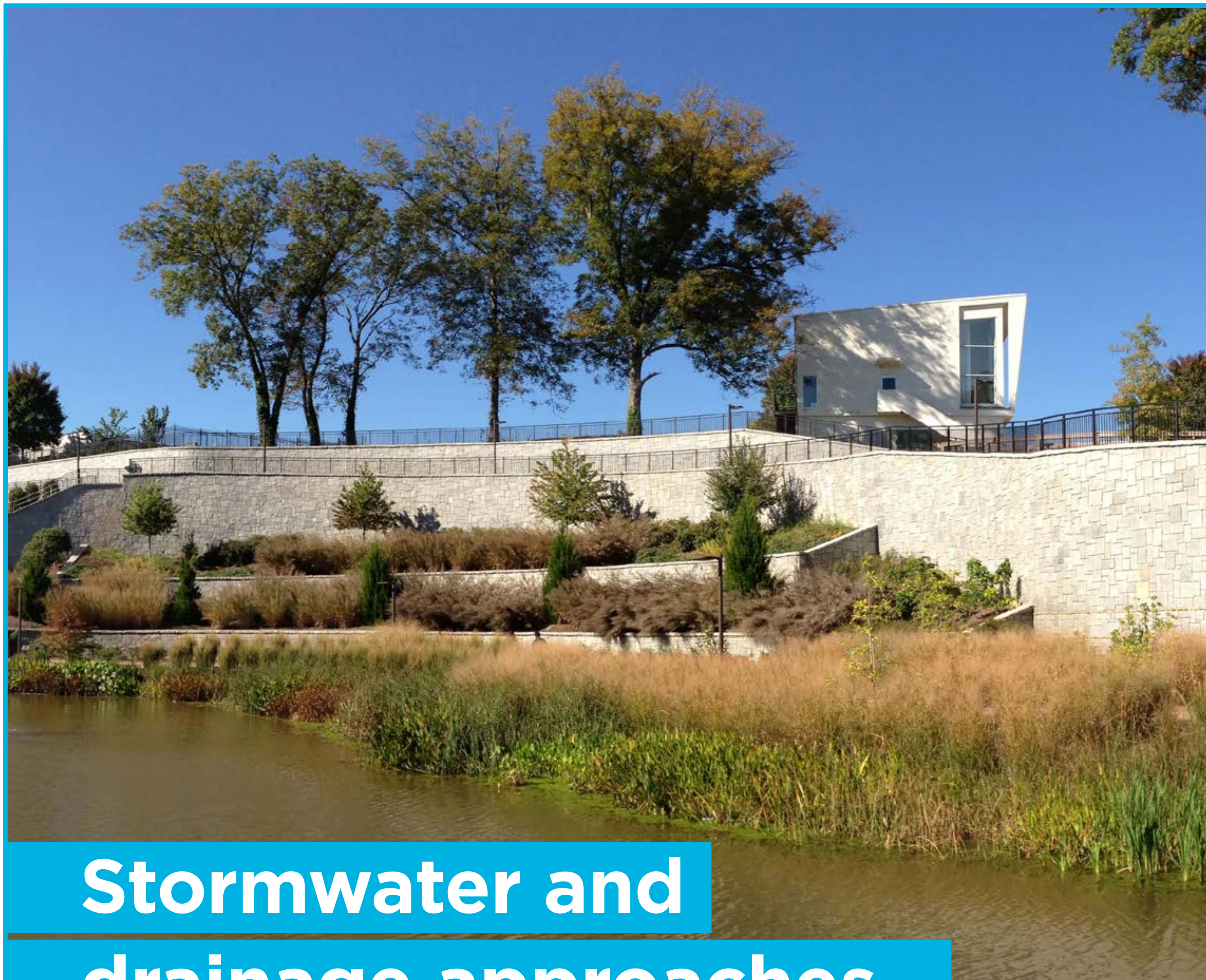
- After flooding from Tropical Storm Irene, **more than 7,000 people requested government assistance** to address damages in Vermont
- In Northfield's historic Water Street neighborhood, more than **80 homes were impacted**
- Several Northfield homeowners volunteered to have their **flood-impacted properties acquired by the Town**
- **FEMA paid 75%** of property acquisition costs, with additional funding from the state and a local civic organization
- The Town **created Dog River Park** not only to reduce flood risk to the community, but also for public recreation and river access
- The complete **process took six years**

Located in the heart of Vermont's Green Mountains, Northfield is a small town of about 6,200 people. Dog River is a popular attraction in the town but has also been the source of flooding.

The community experienced two severe flood events in 2011, the second of which was Tropical Storm Irene, a statewide disaster that led to 7,000 individual requests for federal assistance. Irene dumped more than 6 inches of rain in 12 hours on Northfield, damaging more than 80 homes in the Water Street historic neighborhood, which borders Dog River.

Rather than rebuild, several homeowners volunteered to have their properties acquired by the Town, a process primarily funded by FEMA, with additional funding from the state and Friends of the Winooski, a civic organization. Within three years, a cluster of homes near the river was acquired and demolished. Three years after that, Dog River Park, a five-acre green space, was built in their place.

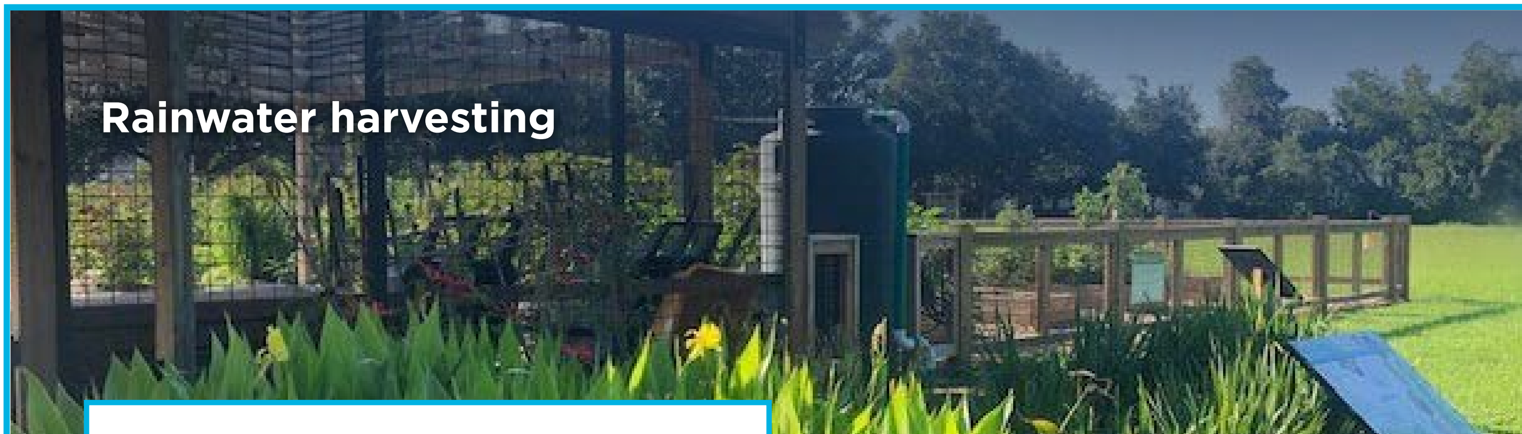
The Dog River Park includes a playground, community garden, lawn, and pavilion located at the park's highest point. In lower-lying areas of the park, walking paths wind through a tallgrass meadow, providing recreational access to the river. On a summer's day, the park is a popular destination for local residents and families. (Source: AFC staff)



Stormwater and drainage approaches

Stormwater and drainage approaches address flooding from water that runs off impervious or water-saturated surfaces such as streets, lawns, and parking lots. Stormwater can cause street flooding by overwhelming existing drainage systems and can affect water quality by carrying pollutants into waterways. Effective stormwater management, however, can minimize flooding and preserve water quality by reducing the amount and speed of stormwater runoff and by filtering pollutants from stormwater moving through the system. Green infrastructure, when integrated into a stormwater management strategy, can reduce and infiltrate stormwater runoff, while also providing wildlife habitat through the use of native vegetation. Local leaders should consider how stormwater and drainage approaches can be implemented alongside other types of approaches, such as land use and open space policies, as part of an integrated flood resilience plan.

Image source: Keizers, CC BY-SA 3.0, Historic Fourth Ward Retention Pond, Atlanta, Georgia



Rainwater harvesting

Rainwater harvesting systems collect rainfall, lower peak runoff volumes, and ultimately reduce flooding. Rain barrels or small cisterns are typically installed to capture roof runoff from a house or building, but larger cisterns can also capture rainwater from a larger area such as a parking lot. Broad application of these techniques can improve stormwater system function for an entire neighborhood or municipality.

Scale: Site (Municipal, in certain cases)

Cost: < $100,000

Operations and maintenance: Low

Investment type: Public/Private

Federal assistance sources:

- FEMA Hazard Mitigation Grants
- HUD CDBG program
- NFWF Five Star and Urban Waters program

Informational resources:

- EPA Rainwater Harvesting Performance Page
- EPA Green Infrastructure Manual

Potential benefits of rainwater harvesting:

- Reduces stormwater runoff and flash flooding by storing rainwater and lowering peak flows during storm events
- Reduces water utility bills by repurposing rainwater for irrigation or indoor plumbing
- Improves ecosystem health by reducing the flow of pollutants entering streams

The average roof collects 600 gallons of water (1.3 times more than could fit in the cistern pictured above) for every inch of rain

Considerations for implementation:

- A standard rain barrel stores around 50 gallons of water and costs $150 or less
- Cisterns store 100 to several thousand gallons of water and can be installed above ground or underground
- A maintenance routine like emptying water after storms can help ensure cisterns and rain barrels continue to function as intended

Image above: Cistern and rain garden in Charleston, South Carolina (Source: Charleston Rainproof)

Case Study: Residential rain barrels Prichard, Alabama

- The **Mobile Bay National Estuary Program** selected Prichard as the focus for a regional rain barrel program
- **Dozens of rain barrels** have been installed in Prichard
- Prichard residents and business owners volunteered to use rain barrels on their properties
- **Donations of materials and labor** came from sources such as the Alabama Power Service Organization and Soterra, a subsidiary of the Greif industrial packaging company
- The water captured in the barrels can be used to wash cars and irrigate plants

The City of Prichard, Alabama, is surrounded by estuaries that flow into Mobile Bay. The region's coastal geography, compounded by its frequent rainfall, can lead to residential street flooding as well as sanitary sewer overflows.

Because of these issues, the EPA-funded Mobile Bay National Estuary Program selected Prichard as an area of focus for a regional rain barrel program. Thanks to this funding, as well as the donations of materials and labor, dozens of rain barrels have been installed around the city.

Community buy-in has contributed to the success of this program. Prichard residents volunteered alongside organizations, businesses, utility companies, and government agencies to install rain barrels, reduce chronic urban flooding, and build community resilience.

The power of volunteers was key to this rain barrel program. In the photo below, volunteers from the Alabama Power Service Organization pose for a picture with a Prichard homeowner after installing rain barrels at her home. (Source: Beth Thomas/Alabama Power)

Case Study: Charleston Rainproof Program Charleston, South Carolina

- **Charleston Rainproof** was created in 2019 and its first **four projects** can store **1,950 gallons** of water
- Working with **Clemson University Extension** helped the City reach more property owners and install more projects
- **Volunteer help** with site selection and installation **kept costs low**
- Charleston Rainproof is a **distributed program** that complements the City's marquee projects and investments
- One of the City's marquee projects is a cistern that can store **200,000 gallons of rainwater** under a parking lot
- In 2018, Charleston created its first-ever **stormwater department** and funded it with **$2.9 million**

As a low-lying coastal city, Charleston, South Carolina, faces flooding from heavy rains, storm surges, and high tides. Additionally, the Charleston region population is growing three times faster than the U.S. average, worsening flooding as sidewalks and streets replace water-absorbing forests and fields. Charleston is also renowned for its historic downtown, but this means that some of its drainage infrastructure dates back to the 1800s, making retrofits increasingly difficult. To better understand these challenges, in 2019, the City convened Dutch Dialogues Charleston, a forum through which American and Dutch experts worked with the Charleston community to develop flood resilience strategies.

Inspired by Dutch Dialogues and the Netherlands' own Amsterdam Rainproof, the City created Charleston Rainproof in 2019, with the aim of capturing more rainwater by using both public and private spaces for water storage.

The network strategy: Amsterdam Rainproof's motto is "every drop counts," emphasizing that making the city rainproof involves everyone. (Source: ©Amsterdam Rainproof)

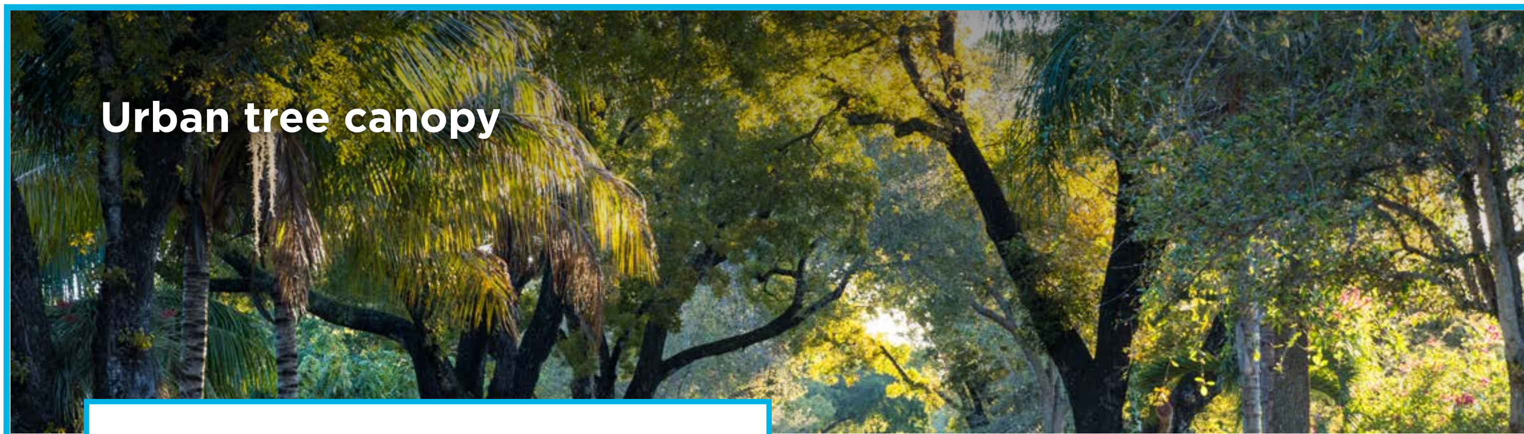
To accomplish this, the Mayor's office and Clemson University Extension partnered on a five-step pilot program to install rainwater harvesting systems across the City. The program consists of volunteer training on how to design and install rainwater harvesting systems through Clemson Extension's Master Rain Gardener (MRG) program and online resources; site selection and analysis, installation, data collection on systems, and long-term maintenance. In 2018 and 2019, Clemson MRG funded and installed three rainwater harvesting pilot projects made up of cisterns and rain barrels, and the City completed a fourth. Combined, the four sites can store 1,950 gallons of water. The project count is increasing rapidly since the original pilot sites were installed, in large part due to Clemson's successful incentive programs, including discount rain barrel sales.

Much of the program's success is attributed to volunteers. They evaluate site suitability, coordinate installation, and submit data to the City so the program can estimate runoff reduction, evaluate projects over the long term, and make improvements.

In addition to its rainproof initiative, Charleston created its first-ever stormwater management department in 2018. With a 2019 budget of $2.9 million, the department focuses on long-term flooding and drainage problems. The City also recently installed a cistern under the parking lot of Grace Homes, a newly-constructed affordable housing project. The cistern holds 200,000 gallons of rainwater, slowing the water's flow into the City's drainage system. A more targeted approach, the Grace Homes cistern complements Charleston Rainproof's distribution strategy. While Charleston's flooding challenges are many, Charleston Rainproof and other recent initiatives help reduce local flooding impacts and improve quality of life.

Clemson Extension designed, funded, and installed the Corrine Jones Community Garden as a rainwater harvesting demonstration project in partnership with The City of Charleston and Charleston Parks Conservancy. (Source: Charleston Rainproof)

Urban tree canopy



Urban tree canopy traps rainfall in leaves and branches and absorbs it into roots and soil, reducing the volume and slowing the progress of precipitation that reaches the ground. The tree canopy is the layer of leaves and branches that hides the ground when viewed from above, and urban tree canopy strategies for flood reduction involve restoring, conserving, managing, and planting trees in urban areas.

Scale: Site, Municipal

Cost: < $100,000

Operations and maintenance: Low

Investment type: Public/Private

Federal assistance sources:

- HUD Community Development Block Grant (CDBG) Program
- DOE Weatherization and Intergovernmental Program

Informational resources:

- Naturally Resilient Communities Urban Trees & Forests
- Urban Tree Canopy (EPA)
- Arbor Day Foundation Community Canopy program

Potential benefits of urban tree canopy:

- Reduce flooding by trapping rainwater in branches and leaves and absorbing it into roots and soil
- Offer shade and relief from heat, improve air and water quality, and enrich wildlife habitat
- Provide aesthetic benefits and reduce noise pollution, which can increase property values

A tree canopy can reduce water runoff by 60% on the ground below

Considerations for implementation:

- Fully grown trees provide the greatest benefits, so conserving existing trees is more cost-effective than planting new ones
- Local leaders can promote healthy tree canopy by investing in proper tree planting and management on public property, and creating standards to encourage these practices on private property
- Foresters and local leaders should account for soil conditions, drainage, overhead power lines, ongoing tree care, and tree growth

Image source: Brizaga

Case Study: Community Canopy Program San Marcos, Texas

- To prevent flooding, the City of San Marcos partners with tree-planting organizations that provide **trees at no cost to the City or its residents**
- Various partners have provided nearly **12,000 trees since 2017**, with the most recent being Arbor Day Foundation's donation of **500 trees**
- For that giveaway, residents could select **up to 2 trees each** and choose between a variety of medium and large shade trees
- San Marcos has around **16% tree canopy coverage but is aiming for 30–40%**, according to the City's urban forester
- San Marcos also has a **Shade Tree Rebate program**, which rebates residents $50 for every tree purchased
- The presence of the additional trees is expected to result in **improved water and air quality** in addition to reduced flooding

Situated between two rivers and a creek, San Marcos, Texas, can flood at a moment's notice. In 2015, extreme rainfall raised the Blanco River 20 feet in one hour, resulting in thousands of flooded homes. The City is working holistically to prepare for floods. One initiative related to this goal is a tree-planting program sustained by in-kind donations from partner organizations. Most recently, in 2020 the City—in partnership with the Arbor Day Foundation, USDA Forest Service, and Texas A&M Forest Service—gave away 500 trees to residents as part of the Arbor Day Foundation's Community Canopy program. The City encouraged homeowners to plant trees in their yards, which will help broaden the tree canopy, reduce runoff, clean the water and air, and increase property value. According to the City's urban forester Kelly Eby, San Marcos has around 16% tree canopy coverage but ideally would have around 30–40%, and this program should help.

This isn't San Marcos' first effort to encourage tree planting, and the City's tree canopy efforts are just one component of its broader investments in a more resilient future.

The City of San Marcos encouraged community members to reserve trees and plant them in their neighborhoods. (Source: City of San Marcos)

Rain gardens and bioretention systems

Rain gardens and bioretention systems are shallow, bowl-shaped areas that are filled with plants growing in gravel, sand and top soil layers. They capture and infiltrate stormwater runoff—often from a specific site such as a roof, parking lot, road, or industrial campus—and can be designed in a range of shapes and sizes to fit in tight spaces.

Scale: Site, Municipal

Cost: < $500,000 (variable depending on scale)

Operations and maintenance: Medium

Investment type: Public/Private

Federal assistance sources:

- FEMA Hazard Mitigation Grants
- HUD Community Development Block Grant (CDBG) Program

Informational resources:

- Naturally Resilient Communities Rain Gardens
- Rain Gardens (EPA)
- Bioretention Stormwater Management Practice Guidance (Philadelphia Water Department)

Potential benefits of rain gardens and bioretention systems:

- Absorb and slow stormwater that could otherwise cause flooding or burden public drainage systems
- Cost little to construct and require minimal technical expertise to build and maintain
- Filter stormwater, while improving water quality and providing wildlife habitat
- Provide educational value to a community

A rain garden can absorb as much as 30–40% more runoff than a standard lawn

Considerations for implementation:

- Local leaders can set up educational programs to encourage adoption on residential properties
- Designers should select plants that can tolerate both wet and dry conditions, and are native or well-adapted to the local environment
- Rain gardens work best in rocky or sandy soils, which allow water to drain quickly, preventing frequent pooling of water and mosquito breeding
- Local leaders should plan for maintenance of public gardens, such as weeding and plant replacement

Image above: A rain garden with pooled water that plants can soak up. (Source: Alisha Goldstein, EPA)

- Jacksonville maintains **four rain gardens** that capture stormwater runoff from streets
- The **City built three of the gardens with volunteers,** a process that took 30 days
- The plants in the rain gardens can retain water in their roots for **up to two days** after a storm
- The gardens **remove contaminants from water,** which helps improve the health of the New River
- The Triangle Rain Garden, built in 2005 from a former asphalt median, **cost $14,000** to construct and now functions as a **demonstration site and community point of pride**
- The Triangle was expanded in 2018 by transforming one of the 3 streets around the triangle into more garden space; the Triangle can now drain **1.4 acres of land area**

The City of Jacksonville, North Carolina, is twenty miles up the New River from the Atlantic Ocean and frequently experiences flooding, both from rainfall and from the river. Water quality issues compound the flooding concerns since the river has elevated sediment and nutrient levels.

To address these issues, the City maintains several rain gardens to absorb and filter rainwater and reduce stormwater entering the drainage system. The City worked with volunteers to construct three rain gardens that capture rainwater from residential streets. The native plants they used tolerate both dry and wet conditions and reduce flooding by storing water in their roots for up to two days after a storm. They also help create habitat for pollinators and attractive streetscape spaces for residents. The Triangle Rain Garden, named for the three streets that surround it, was initially created by retrofitting an asphalt median and cost $14,000 to construct. In 2018, the City expanded it to replace a neighboring street as part of a larger street improvement project. The resulting garden now drains 1.4 acres of land area.

A street median in Jacksonville, North Carolina **before (bottom)** and **after (inset)** being retrofitted to create the Triangle Rain Garden. (Source: The City of Jacksonville)

Permeable pavement

Permeable pavement consists of a porous artificial surface, such as porous concrete, interlocking concrete pavers, or porous asphalt. When used as an alternative to impervious materials like asphalt or concrete, permeable pavement allows stormwater to percolate downward, where it slowly filters into the ground or an onsite drain instead of flowing across the surface into storm drains or waterways.

Scale: Site, municipal

Cost: < $500,000 (variable depending on scale)

Operations and maintenance: Medium

Investment type: Public/Private

Federal assistance sources:

- FEMA Hazard Mitigation Grants
- DOT BUILD Grants

Informational resources:

- Permeable Pavement (EPA)
- Green Infrastructure Municipal Handbook (EPA)

Potential benefits of permeable pavement:

- Reduces the amount of stormwater runoff when compared to typically impervious surfaces, such as solid concrete or asphalt
- Reduces the amount of stormwater flowing into storm drains or waterways

Depending on design, material and soil type, and storm intensity, permeable paving can infiltrate as much as 70%–80% of rainfall

Considerations for implementation:

- Local leaders should incorporate permeable pavement into projects for lightly trafficked areas like sidewalks, alleys, walking paths, driveways, parking lots, and secondary streets
- Permeable pavement is not well-suited for major roadways with heavy trucks or high-speed traffic
- Local leaders should implement maintenance programs to keep permeable pavement pores clear
- Engineers should conduct a geotechnical analysis to ensure permeable pavement is suitable for a site's level of soil filtration and water table height

Image source: Getty

Case Study: Sutton Park permeable paving Palmetto, Florida

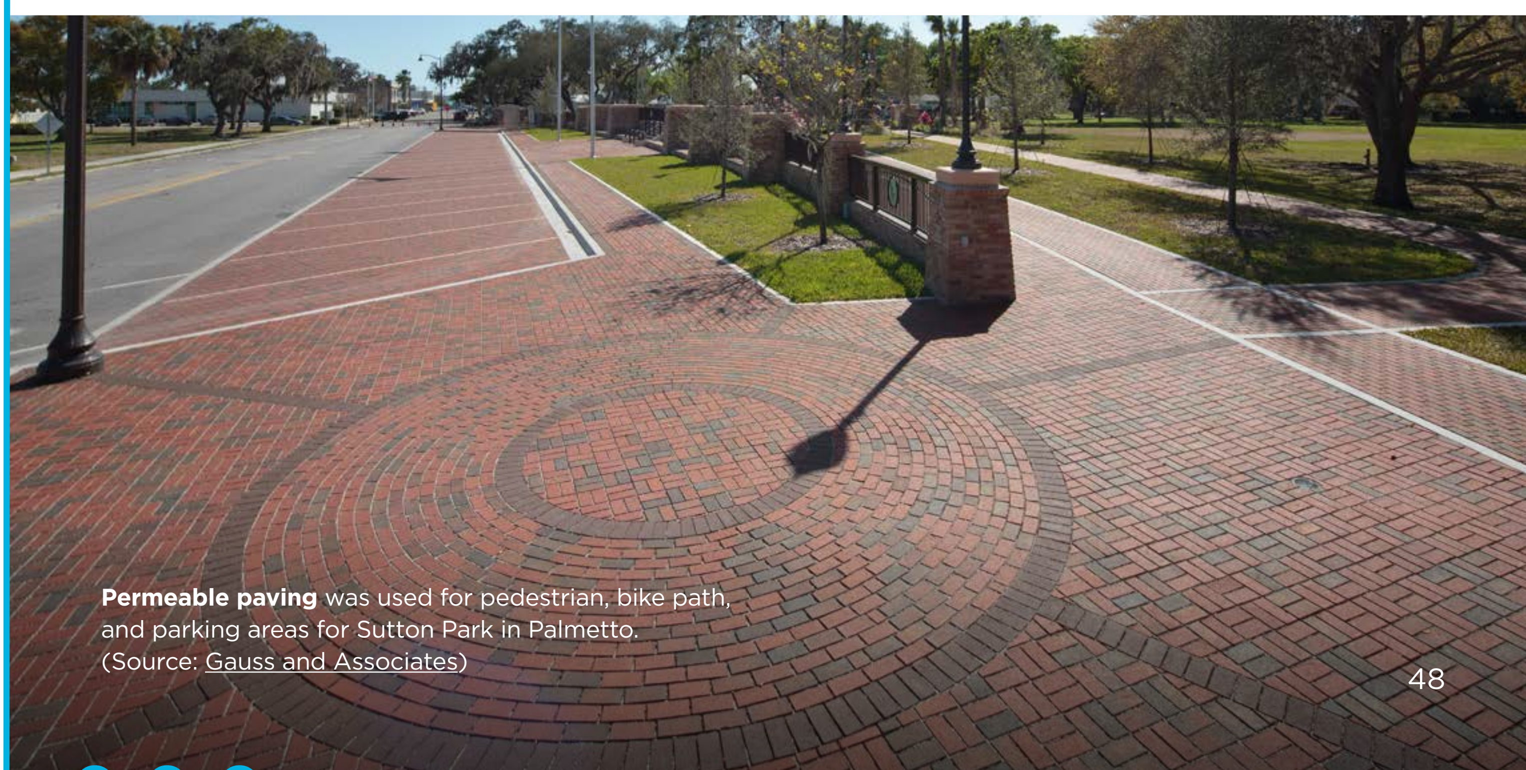
- The City of Palmetto renovated Sutton Park in 2012
- The park's design **minimizes stormwater runoff** and includes a pavilion and pedestrian and bicycle paths
- **Approximately 23,000 permeable pavers** were used for the project, to help stormwater infiltrate into the ground
- The project won an **architecture award** from the National Brick Industry Association

Palmetto, Florida, is a community rich in history, with access to beaches and natural areas, but it is also vulnerable to flooding. One way it has addressed this is by redesigning its community centerpiece: Sutton Park. As a former high school football field, Sutton Park forms a central greenspace between the City's historic and central business district. But after several decades of use, the park was in need of an upgrade.

The challenge was twofold: preserve the City's history and identity, while serving a practical purpose for a flood-prone community. The City engaged consultants to design and construct a park that was durable enough to withstand traffic and heavy rainfall and inexpensive to maintain. The project was completed in 2012 and included permeable paving along with other elements such as a pavilion, lighting, and concrete curbing.

The park's central feature is a new pavilion area with bordering permeable pavement. The park has several other unique features, including one area where paver patterns alternate to help steer pedestrians and bicyclists in separate directions. Clay brick columns and permeable pavers designed for the project are now being incorporated across the community to highlight the historic identity of the City.

Now, in addition to serving as a model for innovative flood mitigation, Sutton Park is a cultural center used for recreation, movies, picnics, parades, and concerts.



Permeable paving was used for pedestrian, bike path, and parking areas for Sutton Park in Palmetto. (Source: Gauss and Associates)

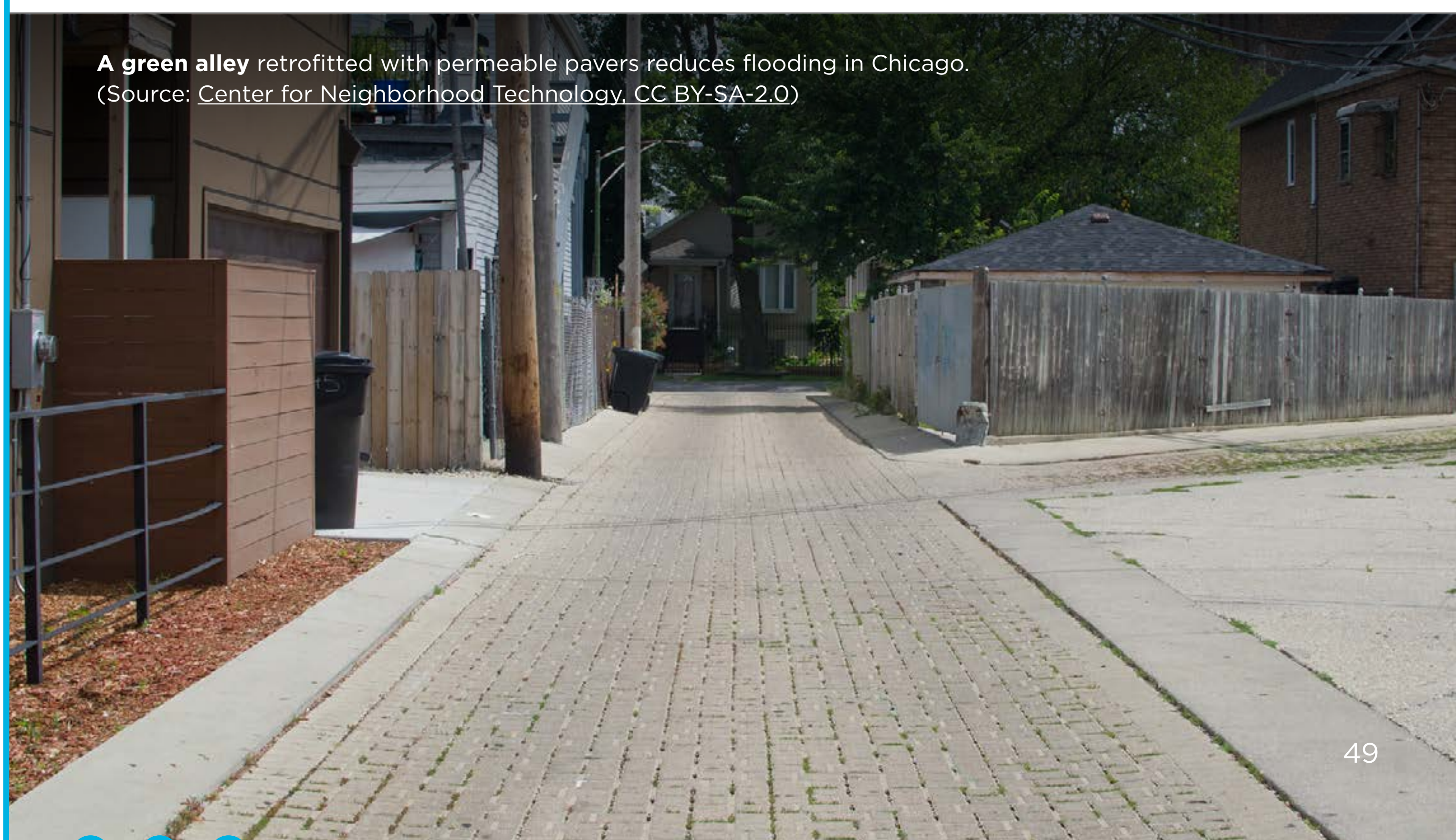
Case Study: Permeable streets and alleys Chicago, Illinois

- The City of Chicago uses stormwater management techniques such as **permeable pavement to decrease stormwater runoff** in streets and alleys
- These efforts have **reduced runoff by up to 80% on a 2-mile stretch of road** in the Pilsen neighborhood
- Since 2001, **the city has installed more than 300 "green alleys"** that use techniques, including permeable pavement, to avoid installing miles of new sewer and stormwater infrastructure while reducing flooding

Since 2001, Chicago has promoted permeable pavement on city streets and alleys to minimize stormwater runoff. Depending on the situation, the City has used different building materials, such as porous pavement or concrete and interlocking permeable pavers.

In the Pilsen neighborhood, the City used permeable pavement, as well as bioswales and rain gardens, to reduce stormwater runoff by 80%. The project was funded by local, state, and federal sources, including a local Tax Increment Financing program, the Federal Highway Administration, Illinois Environmental Protection Agency, and Midwest Generation.

The Pilsen project was part of the City's Green Alley Program, which reduces stormwater runoff in more than 300 alleys, most of which are not connected to the City's combined sewer and stormwater system. The program looks at ways to reduce runoff that are more cost-effective than building new connections to sewer and stormwater systems. The program has allowed for stormwater to percolate through soil, reducing runoff and flood impacts to buildings.



A green alley retrofitted with permeable pavers reduces flooding in Chicago.
(Source: Center for Neighborhood Technology, CC BY-SA-2.0)

Culverts and drainage pipes

Culverts and drainage pipes allow water from rivers and streams, tidal inlets, or storm events to pass underneath a bridge, road, or railway. If properly sized, they reduce flooding by transporting large volumes of water and preventing any backup of floodwater that could spill over onto adjacent roads and properties.

Scale: Site, Municipal

Cost: $100,000 – $1 million (variable depending on scale)

Operations and maintenance: Low

Investment type: Public/Private

Federal assistance sources:

- FEMA Public Assistance program
- EPA Five Star and Urban Waters Restoration Program
- USFWS National Fish Passage Program
- USDA Watershed and Flood Prevention program

Informational resources:

- Naturally Resilient Communities Flood Friendly Culverts
- The Stream Continuity Portal
- TNC Aquatic Barrier Prioritization Tools
- USFS Aquatic Organism Passage Technical Guide

Image above: Gills Creek retrofitted culvert system near Lancaster, South Carolina. (Source: USFWS)

Potential benefits of culverts and drainage pipes:

- Reduce flood damage to roads and properties by transporting large volumes of water, preventing backup or overflow
- Have long lifespans and require little maintenance
- Allow better passage of fish and other aquatic wildlife
- Enhance ecosystem health by facilitating the transport of water and nutrients

A 2015 study found that upgrading culverts was 38% less expensive than replacing and maintaining standard ones for 30 years

Considerations for implementation:

- Engineers must carefully design and size culverts to accommodate peak flows during storm events and to ensure they do not increase downstream flooding
- If undersized, culverts can increase flooding and become more easily damaged
- When prioritizing upgrades to culverts, local leaders should consider social, economic, and environmental factors
- Local leaders can incorporate culverts into larger projects like bridge or road replacements and ecological restoration projects

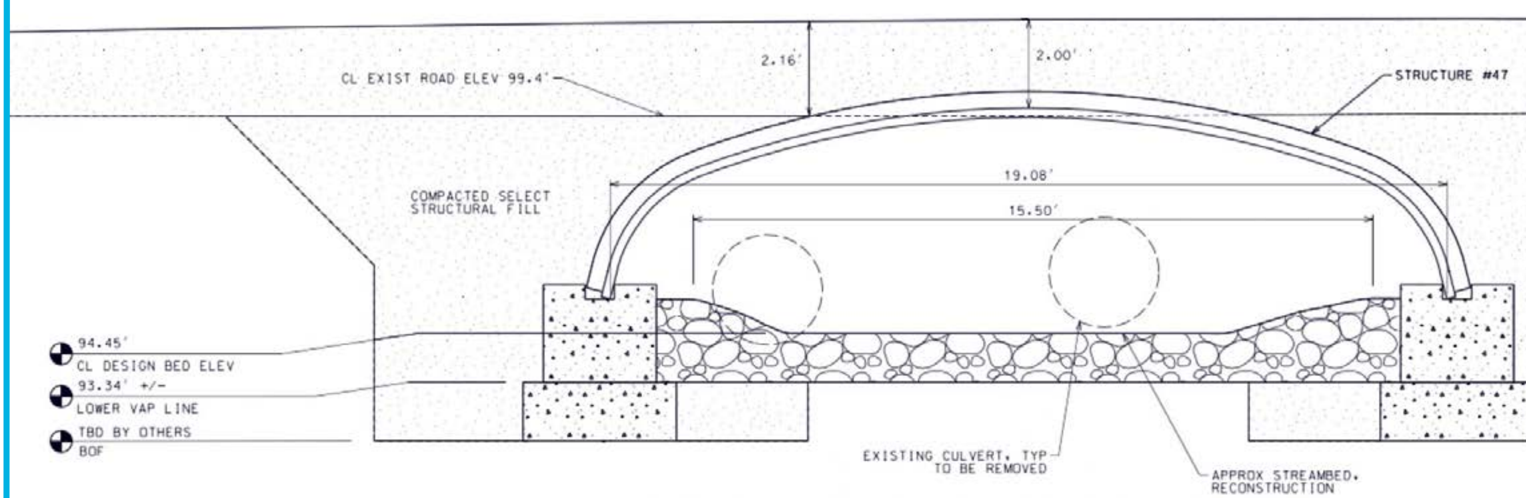
Case Study: Culvert improvements Ausable River Watershed, New York

- From a list of dozens, AsRA selected **five culverts** to be replaced or retrofitted, the first of which was constructed in 2015
- **Community conversations**, as well as **online tools and research** by partners SUNY Plattsburgh and TNC, were key to culvert prioritization
- Each culvert cost **$150,000 or more** to construct, for a total construction cost of **over $750,000**
- Each culvert typically lasts **70 years** and requires little to no maintenance
- AsRA intends for the first installed culvert to **serve as a model** for making cost-effective replacements of small (<20' wide) culverts
- The project was funded by **grants from over 5 entities**, including nonprofits and companies, as well as local, state and federal government agencies

High waters from Tropical Storm Irene and other flood events have overwhelmed culverts, damaging millions of dollars worth of roads, bridges, and property in New York's Adirondacks. In rural Essex County, New York, Irene caused an estimated $2 million in road damages alone. With more intense storms and heavier rainfall expected in the future, many of the culverts in the region will urgently need to be redesigned.

To address this need, the Ausable River Association (AsRA) partnered with The Nature Conservancy (TNC) and the State University of New York at Plattsburgh (SUNY Plattsburgh) to prioritize culverts in the Ausable River watershed for replacement. The team used TNC's Aquatic Barrier Prioritization tool, along with input from town and community leaders, to evaluate the potential social, economic, and environmental impacts of each culvert. To better understand these impacts regionally, AsRA also worked with the North Atlantic Aquatic Connectivity Collaborative to include the status of each culvert in this group's multi-state database on road-stream crossings.

A **construction drawing** for a culvert replacement in Jay, New York. (Source: AsRA)



Case Study: Culvert improvements Ausable River Watershed, New York

After identifying dozens of culverts, the partnership group selected five to be replaced or retrofitted. The first of several new culverts was constructed in 2015, and AsRA hopes to use this as a model to help small communities in the region to replace similar small culverts (under 20′ wide). The new culverts will allow for higher flows of water during storm events, reducing the risk of flood damage to roads and property, while also improving the stream ecosystem. Kelley Tucker, AsRA Executive Director, shared two key principles for culvert design:

(1) Prioritize public safety. Culverts should be designed, sized, and constructed to withstand severe flood events, while also maintaining affordable construction costs. This approach helps keep roads safe, giving residents access to hospitals and food during storms, without draining a local government's limited funding. AsRA typically sizes culverts so that they would reach 80% capacity during a 100-year flood. This is the largest possible size without culvert improvements becoming too expensive—though sizing standards may differ by region.

(2) Ensure safe passage for aquatic species. Undersized culverts and culverts that lie at a different angle than their streams can block the natural flow of a stream, preventing passage of aquatic species like native brook trout. Municipalities should carefully design and set culverts to ensure they are the right size and at the right slope to accommodate fish and other aquatic wildlife.

Each culvert typically costs at least $150,000 to construct. The investment is often worthwhile—each culvert typically lasts over 70 years, with no required maintenance. Additionally, experienced organizations like AsRA have made cost-efficient culvert improvements by building and relying on teams with specialized local knowledge.

The funding for these projects came from grants by TNC, the Wildlife Conservation Society's Climate Adaptation Fund, U.S. Fish and Wildlife Service, Patagonia, U.S. Department of Interior's Hurricane Sandy Coastal Resilience Competitive Grant Program, and other groups.

A culvert in the town of Jay, New York **before (left)** and **after (right)** being replaced to reduce flood impacts and improve stream health. (Source: AsRA)

Green and blue roofs

Green and blue roofs capture stormwater as it falls on building roofs, slowing or halting its progress to storm drains. Blue roofs use artificial structures to retain stormwater and allow it to evaporate or discharge slowly into a drainage system. Instead of using physical structures, green roofs use vegetation and soil that absorb water.

Scale: Site, Municipal

Cost: < $1 million
(variable depending on scale)

Operations and maintenance: Medium

Investment type: Public/Private

Federal assistance sources:

- DOE Weatherization and Intergovernmental Program
- HUD Sustainable Communities Regional Planning Grants

Informational resources:

- Green Roofs (EPA)
- Naturally Resilient Communities – Green Roofs
- Moore Farms green roof and living wall research

Potential benefits of green and blue roofs:

- Reduce runoff to stormwater systems during peak flows
- Last longer than traditional roofs
- Regulate building temperatures, provide wildlife habitat, reduce urban heat-island effect, and increase local air quality

Green roofs can capture up to 80% of rainfall during rainstorms, compared to 24% typical for standard roofs

Considerations for implementation:

- This solution can be used for different types of roofs but is most effective on large, flat roofs
- Local leaders can incorporate incentives or requirements for green and blue roofs into local codes and standards
- This approach may be cost-prohibitive in circumstances when additional structural reinforcement is needed
- Leaders should take advantage of new buildings by integrating green or blue roof designs prior to construction

Image source: Getty

Case Study: Green roof rebate program Nashville, Tennessee

- In Nashville, green roofs can **capture about 55% of rainfall** and prevent that water from reaching the stormwater system
- In 2016, the City created the **Green Roof Rebate Program for homeowners** within the combined sewer area
- The rebate program gives **$10 credit in a property's sewer fees for every square foot of green roof**, a rebate that is applied over 5 years
- For the program, at least 80% of the roof must be covered with hardy, drought-resistant plants
- The Music City Center has a green roof that spans 191,000 square feet and is **capable of offsetting 2.6 million gallons of stormwater**
- In addition to Nashville, smaller communities such as Portland, Maine, and Fife, Washington, have also implemented local policies that encourage green roofs

Over 2,500 miles of streams run through Nashville and Davidson County, Tennessee. Combined with frequent rainfall and a sewer system from the late 1880s, the City's infrastructure is often ill-equipped to handle severe rain.

Nashville has recently turned to green roofs as part of its strategy to address flooding. According to the City, green roofs can capture about 55% of rainfall, reducing burdens on its drainage system. In 2016, the City created the Green Roof Rebate Program to encourage property owners to install green roofs, with a stipulation that 80% of the roof must be covered with hardy, drought resistant plants.

But green roofs are not limited to private residences. Putting a green roof on a public building, such as a library, school, or event center, can be an educational point for communities big and small. For example, Nashville's iconic Music City Center has a green roof with 14 different kinds of plants, selected to tolerate heat and drought. The green roof can handle over 3 million gallons of stormwater.

The green roof at Nashville's Music City Center features 14 types of plants, selected to absorb rainwater and tolerate heat and drought. (Source: Nashville Music City Center)

Stormwater parks and green streets

Stormwater parks and green streets combine absorbent landscaping and stormwater drainage techniques to reduce flooding to streets and properties. They function like regular parks, parking lots, and streets, while providing added flood reduction and health benefits through retrofitted medians, curbs, ponding areas, and drainage elements. Features can include trees and plants, water retention ponds, and bioswales (vegetated channels that move stormwater off roads and into stormwater systems).

Scale: Site, Municipal

Cost: $100,000 - $1 million (variable depending on scale)

Operations and maintenance: Medium

Investment type: Public/Private

Federal assistance sources:

- FEMA Hazard Mitigation Grants
- EPA Clean Water State Revolving Fund
- HUD Community Development Block Grant Programs
- NFWF Resilient Communities Program

Informational resources:

- Naturally Resilient Communities Green Streets
- Naturally Resilient Communities Green Parking Lots
- Naturally Resilient Communities Bioswales

Potential benefits of stormwater parks and green streets:

- Reduce runoff as plants absorb and slow stormwater
- Move excess stormwater off streets and properties and into stormwater systems
- Filter stormwater, reducing treatment costs for local drainage and/or sewer systems
- Create habitat for wildlife, adding aesthetic and educational value to the street or park
- Help reduce heat-related illness by absorbing less heat than pavement

A Tucson, Arizona, report found that for every $1 spent, green streets provide an estimated $2.10 in benefits

Considerations for implementation:

- Local leaders can use street resurfacing and widening projects to turn existing streets into green streets
- Local leaders can look to publicly-owned vacant lots or stream corridors as sites for stormwater parks
- Engineers must carefully consider site features, such as right of way, soil type, and existing utilities
- These approaches are less suitable for areas with major flooding or steep slopes

Image above: A streetscape bioswale. (Source: Chris Hamby, CC-BY-SA-4.0, Brooklyn, New York)

Case Study: Good Neighbor Stormwater Park North Miami, Florida

- North Miami and Van Alen Institute held a design competition to convert a vacant lot into a **stormwater park**
- **Door-to-door community conversations** were essential to the project's success
- The park's retention pond and absorbent landscaping can store **20 times more water** than the vacant lot
- The park's features are designed for the **two feet of sea level rise** expected for North Miami by 2060
- The project took **three months** to build and opened in December 2019
- The project **cost around $150,000** and was funded by grants from Van Alen Institute and the State of Florida

Over half of North Miami is within the low-lying, flood-prone Arch Creek Basin, where many residents experience frequent flooding. Because of this geography, many residents now experience frequent flooding. Those homeowners who file flood insurance claims more than once in 10 years are eligible for buyouts under the federal insurance program. After the buyouts, however, many flood-prone, City-owned vacant lots remain.

To reduce flooding in one vacant lot, the City of North Miami constructed the Good Neighbor Stormwater Park in the City's Sunny Acres neighborhood. Formerly a vacant lot for fifteen years, the half-acre space unveiled in December 2019 earns its "stormwater park" name, boasting a water retention pond that stores excess water, a pipe that brings water to the pond and also functions as park seating, and a marsh and garden that absorb rainfall.

Good Neighbor Stormwater Park's flood reduction structures consist of a pond that stores excess water, a pipe that brings water to the pond and also functions as a bench, and native landscaping that absorbs rainwater. (Source: City of North Miami)

In addition to lowering neighborhood flood risk, the park also provides recreation and education through its walking path, exposed pipe seating, and signage, as well as posts submerged in the pond that mark the water's elevation and help residents visualize how much water is directed off neighborhood properties and streets.

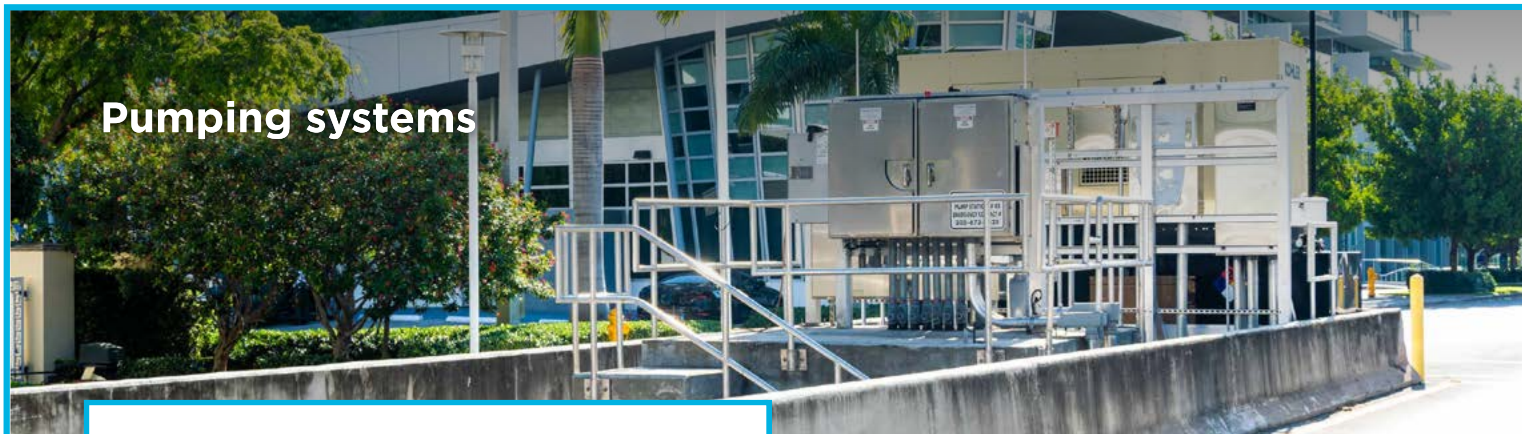
The park is the result of a partnership between Van Alen Institute, which issued an international call for local project proposals to address sea level rise, and the City of North Miami, which proposed the Sunny Acres park. The partners then put out an international call for a design partner to receive Van Alen's $80,000 grant, design the park, and create a plan for other local repetitive loss sites. The partners narrowed sixty two applications down to three, and a jury selected Department Design Office. A $50,000 grant from the Florida Department of Environmental Protection and donated time from Department Design Office supplemented the Van Alen grant.

The City and Van Alen also brought in other partners, including Miami-based Urban Impact Lab to run community engagement. Since the project was located in a residential community where English, Spanish, and Haitian Creole are widely spoken, engagement involved multilingual, door-to-door conversations with residents. Ultimately, the project took three months and $150,000 to complete.

The park is designed for the two feet of sea level rise expected by 2060 and is estimated to hold 20 times more water than the vacant lot it was before. It will also lower flood insurance rates, bring social activity to an underused space, and inspire confidence for other small communities pursuing similar projects.

Educational elements: In addition to reducing flooding, the park allows opportunities to learn. The walking trail provides a vantage point to see both native plants and the markers in the retention pond, which illustrate how much water is diverted from properties. (Source: Saul Martinez © Van Alen Institute)

Pumping systems



Pumping systems move floodwaters when they cannot be conveyed by gravity, or when floodwaters threaten critical facilities or other important areas. While pumping systems are most effective for stormwater control, they can also counter riverine and coastal flooding on a limited scale.

Scale: Site

Cost: $100,000 - $1 million (variable depending on scale)

Operations and maintenance: High

Investment type: Public/Private

Federal assistance sources:

- FEMA Public Assistance Grant Program
- FEMA Hazard Mitigation Grants
- HUD Community Development Block Grant Program

Informational resources:

- Michigan DOT Stormwater Drainage Manual
- Grundfos Designing Flood Pumping Systems

Potential benefits of pumping systems:

- Prevent flooding of critical facilities, residential, commercial, or other developed areas by pumping floodwaters away from them

The Town of Emerald Isle, North Carolina uses 9 stationary pumps located in different neighborhoods to divert stormwater away from streets and homes to designated natural areas

Considerations for implementation:

- Pumping systems can be expensive to design, build, and maintain, so local leaders should pursue other systems first
- Engineers must account for flood risk, particularly in coastal areas where flood damage can disrupt pump station function and exacerbate flooding
- Pumping systems are most effective for inland areas with excessive runoff, coastal areas with increased sea levels, and areas with elevated groundwater levels
- Pumping systems should be one component of a larger flood management strategy, and may require land use planning to designate areas for receiving discharged stormwater

Image source: Brizaga

Case Study: Groundwater pumps Nags Head, North Carolina

- Nags Head comprises more than 11 miles of ocean shoreline and 17 miles of estuarine shoreline
- Nags Head is **vulnerable to coastal hazards**, such as tropical storms and nor'easters, storm surges, flooding, and sea level rise
- In 2015, NOAA's Sea Grant program began a project to provide Nags Head with scientific, policy and legal information to assist the Town's planning for a resilient future
- Engineers are now considering different ways to mitigate neighborhood flooding, including **pumping water from below ground before a storm arrives**
- The town has implemented a new groundwater lowering system at a **cost of $254,000**

Nags Head, part of North Carolina's Outer Banks, is a popular destination for vacationers seeking the sights and sounds of a small-town beach community. But that location comes with a price. Because much of Nags Head sits at or just above sea level, heavy rainfall often overwhelms stormwater infrastructure, with flood depths reaching as much as three feet in some areas.

Nags Head has a history of dealing with flood risks, which has lately been made worse by sea level rise and increasing rainfall. The Town has invested over $254,000 on a pumping system and other groundwater lowering techniques to help reduce the damages of these flood risks.

To improve drainage in low-lying areas, the Town invested in a network of groundwater pumps. Several years ago, the Town piloted a project to drain a particularly low-lying neighborhood, using a series of groundwater pumps to channel water to higher elevations. In the Nags Head Acres and Vista Colony neighborhoods, the Town has constructed seven wells to a depth of 30 feet to draw down groundwater and dump it into a nearby undeveloped ridge.

As storms with heavy rainfall become more frequent and intense, groundwater pumps are just one of many ways municipalities like Nags Head are getting creative with their flooding solutions.

By pumping groundwater to a natural infiltration area on a ridge above town, low-lying neighborhoods are able to reduce the amount of water that floods streets, yards, and driveways. (Source: Ins1122, CC-BY-2.0)

Stormwater basins and constructed wetlands

Stormwater basins and constructed wetlands capture stormwater and hold it in place, preventing peak runoff from flowing to an area where it may cause flooding. Stormwater detention basins slowly release stormwater, whereas stormwater retention basins store it to be withdrawn later for other purposes. Constructed wetlands function similarly to retention basins, with the added benefit of filtering pollutants from stormwater through the use of wetland plants.

Scale: Site, Municipal

Cost: > $100,000
(variable depending on scale)

Operations and maintenance: Medium

Investment type: Public/Private

Federal assistance sources:

- FEMA Hazard Mitigation Grants
- HUD Community Development Block Grant Program
- EPA Clean Water State Revolving Fund and 319 Grant Program

Informational resources:

- Naturally Resilient Communities Detention and Retention Basins

Potential benefits of stormwater basins and constructed wetlands:

- Reduce flooding by slowing or storing stormwater runoff
- Improve water quality and wildlife habitat with the addition of wetland plants
- Provide education and recreation opportunities for visitors when integrated with walkways or other public access elements

The Kuykendahl regional detention basin in Harris County, Texas is designed to hold over 750 million gallons of stormwater

Considerations for implementation:

- Local leaders should encourage public input early on since these projects often require large areas of land and affect drainage patterns in local neighborhoods
- When designing basins, engineers and planners should consider factors such as drainage area, slope, right of way, soil conditions, and existing utilities
- These approaches are more cost-effective when installed as part of new development

Image above: A **dry stormwater detention basin** in Athens-Clarke County, Georgia. (Source: Athens-Clarke County)

Case Study: Jack Smith Creek Stormwater Wetlands New Bern, North Carolina

- The Jack Smith Creek Wetlands are the **largest man-made wetlands in North Carolina**, located in New Bern, a community of 30,000 people
- The wetlands can retain more than **5 million gallons** of stormwater runoff and capture and treat runoff from more than 1,000 acres of residential and commercial properties
- The entire project **cost $2.6 million**, funded mostly by North Carolina's Ecosystem Enhancement Program and Clean Water Management Trust Fund, and New Bern
- To routinely maintain these wetlands and other stormwater management sites, the City created a **new Stormwater Maintenance Division**

Located near the mouth of the Neuse River in North Carolina, the City of New Bern frequently experiences short, intense rainfall that floods streets and yards in low-lying areas. To minimize this flooding, as well as capture some of the water flowing into the Neuse River, the City constructed the Jack Smith Creek Stormwater Wetlands.

Completed in 2013, the wetlands are the largest man-made wetlands in North Carolina, capable of holding more than 5 million gallons of stormwater runoff from more than 1,000 acres of residential and commercial properties. The system includes two large pumps that can be activated during a storm to transport water out of ditches and canals and into the wetlands, as well as over 140,000 wetland plants to help slow high waters and filter it.

Though the project is not designed to handle flooding from major storms, its value is in its ability to treat urban stormwater runoff, caused by smaller, more frequent floods. Now, in addition to reducing flood risk, the wetlands serves as a research park for North Carolina State University.

Wetland plants in the Jack Smith Creek Stormwater Wetlands are key to slowing and filtering stormwater. Over 140,000 were planted (left) in April 2013 and became established within four months (right). (Source: Wetland Plants Inc)

Floodplain restoration

Floodplain restoration reduces flooding in downstream areas by reconnecting waterways with their adjacent, low-lying floodplains. Reconnecting a river to its floodplain can involve multiple techniques to physically reshape the land, including restoring eroded streams, excavating floodplains, or removing barriers like berms or levees to create more space for floodwaters. Planting new vegetation is also commonly a component of floodplain restoration projects and can aid in slowing and absorbing floodwaters while also creating habitat for wildlife.

Scale: Site, Municipal, Region

Cost: > $500,000
(variable depending on scale)

Operations and maintenance: Low

Investment type: Public/Private

Federal assistance sources:

- FEMA Hazard Mitigation Grants
- USDA Watershed Protection and Flood Prevention Program

Informational resources:

- Naturally Resilient Communities: Restoring Floodplain Elements

Potential benefits of floodplain restoration:

- Reduces downstream flooding by creating more space for floodwaters
- Improves habitat for plants and animals that thrive in floodplains

In Louisiana, the Mollicy Farms floodplain restoration project has removed levees and restored over 25 square miles of wetlands and bayous, lowering the water level of the Ouachita River and reducing downstream flood risk

Considerations for implementation:

- Local leaders should consider this approach when a waterway has been disconnected from the floodplain through infrastructure, development, or stream entrenchment caused by erosion
- While this approach can be applied at multiple scales, it is difficult to apply in dense urban areas where land is limited
- In many cases, this approach will require professional expertise to assess and plan project requirements

Image above: A river and floodplain widening project in Nijmegen, Netherlands (Source: Dutch Water Sector)

Dutch Case Study: Room for the River Overdiepse Polder, Netherlands

- The Room for the River program was developed in response to **rising water levels in rivers**, caused largely by more frequent and heavier rainfall
- The program includes **34 projects along four rivers**, with a total cost of $2.7 billion
- Through these projects, **riverbeds and floodplains were deepened and widened**, and water storage basins and overflow channels were created to allow more space for floodwaters
- **Local farmers took a lead role** in developing the idea for Overdiepse Polder, a Room for the River project
- **Overdiepse Polder** includes an overflow channel and mounded earth to reduce flood risks to local farms and communities, with a total cost of over $100 million

Extreme water levels in rivers in the 1990s caused many problems in the Netherlands, leading to a new flood risk management program called Room for the River. Instead of focusing on adding height to existing flood barriers such as levees, this program emphasized giving the rivers room to store and discharge a greater volume of water by deepening and widening riverbeds. These actions were often combined with efforts to preserve or create natural, agricultural, or recreational space.

The program led to 34 different projects along four different rivers in the Netherlands, improving safety for about 4 million Dutch citizens. The projects were a collaboration between the national and regional government and the local citizens. Converted to U.S. dollars, the total cost of the program was approximately $2.7 billion.

Widening low lying floodplains next to rivers can create more space for floodwaters, while also providing space for agriculture, recreation, and natural areas. (Source: Dutch Water Sector)

Dutch Case Study: Room for the River Overdiepse Polder, Netherlands

The Overdiepse Polder, located on the south bank of the Bergsche Maas river, is a Room for the River project. The project converted existing farmland into an overflow channel to relieve pressure during periods of high water flow. Flooding this space lowers the water level at other critical locations along the river by almost a foot, and reduces flood risk to several communities nearby.

It's projected that occurrences of severe high water flow will increase to once every 25 years in the region, making the Overdiepse Polder project imperative for reducing flood impacts.

As part of this project, local farmers developed the idea of reintroducing a historic part of the region's landscape, known as "terpen" (houses and farms situated on mounds to protect them from flooding). The farmers proposed that the construction of the new overflow channel, combined with the mounding of land to lift farms and buildings above the surrounding landscape, would allow them to continue farming, even as river levels rise over time.

The farmers' proposal was translated into a new landscape design where farms were placed on mounds and agriculture was combined with increased drainage capacity and recreational facilities.

The Overdiepse Polder Mound Plan was created by Dutch landscape architects, in close collaboration with local governments and other stakeholders in the area. Converted to U.S. dollars, the project cost over $100 million.

Children from communities where the risk of flooding has been reduced (as a result of the Overdiepse Polder project) help at the ground breaking ceremony. Children in the Netherlands are actively educated about the flood risk of their environment. (Source: Werry Crone/ Rijkswaterstaat)

Stream daylighting

Stream daylighting involves reconstructing urban waterways to flow more naturally, specifically waterways that have been hardened and covered during development of the surrounding area. Daylighting addresses downstream stormwater flooding by reducing peak volume and speed of runoff. It also addresses upstream stormwater flooding by increasing the amount of water that can be moved through the channel during wet periods.

Scale: Site, Municipal

Cost: $100,000 - $5 Million (variable depending on scale)

Operations and maintenance: Low

Investment type: Public

Federal assistance sources:

- FEMA Hazard Mitigation Grants
- EPA Five Star and Urban Waters Restoration program

Informational resources:

- Naturally Resilient Communities Daylighting Rivers
- American Rivers – Daylighting Rivers Report

Potential benefits of stream daylighting:

- Reduces flooding and downstream erosion by slowing water
- Contributes to groundwater recharge
- Reduces ongoing culvert maintenance and keeps stormwater out of combined sewer systems
- Adds vegetation within floodplains to reduce the urban heat island effect
- Provides wildlife habitat, aesthetic benefits, and recreation space, all of which can raise property values or generate local economic activity

Daylighting of the Westerly Creek in suburban Denver reduced flooding by an average of 44%

Considerations for implementation:

- Engineers should apply daylighting only to areas with enough space to restore stream channels, banks, and buffer areas—a challenge in developed areas
- Local leaders can combine daylighting with larger urban development, which can decrease project costs

Image source: Getty

Case Study: Saw Mill River Project Yonkers, New York

- After years of planning, this project was designed to improve flooding and water quality, and took one year to construct
- The project **cost $19 million**, funded by federal and state agencies, community partners, businesses, and the City
- The stream was daylighted, and its old channel was intentionally left underground to receive overflow during heavy rainstorms
- The project **restored an ecosystem of 14,000 square feet** and created space for events, sparking a downtown revitalization project
- As a result of the project, the city predicts that approximately **950 permanent jobs will be created** within 5 to 10 years
- To be cost effective, smaller communities can combine funding sources to daylight smaller creeks and streams

Over a century ago, to keep up with development and a growing population, leaders started paving over the Saw Mill River—a 23.5 mile tributary, which flows into the Hudson River at Yonkers, New York.

Starting in the 1990s, Yonkers began considering daylighting the Saw Mill River to address pollution and flooding problems. After much planning in collaboration with partners, the City initiated the Saw Mill daylighting project in 2010. Within a year, the project was constructed, with a cost of $19 million, funded through EPA, state-level, and city resources.

To minimize flooding, planners intentionally left the old underground river channel to receive overflow stormwater during heavy rainstorms.

The City approached the project as a way to both reduce flooding and increase economic development, two principles smaller communities and projects can also achieve. The project restored the stream ecosystem and created space for civic and cultural activities and events, all of which have brought more residents downtown.

Stream daylighting of the Saw Mill River in downtown Yonkers, New York. (Source: Getty)

Coastal and shoreline approaches

Coastal and shoreline approaches address flooding typically caused by storm surge and high tides. In inland areas, shoreline approaches can also address flooding from rivers, lakes, or streams. This guide includes several inland case studies but focuses primarily on examples in coastal, tidally influenced areas. Local leaders should consider how to implement multiple coastal and shoreline approaches together and how to incorporate them with other types of approaches (such as land use and policy) as part of an integrated flood resilience plan.

Beach in Naples, Florida. (Source: Getty)

Outfall tide gates

Outfall tide gates (also called floodgates, box gates, or flap gates) are flow-prevention devices installed on stormwater outfalls or buried pipes. They can prevent flooding in two ways: by stopping floodwaters from traveling up those conduits and inundating upland areas during a storm, or by slowing floodwaters in drainage areas and preventing them from inundating smaller watersheds.

Scale: Site

Cost: < $500,000

Operations and maintenance: Medium

Investment type: Public/Private

Federal assistance sources:

- Clean Water State Revolving Fund
- FEMA Hazard Mitigation Grants

Informational resources:

- Tide Gates in the Pacific Northwest: Operation, Types, and Environmental Effects
- Tide Gates: Technical and Ecological Considerations

Potential benefits of outfall tide gates:

- Can regulate the amount of water that infiltrates stormwater systems
- Can be a less expensive alternative to upgrading large portions of underground stormwater systems

As part of its Miami Forever Bond, the City of Miami, Florida, plans to install 400 tidal backflow valves, which allow water to flow out of drainage pipes but stop it from seeping back in

Considerations for implementation:

- To reduce the risk of shifting flooding elsewhere, communities should weigh the effects of outfall tide gates on upland areas
- Engineers and scientists should study and consider how tide gates affect natural ecosystems in the project area
- Communities can use automatic or manual tide gate systems

Image source: Getty

Case Study: Tidal backflow preventers Tybee Island, Georgia

- Heavy rainfall and high tides overwhelm the Tybee Island's stormwater infrastructure
- Up to **60% of the island's stormwater system** experiences saltwater intrusion
- In 2016, the City completed the **first Sea Level Rise Adaptation Plan in the state of Georgia**
- As one component of its adaptation strategy, the City installed large-diameter pipes with tide gates—a multimillion-dollar project—to prevent seawater from flowing into the sewer system

Sitting just east of Savannah, Georgia, Tybee Island is a low-lying barrier island, home to about 3,000 people. Given its location between the Atlantic Ocean and mouth of the Savannah River, Tybee Island faces increasing sea level rise and flooding—it sees flooding about 10 times a year, up from 5 times a year in the 1980s.

During extreme weather, saltwater flows into the City's stormwater drainage system, sometimes spilling onto nearby streets and yards. In 2016, to assess the long-term problem of this flooding, Tybee Island completed Georgia's first Sea Level Rise Adaptation Plan.

Using the data collected for this plan, the City invested in several projects, such as upgrading stormwater pipes and engineering a seawall, as well as installing tidal backflow preventers in places where stormwater discharged during floods. These preventers are successful immediate solutions, but are not designed to withstand sea level rise over the longer term. Still, together with the City's other investments, the preventers address direct flood risks from saltwater overflow and contribute to the City's comprehensive resilience planning.

Tybee Island's stormwater tidal backflow preventers are a key component of the island's strategy to reduce flooding.

Source: Image courtesy of Tybee Island

Deployable flood barriers

Deployable flood barriers are used to reduce flood impacts to an area or to specific structures such as power stations, hospitals, or museums. Traditional deployable barriers rely heavily on human intervention to activate the system, requiring coordination and advance warning. Recently, self closing deployable barriers have been developed as a way to increase reliability and reduce reliance on human intervention during sudden flood events.

Scale: Building, Site

Cost: $100,000 – $500,000 (varies by barrier type and size)

Operations and maintenance: Medium (varies by barrier type)

Investment type: Public/Private

Federal assistance sources:

- FEMA Hazard Mitigation Grants

Informational resources:

- Floodproofing Non-Residential Buildings (FEMA)

Potential benefits of deployable flood barriers:

- Reduce flood impacts by providing a temporary barrier to protect vulnerable buildings or areas
- Provide flexibility in areas where a permanent barrier would disrupt daily activities or operations
- Apply to all types of flooding and can be designed at multiple scales

During Tropical Storm Irene, volunteers took only 30 minutes to deploy steel flood barriers on doors, windows, and walls to successfully protect a historic building in Lincoln, Vermont

Considerations for implementation:

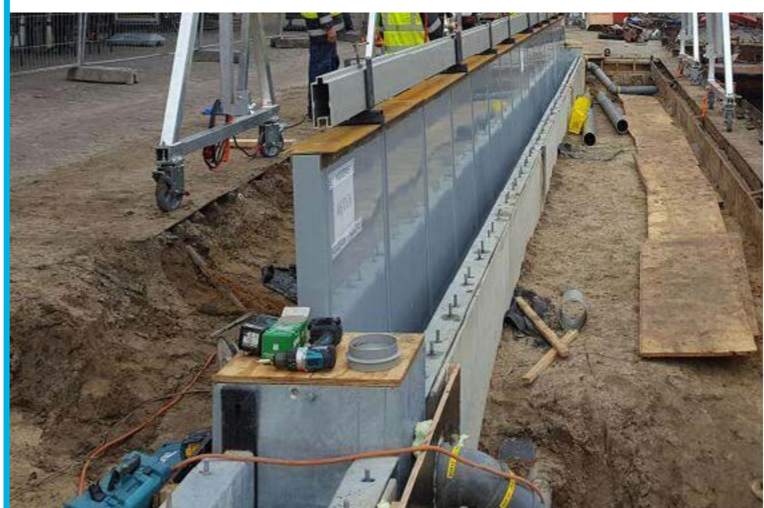
- Traditional deployable flood barriers can be time-consuming to install, requiring setup in advance by a team of people
- To minimize human error during a disaster, emergency teams should identify clear responsibilities for each member of the setup team and practice setting up the barrier ahead of time
- In areas at risk of sudden flash flooding, local leaders should consider investing in self-closing deployable barriers, which require little or no human intervention

Image above: A deployable flood barrier in Spakenburg, Netherlands. (Source: Aggeres, aggeres.com)

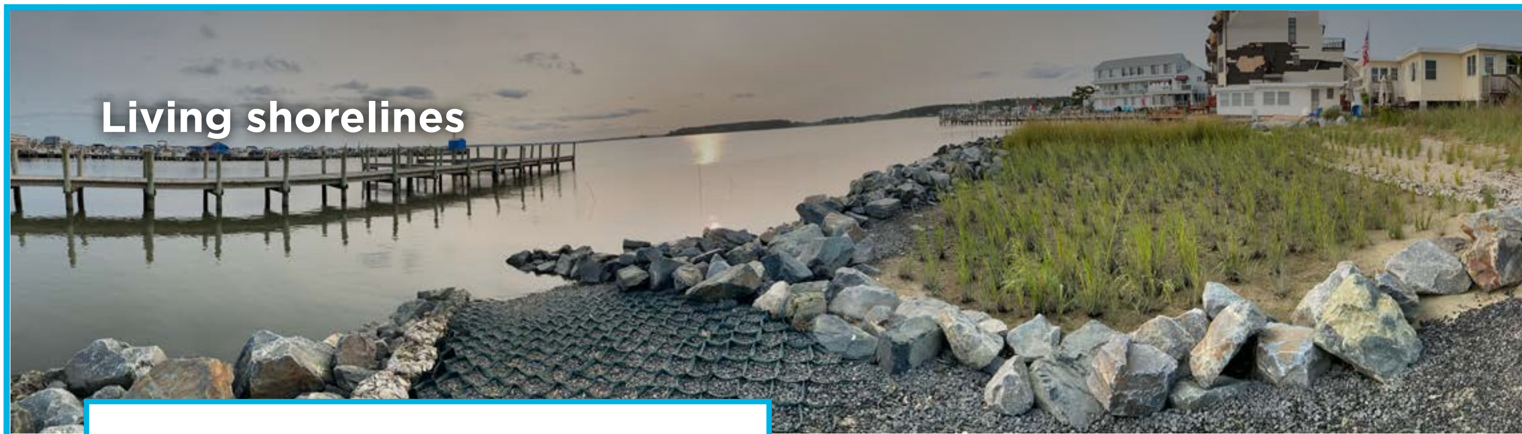
- While most deployable barriers are designed at a smaller scale, the Dutch town of Spakenburg is home to the **world's longest self-closing flood barrier**
- The approximate **construction cost was $8 million**, and the barrier is **nearly 1,000 feet long**
- It is integrated into the pavement of the historic streetscape, and automatically raises to a **height of nearly 3 feet** during a flood

A nearly 1,000-foot long self-closing flood barrier—the longest in the world—was built in 2017 in the historic fishing harbor of Spakenburg, in central Netherlands, a town with a population of 20,000 people.

While traditional deployable flood barriers require warning in advance so that parts can be put in place ahead of a flood event, the self-closing flood barrier in Spakenburg is automatically deployed. Spakenburg's self-closing barrier protects the historic town against flooding and when not deployed, it sits in the ground, flush with the pavement, and is integrated into the streetscape.



Automatic deployment: The barrier was constructed to rise and fall within a vertical sleeve. Pressure generated by rapidly rising floodwaters causes the barrier system to automatically rise. (Sources: Aggeres, aggeres.com, top; Self Closing Flood Barriers, selfclosingfloodbarrier.com, bottom)



Living shorelines

Living shorelines are a group of methods for stabilizing shorelines and mitigating coastal flood risks through the use of living features. They can take many forms, such as vegetated slopes, oyster and mussel habitat, green breakwaters, and ecologically enhanced rock revetments. They are often sited in tidal areas where space is limited.

Scale: Site, Shoreline Segment

Cost: $100,000 – $1 million

Operations and maintenance: Low

Investment type: Public/Private

Federal assistance sources:

- NFWF Emergency Coastal Resilience Fund
- NFWF Coastal Resilience Fund
- NOAA Community-based Restoration Program
- FEMA Hazard Mitigation Grants

Informational resources:

- Naturally Resilient Communities Restoring Coastal Features and Beaches and Dunes
- VIMS Living Shoreline Design Guidance

Potential benefits of living shorelines:

- Stabilize soil and prevent erosion from wind, waves, or stormwater
- More cost effective in some cases than hardened shoreline structures
- Often pursued as a more environmentally friendly and visually pleasing alternative to hardened structures (e.g., bulkheads and seawalls)

Fifty feet of marsh plantings can reduce wave energy by up to 50%

Considerations for implementation:

- Local leaders can combine living shorelines with hard structures
- Living shorelines are less suitable for areas exposed to high boat traffic
- Design, construction, and permitting standards differ by region
- Flood risk benefits vary depending on a living shoreline's design, location, and features
- Methods and standards for including living shorelines in cost-benefit analyses are still emerging

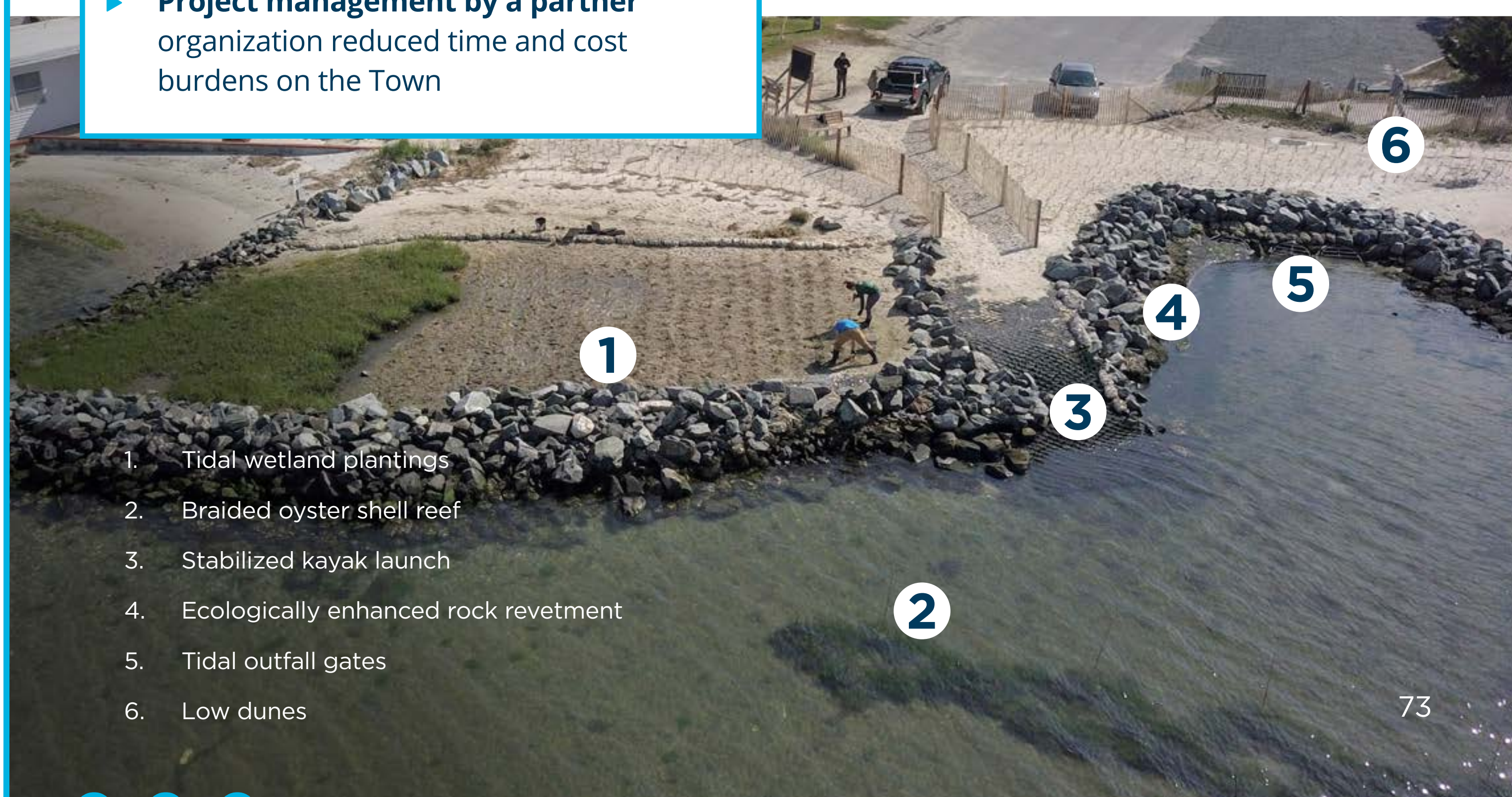
Image above: Living shoreline project in Lewes, Delaware (Source: DECIB)

- The project took **three years to design and construct**, for a total cost of **$215,000**
- The project was funded by a **state grant** to the Delaware Center for Inland Bays, with **cash matches** from DelDOT and Dewey Beach
- The town's **stormwater management plan** led to the integrated design of living shoreline and stormwater management features
- Like many grant-funded projects, a cash match was required, prompting the town to consider a **budget set-aside** to fund future similar projects
- Establishing a **partner agreement** at the outset helped this multi-year project navigate staff turnover
- The **permitting** process drove the schedule and required planning ahead
- **Project management by a partner** organization reduced time and cost burdens on the Town

Sitting nearly at sea level, the Town of Dewey Beach, Delaware, is prone to frequent flooding from stormwater runoff, high tides, and storm surges. To address these issues, the Town recently constructed a project with living shoreline features, including a low dune, ecologically enhanced rock revetment (i.e., rocks of various sizes layered onto a sloped bank), tidal wetland plantings, and an offshore oyster reef. The project also includes stormwater management features, such as new tidal outfall gates to prevent tidal water from flowing into the drainage system.

The project was implemented through a partnership between the Town, the Delaware Center for Inland Bays, the Delaware Department of Transportation (DelDOT), and design and construction consultants. The Town's stormwater management plan, developed with community members and stakeholders, served as a roadmap for the project.

Constructed project during planting. (Source: DECIB)



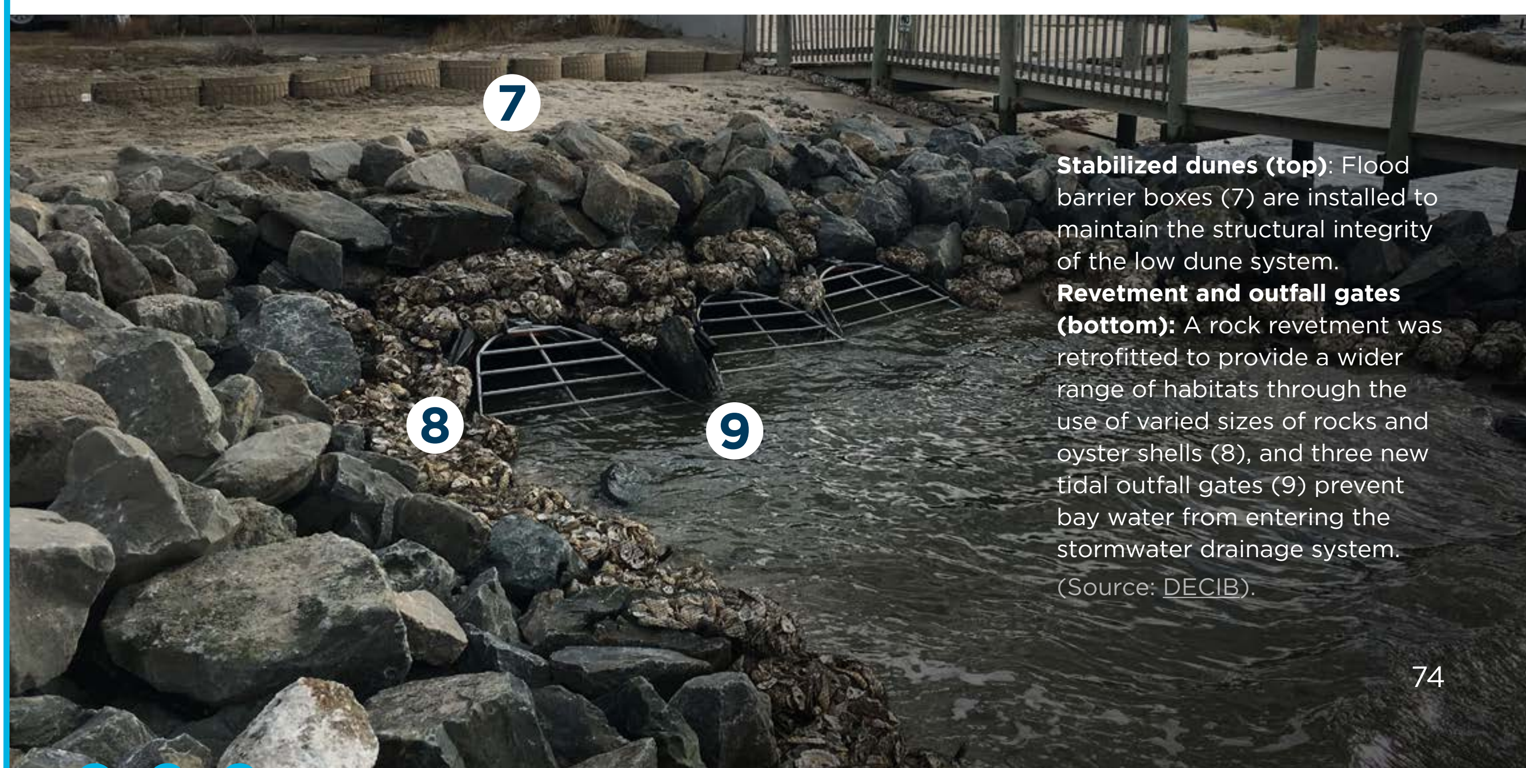
1. Tidal wetland plantings
2. Braided oyster shell reef
3. Stabilized kayak launch
4. Ecologically enhanced rock revetment
5. Tidal outfall gates
6. Low dunes

Analysis conducted for this plan confirmed that Dewey Beach's lowest-lying bayside is the Town's most flood prone area, and that impervious surfaces—which cover up to 80% of land in certain areas and include paved surfaces like asphalt—worsen the problem. These findings showed the need not only for the living shoreline on the bayside of Read Avenue, which is one of the Town's most flood prone areas, but also for upland stormwater retention measures, which would reduce surface runoff flowing to the bayside.

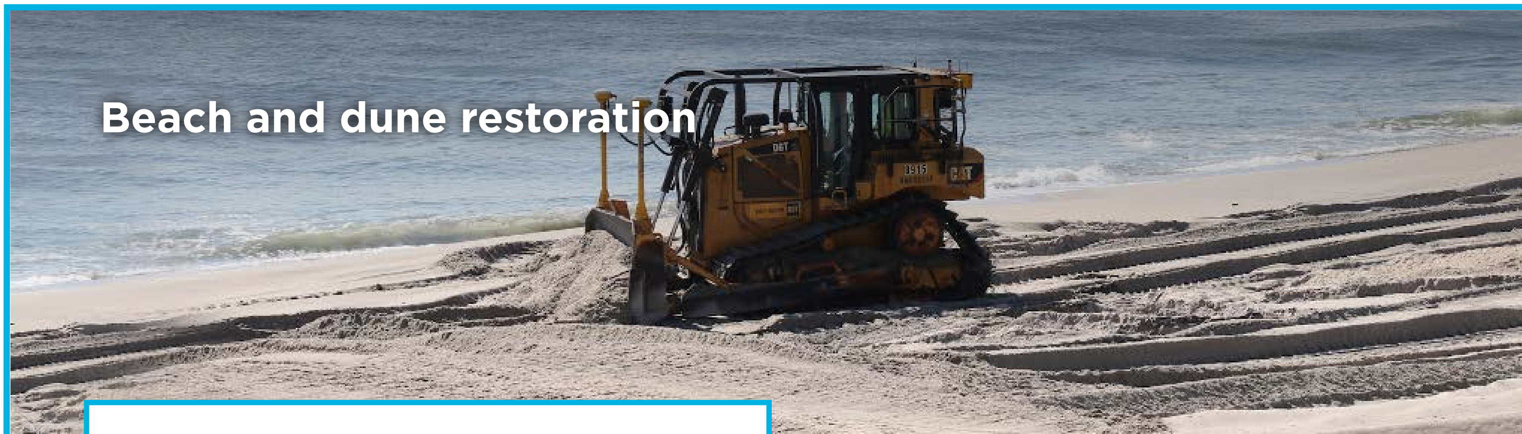
At the start of the project, the Town signed a partner agreement that defined the project's vision and goals, as well as each party's role. The agreement set out the Delaware Center for Inland Bays' responsibility for project management, reducing the burden of work on the Town, which has few paid staff. While each project partner had a different role, everyone was committed to the success of the project, whether that success was measured by watershed restoration, the protection of a major road, or improved quality of life. The partnership model also made the project more affordable for the Town, which paid $35,000 (16%) of the total project cost of $215,000.

The project team met with permitting officials early on in order to minimize project timeline and costs. One best practice for communities considering similar projects, therefore, is to start permit applications as early as possible, ideally as soon as the project vision is defined.

While Dewey Beach's flooding and stormwater challenges will take years to tackle through a larger system of projects, Dr. Marianne Welch, Science and Restoration Coordinator for the Delaware Center for Inland Bays, sees this project an important step forward. Welch explains that the project will reduce chronic flooding, create natural shoreline habitat for fish and wildlife, restore 1,750 square feet of tidal wetlands, and increase water quality. The project also supports recreation through a new kayak launch that pedestrians can access without disturbing the dune and wetland systems.



Stabilized dunes (top): Flood barrier boxes (7) are installed to maintain the structural integrity of the low dune system. **Revetment and outfall gates (bottom):** A rock revetment was retrofitted to provide a wider range of habitats through the use of varied sizes of rocks and oyster shells (8), and three new tidal outfall gates (9) prevent bay water from entering the stormwater drainage system. (Source: DECIB).



Beach and dune restoration

Beaches and dunes reduce impacts from coastal storms and tidal flooding by absorbing wave energy. When properly maintained and protected, these natural flood barriers can reduce impacts to inland areas. In areas with erosion (sand loss from tidal wave action and winds), communities often employ long-term beach nourishment projects, periodically adding sand to beaches and dunes.

Scale: Shoreline Segment

Cost: $100,000 to $5 million per nourishment cycle (variable depending on scale)

Operations and maintenance: Medium to High, depending on erosion rates

Investment type: Public/Private

Federal assistance sources:

- USACE Feasibility Studies
- USACE Regional Sediment Management Program
- USACE Continuing Authorities Program
- FEMA Public Assistance Mitigation Program

Informational resources:

- Naturally Resilient Communities Beaches and Dunes
- Urban Waterfront Adaptive Strategies (NYC Department of City Planning)
- Beach Nourishment: How Beach Nourishment Projects Work (American Shore & Beach Preservation Association)

Potential benefits of beaches and dunes:

- Reduce flood impacts to inland areas by serving as a natural buffer to waves, tides, and storms
- Provide public recreation opportunities
- Serve as habitat for wildlife such as sea turtles and birds

A post-Hurricane Sandy analysis found that beach nourishment projects in New York and New Jersey saved an estimated $1.3 billion in avoided damages

Considerations for implementation:

- Local leaders should develop long-term funding and financing plans for projects that need periodic renourishment
- Since beach and dune projects are dynamic rather than permanent, local leaders should communicate with the public about expected natural sand loss and renourishment needs
- Most beach and dune projects are at least partially funded by local communities, and many rely on state, county, and federal funding
- Larger, wider dunes and beaches typically reduce flood risk more than smaller ones

Image source: USACE

- As it pursued federal funding for long-term beach improvements, the community of South Hutchinson Island spearheaded a **locally-funded beach restoration project**
- The project was initiated in 2013, **costing $12.1 million to add 650,000 cubic yards of sand** to the beach
- A **Special Assessment District was developed** to fund the balance of construction not covered by the county or state
- The project **reduced flood risk to 51 properties**, predominantly high-density condominiums
- The project restored habitat for turtles and shorebirds and included the **planting of 200,000 native dune plants**

As a small barrier island off the coast of St. Lucie, Florida, South Hutchinson Island bears a large brunt of Atlantic hurricanes and tropical storms. No time was that more apparent than in 2004, when back-to-back hurricanes crashed into the island within 21 days.

With its beaches heavily damaged by the storms and a long-term effort to secure federal funding underway, the community of 5,000 people spearheaded a locally funded beach restoration project. In 2013, the island initiated the project, which cost $12.1 million, added 650,000 cubic yards of sand to the beach, and reduced flood risk to 51 properties, mostly high-density condominiums. To offset potential environmental impacts, the project included native dune plants as well the construction of a 2-acre offshore reef, along with 3 years of post-construction monitoring of turtles, shorebirds, and underwater habitats. The cost of the project was divided between the state, county, and the local community. The resulting improvements also offer recreational benefits to the public, as three county-owned parks are within the project area.

Dune grasses used to stabilize beach sand were part of a locally-funded beach and dune restoration project on South Hutchinson Island. (Source: St. Lucie County)

Coastal wetland restoration

Coastal wetlands are naturally occurring ecosystems that when maintained can serve as natural protection from storms. Wetlands can become submerged due to sea level rise. While the natural process is for wetlands to migrate upland, development often prevents this. Communities can take steps to protect and restore wetlands that have been reduced by the impacts of sea level rise and development.

Scale: Site, Shoreline Segment

Cost: $100,000 to $5 million (variable depending on scale)

Operations and maintenance: Low

Investment type: Public/Private

Federal assistance sources:

- Five Star and Urban Waters Restoration Grant Program
- FEMA Hazard Mitigation Grants
- USFWS Coastal program

Informational resources:

- Naturally Resilient Communities – Coastal Marshes
- Naturally Resilient Communities – Restoring Coastal Features
- Urban Waterfront Adaptive Strategies (NYC Department of City Planning)

Potential benefits of coastal wetlands:

- Reduce coastal flooding, erosion, and damage to built areas by reducing the effect of waves
- Provide habitat for wildlife and improve water quality by filtering stormwater runoff
- Create recreational opportunities, such as birdwatching, cycling, kayaking, canoeing, hunting, and fishing

During Hurricane Sandy, coastal wetlands in New Jersey prevented approximately $425 million in private property damage

Considerations for implementation:

- Communities can restore existing, damaged wetlands to protect upland communities from flood risk
- Wetland restoration typically requires sufficient waterway space away from navigational channels
- Local leaders can use regulatory approaches that limit encroachment into wetlands and adjacent buffer areas
- In some cases, sediment diversion or the use of dredged material can be used to augment natural sedimentation processes in wetlands, preventing them from becoming submerged

Image source: Getty

Case Study: Tidal marsh sediment placement pilot project Jekyll Island, Georgia

- The Jekyll Island Authority piloted a method called **thin layer placement,** which places dredged sediment on tidal marshes to raise their elevation and buffer inland areas from flooding
- While thin layer placement has proven effective in other coastal states, this is the first large pilot in Georgia
- The project deepened a channel near Jekyll Creek to 10 feet, **placing 5,000 cubic yards into the nearby marsh**
- The sediment raised the height of the marsh by anywhere **from 2 inches to over a foot**, across five acres of marsh
- Planning began in 2016 and was completed in 2019; the actual **construction took three months**
- The project was funded by the federal government and **cost $6 million**

As a barrier island on Georgia's Atlantic coast, the Jekyll Island shoreline experiences frequent erosion and flooding, which is only expected to worsen with stronger storms and rising sea levels. To prepare for these impacts, as well as preserve recreational, residential, and commercial development, the Jekyll Island Authority oversaw a $6-million, federally funded dredging project.

The project, which was completed over three months in 2019, piloted a method called "thin layer placement." Thin layer placement uses dredged material to bolster and elevate tidal marshes, which serve as a natural barrier against flood impacts.

To do this, workers dredged a channel in Jekyll creek to a depth of 10 feet, placing 5,000 cubic yards of material into a nearby tidal marsh to raise the height of the marsh by anywhere from 2 inches to over a foot, across five acres of marsh. If successful, thin layer placement could be used to reduce flooding in other coastal areas across Georgia.

1. Dredging vessel deposits sediment in the marsh Tidal wetland plantings
2. Five-acre sediment placement area
3. Coconut coir logs contain sediment in the placement area

(Source: USACE)

Case Study: Four Mile Run Park Restoration Project Alexandria, Virginia

- The Four Mile Run project **restored two acres of wetland and over two miles of a stream** within the watershed to reduce flooding
- The two acres of wetland restoration occurred in Four Mile Run Park (seen in the photo below), at a cost of $1.8 million
- The project **integrates pedestrian and recreational use, wetland restoration, and flood risk reduction** into an area where land and space are limited
- A **citizen-led joint task force** examined project alternatives, gathered public input, and provided recommendations
- The project is ongoing, with added recreation and gathering features still in the works

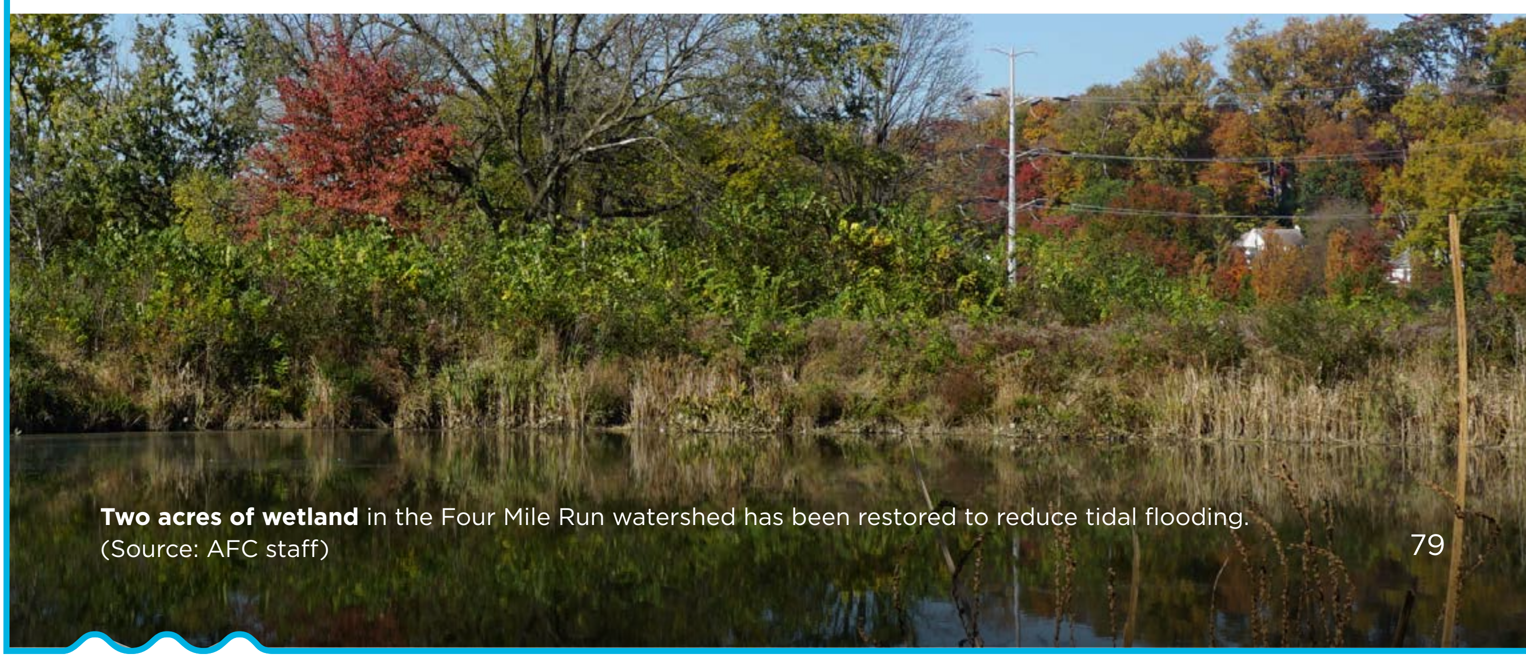
Four Mile Run, a nearly 20 square mile watershed that covers parts of Arlington, Alexandria, and Falls Church, Virginia, has seen increasing floods as a result of growing population over the past few decades.

To address this flooding, the municipalities partnered with the U.S. Army Corps of Engineers (USACE) to build a flood-control channel in the lower part of Four Mile Run. The project was designed to prevent flooding by directing high storm flows into this channel.

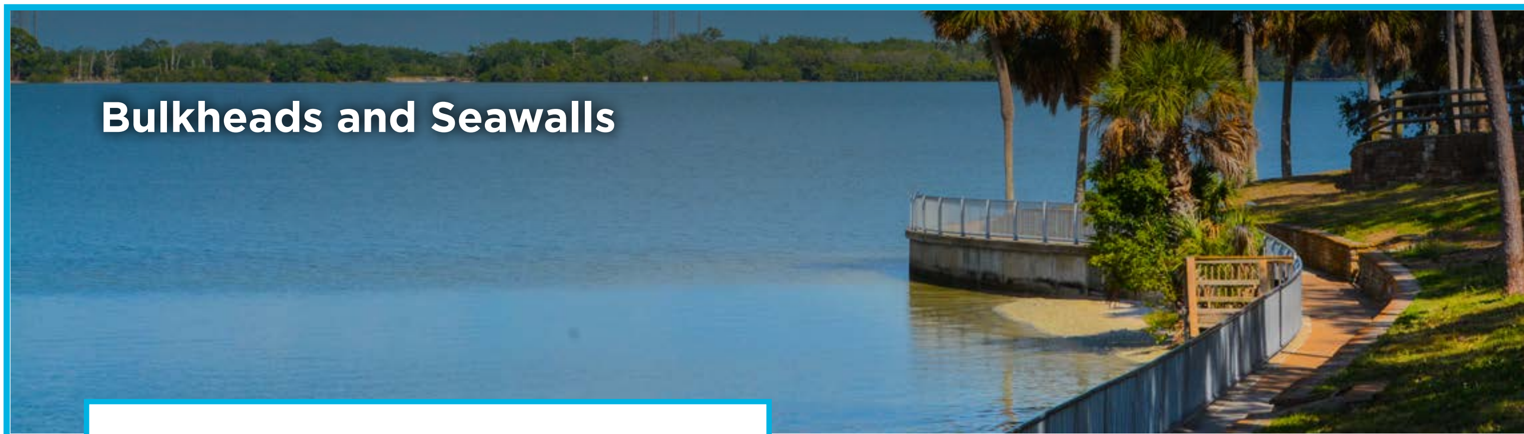
In 2006, officials launched a renewed effort, the Four Mile Run Restoration Master Plan. The Plan would restore the degraded stream in the broader watershed, including two acres of wetlands within Four Mile Run Park in the City of Alexandria, where water levels fluctuate with the daily tidal cycle.

Over the years, as features have been added, the project has reduced flooding, revitalized the community, improved aesthetics, restored ecosystems, and created more recreational opportunities.

The full watershed plan and guidelines were made possible through a collaboration of neighboring municipalities and the regional planning district commission, as well as support from the EPA and USACE. The project also relied heavily on a citizen-led joint task force, which examined project alternatives, gathered public input, and provided recommendations.



Two acres of wetland in the Four Mile Run watershed has been restored to reduce tidal flooding. (Source: AFC staff)



Bulkheads and Seawalls

Bulkheads and seawalls are shoreline structures, typically built in coastal locations where upland development and land uses are highly exposed to storm surge and wave forces. Seawalls are designed to prevent flooding and erosion, and bulkheads are typically designed to improve maritime access for boating or other uses along shorelines where space is limited.

Scale: Site, Shoreline segment

Cost: $100,000 to $5 million (variable depending on scale)

Operations and maintenance: Medium

Investment type: Public/Private

Federal assistance sources:

- FEMA Hazard Mitigation Grants
- FEMA Public Assistance program
- USACE Feasibility Studies
- USACE Continuing Authorities Program

Informational resources:

- Urban Waterfront Adaptive Strategies
- USACE Design Manual for Coastal Revetments, Seawalls and Bulkheads

Image source: Getty

Potential benefits of bulkheads and seawalls:

- Reduce flood impacts while also serving as retaining walls that support boat access, pathways, or roads

Broward County, Florida estimates that currently proposed seawall upgrades could reduce the economic impact of flooding up to 40%

Considerations for implementation:

- Local leaders should consider long-term sea level rise and increased severity of coastal storms when designing, retrofitting, or drafting ordinances for these structures
- Designs must be uniform across adjacent seawalls to reduce "weak links" in the system
- In communities where seawalls are built on private property, local leaders should pay special attention to engaging local residents when considering updates to ordinances or standards
- Seawalls typically have lifespans of 30-50 years and structural limitations on how much height can be added to the original wall

Case Study: Seawall Ordinance Fort Lauderdale and Broward County, Florida

- After record seasonal tides, the City of Fort Lauderdale began the process of developing an ordinance requiring private property owners to elevate their seawalls
- The City passed an ordinance in 2016 increasing the required minimum seawall height to 3.9 feet NAVD88[1]
- In Fort Lauderdale, new seawall construction **can cost between $650 - $2,000 per square foot**, putting a large cost burden on private property owners that must comply with new elevation requirements
- In 2020, Broward County, which comprises Fort Lauderdale, passed an ordinance that sets a minimum elevation for all seawalls at 5 feet NAVD88
- Fort Lauderdale has since passed an amendment to meet the County standards
- Updating seawall ordinances is **a complicated but essential step to adaptation**

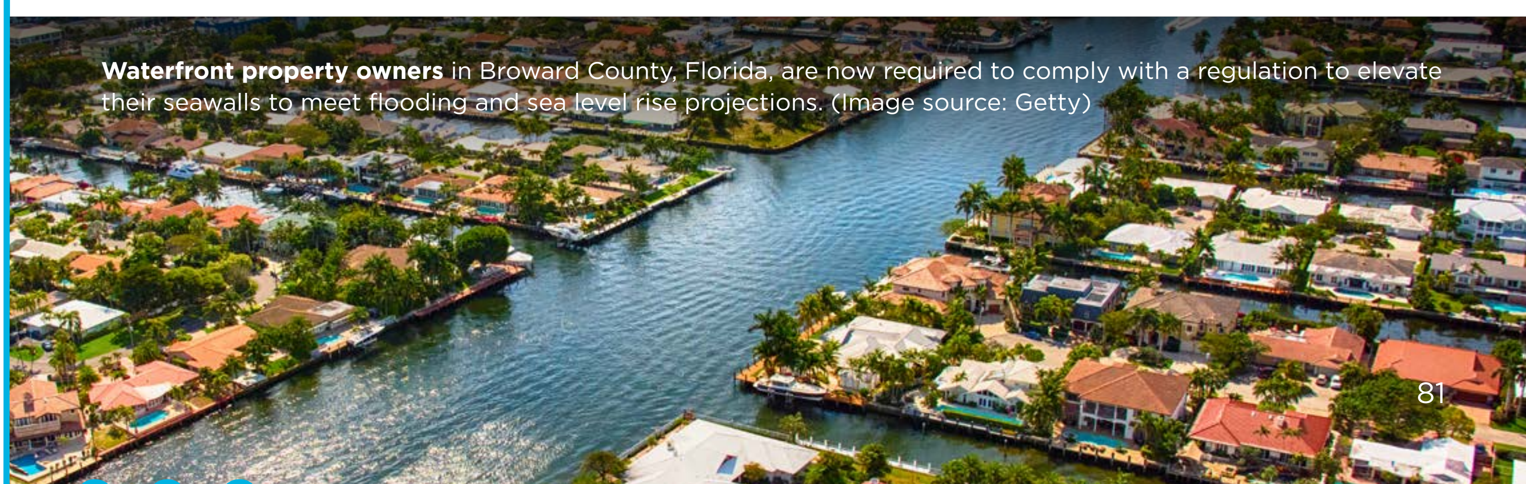
[1] The North American Vertical Datum (NAVD) of 1988 is a datum surveyors, engineers, and architects should use when measuring or designing a building or seawall.

Fort Lauderdale, Florida, has seven miles of shoreline and 300 miles of canal coastline. Combined with its flat, low-lying topography and porous limestone aquifer, the City is extremely vulnerable to major flood events.

In 2015, Fort Lauderdale saw unprecedented flooding from seasonal King tides that were 18 inches above average tide. Rising sea levels, onshore wind, and intense rainfall exacerbated the problem, especially in low-lying coastal areas.

In response, the City adopted a new seawall ordinance in 2016, making the old maximum seawall height of 3.9 feet NAVD the new required minimum height. In early 2020, Broward County, which comprises Fort Lauderdale, passed an ordinance aimed to prepare properties for flooding until 2070 that sets the minimum seawall height at 5 feet NAVD88. In 2020, Fort Lauderdale passed an amendment to adopt the standards and requirements of the County ordinance.

The resulting ordinances for both the County and City also include provisions encouraging property owners to consider the incorporation of living shoreline features and other elements to enhance the biological value of a traditional seawall.



Waterfront property owners in Broward County, Florida, are now required to comply with a regulation to elevate their seawalls to meet flooding and sea level rise projections. (Image source: Getty)

Case Study: Seawall Redesign and Reconstruction Weymouth, Massachusetts

- The Town of Weymouth is raising its Fort Point Road seawall 1.5–2 feet
- The preliminary seawall design was funded by a **$130,000 grant** from the Massachusetts Municipal Vulnerability Preparedness program
- The Town is pursuing additional state funding for final design and eventual construction
- The seawall is **55 to 87 years old; the new infrastructure would last 50 years**, with additional height increases possible
- In addition to raising its height, Weymouth would **redesign and reconstruct the seawall's drainage**
- Weymouth gathered community feedback on viewsheds and beach access, and worked with stakeholders to acquire necessary property easements

In 2018, the Town of Weymouth, Massachusetts was awarded a $130,000 Municipal Vulnerability Preparedness Action Grant to address flooding on Fort Point Road. With the funds, the Town came up with a design approach that considers sea level rise and increased frequency and severity of coastal storms. The solution includes reconstructing the existing Fort Point Road seawall as a concrete-encased sheet pile wall and raising it 1.5–2 feet higher than its current elevation. This includes driving sheet pile to 12 feet below sea level, enhancing structural strength, reducing water seepage, and minimizing loss of backfill in the rocks that support the wall.

The second part of the solution would redesign and reconstruct the drainage area around the seawall to be a continuous system—rather than a patchwork of independent structures—that rapidly drains floodwaters after a storm. The Town hosted a public forum to present this solution and get public feedback, specifically on the impacts of a higher seawall system on viewsheds and beach access. The Town designed the new seawall, which is expected to last 50 years, with the projected sea level rise of 2070 in mind, while also providing for additional height increase in the future.

A proposed increase in the height of the Fort Point Road seawall (right) up to 2 feet above its current height (left) is being explored as a way to reduce flood risk in Weymouth. (Source: © Tighe & Bond)

Floodwalls and berms

Floodwalls and berms are permanent vertical infrastructure elements that provide continuous lines of protection against coastal and riverine flooding for upland areas. Floodwalls are walls designed to hold back floodwaters. Berms are earthen mounds designed to do the same—they are similar to levees but smaller in size.

Scale: Site, Shoreline segment

Cost: < $5 million
(variable depending on scale)

Operations and Maintenance: Medium

Investment Type: Public/Private

Federal Assistance Sources:

- HUD Community Development Block Grant (CDBG) Program
- FEMA Hazard Mitigation Grants

Informational Resources:

- FEMA Selecting Appropriate Mitigation Measures for Floodprone Structures
- New York Urban Waterfront Adaptive Strategies

Potential benefits of floodwalls and berms:

- Protect against flooding for upland communities and properties
- Reduce flood risk in riverine and coastal environments
- Deliver recreation opportunities and vegetation growth

The Town of Haverhill, Massachusetts, built a 1,200-foot boardwalk along the 30-feet tall, 2,250-foot long flood wall that borders the Merrimack River

Considerations for implementation:

- Floodwalls and berms are most applicable for areas with existing structures and infrastructure vulnerable to flooding, in areas with low to moderate exposure to waves
- Berms require substantial land to allow for adequate slopes
- This approach must provide a closed system so water cannot “go around” the structures to the areas it is meant to protect
- When installing floodwalls and berms, engineers should use hydrologic modeling to ensure this approach will not worsen the problem of flooding elsewhere

Image source: Getty

Case Study: Residential shoreline berms Woodbury, Minnesota

- Responding to frequent and localized flood impacts along Battle Creek Lake, the City of Woodbury relocated two homes and constructed a **berm system to reduce flood impacts** to another home
- The project was completed in 2003, costing $134,230. That cost included the construction of an earthen berm, a water collection manhole, and a pumping station
- Student volunteers planted prairie seedlings, while project staff installed **flood-tolerant plants to stabilize the berm** and provide wildlife habitat
- The lift station was installed to pump water that collects behind the berm into the lake

With trails, playgrounds, and picnic tables, Battle Creek Lake serves as one of the main points of interest within Minnesota's Ramsey County. After a long history of flood impacts to communities near the lake, the City of Battle Creek, along with the Ramsey Washington Metro Watershed District (RWMWD), constructed a berm system.

The City and RWMWD completed the Battle Creek Lake Berm project in 2003. Using a localized flood risk reduction strategy, the City and RWMWD relocated two homes and constructed an earthen berm to increase the height of the low-lying lakeside edge of a third home. If floodwaters overflow the berm, the water is collected by the manhole and pumped back to the lake.

The project also engaged the community, relying on student volunteers to plant prairie seedlings and working with District members to install a variety of plants that are tolerant of fluctuating water levels.

A newly constructed earthen berm along the Battle Creek Lake shoreline. (Source: RWMWD)

Case Study: Roanoke River floodwalls and berms Roanoke, Virginia

- As early as 1970, flood risk reduction projects were on the minds of Roanoke city planners—after the devastating 1985 flood, planning intensified, leading to the **construction of a large flood reduction project** in the 1990s
- The Roanoke River flood reduction project was designed to protect the community from a storm that amounts to **3 to 4 inches of rainfall in a single day**
- The 10 miles of floodwalls, channel widening, and berms are designed to **protect against peak water levels of up to 16 feet**

The Roanoke River weaves through the outskirts of downtown Roanoke, Virginia, providing a scenic waterway, as well as a flood-prone liability. In 1985, nearly 7 inches of rain fell on Roanoke in a single day, surging the river over 23 feet (13 feet above flood stage). The ensuing flood caused the deaths of 10 people along with $200 million in damages.

Since that devastating flood, the City of Roanoke has implemented various flood risk reduction measures, including the construction of floodwalls and berms. In 2012, the City marked the end of a multi-decade, $72 million flood risk reduction effort. The project included widening channels and building sections of floodwalls along the Roanoke River, and 66% of the effort was funded by the U.S. Army Corps of Engineers.

Since then, three major downpours have tested the project: In 2013 and 2015, river water levels peaked at over 14 feet; In 2018, river water levels peaked at over 16 feet. In all three cases, the wall successfully held the water.

For communities with limited resources, these types of flood risk reduction projects can be done on a smaller scale, over time, and in collaboration with other municipalities and partners.

Floodwalls and berms border 10 miles of the Roanoke River near Roanoke, Virginia. (Source: Patriarca12, CC BY-SA 3.0)

Flood-ready critical facilities

Flood-ready critical facilities are created through a wide range of actions to reduce flood risk for facilities that are essential to community health and safety. Examples include constructing floodwalls, berms, waterproof doors, and waterproof windows; raising roadways and equipment above flood levels; and installing pumps, waterproof equipment, and backup power generators. In many cases, multiple actions are combined to provide a comprehensive solution.

Scale: Building, Site

Cost: Variable depending on approach

Operations and maintenance: Variable

Investment type: Public/Private

Federal assistance sources:

- HUD CDBG-MIT program
- FEMA Hazard Mitigation Grants

Informational resources:

- FEMA Design Guide for Improving Critical Facility Safety from Flooding and High Winds
- ASCE 24 Flood Resistant Design and Construction
- ASCE 7 Minimum Design Loads and Associated Criteria for Buildings and Other Structures

Potential benefits of flood-ready critical facilities:

- Reduce the consequence of or damage caused by inundation
- Reduce risk from all types of flooding
- Protect facilities and infrastructure that are essential to community health and safety

The Spaulding Rehabilitation Center, a critical hospital facility, is the first waterfront building in Boston designed to withstand a 500-year flood

Considerations for implementation:

- Local leaders can combine multiple techniques to provide a comprehensive solution
- The nature and cost of this approach varies depending on the facility and type of flooding expected
- High costs are appropriate when inaction will result in costly flood damages
- Some communities may prefer passive flood risk reduction measures that do not require human or mechanical intervention to activate

Image source: Getty

Case Study: Flood-ready wastewater treatment plant St. Augustine, Florida

- St. Augustine is America's oldest city, with aging infrastructure that can complicate efforts to reduce flooding
- 90% of St. Augustine residents live in a flood plain
- The City's wastewater treatment plant, which serves the entire City and more, lies **only a few feet above sea level**
- The first popular proposal was a seawall around the plant, costing the City between $3.7 million and $5.3 million
- Eventually, the City landed on portable flood barriers, at the **total cost of $140,000**

The City of St. Augustine enjoys the natural beauty of the Atlantic Ocean. But with that natural beauty comes natural flood hazards: 90% of St. Augustine residents live in a floodplain.

To reduce damages from floods—caused by more frequent hurricanes, heavy rainfall, and tidal surges—the City has taken steps to protect some of its most critical facilities, including its wastewater treatment plant.

For years, the City had been wrestling with several ideas to protect its wastewater treatment plant, which is only a few feet above mean sea level. After flood impacts from 2016's Hurricane Matthew and 2017's Hurricane Irma, however, the City sped up its plans. It eventually landed on mobile sea barriers.

The portable, watertight barriers can be quickly installed ahead of a storm and can protect against a Category 3 Hurricane. "All 45 panels take just half a day and two people to set up," said Stephen Curmode, the facility director of the wastewater treatment plant. Just as importantly, the solution cost the City only $140,000, by far the lowest price tag among alternative solutions the City had been considering.

St. Augustine's wastewater treatment plant employs portable watertight barriers to protect the critical infrastructure facility from flood damage. (Source: City of St. Augustine)

Glossary of definitions

Annual probability – The probability of a flood event occurring in any year. The probability is expressed as a percentage. For example, a large flood which may be calculated to have a 1% chance to occur in any one year, is described as 1% annual chance or commonly the 100-year flood event. A 1% annual chance of flooding today translates to a roughly 25% or 1 in 4 chance of flooding over the course of a 30-year home mortgage.

ASCE – American Society of Civil Engineers.

Base Flood Elevation (BFE) – BFE refers to the elevation that water is expected to rise, including surge and wave effects, during a 100-year flood event (1% annual chance). The Base Flood Elevation is determined by FEMA by modelling surge coupled with different historical levels of tides and wave action. Because the BFE includes wave action and surge, it is higher than the average high tides.

Building codes – a regulatory tool that ensures structures are constructed to minimize risks to life-safety both under normal conditions and in the event of natural disasters.

Coastal Barrier Resources Act (COBRA) – passed by Congress in 1982 to encourage conservation of hurricane-prone, biologically rich coastal barriers. CBRA prohibits most new federal expenditures that encourage development or modification of coastal barriers.

Co-benefits – additional community benefits, such as recreation, ecological restoration, improvement to the aesthetic quality of the community, public education, among others, that extend beyond the core flood risk reduction function of an investment.

Community Rating System (CRS) – a program that enables communities to reduce federal flood insurance premiums for policyholders by undertaking certain floodplain management activities beyond the minimum requirements of the National Flood Insurance Program (NFIP), such as public education, adopting higher regulatory standards, or providing technical or financial assistance for flood mitigation projects.

Consequences – impacts of flooding, such as property damage or regional economic loss.

Deployable Flood Protection – flood protection measures or systems that require human intervention to install prior to a flood event. Deployable flood barriers are intended to stay in place for the duration of a flood event and be removed during dry weather. Certain types of deployable barriers require the installation of permanent fixtures.

Design Flood Elevation (DFE) – DFE refers to the regulatory elevation that new, substantially improved, or substantially-damaged structures must be built to, according to building code. The DFE includes the Base Flood Elevation as well as freeboard (see definition below).

FEMA – Federal Emergency Management Agency, primarily responsible for disaster response and recovery following a federally declared state of emergency.

Flood risk – calculated by multiplying the probability that a flood event will happen by the consequences of that event.

Flood Insurance Rate Maps (FIRM) – the official flood map of a community on which FEMA has delineated both the special hazard areas and the risk premium zones applicable to the community.

Flood Insurance Study (FIS) – identifies flood risk for watercourses, lakes, and coastal flood hazards within a community. The FIS provides important flood source information, such as flood elevation data from flood profiles, streambed elevations, flood discharges, and wave information for coastal zones.

Freeboard – factor of safety above a flood level used in floodplain management. Usually expressed in feet, freeboard accounts for unknown factors that could raise flood heights above the calculated base flood elevation.

HUD – Department of Housing and Urban Development, responsible for providing housing and community development assistance, including assistance to flood-impacted communities.

Local Floodplain Administrator – the work of a local floodplain administrator consists of determining what flood maps and data are available, determining whether all flood maps are up to date, and dictating what local restrictions could impact flood mitigation.

Low Impact Development – systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration, or reuse of rainfall to reduce stormwater runoff, protect water quality, and enhance habitat.

National Flood Insurance Program (NFIP) – provides flood insurance to property owners, renters and businesses and encourages communities to adopt and enforce floodplain management regulations.

Nonstructural flood risk management – approaches that reduce damage without influencing or obstructing the natural direction and flow of flood waters, including planning and regulatory approaches, property acquisition, and community awareness programs.

North American Vertical Datum of 1988 (NAVD88) – provides for a consistent comparison of elevations when measuring items such as ground, building, and flood elevations, as well as sea levels. In technical terms, it is the vertical control datum of orthometric height established for vertical control surveying in the United States of America based upon the General Adjustment of the North American Datum of 1988.

Passive flood protection – flood protection measures or systems not requiring human intervention; for example, a permanent flood wall or emergency generator elevated on a pedestal.

Perigean high tides (King tides) – higher than normal astronomical tidal events which typically occur between 6-8 times each year when the moon is closest to the Earth.

Sea Level Rise (SLR) – an increase in the level of the world's oceans.

Special Flood Hazard Area (SFHA) – the area with a 1% annual chance of flooding modeled based on historic flood events.

Stillwater flooding – coastal flooding that does not include wave action.

Substantially improved – any reconstruction, rehabilitation, addition or other improvement to a structure, the total cost of which equals or exceeds 50 percent of the market value of the structure before the start of construction of the improvement.

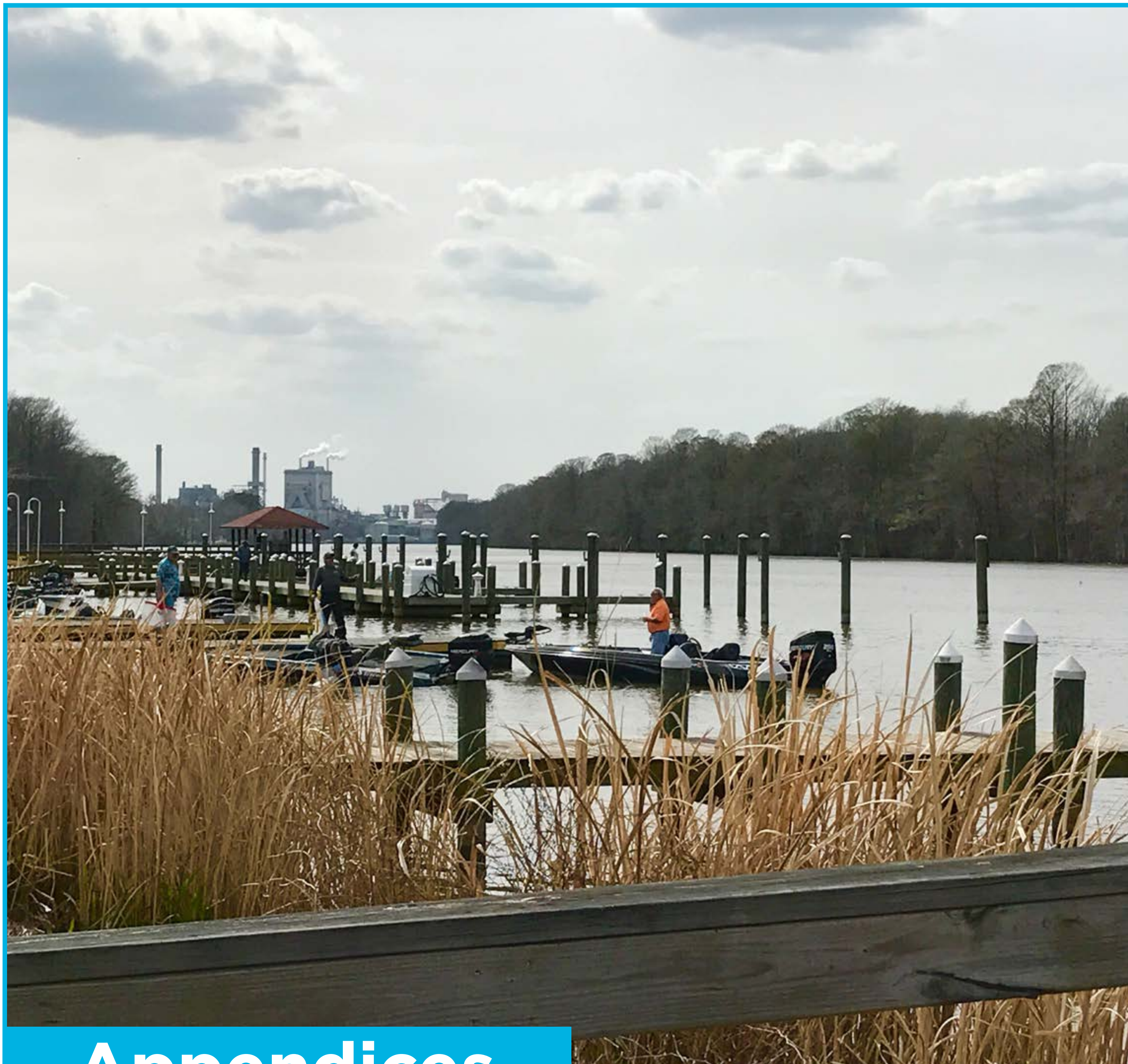
Substantially damaged – means damage of any origin sustained by a structure whereby the cost of restoring the structure to its before damaged condition would equal or exceed 50 percent of the market value of the structure before the damage occurred.

Structural flood risk management – flood risk mitigation approaches that reduce damage through engineered methods, such as through flood walls, storm drains, and sewers, that alter the natural flow of flood water.

USACE – U.S. Army Corps of Engineers, responsible for water resource management and development activities, including those focused on reducing flood and storm damage.

Water Environment Federation – a nonprofit association that provides technical education and training for thousands of water quality professionals.

Watershed – a land area that channels rainfall and snowmelt through water bodies to an outflow point, such as a reservoir, lake, ocean, or bay.



Appendices

These Appendices provide an opportunity for readers to delve more deeply into the concepts and approaches within this guide. What does the term "100-year floodplain" mean? Are there helpful resources that designers, planners, or technical experts such as engineers can use when planning for flood resilience and adaptation? These are some examples of the questions that are addressed in this section.

Image source: Indy beetle, CC0 1.0, Plymouth, North Carolina

APPENDIX A: Floodplains and levels of risk

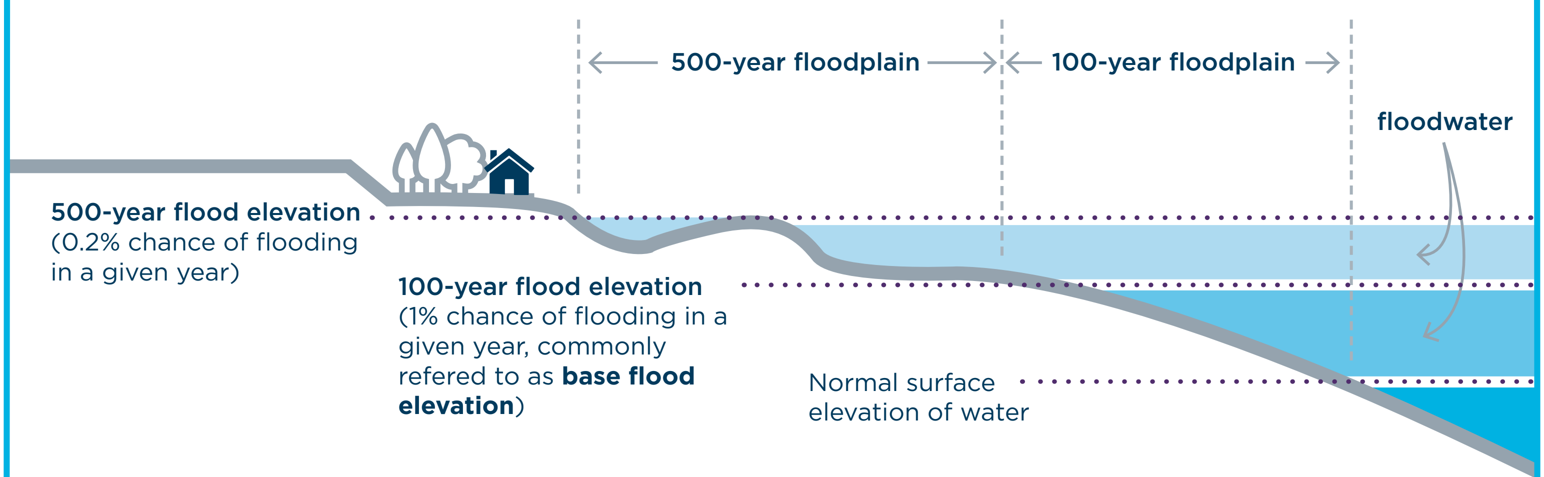
Why are floodplains and levels of flood risk important? These terms and concepts are used across the country, with direct impacts on local residents. For instance, a home's level of flood risk can determine whether or not flood insurance is mandatory for the mortgage holder. By understanding and communicating clearly about floodplains and levels of flood risk, local leaders can work with community members to build resilience.

How are floodplains and levels of risk defined? Regulatory floodplains are defined by the Federal Emergency Management Agency (FEMA) as any land area that is prone to being covered by floodwaters from any source. Within a floodplain, there are many different levels of flood risk. Two major levels are often used for local regulations: the 100-year and 500-year flood. FEMA Flood Insurance Rate Maps (FIRMS), Flood Insurance Studies (FISs), and other locally available flood hazard models or stormwater master plans often identify levels of flood risk in a community.

FEMA regulations also allow communities to identify future floodplains to account for changing conditions. In addition, local communities can identify and map floodplains in areas not identified by FEMA.

A **100-year flood** is a large flood that has a 1 in 100, or 1% chance of happening in a given year, and a **26% chance of flooding at least once over the life of a 30-year mortgage**. The area that its floodwaters may cover is the 100-year floodplain (also referred to in FIRMs as the Special Flood Hazard Area); and the height that its floodwaters may reach is the 100-year flood elevation (also commonly referred to as the base flood elevation).

A **500-year flood** is an even larger flood, but expected to happen less frequently than a 100-year flood. A 500-year flood has a 1 in 500, or 0.2% chance of happening in a given year, and a **6% chance of flooding at least once over the life of a 30-year mortgage**. The area that its floodwaters may cover is the 500-year floodplain, and the height that its waters may reach is the 500-year flood elevation.



The 100-year and 500-year floodplain (diagram adapted from the Greater Houston Mitigation Consortium)

APPENDIX B:
Historic flood assessments

Why conduct a historic flood assessment? By understanding historic flooding, local leaders can inform future planning. Past flood impacts can also be used to justify public investment in projects to reduce flooding. While rain, rivers, or the ocean are all common sources of flooding, poor performance of stormwater and drainage systems can also cause flooding – and flooding may occur both within and outside of designated floodplains. A comprehensive assessment of these past patterns can prepare communities for future risks.

What are the limitations? Future flooding will never look exactly like past flooding, and in many communities across the U.S., shifting weather patterns and environmental changes are expected to lead to rising sea levels, more frequent and intense storms, and more extreme rainfall over the rest of this century, meaning that future flood losses are likely to exceed those of **the past.**

How can historic data be sourced? Qualitative information about past flooding can be documented through interviews or documentary research into historic images and newspaper reports. Quantitative data is also often available and can provide a more robust foundation for decision-making.

Is there publicly available historic data? FEMA makes a range of information available, including data on all claims filed through the National Flood Insurance Program dating back to 1978 with details such as state, census tract, zip code, year of loss, and amount paid on claims. Similarly, communities may access data and guidance on Repetitive Loss and Severe Repetitive Loss Properties by contacting their local and State Floodplain Manager's office.

EXAMPLE QUESTIONS TO ASSESSING HISTORIC FLOOD LOSSES

- When was the flood event and where did it occur?
- What was the source of flooding (e.g., ocean, river, rain, or drainage or stormwater systems)?
- How deep were the flood waters across the area of impact?
- How long did the flooding last?
- How many properties, facilities, and assets were impacted and what were the consequences?
- Is there available data on federal insurance claims and/or federal aid supplied as a result of the flood?
- What type of mitigation actions were taken as a result of the flood, and where?

APPENDIX C:
Local conditions

Why are local conditions important? Understanding flood risk requires having a detailed understanding of the community's physical, social, and economic composition.

How can local conditions data be sourced? Many communities maintain local conditions datasets for general planning purposes, but these may be held in different departments or agencies of the local and state government or be referenced in plans and reports that are not readily accessible. Communities that do not have data may look to state and federal data sources such as the U.S. Census Bureau for available datasets. Datasets from external sources should be validated and updated as appropriate to ensure they capture local realities.

Which planning documents reference local conditions? Some communities may have existing documents, such as a Vulnerability Assessment, Comprehensive Plan, Watershed Management Plan, Hazard Mitigation Plan, or Stormwater Master Plan, that can provide helpful information. Such plans should be reviewed for relevant information and opportunities for alignment with flood resilience investments.

LOCAL CONDITIONS DATA USEFUL FOR ASSESSING FLOOD RISK

- **Public infrastructure** including critical facilities and those providing for life safety
- **Transportation infrastructure** such as roads, railways, bridges, tunnels
- **Building location and types** such as single or multi-family, attached or detached
- **Land elevation** such as Lidar maps
- **Land use** such as residential, commercial, industrial, agricultural, open space
- **Demographics** such as population count, density, age, race, language, income
- **Environmentally sensitive areas** such as wetlands, aquifers, habitat, remediation sites
- **Open space** such as parks, conversation lands, greenways
- **Water bodies** such as rivers, streams, lakes, ponds, bays, ocean
- **Stormwater infrastructure** such as sewer, drainage, and stormwater management systems including green infrastructure and flood risk management assets

APPENDIX D: Modeled flood hazard data

Why are modeled flood hazard data important? Future flooding may not look like past flooding in many areas, due to environmental and land use changes, and changing weather patterns.

What types of flood hazards can be modeled? Riverine flooding, coastal flooding, and surface runoff or ponding from stormwater can be included in flood hazard models.

How can communities create modeled flood hazard data? Communities or groups of communities can create their own datasets, such as modeled stormwater master plans and future flood hazards that incorporate projected sea level rise or increases in precipitation frequency and intensity. These datasets can be relied upon if they are transparent in their assumptions, applications, and limitations; technically credible; and perceived as legitimate by stakeholders.

How can communities access modeled flood hazard data from FEMA? FEMA Flood Insurance Rate Maps (FIRMs) are a common source of flood hazard data. FIRMs illustrate the areas of a community in the Special Flood Hazard Area and may delineate other flood zones depending on the year of release and information available. While these maps are a vital resource for regulatory decision making and risk quantification, they are not available in all communities and also have some limitations, which are listed on the following page.

Visualizing local conditions and modeled flood data

- The City of Coral Gables, Florida developed a detailed Lidar map of the community, using color coding to rank critical infrastructure from lowest to highest elevations. These visual representations were useful for engaging the community in resilience planning.
- NOAA's Sea Level Rise Viewer, Flood Factor, and Surging Seas are web-based resources that communities can use to visualize potential current and future flood risk. These should be used to complement, but not replace, FEMA FIRMs in locations where these are available, or other modeled flood hazard data such as best available locally-developed datasets.

LIMITATIONS OF FEMA FLOOD INSURANCE RATE MAPS

In many locations, available FIRMs are outdated due to changes in land-use, man-made and natural changes to the landscape, sea level rise, subsidence, and evolutions in our understanding of flood hazards since the maps were created.

FIRMs present a binary view of flooding, where a given property is either designated as inside our outside of a flood zone. In reality, flooding often occurs in areas outside of FEMA-identified floodplains, from sources such as smaller streams and/or inadequate stormwater management systems. In fact, a FEMA Fact Sheet states that "anywhere it can rain, it can flood." FEMA is in the process of developing new products that will enhance the assessment of flood risk in FEMA-identified floodplains.

FIRMS may not accurately show all areas where future flooding could occur. Instead, these maps indicate areas where flooding has occurred in the past. This is because most FIRMs, even those created in recent years, use flood hazard models that are based on historic flood events and do not account for changing conditions such as sea level rise.

APPENDIX E: Performance and evaluation criteria

Why and how should performance and evaluation criteria be used? These criteria can help communities decide among a range of alternative potential plans for reducing flood risk. They can help to define the expected results of each approach, in order to narrow down the set of approaches that would be most likely to meet the community's needs. When applying performance and evaluation criteria, local leaders should consider the specific context of the community's needs and goals.

EXAMPLE CRITERIA FOR EVALUATING ALTERNATIVE PLANS

- Effectiveness in reducing flood risk (including risk from storms of varying magnitudes)
- A specified maximum down-time (period of inoperability) for a facility or system
- Continued accessibility and utility services to a site or facility during a flood
- The ability of residents to return home from evacuation soon after a flood
- The ability of a flood risk reduction system to operate passively, without manual action to activate it
- Construction, lifecycle, operation and maintenance costs and requirements
- Implementation timeline
- Potential and secured funding sources and support from authorities and stakeholders whose approval is needed

APPENDIX F: Consequences and critical infrastructure

EXAMPLE FLOOD CONSEQUENCES

After a flood, it may be helpful to measure the consequences in order to inform future investments in enhancing flood resilience. Some examples of flood consequences include

- Damage to property and injuries or loss of life
- Environmental damage or contamination
- Disruption of public services, emergency response and evacuation costs
- Lost wages or revenue and local or regional economic disruption

EXAMPLE CRITICAL INFRASTRUCTURE STANDARDS

Critical infrastructure and facilities are important components of any resilience strategy. Standards can be helpful for categorizing different types of these assets in order to prioritize flood resilience actions. Example standards include:

- The ASCE Standard 24 on Flood Resistant Design and Construction is often used to assign levels of criticality to facilities. State building codes will often translate these standards into risk classes based on importance to community life and safety, with the most critical facilities, such as hospitals, emergency response facilities, and evacuation routes, ranking highest.
- Local or state code often include specific standards that need to be met for the most critical facilities
- Critical infrastructure can also be classified based on locally-driven values and needs

APPENDIX G: Considerations for all flood resilience approaches

The following questions can help local leaders develop and evaluate all types of flood resilience approaches:

- Do the approaches reflect the vision and goals of a wide range of stakeholders?
- Can civic, academic, or governmental partners provide resources or technical assistance to advance the effort?
- Can the approaches be easily adapted if conditions change?
- How can approaches be planned and designed to work together over time?
- Can acting today negate the need for more significant action in the future?
- Are critical facilities located in the floodplain, and do the approaches consider these?

APPENDIX H: Considerations for land use and policy approaches

The following questions can help local leaders develop and evaluate different land use and policy approaches:

- Are there areas of the community that have flooded repeatedly in the past? If so, how many times and at what cost?
- What, if any, existing municipal codes or regulations restrict or place special conditions on development in the floodplain?
- Does the community have awareness and engagement programs about flood risk?
- Are resources or funding available to support approaches such as property acquisition or zoning code amendments?
- What community plans or policies, such as a comprehensive plan, already address flooding? Could these be improved to align more closely with the community's goals for long-term resiliency?

Identifying partnering opportunities to align with community vision and goals

When their coastal community was heavily impacted by Hurricane Sandy, community members from the Shinnecock Indian Reservation in Long Island, New York identified clear goals and about on exploring alternatives to hard infrastructure to restore shoreline areas. Based on these goals, they collaborated with the Cornell Cooperative Extension of Suffolk County and United States Geological Survey in 2014 to apply for and receive a $3.8 million grant to construct a living shoreline and advance other adaptation actions.

APPENDIX I:
Considerations for stormwater and drainage approaches

- Does the proposed project help connect a waterway to its floodplain or stabilize a streambank or channel?
- What is the flood history on the project site, and upstream and downstream of it?
- Will the project negatively affect upstream or downstream flooding or cause stream erosion?
- Are roadway crossings or other infrastructure vulnerable?
- Will the project reduce combined sewer overflow or provide water quality improvements?
- Does the solution require action on public property/right-of-way? Is private action necessary?

APPENDIX J:
Considerations for coastal and shoreline approaches

The following questions can help local leaders develop and evaluate different coastal and shoreline approaches:

- Where do current and future coastal and shoreline flood issues exist?
- Is key infrastructure vulnerable?
- What type of flooding is expected? Are some areas exposed to wave hazards?
- What land uses are within the floodplain adjacent to coastal or shoreline areas?
- Are there key areas prone to flooding from a combination of inland (e.g. stormwater or riverine) and coastal (e.g. storm surge or tidal) sources?
- Does the soluvtion require action on public property/right-of-way? Is private action necessary?

APPENDIX K:
Flood information and data for technical professionals

Example resources with information on rainfall, sea level rise, and waterways are included below:

- NOAA Atlas 14 for Rainfall: In 2013, NOAA developed Atlas 14 to determine the recurrence intervals (frequency) for precipitation events. Users can select the state and enter latitude and longitude for the site of interest. This information is important for sites with historical losses due to riverine and urban drainage issues.
- FEMA HAZUS: The HAZUS dataset uses GIS to estimate physical, economic, and social impacts (potential losses) from natural disasters (earthquakes, floods, and hurricanes). It is useful for community level assessments.

Planning for long term maintenance of beaches and dunes

- Sustained local, state, and federal commitment to the ongoing maintenance of beaches and dunes has helped vulnerable coastlines. For instance, on the Atlantic coast of Ocean County, New Jersey, a 14-mile stretch of beaches and dunes was nourished with sand in 2019, and is eligible for periodic renourishment over 50 years. Collaboration between the U.S. Army Corps of Engineers, New Jersey Department of Environmental Protection, and several local municipalities have been central to this project.

- FEMA CHAMP: With FEMA's Coastal Hazard Analysis Modeling Program (CHAMP), users can import digital elevation data; perform storm-induced erosion treatments, wave height and wave run-up analyses; plot summary graphics of the results; and create summary tables and report.
- NOAA Sea Level Rise Viewer: The National Oceanic and Atmospheric Administration developed this web mapping tool that visualizes community-level impacts from coastal flooding or sea level rise
- USACE Sea Level Change Curve Calculator: This web-based tool can be used for calculating projected rates of sea level change for coastal locations. Users can select from a range of variables, including location, published sea level rise scenarios (USACE or NOAA), time period, and project details. It is a useful tool for communities to assess how they may be impacted by future sea level rise.
- USACE HEC-FIA: The Hydrologic Engineering Center Flood Impact Analysis (HEC-FIA) package analyzes the damage to structures and contents, losses to agriculture, and estimates for potential loss of life during a flood event.
- USACE HEC-RAS: The HEC River Analysis System (HEC-RAS) allows the user to perform one- and two-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling of individual waterways.
- USACE HEC-FDRA: The HEC Flood Damage Reduction Analysis (HEC-FDRA) software provides the capability to perform an integrated hydrologic engineering and economic analysis during the formulation and evaluation of flood risk management plans.

APPENDIX L: Technical flood standards and guidelines

Example resources with design guidelines, guidance, standards, and principles are included below:

- ASCE Multidisciplinary Assessment of Critical Facility Response to Natural Disasters
- FEMA 543: Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings
- FEMA 577: Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds
- FEMA 259: Engineering Principles and Practices of Retrofitting Floodprone Residential Structures, Third Edition
- FEMA P-424: Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds
- FEMA P-936: Floodproofing Non-Residential Buildings
- FEMA P-55: Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas