

OFFICE FOR URBANIZATION

Future of the American City:

THE CASE OF CAPE ANN:
Adaptation Strategies and
Precedents

May 17, 2022



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Observations



Dave Cleaveland, *Gloucester Harbor*, 2010, Photograph, Gloucester, Massachusetts

No single strategy can eliminate coastal flooding impacts.

Strategies must work synergistically to reduce losses. Comprehensive coastal adaptation lies at the intersection of communication, accommodation, avoidance, resistance and resource allocation.



Justine Christianson, *Beacon Marine Basin*, 1968, photography, Historic American Buildings Survey, Library of Congress Archives

Adaptation strategies must be both regional and equitable.

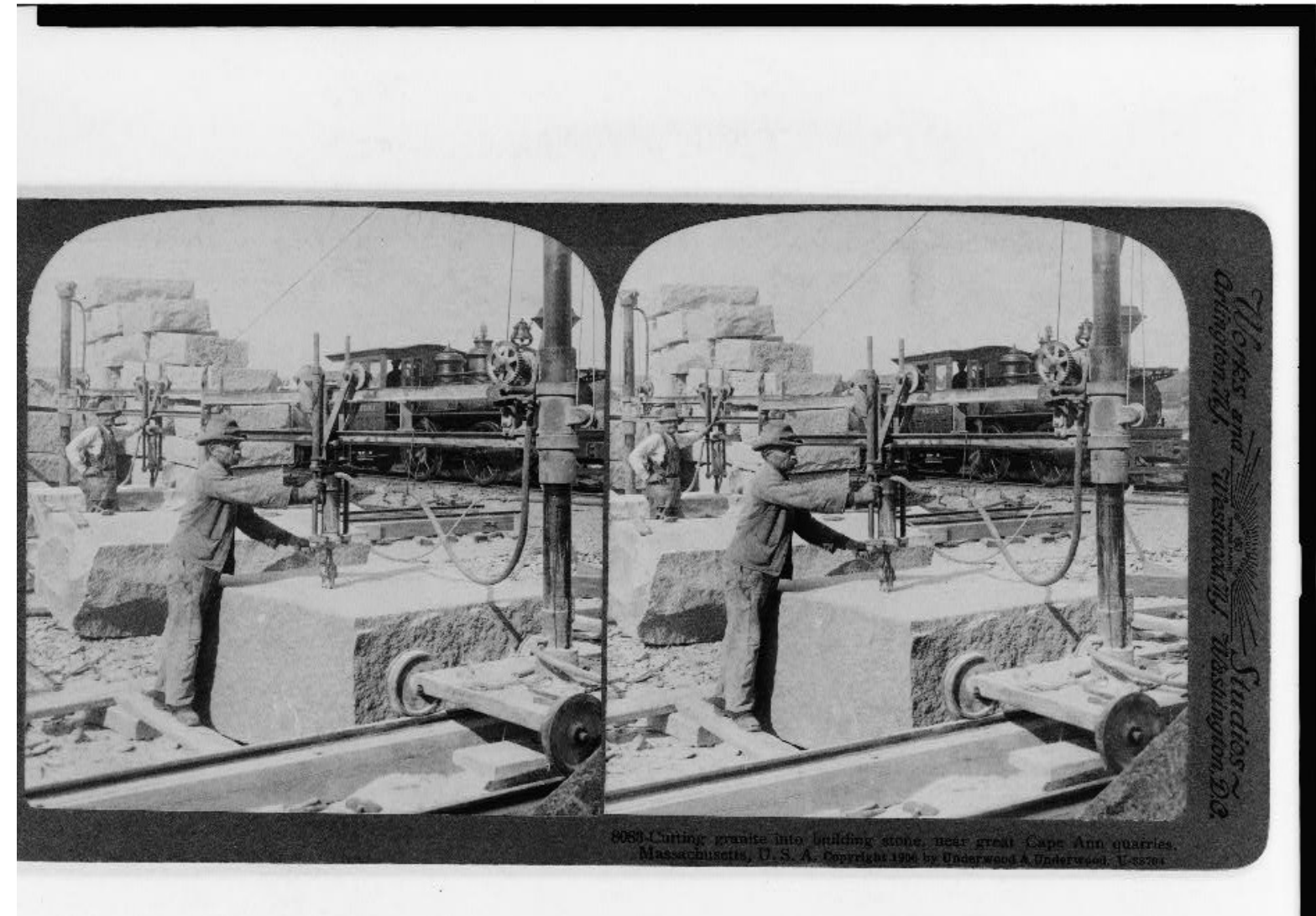
Regional agencies must consider the scale and impact of all proposed strategies to ensure that no adaptation strategies protect some communities at the expense of others.



Kim Smith, *Gloucester Fisherman's Memorial Man at the Wheel Snowy Day*, 2017, Good Morning Gloucester

Coastal adaptation strategies must align with inland adaptation.

Sea level rise creates new shorelines in low-lying, formerly non-coastal areas. As people move inland, increases in impermeable surfacing can lead to higher runoff and oversaturated ground. This can exacerbate long-term flood risks.



Underwood and Underwood, *Cutting granite into building stone*, 1906, Library of Congress

The resources to hold shorelines are, and will continue to be, limited.

The tools we use to measure coastal risk are based on population density, not landscape morphology. As the rate of sea level rise increases and coastal storms become more severe, funding to armor the coast will be directed to large population centers. Smaller communities will have less funding to defend the coast and their pace of retreat will increase relative to larger cities.



Gloucester Waterfront Festival, *Waterfront Festival Celebrates 40 years*, 2021, The Gloucester Times

Adaptation faces psychological, institutional, and practical barriers.

A comprehensive vision for adaptation can ameliorate these barriers. This vision should prioritize equity, leadership, and follow a clear plan that is communicated to residents. This vision must include critical infrastructure, cultural resources and other factors that influence adaptation decisions.



Catherine Ryan, *Walkway to Cape Hedge underwater*, 2021, Good Morning Gloucester

Local governments have broad powers to protect the public health, welfare, and safety of residents.

Municipal governments have primary authority to regulate land use through zoning and floodplain ordinances. Zoning ordinances provide the legal framework that governs the use and development of land in a municipality by permitting different uses in different districts. Local governments can adjust zoning or development rights to climate change.



Paul Bilodeau, *Sledding at Evans Field in Rockport, 2022*, The Gloucester Times

Sea level rise and flooding are public health issues.

The health consequences of sea level rise exceed the immediate loss of life associated with storm surge and flooding during severe storm events. It can also result in respiratory issues that arise from waterlogged buildings, the spread of communicable diseases from sewage runoff and mosquito breeding, and long-term mental health impacts.



Detroit Publishing Co., *A Cape Ann fisherman and dory*, 1905, Detroit Publishing Company, Library of Congress

Climate change causes cascading infrastructure failures that require a system-wide response.

The breakdown of one piece of a complex infrastructural web causes disruptions elsewhere, which diminishes critical response systems. This diminishes the community's capacity to respond adaptively.



Nicole S, *Capturing the Flag*, 2017, Good Morning Gloucester

The rules of property ownership are changing to respond to sea level rise.

Retreat strategies are part of a multi-jurisdictional legal framework. There are three primary considerations that arise in a retreat context: the regulation of private land uses and acquisition limitations, the duty to maintain public infrastructure and the potential for negligence claims, and possibilities for cross-jurisdictional or regional governance structures. Governments must balance financial limitations, safety, and environmental benefits with private property rights.



Catherine Ryan, *Good Harbor Beach low tide Salt Island tombolo*, 2020, Good Morning Gloucester

Climate adaptation should enhance the public realm.

The elevation of the first floor in buildings, not street elevations, govern whether properties are in or out of flood zones.

This prioritizes individual property over public property and encourages rebuilding in the same places with elevated building structures, creating an unsustainable cycle of repetitive loss and redevelopment that cannot be financed long-term.



Historic American Engineering Record, *Annisquam Bridge Spanning Lobster Cove Between Washington and River Streets*, 1968, Photography, Historic American Buildings Survey, Library of Congress Archives

Communication

Strategies to share and convey information



Detroit Publishing Co., *Eastern Point Light, Gloucester, Mass*, 1905, Photograph, Gloucester, Massachusetts

American Community Survey

COSTS

Variable

LIFESPAN

1 year

SITING FACTORS

DECISION MAKER(S)

US Census Bureau,
Federal Government

The American Community Survey is an ongoing survey that provides information on a yearly basis about American places and people. The survey helps determine how \$675 billion in federal and state funds are distributed every year.¹

It includes questions about jobs and occupations, education attainment, veterans, home ownership and renting, and demographics. Public officials, planners and entrepreneurs use this information to assess the past and plan the future. The survey is helpful to understand who the stakeholders in specific places are.

Coastal Management Plans

COSTS

Variable

There is significant overlap between institutions and actors in the coastal zone.

LIFESPAN

1-30 years

Coastal zone management plans take stock of major actors, institutions and laws. They are also used to inventory existing measures and analyze further needs, including specific actions for key coastal activities, measures to promote public participation, and mechanisms to ensure vertical and horizontal coordination.²

SITING FACTORS

Coastal access

DECISION MAKER(S)

Municipal government, state government, tribal government, Office for Coastal Zone Management, US Army Corps of Engineers, NOAA

After identifying actors, activities and risks, they develop long-term strategies and funding sources, and include a variety of stakeholders.



Rhode Island Coastal Resources Management Council, Shoreline Change Special Area Management Plan (SAMP), 2018

CASE STUDY

Beach SAMP³

Rhode Island, USA (2018)

Variable costs

The Rhode Island Coastal Resources Management Council prepared a Shoreline Change Special Area Management Plan (SAMP) to address the coastal resiliency of towns and cities along the state's coast.

The Shoreline SAMP program identifies areas at risk from one foot, three feet and five feet of sea level rise and the flood extent of a 4% annual flood event. It created a database of property and infrastructure exposed to sea level rise and flooding was created, and property owners were notified of their expected exposure to projected sea level rise. The information on sea level rise and storm surge was then integrated into the municipal permit and variance review process. This research guides state and local policy and planning initiatives and helps to coordinate organizations working across scales.

Business Engagement

COSTS Variable	As state and municipal governments cope with climate change, local businesses face economic and ethical choices: for example, whether to sell assets at risk of sea level rise while market values remain high and devote resources to planning for storms.
LIFESPAN Variable	
SITING FACTORS Existing businesses	Business leaders bring important perspectives to the planning process. They can help the community understand the risks they consider acceptable and the risks that would prompt them to invest in protection structures or relocate.
DECISION MAKER(S) Business owners, municipal government, local Chamber of Commerce	

Design Guidelines

COSTS

\$20,000+

Design guidelines are step-by-step instructions for developers and homeowners that go beyond a traditional building code.⁴

LIFESPAN

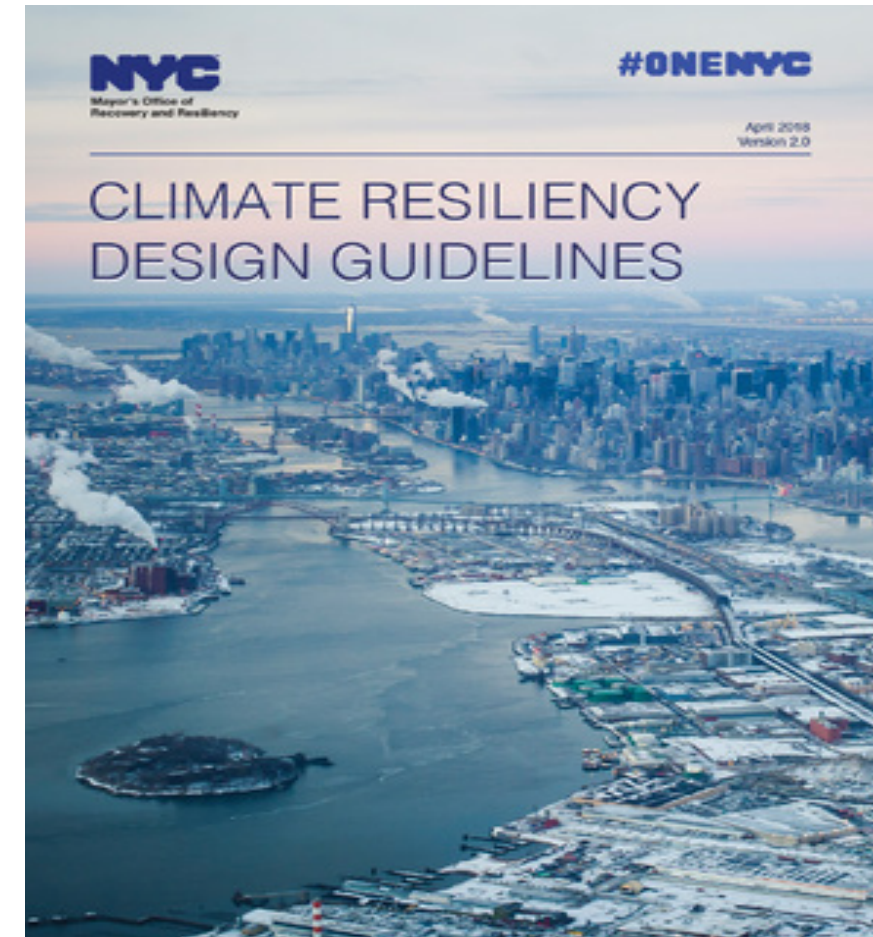
5+ years

These guidelines are informed by historic climate data.

SITING FACTORS

DECISION MAKER(S)

Municipal government, architects, developers



NYC Mayor's Office of Recovery and Resiliency, *Climate Resiliency Design Guidelines*, 2020

CASE STUDY

Climate Resiliency Design Guidelines⁵

New York City, New York, USA (2020–)

The New York City resiliency design guidelines use projected climate data for use in the design of City facilities. The guidelines include a toolkit that outlines a resilient design process and focuses on three key areas of resilient design: reducing the urban heat island effect, reducing flooding, and managing sea level rise.

Early Warning Systems

COSTS

\$20,000+

LIFESPAN

5+ years

SITING FACTORS

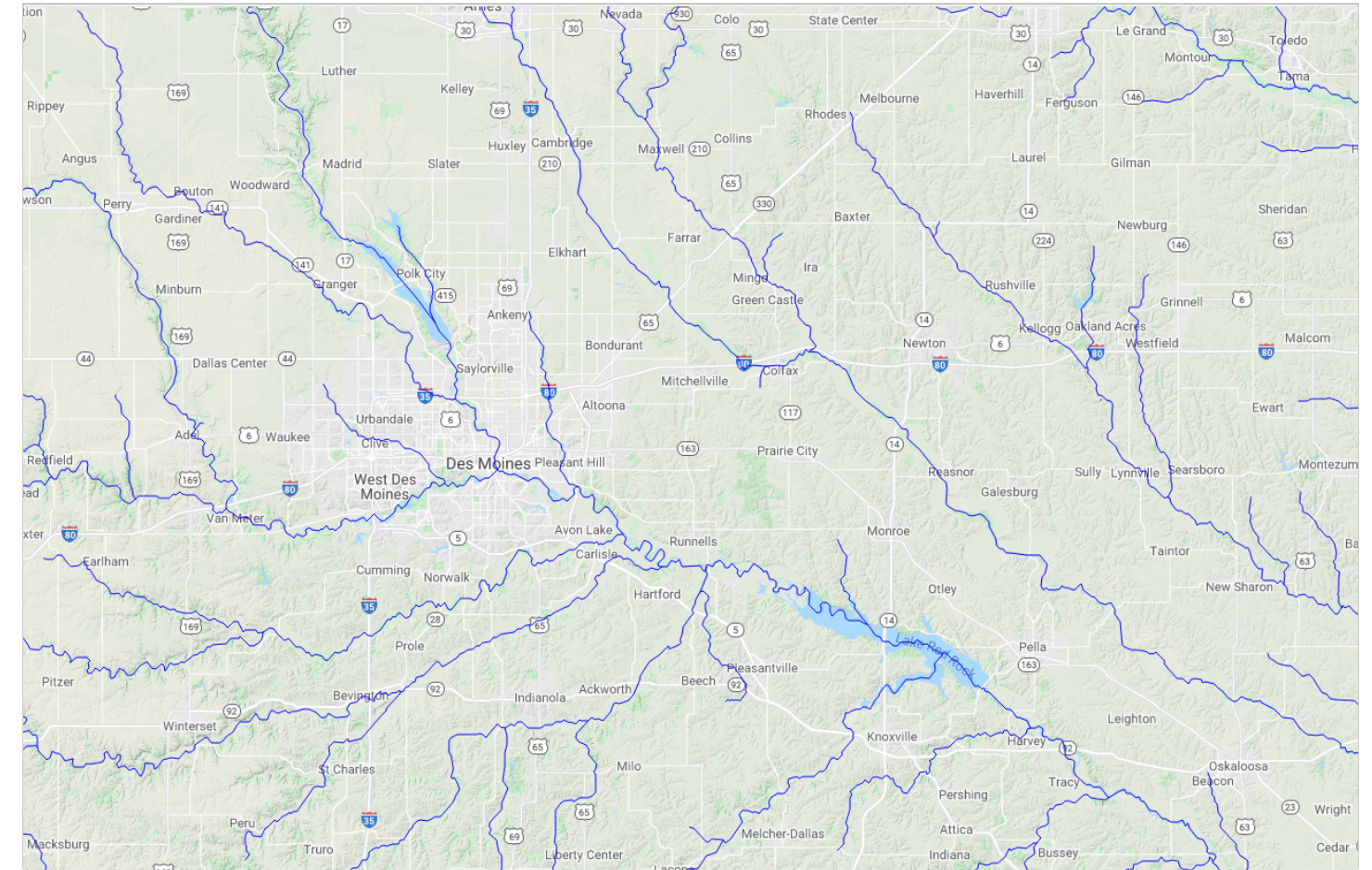
Areas exposed to risk, including flooding and other extreme weather events

DECISION MAKER(S)

Municipal government, state government

Early warning systems communicate the path and severity of storm systems with accurate predictions of river flows and water depths.⁶

Early warning systems collect, analyze and disseminate hydrological information to provide advance warning during impending flood conditions. These forecasts and warnings can prompt residents to reduce their vulnerability before or during a flood event and can help reduce damage to property and loss of life.



University of Iowa, *IFIS*, 2022

CASE STUDY

Iowa Flood Information System⁷
Iowa, USA (2012–)

The University of Iowa developed the Iowa Flood Information System, a web-based platform that provides an interactive environment for one thousand communities in Iowa and includes flood conditions, flood forecasts, data visualizations and flood-related data, information, and applications. The program uses live streaming data from stream gauges, LiDAR data, and bridge sensors. Users can filter data sources for their communities and selected rivers.

Education/Training

COSTS Variable	It is important to provide training to all stakeholder groups, including classes, workshops and certifications around climate mitigation, resiliency and adaptation. ⁸
LIFESPAN	
SITING FACTORS	Climate education can take many forms, from building awareness to vocational training.
DECISION MAKER(S) Academic institutions, NGOs, municipal government, state government, local businesses, conservation groups	

Flood and Hazard Disclosure Information

COSTS

Buyers purchasing a home in a FEMA flood zone are mandated to purchase flood insurance to qualify for government-backed mortgages. Sellers and realtors should disclose these flood hazards to prospective buyers.⁹

LIFESPAN

SITING FACTORS

DECISION MAKER(S)

Municipal government, state government

The real estate transaction process is the most important time to communicate flood risk (including whether a home is within or close to a 100-year floodplain or if the structure has been inundated in the past) that will help home buyers make more informed decisions.

A private website, www.buyersbewhere.com, discloses 10 risks, but localized information and requirements makes these regulations more stringent.



David J. Phillip, *Hurricane Harvey*, 2017

CASE STUDY

Texas Flood Disclosure Law¹⁰

Texas, USA (2022–)

After Hurricane Harvey, the State of Texas passed the nation's most stringent flood disclosure laws.

Under the law, sellers must disclose whether there has been previous water damage to a structure due to a natural flood event, if there has been previous flooding due to a natural failure or a breach of a reservoir or a controlled emergency release of water from a reservoir, if the property is located wholly or partly in a 100-year floodplain, a 500-year floodplain or a reservoir, if the seller has ever filed a claim for flood damage to property with any insurance provider, if flood insurance covers the property, and if the seller has ever received assistance from FEMA or US Small Business Administration (SBA) for flood damage to the property.

Flood Risk Information

COSTS

Municipal governments should establish relationships with multiple media outlets to communicate flood risk information.¹¹

LIFESPAN

Variable

SITING FACTORS

DECISION MAKER(S)

Municipal government, state government, federal government, local media outlets



Bert de Sola, *Parque Fluvial*, 2005

CASE STUDY

Parque Fluvial del Besos¹²
Barcelona, Spain (2002–2004)

The Besos River in Barcelona was narrow concrete channel.

The river caused significant damage when it flooded, posing major public safety risks. The Parque Fluvial was designed as a 4.7 mile park with an additional 115 miles of wetlands. The Barcelona Provincial Council monitors the park to ensure that it is not subject to flash flooding and a series of optical and acoustic signals have been placed throughout the park and surrounding areas to alert visitors about heavy rainfall. Entrances to the park include electronic panels that provide updated information on permissible use conditions of the park. Additional broadcasts are shared through radio and social media.

Hazard Mitigation Plans

COSTS	State, tribal, and local governments identify natural disaster risks and vulnerabilities that are common in their area. After identifying these risks, they develop long-term strategies for protecting people and property from similar events. All states and over 20,000 local jurisdictions have Hazard Mitigation Plans that are required to receive federal disaster assistance. ¹³
Variable	
LIFESPAN	
5 years	
SITING FACTORS	
DECISION MAKER(S)	
Municipal government, state government, tribal government	These plans have been criticized for the strong emphasis on structural preparedness, including flood defenses, culverts and building codes, but non-structural actions including policy changes and the use of natural systems are often missing. ¹⁴

Local Flood Survivor Organizations

COSTS

Variable

LIFESPAN

Variable

SITING FACTORS

Areas that have experienced major flood events

DECISION MAKER(S)

NGOs, activists

These organizations offer flood survivors practical advice on how to prepare for flooding and supports campaigns to better prepare for more severe storms and rising seas.¹⁵



Anthropocene Alliance, *Higher Ground Pensacola*, 2017

CASE STUDY

Higher Ground USA (2017-)

Higher Ground was launched in 2017 by Anthropocene Alliance.^{16 17}

The group is now the largest flood-survivor network in the United States with fifty-eight members in twenty-one states. The network of chapters are diverse, mostly led by women and representing low-income communities and communities of color. Higher Ground advocates for policy change and serves as a clinic to teach grassroots community organizing, leadership training, and peer-to-peer learning. The group provides science, counseling, policy, legal and art and communications expertise so communities can successfully convey the complex challenges they face and the advocate for the best solutions to government officials.

Local Plans

COSTS

Variable

LIFESPAN

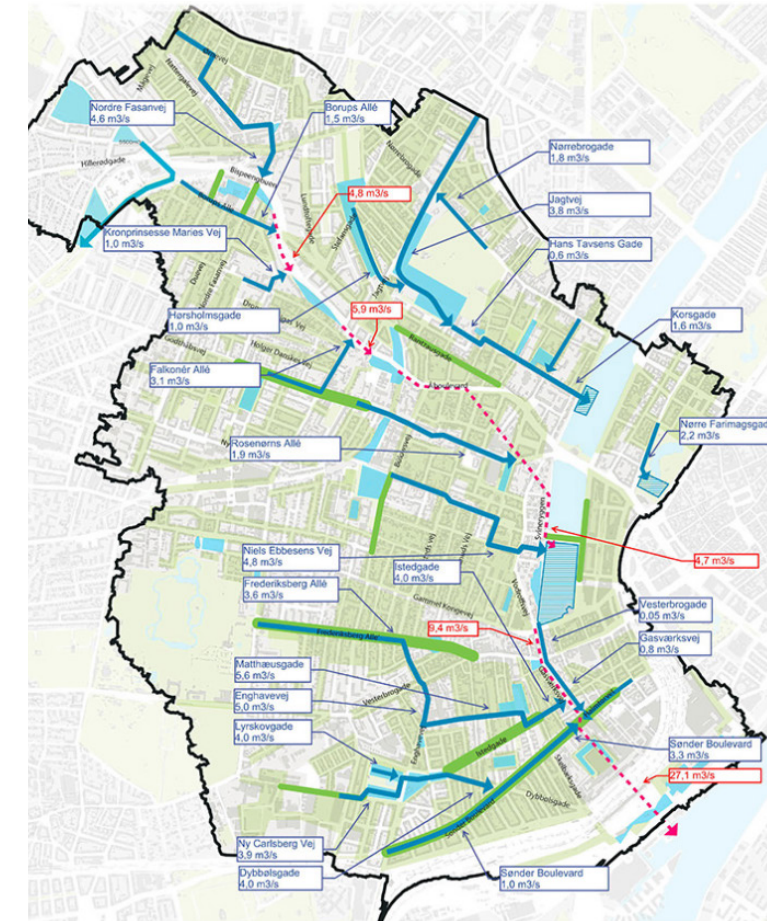
1-30 years

SITING FACTORS

DECISION MAKER(S)

Municipal government, state government

Municipal and state governments can adopt local planning instruments (floodplain plans, comprehensive plans, local mitigation strategies, etc.) that set forth a series of coordination policies aimed at mitigating flood impacts.¹⁸



City of Copenhagen, *Cloudburst Management Plan 2012*, 2012

CASE STUDY

Copenhagen Cloudburst Plan¹⁹
Copenhagen, Denmark (2011–)

Copenhagen was flooded during a storm in 2011 and spent \$1 billion repairing damages.

The Cloudburst plan emerged in response to the storm. It is a series of flexible, adaptable models to mitigate extreme flood events using Blue-Green solutions that integrate urban planning, traffic and hydraulic analysis with funding.

The plan identified three hundred city-wide pilot projects to incorporate flood management guidelines within local developer requirements.

The project began with a data and investigation phase, followed by modeling and mapping stormwater catchments, an analysis of the cost of doing nothing, a design challenge that created a toolkit of strategies, and a detailed cost-benefit analysis of the plan that incorporated health, environmental and urban quality improvements.

Long-term/Visioning Plans

COSTS

Variable

LIFESPAN

1-30 years

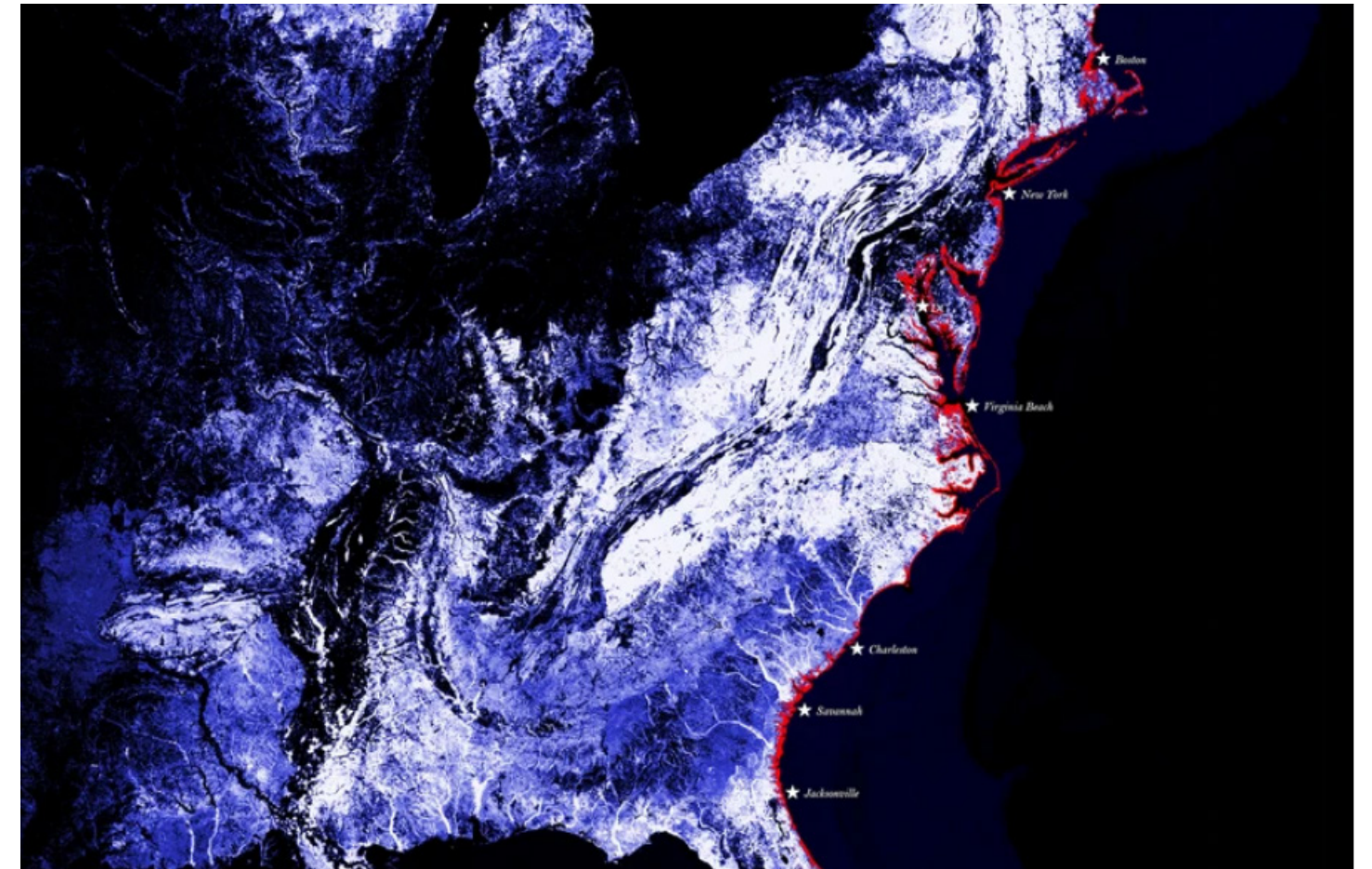
SITING FACTORS

DECISION MAKER(S)

Municipal government, state government, NGOs, academic institutions, consultants

Long-term or visioning plans take into account how climate and other factors will change over decades. Visioning plans should recognize vulnerabilities and ensure there is equity for disadvantaged groups who will be disproportionately affected by the impacts of climate change.²⁰

Visioning plans should identify leadership and expertise needs within and beyond the community.



Rosetta S. Elkin and Mariel Collard, *National Seashore to Unify Coastline*, 2018

CASE STUDY

National Seashore²¹
East Coast, USA (2018)

The National Seashore is a vision of the coastal United States that is protected as a national park. The coastline is protected as public land that is accessible for recreation and provides a buffer against storms and a critical setback for development. The designation would not prevent working shores, remove ports, or fishing harbors, or infringe on tribal rights or historic sites, but it would limit infrastructural development and limit second, third, and fourth vacation homes to prevent buildings from accumulating close to the coast.

The seashore would be achieved at a patchwork of different scales, including small foot paths, mile-wide buffer zones, and conservation easements. Each state or local area would implement their own needs.

While the National Seashore proposal is a grand vision, it enables communities to discuss what a smaller project would look like at a local scale and how people can unite around a common cause.

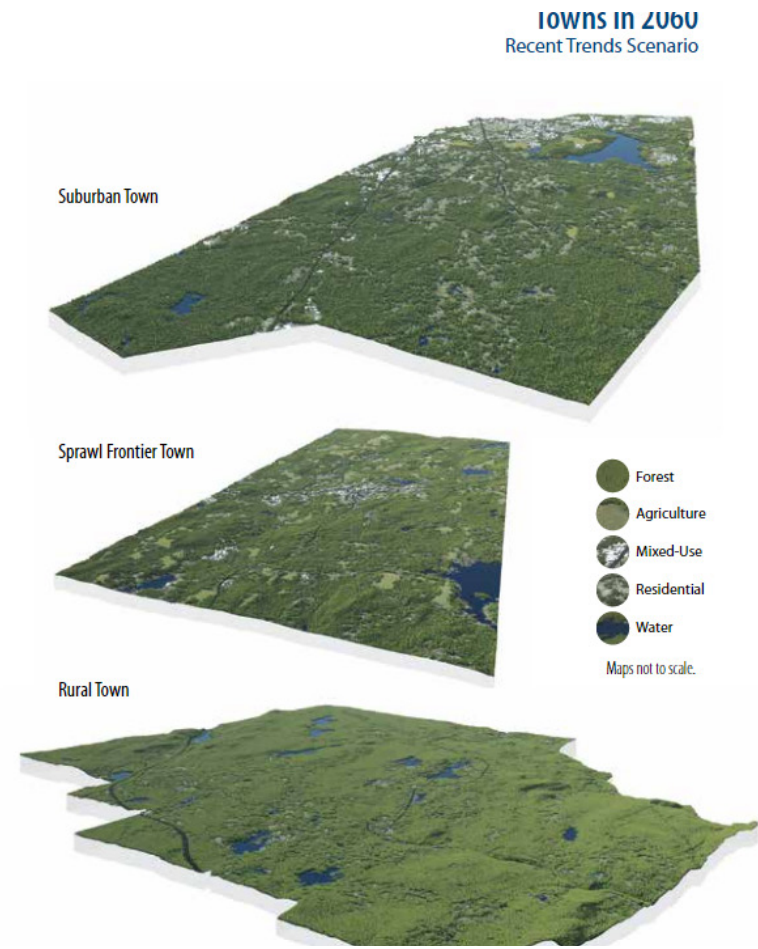
Communication: Share and Convey Information

SCENARIO #1 | Recent Trends



The *Recent Trends* scenario represents a linear continuation of the trends in forest conversion to development and timber harvesting for the period from 1999 to

2005. This was a period of relatively low residential and commercial development in which approximately 7,500 acres of forest were converted to developed land each year. This compares with 16,000 acres of forest loss per year during the period spanning 1980 to 1986 and 11,000 acres per year from 1985 to 1999 (DeNormandie 2009). There were negligible changes in agricultural land during this time. Timber harvesting rates were moderate during this time, with 25,000 acres harvested annually (less than 1% of the forest), mostly in the western part of the state (McDonald et al 2006).



Jonathan Thompson et al., *Changes to the Land: Four Scenarios of the Massachusetts Landscape* (Petersham: Harvard Forest, 2014)

CASE STUDY

Changes to the Land²² Massachusetts, USA (2014–)

This scenario planning project was led by Harvard Forest. The report projects four land use scenarios: recent trends, opportunistic growth, regional self-reliance, and forests as infrastructure. The scenarios reflect different amounts of land development, timber harvesting, farmland expansion, and forest conservation. The scenarios were used to analyze the plans with the most benefits to people and the environment and develop ways to conserve priority forest land across the Commonwealth.

Long-Range Transportation Plans

COSTS

Variable

LIFESPAN

20 years

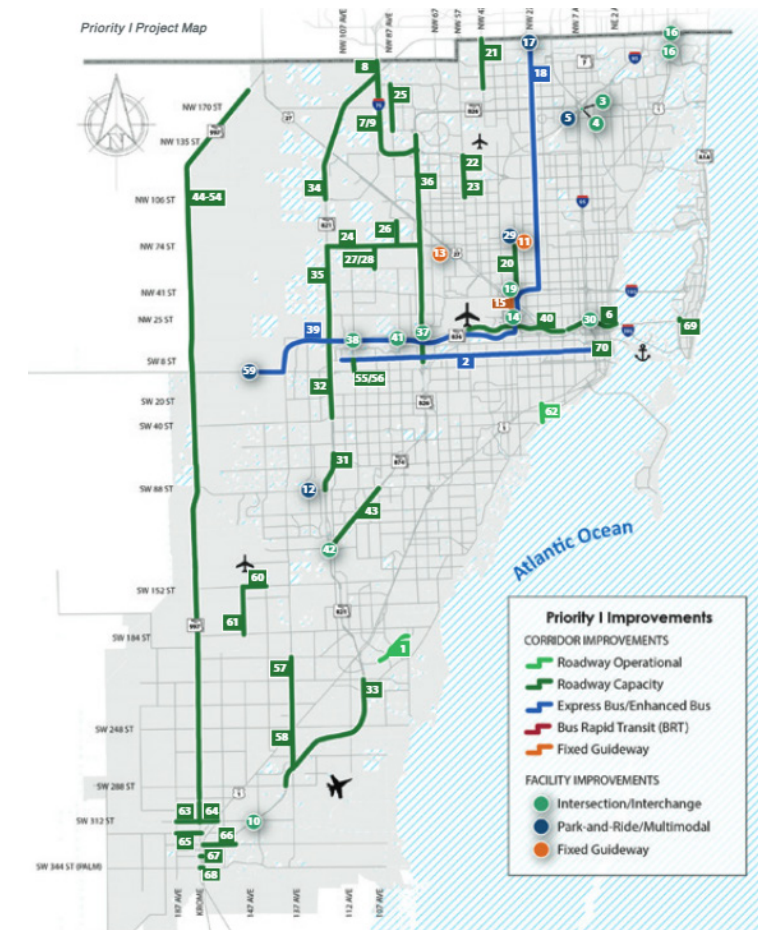
SITING FACTORS

DECISION MAKER(S)

State Department of Transportation,
US Department of Transportation,
Municipal Government,
developers,
transportation engineers

These plans are used to prioritize how transportation can be implemented, which private and public resources will be available to carry out long-range plans, and the additional financing strategies needed to fund projects and programs.²³
24

Long-range transportation plans can help achieve the goals of managed retreat and densifying urban areas by creating public transit hubs.



Miami-Dade Metropolitan Planning Organization, *Miami-Dade Long Range Transportation Plan*, 2020

CASE STUDY

2045 Long Range Transportation Plan²⁵

Miami-Dade, Florida, USA (2020–)

The Miami-Dade Long Range Transportation Plan was created to address sea level rise and climate change in addition to land use planning concerns. The plan includes rapid transit expansion, land use changes, densification, connectivity, and multimodal activity as well as financing proposals.

Managed Retreat/Relocation Specific Plans

COSTS

Variable

LIFESPAN

1-30 years

SITING FACTORS

Areas within a coastal or inland floodplain

DECISION MAKER(S)

Municipal government, state government, federal government

These plans proactively guide a community in developing different aspects of a managed retreat strategy.^{26 27}

They are focused on a community's specific managed retreat goals and objectives and can facilitate easier project implementation because they provide a strategic look or analysis on one subject instead of including managed retreat as one element of a larger plan.

The managed retreat plan helps communities identify, prioritize, organize and coordinate a multifaceted approach to climate adaptation for a defined spatial area or a number of interested parties.



Hawai'i Office of Planning and Sustainable Development, *Assessment of Managed Retreat in Hawai'i*, (Honolulu: Hawai'i Office of Planning and Sustainable Development, 2018)

CASE STUDY

Assessing the Feasibility and Implications of Managed Retreat Strategies for Vulnerable Coastal Areas in Hawai'i²⁸

Hawai'i USA (2018–2019)

The managed retreat plan for Hawai'i was commissioned to correct the emphasis on hard engineering in response to coastal climate change across the state.

The plan includes four scenario profiles that represent portraits of areas in Hawai'i: resorts, hotels and condominiums on Maui, urban areas on Kaua'i, single family homes on Hawai'i Island, and critical infrastructure on O'ahu. Each scenario applies research to how managed retreat could be conducted in the state. An all-day symposium was held in 2018 in Honolulu to play out the scenarios.

Post-Disaster Recovery and Redevelopment Plans

COSTS

Variable

Post-disaster recovery and redevelopment plans guide how a community will recover and rebuild after a major disaster.²⁹

LIFESPAN

1-30 years

They help state and local governments implement post-disaster response and recovery actions to mitigate future risk in coastal areas.

SITING FACTORS

DECISION MAKER(S)

Municipal government, state government, federal government, academic institutions, NGOs

PRINCEVILLE CONCEPT

The history and culture of Princeville are of national importance and value. Historic features include Shiloh Landing, the Tar River baptismal site, historic cemeteries, and a historic school that now serves as a museum. For the purpose of this guide, we support maintaining a physical presence of the community in its historical setting. We recommend building a village core, along the edge of a new lake that would be established south and east of the historic settlement area. Soil from the lake excavation could be used for local infrastructure improvements, including the elevation of certain areas beyond the reach of floodwaters.



Coastal Resilience Design Laboratory, *Homeplace: A Conversation Guide for the Princeville Community*, (Raleigh: North Carolina State University, 2018)

CASE STUDY

Homeplace: A Conversation Guide for the Princeville Community

Princeville, North Carolina, USA (2011–)

After Hurricane Matthew struck North Carolina, the Hurricane Matthew Disaster Recovery and Resiliency Initiative (HMDRRI) provided six communities with technical assistance to address issues that go beyond what is usually covered in post-disaster programs, including developing and implementing a housing relocation strategy, creating open space guidance, and flood retrofitting historic downtowns.³⁰

The Homeplace guide is a menu of high-quality, community-specific designs and strategies at multiple scales that results in coordinated post-disaster rebuilding. The guide positions design as a way to improve accessibility, curb appeal, affordability, efficiency and flexibility. It provides five model homes with options to abandon or elevate and a network of landscape options for the community.

Public Demonstrations and Protests

COSTS

Variable

LIFESPAN

SITING FACTORS

DECISION MAKER(S)

Citizens, activists

Protests can guide how a community will recover and rebuild after a major disaster and help state and local governments implement post-disaster response and recovery actions to mitigation future risk in coastal areas.



J.C. Bott, Keystone, Picture Alliance, 2019

CASE STUDY

Fridays for Future³¹

Global (2018–)

Fridays for Future (FFF) is a youth-led and organized global climate strike movement started in 2018 by Greta Thunberg. The movement demands urgent action on the climate crisis with a goal to put moral pressure on policymakers to take action to limit global warming.

Public Service Announcements

COSTS

Variable

Media dissemination of information in the public interest without charge is an important means of raising public awareness and changing behavior.

LIFESPAN

SITING FACTORS

DECISION MAKER(S)

Municipal government, state government, NGOs, activists, media outlets

Regional Policy Plans

COSTS
Variable
Regional policy plans provide objectives to guide development and protect the region's resources.³²

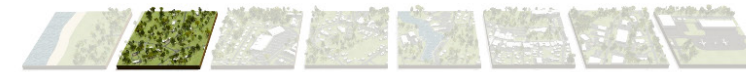
LIFESPAN
1-30 years
These plans should identify critical resources and management needs, including a growth policy, contain regional goals, and provide a policy for coordinating regional and local planning efforts.

SITING FACTORS

DECISION MAKER(S)
Municipal government, regional commission, state government



VISION: To ensure that development is located, sited, and scaled appropriately to avoid impacts on scenic and/or cultural resources, and to help maintain the economic diversity that agriculture can provide for the region including opportunities for the continuation of traditional agricultural occupations, and for the availability of locally-grown food.



CAPE COD PLACETYPES

Cape Cod Commission, *Cape Cod Regional Policy Plan: Framing the Future* (Barnstable: Cape Cod Commission, 2021)

CASE STUDY

Cape Cod Regional Policy Plan³³
Barnstable County, Massachusetts, USA (1990–)

The Cape Cod Commission is a regional agency established in 1990 to coordinate land use planning, economic development, and regulatory agency across the 15 towns of Barnstable County. The Commission was established by the Massachusetts state legislature by the Cape Cod Commission Act in 1989. The organization provides the public with opportunities to voice concerns and ideas on land use policies and issues, brings diverse decision makers together to share a regional viewpoint about significant resources, and uses interdisciplinary tools to solve challenges.

The regional plan identifies the assessed value of all property in the FEMA Special Flood Hazard Area and creates a regional growth policy that includes natural, built, and community systems with specific goals and metrics for each system. The guide also creates a series of place types with specific visions for each placetype.

Task Force on Climate-Related Financial Disclosures (TCFD)

COSTS
Variable

LIFESPAN

SITING FACTORS

DECISION MAKER(S)
Corporations,
shareholders,
Financial Stability
Board

The TCFD is a group supported by the international Financial Stability Board. The group created a set of recommendations for effective climate-related corporate disclosures to promote more informed investment, credit, and insurance underwriting decisions and enable stakeholders to better understand the concentrations of carbon-related assets in the financial sector and the financial system's exposures to climate-related risks.³⁴

The TCFD approach moves beyond previous initiatives to acknowledge risk and encourages companies to frame a strategy to respond to the risk, find financial and other support for work within the structure of the company, and track progress with clear metrics. The task force encourages companies to report under existing requirements, but the international sponsorship of the framework provides comparable information among companies in different countries and sets a common standard that investors can use to make investment choices.

Wetlands Migration/Ecosystem Specific Plans

COSTS

Variable

LIFESPAN

1-30 years

SITING FACTORS

Wetlands

DECISION MAKER(S)

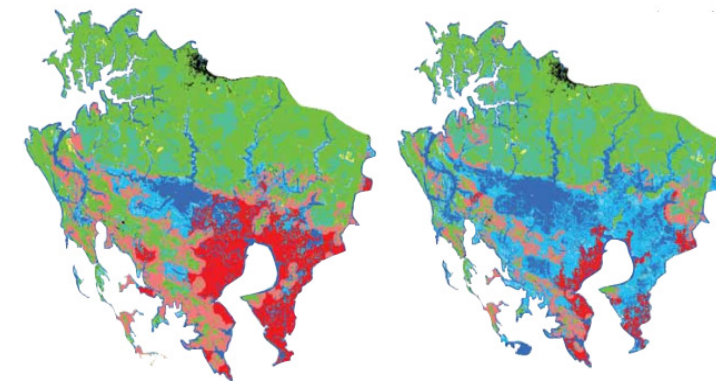
Municipal government, state government, federal government, US Army Corps of Engineers, Office of Coastal Zone Management

Wetlands are regulated under complex and overlapping jurisdictional frameworks. Wetlands migration plans bring together actors, usually in public-private partnerships, to coordinate wetland migration inland away from the coast across different temporal scales.^{35 36}

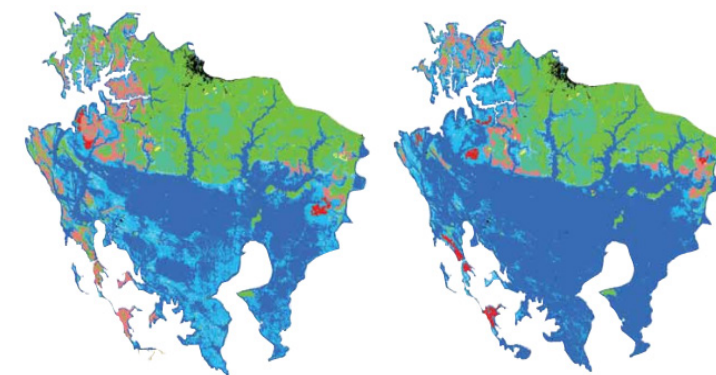
Wetlands migration plans must be considered for short and long term to preserve future wetland corridors and establish areas in the present that wetlands can retreat to in the future.

In doing so, wetland migration plans must be coordinated with other local plans.

2025 Modeled Marsh Bird Habitat 2050 Modeled Marsh Bird Habitat



2075 Modeled Marsh Bird Habitat 2100 Modeled Marsh Bird Habitat



The Conservation Fund, *Blackwater 2100: A Strategy for Salt Marsh Persistence in an Era of Climate Change* (Arlington, VA: Conservation Fund, 2013)

CASE STUDY

Blackwater 2100³⁷
Maryland, USA (2013–)

The Conservation Fund, National Audubon Society, and U.S. Fish and Wildlife Service created a “salt marsh persistence” report for Blackwater National Wildlife Refuge to address marsh migration in response to sea level rise and tidal erosion. The report identifies areas of current tidal marsh most resilient to sea level rise and of the highest value to salt marsh bird species as well as future locations that may support marsh migration corridors.

The authors selected one of three different adaptation strategies within the park by evaluating the tradeoffs of different strategies and identifying the stakeholders to partner with to investigate marsh migration on an ecosystem scale.

Resistance

Strategies to remain in place



Paul Bilodeau, *Work on the Seawall at Conomo Point in Essex has begun*, 2022, Photograph, Essex, Massachusetts

Artificial Reefs

COSTS

\$46,000-\$2 million to install, \$181,000-\$253,000 five year maintenance costs

LIFESPAN

5+ years

SITING FACTORS

Bathymetry, water quality, construction access, erosion, wave energy

DECISION MAKER(S)

State government, municipal government, developer, US Army Corps of Engineers, US Environmental Protection Agency, state environmental agencies

The construction of artificial reefs in nearshore areas can reduce the impacts of storm surge and waves. These reefs can be established using a variety of materials to mimic natural formations of coral, oysters, or worms in high wave energy environments. There are no general design rules for these artificial structures.³⁸

There are several artificial reef sites in Massachusetts. A 127-acre site in Yarmouth has operated since 1978.



Neptune Memorial Reef, *Construction of Mausoleum, Neptune Memorial*, 2012

CASE STUDY

Neptune Memorial³⁹

Key Biscayne, Florida, USA (2008-)
\$1.5 million

Neptune Memorial Reef is an underwater columbarium and burial ground 3.25 miles off the coast of Florida. The Reef occupies a half acre with permitting for 16 additional acres. The reef is laid out like a city, with underwater roads, benches and a large sanctuary. The burial at sea can accommodate over 125,000 remains.

The reef, re-engineered after Hurricane Andrew, is a popular destination for boaters and divers and incorporates active coral building.

Resistance: **Remain in Place**



Massachusetts Division of Marine Fisheries, *Yarmouth Habitat, Cape and Islands*, 2020

CASE STUDY

Yarmouth Artificial Reef⁴⁰

Yarmouth, Massachusetts, USA (1978–)

\$225,097 for 5 years of maintenance

There are five artificial reef sites across Massachusetts. The Yarmouth artificial reef is a 127-acre site located two miles south of the Bass River in southern Massachusetts. The reef is made of individual, modular units consisting of three to five tires filled with concrete and strapped together in bundles. There are 2,500 reef units in the area.

The reef provides habitat for bass, mussels and shellfish including lobster.

The site was reopened to accept new materials in 2014.

Beach Nourishment

COSTS

\$2-\$6/ft³

LIFESPAN

1 month-5 years

SITING FACTORS

Wave energy

DECISION MAKER(S)

Municipal
government, state
government, property
owner, developer

Beach nourishment is the process by which sediment, usually sand, that has eroded or drifted away is replaced from other sources. It can reduce storm damage to coastal structures by dissipating energy across the surf zone.⁴¹

Beach nourishment is a temporary solution and is a repetitive process that must be deployed regularly. It is used by public and private actors.



Resilient Hague, *Sand Motor*, 2011

CASE STUDY

Sand Motor⁴²

Ter Heijde, Netherlands (2011-)

\$75 million

The Sand Motor is an artificial peninsula constructed off the coast of Ter Heijde. The Netherlands government previously replenished the sand on the beach and off the coast every five years by dumping sand from bulldozers along the shore.

The Sand Motor project involves the creation of two kilometer wide artificial peninsula that erodes over time and accretes ten kilometers down the coastline, replenishing the beach over time by harnessing the power of the ocean current.

This “mega-nourishment” scheme is applied every fifteen to thirty years, and creates recreational opportunities in addition to flood protection.

Breakwaters

COSTS

\$1,500/ft², \$96 million/mile, \$96,000/mile ten year maintenance costs

LIFESPAN

30+ years

SITING FACTORS

Bathymetry, wave energy

DECISION MAKER(S)

State government, US Army Corps of Engineers, municipal government, Department of Conservation

Breakwaters are detached structures built parallel to the coast that disperse or redirect wave energy and reduce impacts along the shoreline.⁴³

The reduction in wave energy produces sediment deposition and a shoreline bulge in the sheltered area behind the breakwater. Breakwaters help maintain beach width for recreational purposes, reduce erosion, and stabilize wetlands. These structures can accelerate erosion on the front or up-shore side of the structure and deflect waves onto unprotected areas, creating adverse impacts in adjacent communities. Breakwaters must be considered as a regional solution so they do not prioritize more affluent communities at the expense of others.



Tidal Lagoon Power, "Seawall with turbines", *The Guardian*, 2019

CASE STUDY

Swansea Bay Tidal Lagoon⁴⁴
Swansea, United Kingdom (2015–)

The tidal lagoon is a U-shaped breakwater proposed on the southwest coast of Wales with a tidal lagoon power plant. Hydroturbines located in the breakwater would generate electricity as the tide rises and falls in the lagoon twice a day, generating electricity four times each day with the cycles of the tides. The project, when completed, will generate electricity for 155,000 homes for 120 years.

The project includes a walkway over the breakwater, lookout spaces with public gathering spaces, and sheltered rooms for fishing. Inside the breakwater, a marine farm has been proposed, potentially containing mussels, oysters and eelgrass. A five-mile-long marine reef will be installed beyond the lagoon.



Jon Mael, "A jetty reaches out into the sea at the top of Bearskin Neck," *The Boston Globe*, 2016

CASE STUDY

Bearskin Neck Breakwater⁴⁵

Rockport, Massachusetts, USA (1800s-)

\$1,382,304 to repair

The Bearskin Neck Breakwater at the mouth of Rockport Harbor runs 560' and is over 15' tall. The stones move during large storms and the structure has been scoured with section loss, cracking, and spalling. Last repaired in 2015, the breakwater is critical and protects inshore structures from high velocity waves during tropical and extratropical storms.

Resistance: **Remain in Place**

Bulkheads

COSTS

\$16 million-\$65.6 million/mile, \$16,000/mile annual maintenance costs

LIFESPAN

30+ years

SITING FACTORS

Bathymetry, wave energy, substrate

DECISION MAKER(S)

Municipal government, state government, US Army Corps of Engineers, property owners

Bulkheads are vertical retaining walls to hold or prevent soil from sliding seaward.⁴⁶



Compass Realty, *Cripple Cove Public Landing*, Compass Realty, 2020

CASE STUDY

Cripple Cove Public Landing⁴⁷

Gloucester, Massachusetts, USA (2001-)

\$50,160 to repair

The Cripple Cove Public Pier is a stone bulkhead with a mortared top that is in front of a playground and gangway for a public landing.

Coastal Bank

COSTS

\$80,000/acre,
\$5,000/acre annual
maintenance fees

A coastal bank is a landform with a steep slope that acts as a vertical buffer to confine elevated storm waters.⁴⁸

LIFESPAN

5+ years

These landforms can be stabilized using bioengineering to protect upland areas from erosion and maintain habitat and ecosystem function for coastal species. Such projects use natural fiber blankets, coir rolls and vegetation buffers with deep-rooted local species.

SITING FACTORS

Bathymetry, wave
energy, topography,
erosion, vegetation

The Massachusetts Wetlands Protections Act only allows hard structures on coastal banks to protect existing structures permitted before August 10, 1978, making bioengineering projects and non-structural alternatives necessary to reduce erosion and storm damage on coastal properties.

DECISION MAKER(S)

Municipal
government, state
government, state
environmental
agencies, NGOs

Resistance: **Remain in Place**

Constructed Dunes

COSTS

\$3/ft³, \$0.66/ft³
annual maintenance
costs

LIFESPAN

1+ years

SITING FACTORS

Bathymetry,
topography, wave
energy, vegetation

DECISION MAKER(S)

Municipal
government, state
government, property
owners, NGOs

Building or replacing dunes can protect communities from storm surge and wave action.⁴⁹

The construction of dunes depends on a source of sand for renourishment, successful planting to hold the sand in place, and a commitment to long-term management.



Provincetown Government, *Ryder Street Beach Dune Restoration Project*, (Provincetown: Town Government, 2018)

CASE STUDY

Ryder Street Dune Enhancement Project⁵⁰

Provincetown, Massachusetts, USA (2018–)

\$180,000

Ryder Street Beach was identified as a storm tide pathway that brings water quickly from the coast into low-lying areas. Repeated flooding in the downtown area of Provincetown is partially due to the gradual erosion of the Provincetown dunes.

This dune restoration project provides wildlife and shorebird habitats, uses local plant species, and is sited to provide the largest benefits in flood reduction for the lowest costs.

Resistance: **Remain in Place**

Dams

COSTS

\$100/yard³

LIFESPAN

30+ years

SITING FACTORS

Topography, water velocity, precipitation, winter temperatures, soil

DECISION MAKER(S)

State government, US Army Corps of Engineers, property owner, municipal government

Dams are artificial barriers that are usually constructed across a stream channel to impound or store water.⁵¹

Dikes

COSTS

\$16.8 million-\$25.92 million/mile riverine, \$46 million/mile sea, \$40,000 annual maintenance costs⁵³

LIFESPAN

20+ years

SITING FACTORS

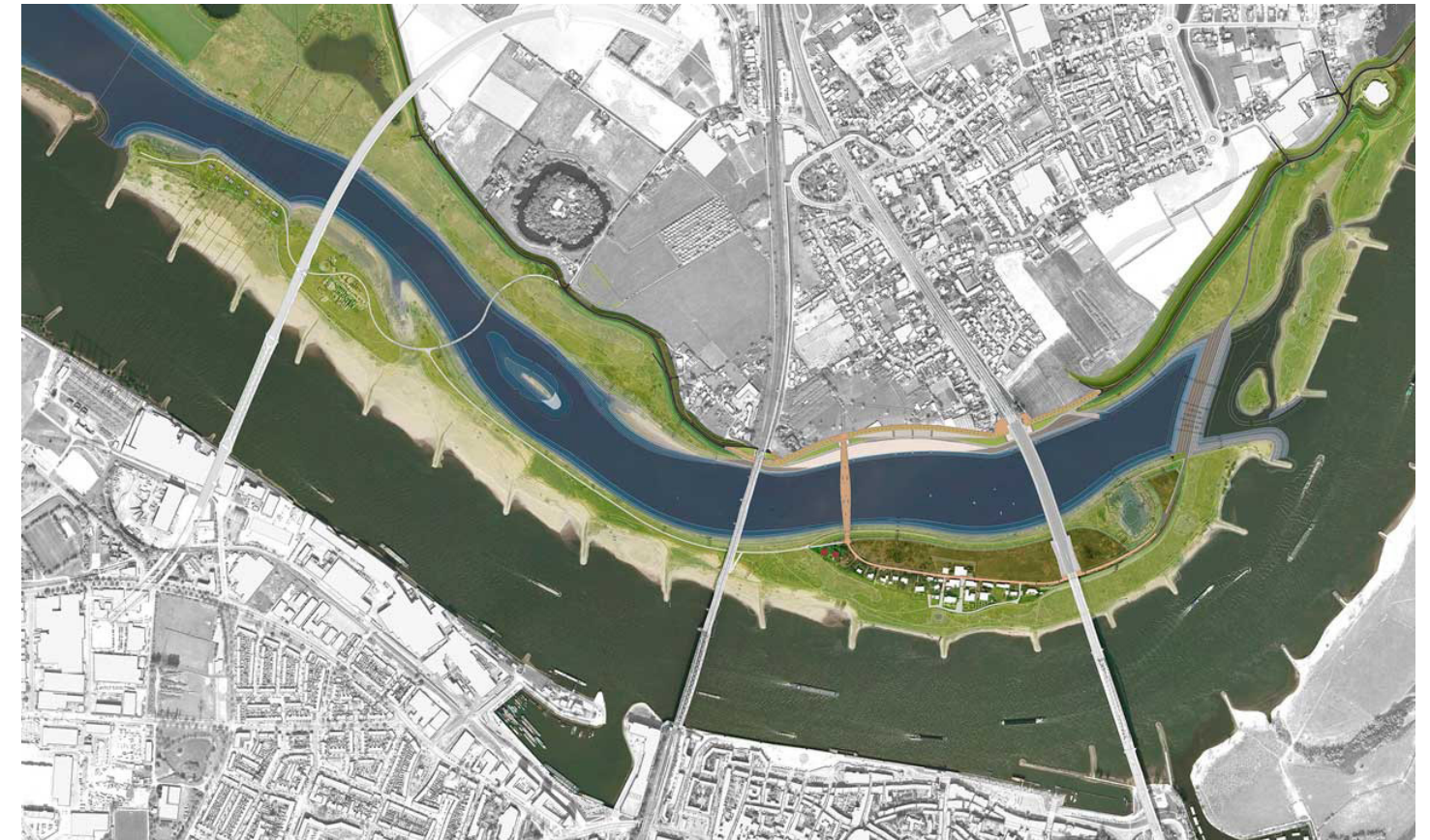
Topography, soil, wave energy, vegetation

DECISION MAKER(S)

State government, US Army Corps of Engineers, property owner, municipal government

Dikes are solid constructed walls that prevent elevated water levels from flooding interior lowlands and are used to eliminate wave-based flooding caused by storm surges along the coast. These structures are deployed around existing developments or critical facilities.⁵²

Dikes are expensive and can encourage floodplain development, increasing values at risk. If they are not properly maintained, the risk of failure that could cause catastrophic damage increases.



H+N+S, Room for the River, 2010

CASE STUDY

Room for the River⁵⁴

Nijmegen, Netherlands (2012–2016)

\$126 million

The Room for the River Program was a Dutch initiative to unbuild development in floodplains and provide more space for inland flooding.

H+N+S Landscape Architects completed the most complex of the thirty-three projects, involving an artificial island that also serves as a dike and a bypass channel with a bridge and pathway that flood.

The project integrates recreational space with ecological wetland planting and creates a flood protection barrier. This barrier is used by residents for half the year and is flooded during the remaining half.

Resistance: **Remain in Place**

Floodgates/Flood Barriers

COSTS

\$10,000/ft³

LIFESPAN

30+ years

SITING FACTORS

Bathymetry, wave energy

DECISION MAKER(S)

State government, US Army Corps of Engineers, municipal government, federal government

Floodgates are adjustable gates that prevent storm surge from flooding coastal areas. These structures are usually integrated into larger flood-protection systems. They are situated at the mouths of estuaries and river outflows, and allow water to pass under natural conditions. However, the structure closes in the event of an impending storm.⁵⁵

These structures can eliminate storm surge-based flooding without significant environmental impacts, but they are time-consuming, expensive, and require significant engineering capabilities. Floodgates also pose equity issues as their high expense tends to limit their implementation to wealthier areas.



Awakening/Corbis, "The MOSE project may not be enough to keep the city dry", *Curbed*, 2020

CASE STUDY

MOSE

Venice, Italy (1976–)

\$6 billion

MOSE is a semi-permeable steel flood barrier that is deployed at three entrypoints to the Venice lagoon. Each barrier is thirty meters long and twenty meters wide and are embedded in concrete chests under the lagoon. The barriers are designed to be invisible during dry conditions. During flooding and storm events, the barriers are raised with air. At other times they are filled with water and sunk below the surface of the water.

The project is controlled by an artificial island with a team of one hundred engineers and technicians and requires careful monitoring and maintenance. The barriers will be effective until sea level rise or storm surge exceeds ten feet.

Resistance: **Remain in Place**

Groins/Jetties

COSTS

\$1.6 million/groin,
\$25,000/mile annual
maintenance costs

Groins and jetties are typically short structures attached perpendicular to the shoreline, and extend across at least part of the beach out into the surf zone.⁵⁶

LIFESPAN

5+ years

They can accelerate erosion on the front or up-shore side of the structure and deflect waves onto unprotected areas, creating adverse impacts in adjacent communities.

SITING FACTORS

Bathymetry, wave
energy

DECISION MAKER(S)

Property owner,
municipal
government, state
environmental
agencies, US Army
Corps of Engineers

Resistance: **Remain in Place**

Levees

COSTS

\$34.4 million/mile

LIFESPAN

20+ years

SITING FACTORS

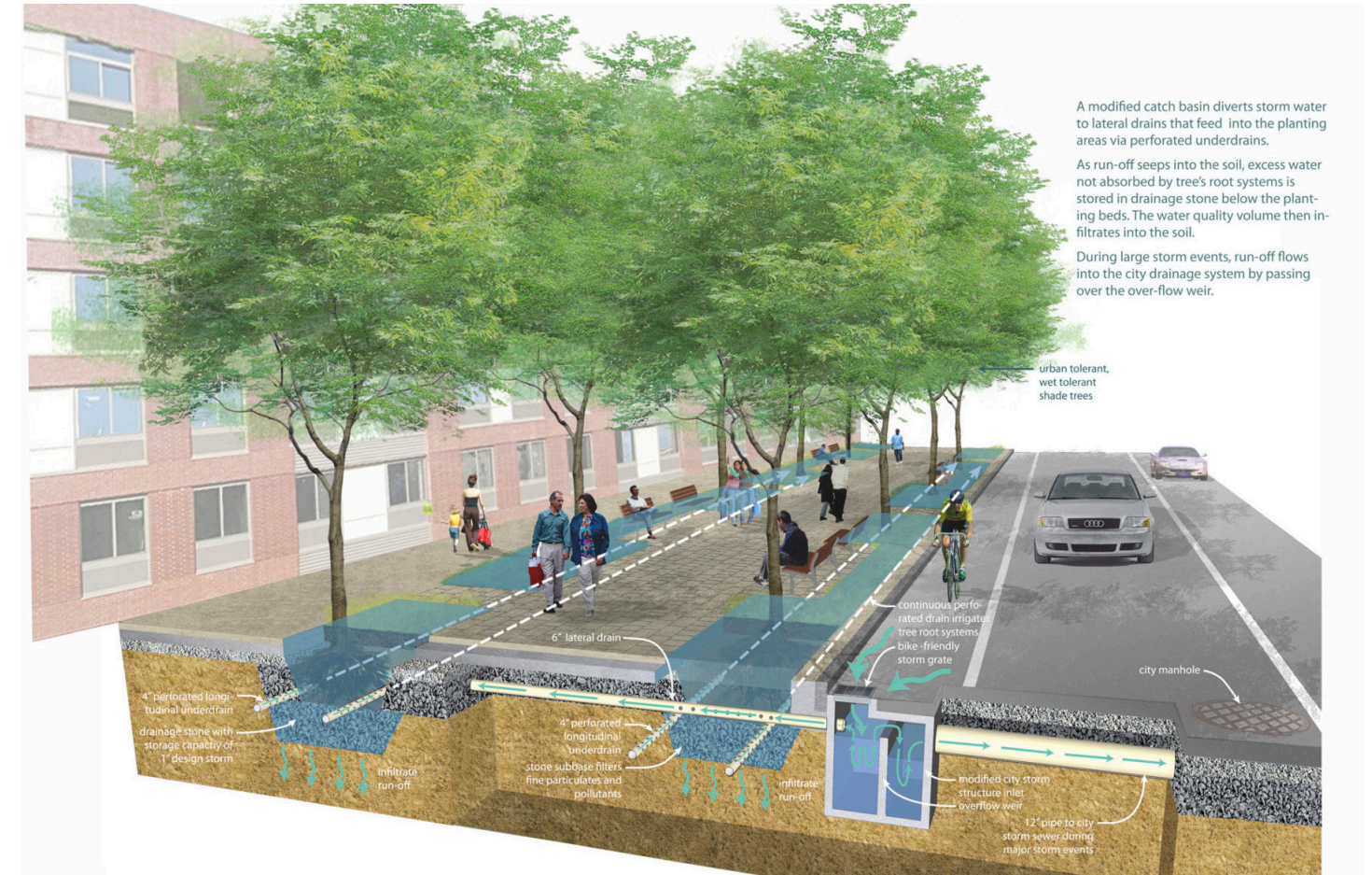
Bathymetry, topography, wave energy, existing development

DECISION MAKER(S)

State government, US Army Corps of Engineers, municipal government

Levees are solid constructed walls that prevent elevated water levels from causing flooding in interior lowlands. They are used to prevent flooding from rainfall runoff or storm surge that travels upstream along stream or river channels along the floodplain.⁵⁷

These structures are deployed around existing developments or critical facilities. Levees are expensive and can encourage floodplain development, increasing risk. If levees are not properly maintained, the risk of failure and catastrophic damage increases dramatically.



Sasaki, Cedar Rapids Riverfront, 2010

CASE STUDY

Cedar Rapids River Corridor Redevelopment Plan⁵⁸

Cedar Rapids, Iowa, USA (2010)

Sasaki and the USACE led a team of engineers and consultants to complete a masterplan for Cedar Rapids, Iowa. In 2008, the Iowa Flood inundated the city and flooded over 5,000 homes.

The plan proposed a flood management strategy with a greenway that increases connectivity to the river through the city. It transforms six hundred and fifty parcels that were damaged beyond repair into civic open space that clears part of the hundred-year floodplain.

The project's flood management solutions include permanent flood walls, removable flood walls, gates, and a levee and greenway system.

Resistance: **Remain in Place**

Living Breakwaters

COSTS

\$45–\$1,661/ft²

LIFESPAN

5+ years

SITING FACTORS

Bathymetry, topography, winter temperatures, wave energy, substrate

DECISION MAKER(S)

State government, US Army Corps of Engineers, property owner, municipal government

Living breakwaters are breakwaters that are designed to incorporate natural habitat components, including oyster, mussel, or hard coral habitats.⁵⁹

Living breakwaters are generally constructed in deeper water with energetic wave climates. The US Army Corps of Engineers (USACE) determines the allowable materials for artificial reefs with state agencies that have jurisdiction over marine resources.



Joseph Sullivan, *Sacred Heart University Living Shoreline*, 2020

CASE STUDY

Stratford Point Living Shoreline Project^{60 61}

Stratford, Connecticut, USA (2010–)

\$455,000

This one-thousand-foot living breakwater uses pre-cast reef balls at mean-tide elevation seventy-five feet offshore and is supplemented by the restoration of low and high marshes and the dune behind the reef. The project is supplemented by meadow mosaic and coastal forest planting.

The project was led by a restoration team of land managers, restoration ecologists, and environmental engineers who began by studying the local bathymetry, wind and wave trajectory, sediment loads, and the causes of erosion. The reef balls provide a habitat for oysters.

Resistance: **Remain in Place**

Replumbing

COSTS

\$50-\$200/ft²

LIFESPAN

5-30 years

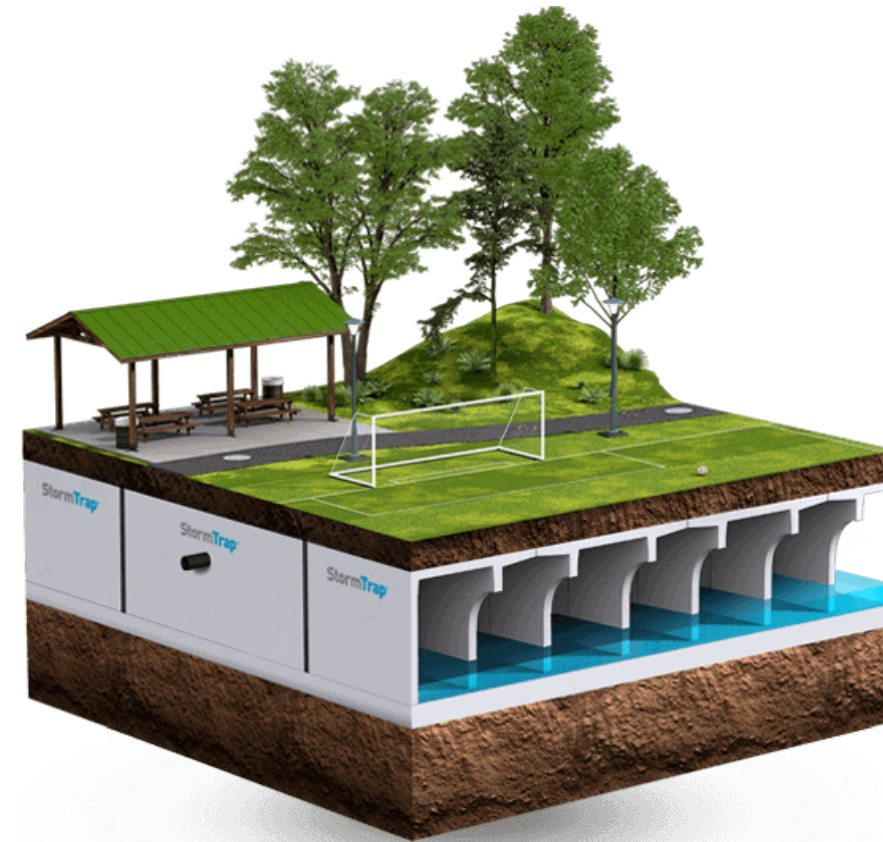
SITING FACTORS

Existing roadways,
water supply systems,
wastewater supply
systems, buildings

DECISION MAKER(S)

Municipal
government, property
owner, developer

Replumbing involves replacing stormwater infrastructure with larger capacity pipes and using vegetation and soils to infiltrate and filter polluted runoff at the source.⁶²



City of Grand Rapids, *Green Infrastructure Guidance*, (Grand Rapids: City of Grand Rapids, 2016)

CASE STUDY

Grand Rapids CSO Separation⁶³

Grand Rapids, Michigan, USA (1998-2015)

\$250 million

The original sewer system in Grand Rapids was a combined sewer system (CSS). During heavy rain events, untreated sewage flowed into the Grand River. The State of Michigan mandated that the city eliminate all combined sewer system overflows (CSOs) by 2019.

The stormwater control project increased the size of stormwater pipes and added rain gardens, pervious pavement to infiltrate runoff, and hydrodynamic separators to remove sediments. Existing roadways were narrowed and green parkways were added to decrease runoff.

Underground filtration basins provide storage for stormwater until it can be released into the river. The project also installed a series of 678 chambers to store stormwater under a municipal public park.

Revetments

COSTS

\$2,000/ft², \$5 annual maintenance costs

LIFESPAN

5+ years

SITING FACTORS

Bathymetry, construction access, erosion, wave energy

DECISION MAKER(S)

State government, municipal government, developer, property owner

Revetments are armoring materials placed on an existing slope, embankment or seawall to protect the backside area from storm-driven waves.^{64 65}

Different types of materials can be used to absorb wave action, including geotextiles, sandbags, concrete tetrapods, rocks, and wood. Revetments are low-cost coastal mitigation techniques that complement other structural approaches.

While the costs are initially less than seawalls and other hardened infrastructures, they are prone to failure without maintenance and require careful monitoring of the engineered toe. Overtopping and loss of foundation material can negate the effectiveness of this armoring approach.

Most repairs and reconstruction require a permit through a state environmental agency, including the Massachusetts Department of Environmental Protection.



Paul Bilodeau, *Back Beach*, *Gloucester Times*, 2021

CASE STUDY

Back Beach Revetment⁶⁶

Rockport, Massachusetts, USA (1930–)
\$2,320,296 to repair

The Back Beach revetment is a 940-foot-long stone riprap revetment that is fifteen feet tall. The middle of the revetment had washed out before 2009 and was replaced with cobble that is tossed up onto the houses behind the revetment during storms.

The Back Beach revetment failed in 2013 during a nor'easter and was repaired in 2017.

Resistance: **Remain in Place**

Seawalls

COSTS

\$150-\$800/ft²
residential seawalls,
\$650-\$2,000/ft²
commercial seawalls

Seawalls are vertical retaining walls built parallel to the shoreline to hold or prevent soil from sliding seaward and provide shoreline protection from waves.⁶⁷

LIFESPAN

5+ years

Seawalls accelerate erosion at other locations along the coast and increase scour and turbidity on estuarine shorelines.

SITING FACTORS

Wave energy, soil,
erosion rates

DECISION MAKER(S)

Property owner,
developer

Resistance: **Remain in Place**

Site Layout and Grading

COSTS

\$1/ft³

LIFESPAN

30+ years

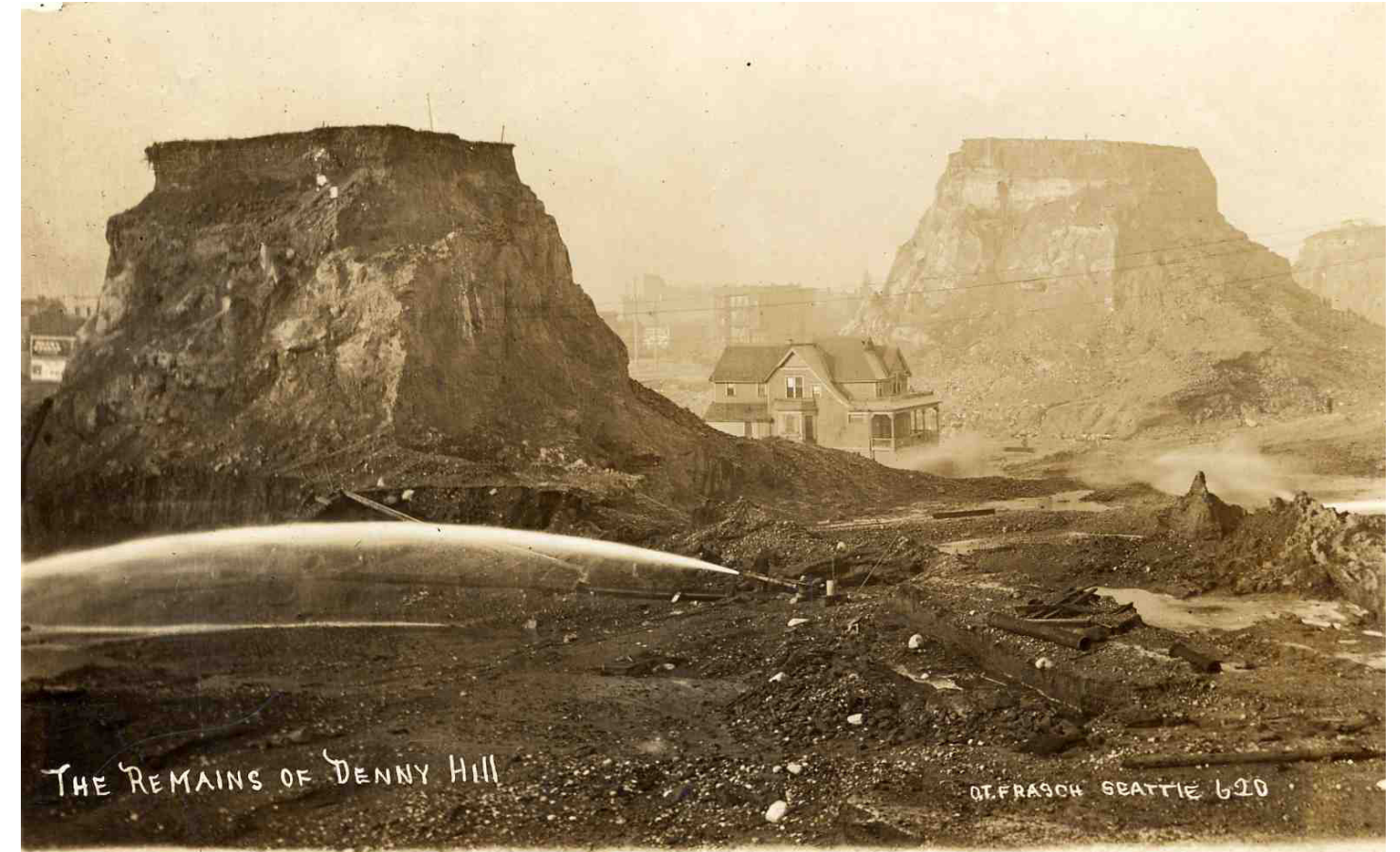
SITING FACTORS

Topography, flood risk, existing infrastructural lines

DECISION MAKER(S)

State government, municipal government, property owner, developer

Site layout and grading involves applying constraints for locating critical assets across a site in areas that are graded at higher elevations. This strategy can be applied at parcel or individual building scale or at the scale of the city or region.⁶⁸



O.T. Frasch, *The Remains of Denny Hill*, 1910

CASE STUDY

Seattle Regrading

Seattle, Washington, USA (1850–1950)

Seattle is built on large man-made islands. Over a series of fifty-eight regrading projects, the city infilled the waterfront downtown district and cut several hills to fill in the city, connecting disparate parts to allow easier movement.

The regrading movement increased land values but made establishing public infrastructure, especially streets, more difficult due to the changes in grade.

Resistance: **Remain in Place**

Temporary Flood Barriers

COSTS

\$300-\$2,000/ft+

LIFESPAN

5–10 years

SITING FACTORS

Bathymetry, topography, winter temperatures, wave energy, substrate

DECISION MAKER(S)

Developer, property owner, municipal government

Temporary flood barriers are erected immediately before a rain or storm event to protect buildings, facilities, critical assets, or multiple blocks.⁶⁹

Commercial systems require advanced site work to be deployed.



"AquaFence deployed in downtown Boston", *Level Infrastructure*, 2017

CASE STUDY

Stratford Point Living Shoreline Project⁷⁰

Stratford, Connecticut, USA (2010–)

\$455,000

The One Channel property is a 500,000-square-foot property in Boston. When FEMA updated its flood maps in 2015, the property was marked within the 100-year flood plain. The developer hired an engineering team to review future flood risk to the property, and ultimately selected a temporary flood barrier, called AquaFence, as a deployable flood barrier.

The four-foot-tall AquaFence is deployed around the perimeter of the property before storm events. The modules are interchangeable and can be bolted into bricks or other hardscaping and anchored to the ground.

Resistance: **Remain in Place**

Terps

COSTS

\$9/ft³

LIFESPAN

30+ years

SITING FACTORS

Topography, wave energy, inland flooding potential

DECISION MAKER(S)

Municipal government, developer

Terps are artificial elevated dwelling mounds built to provide safe ground during storm surges, high tides, and sea or river flooding.⁷¹

This practice originated in the Netherlands.



KCAP, *HafenCity*, 2017

CASE STUDY

HafenCity⁷²

Hamburg, Germany (2000–)

\$13.6 billion

HafenCity is an urban waterside development project in downtown Hamburg. Hamburg's industrial harbor has declined for half a century, so the city transitions toward a knowledge economy.

HafenCity is built on a raised terp eight meters above the existing high tide line. These mounds are graded to retain water to further protect the development from flooding.

The city includes low income housing, car sharing, and geothermal energy and is fully owned by the City of Hamburg and a city-owned subsidiary that acts as the master developer to finance the project's public infrastructure.

Accommodation

Strategies to remain in place and allow flooding



Bruce Roberts, *Haskell's Pond Dam*, 2018, Photograph, Gloucester, Massachusetts

Accommodation: **Remain in Place and Allow Flooding**

Blue Streets

COSTS

N/A

LIFESPAN

1+ years

SITING FACTORS

Existing roadways

DECISION MAKER(S)

Municipal
government, state
government, property
owner

Blue streets are streets regraded to channel water during flood events. These streets may be maintained or divested gradually by lowering minimum design standards for abandonment.^{73 74}



St John's County Sheriff's Office, *Flooding Caused by a Vehicle Striking a Fire Hydrant, 2021*

CASE STUDY

Environmentally Compromised Roads Ordinance⁷⁵

St. John's County, Florida, USA (2012-)

This model ordinance for the state of Florida builds on a 2012 ordinance passed in St. John's County that balances private property rights and community interests in areas under high risk of flooding from storm surge and sea level rise.

The ordinance modifies the Florida Department of Transportation minimum design standards for "environmentally challenging locations" where typical road design standards are not feasible due to repetitive naturally occurring conditions. These locations are defined as ones where costs are prohibitive.

Private property owners along the road must accept that they may need to use four wheel drive or that vehicle passage may be impossible at times.

Breakaway Walls

COSTS

\$50+

LIFESPAN

1+ years

SITING FACTORS

Building code, zoning regulations, flood zone

DECISION MAKER(S)

Developer, property owner

Breakaway walls are first-story walls on elevated homes designed to break away during storm surges.⁷⁶

Breakaway walls must break cleanly away from the building. Utilities should not be attached to or pass through breakaway walls. Homeowners and developers should expect to lose and replace these walls.

Accommodation: **Remain in Place and Allow Flooding**

Constructed Wetlands

COSTS

\$4,000-\$400,000/
acre surface-flow
wetlands, \$40,000-
\$80,000/acre
subsurface flow
wetlands, \$785
annual maintenance
costs

LIFESPAN

5+ years

SITING FACTORS

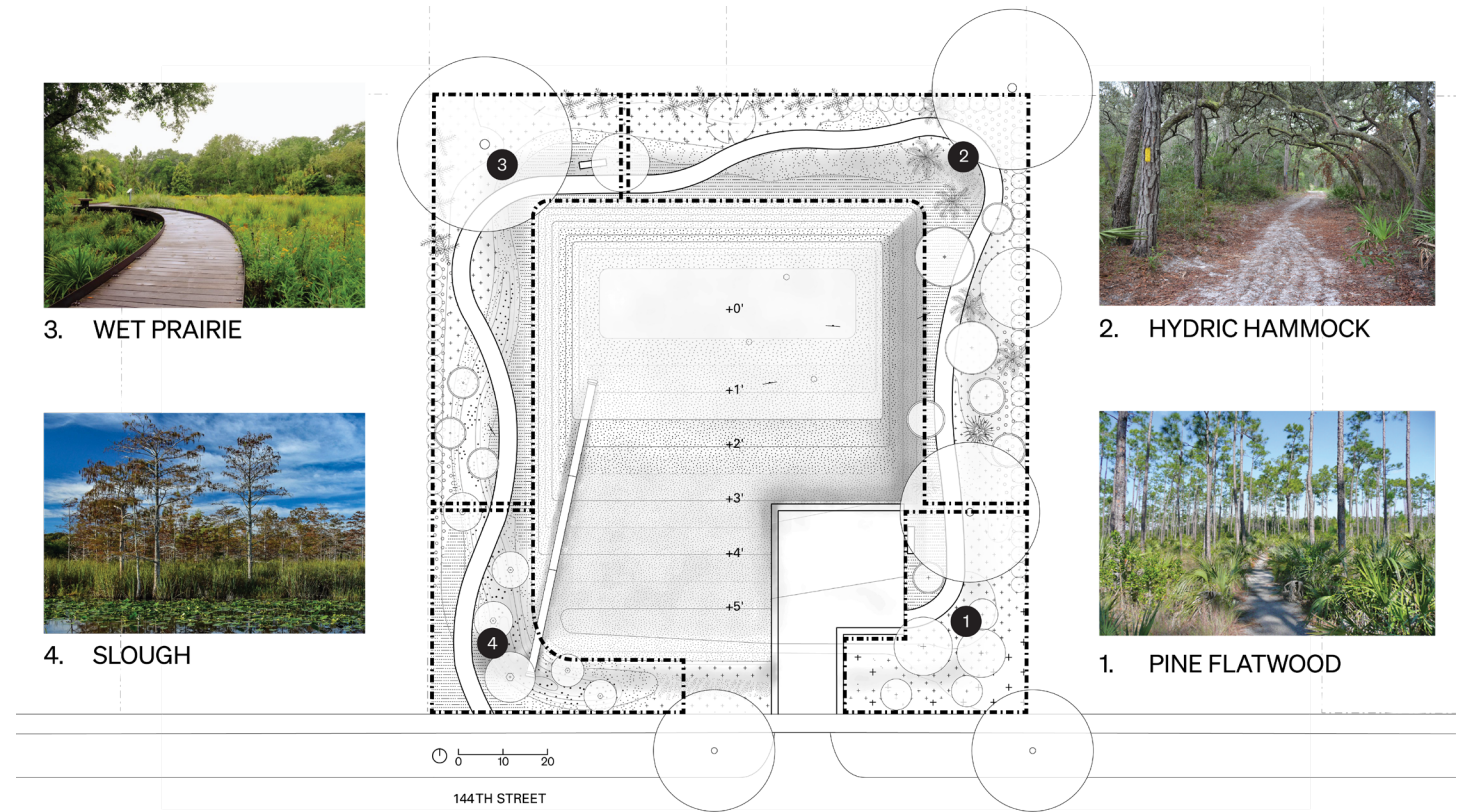
Hydrology, soils

DECISION MAKER(S)

Municipal
government, state
government, federal
government, state
environmental
agencies, NGOs

Constructed wetlands are created around structures or on vacant parcels. Wetlands function as natural retention/detention areas that collect, hold, and slowly release floodwater.^{77 78}

Constructed wetlands can be designed to reflect ecological, aesthetic, and recreational values.



Department Design Office, *Good Neighbor Stormwater Park*, 2020

CASE STUDY

Good Neighbor Stormwater Park⁷⁹
North Miami, Florida, USA (2018-)
\$65,000

This community park functions as a stormwater retention basin to reduce flooding in the neighborhood. The park is built on a repetitive loss property on a residential lot.

The project localizes floodplain management and creates community open space with a central basin that exposes the shallow water table and provides additional storage space for stormwater. The path around the park tours a demonstration garden of South Florida habitats.

Desalinization

COSTS

\$80 million+

LIFESPAN

25-30 years

SITING FACTORS

Hydrology, soils

DECISION MAKER(S)

Municipal
government, state
government,
developer, utility
companies

Desalinization is the process of removing salt from sea or brackish water to make it useable for purposes including drinking. Desalinization is used largely in the Middle East and North Africa, but will become more widespread due to saltwater intrusion and increasing salinity in groundwater areas.⁸⁰



Peter Bennetts, *The Victorian Desalination Reserve*, 2012

CASE STUDY

Victoria Desalinization Project and Ecological Preserve

Wonthaggi, Australia (2012–)

\$5.7 billion

In 2012, the Victorian Government and Aquasure consortium established a public-private partnership to build a desalination plant surrounded by 225 hectares of restored wetlands planted with low irrigation species.

The ecological preserve surrounding the desalination plant includes recreational trails that are open to the public.

Detention Areas

COSTS

\$800-\$4,470/ft²

LIFESPAN

30+ years

SITING FACTORS

Hydrology, soils

DECISION MAKER(S)

Municipal
government, property
owner

Detention areas are either dry or wet holding areas/ ponds that collect stormwater. Detention ponds are usually vegetated depressions in residential areas that hold water for a short term during flood events while otherwise remaining dry. They are most effective in well-planned communities where they can be strategically placed for maximum effect.⁸¹



Mike Bailey, "Dell Ulrich Golf Course," *Golf Pass*, 2014

CASE STUDY

Stratford Point Living Shoreline Project

Tucson, Arizona, USA (1990s-)

This golf course was redesigned in the mid-1990s with deeper depressions along the fairway to store rainwater in the event of flooding.

The golf course intercepts flow from a three-square-mile area, with the runoff ultimately draining through a large culvert into a nearby waterway. The redesign of the course mitigates flooding for six hundred residential homes that are part of a FEMA-designated flood zone nearby.

Accommodation: **Remain in Place and Allow Flooding**



Joseph Sullivan, *Sacred Heart University Living Shoreline*, 2020, photograph, Stratford, CT

CASE STUDY

Bentemplein Water Square⁸²
Rotterdam, Netherlands (2013–)
\$5.5 million

Located in a highly developed urban setting, Bentemplath Square is a public park that also functions as drainage infrastructure to collect and store water during periods of intense rainfall.

The square absorbs water from the pavement and rooftops of surrounding buildings using three concrete basins of different depths. The water is then released into the city's canal system after rainfall events. The squares also include water-tolerant planting and trees.

Accommodation: **Remain in Place and Allow Flooding**

Drainage Maintenance

COSTS

Variable

LIFESPAN

1-5 years

SITING FACTORS

Existing and proposed
stormwater facilities

DECISION MAKER(S)

Municipal
government, state
government, utility
providers

Drainage maintenance involves maintaining drainage devices (canals, ditches, storm drains, etc.) to ensure they operate effectively during a flood event.⁸³



Chesapeake Stormwater Network, "Bioretention in street median in Arlington County", *Chesapeake Stormwater Network*, 2015

CASE STUDY

Stormwater Management Master Plan⁸⁴
Arlington, Virginia, USA (2001–)

Arlington's Stormwater Master Plan evaluates the current state of stormwater management and provides a comprehensive framework to manage stormwater, streams and watersheds for the next twenty years. The plan suggests creating a single county-wide maintenance group that specifies the types of facilities that can be built as well as their engineering requirements.

The municipality already requires property owners to include maintenance agreements in land records for stormwater facilities. The plan includes a system-wide review of stormwater systems and a recognition that new construction projects and retrofitting will increase the maintenance burden. Operating budgets will be increased over time to account for maintenance costs.

Accommodation: **Remain in Place and Allow Flooding**

Flood/Garage Vents

COSTS

\$120+

LIFESPAN

5+ years

SITING FACTORS

Building code, zoning regulations, flood zone

DECISION MAKER(S)

Developer, property owner

Flood and garage vents are openings at the base of a garage that allow water to pass through the structure.⁸⁵

Negative Planning

COSTS

Variable

LIFESPAN

In perpetuity

SITING FACTORS

Variable

DECISION MAKER(S)

Municipal government, state government, planner, developer

Negative planning is a landscape urbanism approach to urban planning introduced by Chinese architect and ecological planner Yu Kongjian. Negative planning proceeds by identifying critical ecological zones, or "ecological infrastructures," which are then delimited and safeguarded through the urban planning process in order to preserve important natural assets and ecosystem services.⁸⁶

This approach can generate different scenarios for regional urban growth by overlapping landscape security patterns related to various ecological processes.

05 Large scale: Planned ecological network for biodiversity

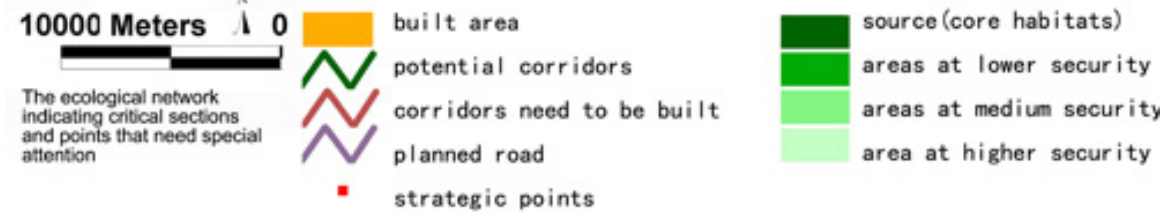
Using landscape ecological principles, an ecological network was designed. In this map, strategic points and critical areas were also identified for special management attention and design specifications.



under pass for species and flows



ecological bridge for animals



Turenscape, *Biosecurity Pattern*, 2005

CASE STUDY

Taizhou Ecological Infrastructure

Taizhou, Zhejiang, China (2004)

Turenscape developed an ecological infrastructure system to guide and frame urban sprawl in the city of Taizhou. They used suitability analysis, minimum cost distances and surface models to identify security patterns for ecological infrastructures, which were ranked from low to high security levels.

Using these ecological infrastructure systems, Turenscape proposed three scenarios of regional growth patterns: an adjusted sprawl scenario, an aggregated scenario, and a scattered scenario. Comparative impact evaluations for each scenario were made by a planning committee including state and federal government officials and government agencies.

The proposal uses the sponge city concept, which incorporates urban water management into urban planning policy and design.

Retention Areas

COSTS

\$6–\$12/ft³

LIFESPAN

5+ years

SITING FACTORS

Floodplain, hydrology, soils

DECISION MAKER(S)

Municipal government, land owners, NGOs

Retention areas are either dry or wet holding areas/ ponds that collect stormwater. Retention ponds always contain water and store floodwater by allowing it to infiltrate slowly. These facilities are usually placed in full view as amenities (e.g., lakes).⁸⁷

While this adds value to a community or region, retention areas must incorporate long-term management to ensure they do not overflow during heavy rains. They are most effective in well-planned communities where they can be strategically placed for maximum effect.



City of Salisbury, "Unity Park," 2012

CASE STUDY

Salisbury Stormwater Harvesting

Salisbury, Adelaide, Australia (2009–2012)

\$9 million

The Salisbury government in Adelaide, Australia, secured a grant to fund a bio-filtration park that includes retention ponds that harvest stormwater each year. During large storms, the park becomes a wetland: ponds collect the stormwater before slowly draining it, and additional urban runoff, using bio-filtration.

The city also employs additional water-sensitive urban design principles to minimize hardscaping and reduce the amount of urban runoff.

Underground Cisterns

COSTS

\$130-\$200/ft³, \$13/ft³
annual maintenance
costs

Underground cisterns are large stormwater holding areas located underground. They are expensive to build and require viable soil substrates to properly maintain their function.⁸⁸

LIFESPAN

30+ years

SITING FACTORS

Soil, existing
infrastructure, flood
frequency and
intensity

DECISION MAKER(S)

Municipal
government, state
government,
developer, property
owner



Kentaro Takahashi, "Underground surge tanks," *The New York Times*, 2017

CASE STUDY

Kasukabe Surge Tanks⁸⁹

Kasukabe, Japan (2006–)

\$2 million

Kasukabe's cistern system comprises five vertical underground cisterns that were dug two hundred and fifty feet into the ground. These cisterns take in storm water from four rivers north of Tokyo. The cisterns are connected by tunnels to a vast tank where floodwater is discharged by pumping at a controlled pace into Tokyo Bay.

The system is dry between floods, when the government runs tours of the complex.

Accommodation: **Remain in Place and Allow Flooding**

Wetland Enhancement

COSTS

\$228,657/hectare,
\$11/hectare annual
maintenance costs

Existing wetlands may be enhanced by highlighting and/or incorporating ecological, aesthetic, and recreational features.⁹⁰

LIFESPAN

5+ years

SITING FACTORS

Hydrology, soils

DECISION MAKER(S)

Municipal
government, state
government, state
environmental
agencies, developer,
property owner



Kristin Foresto, *New Restoration Underway at Tidmarsh, 2020*

CASE STUDY

Tidmarsh Wildlife Sanctuary⁹¹

Plymouth, Massachusetts, USA (2018–)

\$13,600/acre

This former cranberry farm was restored to wetlands by the MIT Media Living Laboratory and Mass Audubon. The project included removing seven earthen dams, laying three thousand logs to restore stream channels, and required laying trails and paths for recreational visitors and birdwatchers. The topography includes “pit and mound” designs for resilient and diverse flora.

Accommodation: **Remain in Place and Allow Flooding**



Joseph Sullivan, *Sacred Heart University Living Shoreline*, 2020, photograph, Stratford, CT

CASE STUDY

Zhongshan Shipyard Park

Zhongshan, Guangdong, China (2002–)

Turenscape built this urban waterfront park on the site of an abandoned shipyard originally constructed in the 1950s. The site preserves the cultural heritage of the shipyard and recycles materials found on-site. The firm built a series of wooden bridges at various elevations with terraced planting, including saltmarsh species, so the park can flood during periods of heavy rainfall. The project employs large formal elements to highlight the abandoned rust docks and machinery.

Avoidance

Strategies to move out of the way



Kathy Chapman, *Moving Day*, 2012, Photograph, Gloucester, Massachusetts

Avoidance: **Move Out of the Way**

Abandon Lowest Floor

COSTS

Variable

Some may choose to reduce flood damage by abandoning the lowest floor of their home, instead using it for storage, parking, or access.^{92 93}

LIFESPAN

10-30 years

The floor can be filled to the lowest adjacent grade or enclosed in latticework or insect screening to minimize obstruction. The abandoned floor should include flood vents to allow water to pass through. It is critical to ensure that there is access from the grade to the lowest floor.

SITING FACTORS

Sea level rise, storm surge

DECISION MAKER(S)

Property owner

Acquisition/Buyout

COSTS

\$479,000/unit

LIFESPAN

In perpetuity

SITING FACTORS

Flood hazards

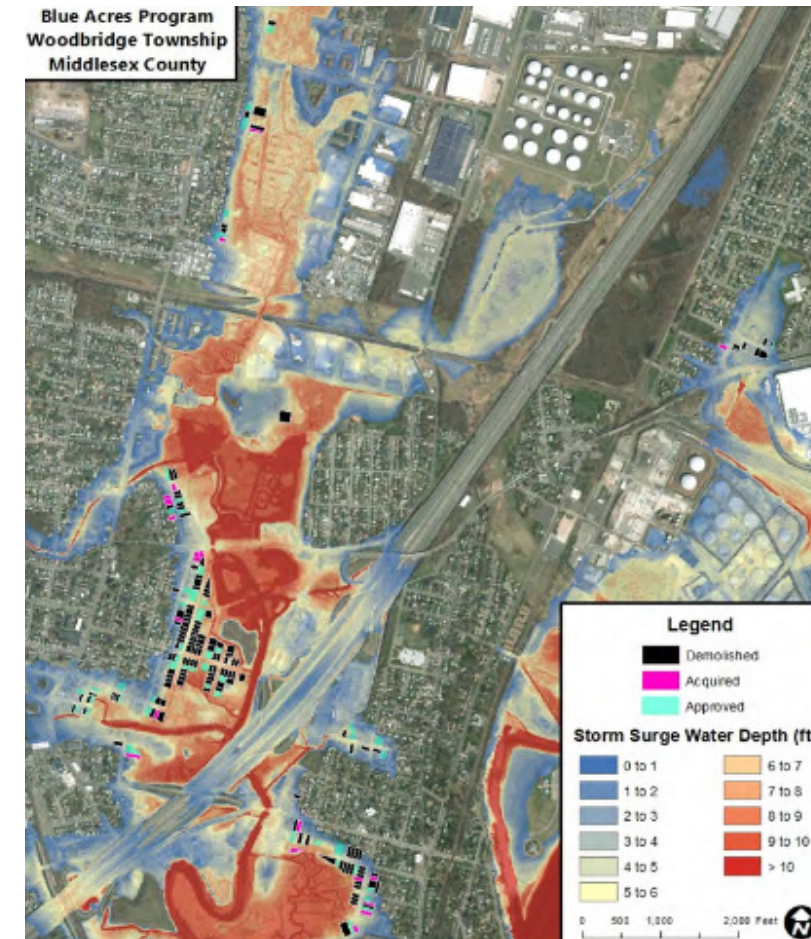
DECISION MAKER(S)

Property owner,
FEMA HMGP, state
government, local
government

Acquisition involves purchasing some or all property rights for open space protection for flood mitigation. Acquisitions can remove residents from harm's way while compensating them financially. Buyouts can protect natural habitats and return the land to its natural flood function while creating open space amenities for local residents, but can also reduce a municipality's tax base.⁹⁴

These are voluntary measures that target the most chronically and severely damaged properties. The land that is acquired cannot be developed again but can be used for an open space purpose specified by FEMA, including wetland restoration, wildlife refuges, gardens and campgrounds. Buyout programs must consider household income, as lower income households have fewer resources to move and compete with higher-income households in neighborhoods with fewer risks. Floodprone populations tend to be low-to-moderate income groups with high nonwhite populations and high rates of renter-occupied housing.

FEMA's Hazard Mitigation Grant Program (HMGP) provides 75% of funds needed for a buyout and requires a 25% match from state or local government. Buyout programs were used in the northeast after Hurricane Sandy in 2012 in New York, New Jersey and Connecticut, but they have been used more frequently in Midwestern America around riverine floodplains.



Woodbridge Township and New Jersey Blue Acres Program, *Woodbridge Buyouts* (Woodbridge: Woodbridge Township, 2013)

CASE STUDY

Woodbridge Township Blue Acres Buyouts⁹⁵

Woodbridge, New Jersey, USA (2012–)

\$2.5 million+

The New Jersey Blue Acres Program began in 1961 to preserve open space in New Jersey. It was funded by the Blue Acres Bond Act in 1995 and again in 2007 and 2009. The program uses a willing seller approach that identifies properties that have suffered repetitive or severe repetitive losses.

In 2012, after Hurricane Sandy, Woodbridge Township offered over two hundred residents buyout offers. These offers were given to residents along a 120-acre area adjacent to the Woodbridge River containing homes that were most significantly affected during Hurricane Sandy.

The town established an Open Space Conservation Zone to create a natural flood buffer after demolishing the existing homes. The township has a history of tidal and fluvial flooding, which is exacerbated by impervious surfaces and the limited availability of open spaces.

The Blue Acres program operates outside of active disaster recovery contexts.

Asset Realignment

COSTS

\$4 million-\$10 million/
mile

LIFESPAN

10+ years

SITING FACTORS

Topography, existing
roadways, wave
energy, sea level rise,
erosion, sensitive
habitat

DECISION MAKER(S)

Municipal
government, state
government

Asset realignment involves relocating or realigning assets to less vulnerable locations. This approach can be used on high-risk segments, roads or entire transportation systems that are threatened by erosion, frequent inundation or washout from storms.⁹⁶

This approach encourages long-term planning and cost-effective investment. Road realignment can be coupled with natural systems planning, including planting marshland for coastal buffers, but may have negative environmental impacts if new or additional roadways must be constructed.



Jim Shivers, "Existing lanes of Hwy 1 with grading for new lanes", *Big Sur Blog*, 2017

CASE STUDY

Piedras Blancas Highway 1 Realignment⁹⁷

San Luis Obispo, California, USA (2015–2017)

\$19.7 million

The California Department of Transportation chose to relocate a 2.8-mile section of Highway 1 between 2015 and 2017. The road was already experiencing flood damage due to storm surge and erosion and was projected to be significantly impacted by sea level rise and extreme flood events.

The highway was shifted 475 feet inland from the coast. Previous coastal armoring work, including culverts, were removed and the oceanside area was restored, incorporating coastal prairies, lagoons, and wetlands.

Avoidance: **Move Out of the Way**



Miami Real Estate Guy, *Purdy Avenue*, 2021

CASE STUDY

Miami Beach

Miami, Florida, USA (2016–)

\$400 million

Roads along the low-lying western edge of Miami Beach are being raised by two feet and eighty pump stations are being installed throughout the city. The roads were elevated before buildings, leading to a series of lawsuits from property owners and developers whose properties are at risk of flooding from elevated roads that push water onto private property.

Additionally, the city added drains on private property without permitting, leading to additional lawsuits. Property owners are now asking the city to re-classify first floors as basements and amend the zoning code to account for the elevated streets.

Avoidance: **Move Out of the Way**

Basement Infill

COSTS

\$9/ft³

LIFESPAN

30+ years

SITING FACTORS

DECISION MAKER(S)

Municipal
government, property
owner

Subgrade basements can be infilled with gravel or other material. Basements with exits at grade can be wet floodproofed and used for parking, storage, crawl space and building access.^{98 99}

Avoidance: **Move Out of the Way**

Buffers/Setbacks

COSTS

LIFESPAN

In perpetuity

SITING FACTORS

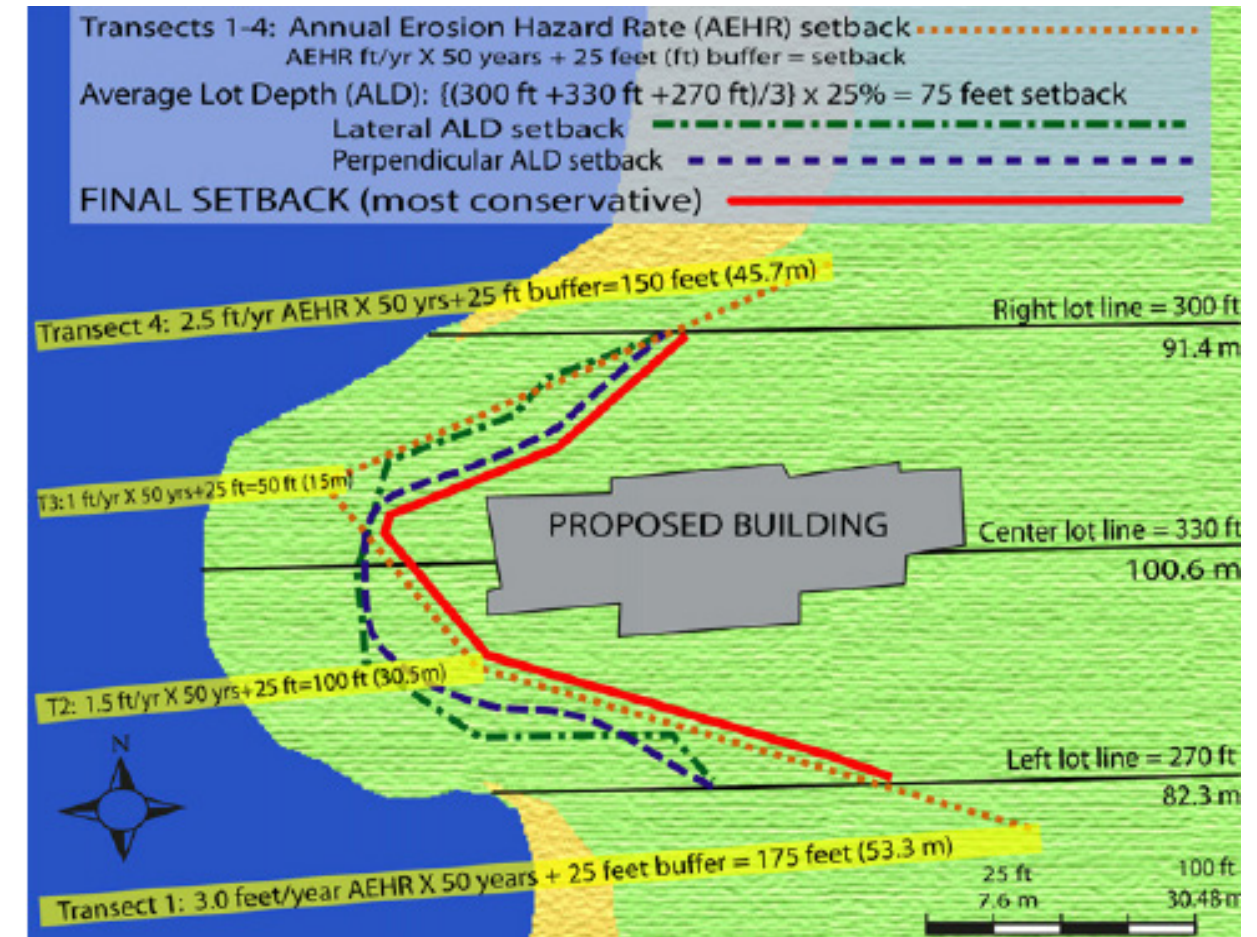
Flood zones, coastline

DECISION MAKER(S)

Municipal government, state government

Buffers or setbacks define a specific distance for which structures must be set back. Buffers are one of the most effective avoidance methods because such measures can build on existing local plans to protect critical natural habitats and regulate development in riparian areas, sensitive tidal surge areas, and other vulnerable locations. Buffer distances can vary depending on the specific locational characteristics being considered.¹⁰⁰

Governments can require that development adjacent to the shore leaves buffers to provide natural protection while allowing for upland migration of beaches and wetlands.



Kaua'i County Government, *Shoreline Setback Ordinance*, (Kaua'i: Kaua'i County Government, 2014)

CASE STUDY

Kaua'i Shoreline Setback Ordinance¹⁰¹

Kaua'i, Hawai'i, USA (2014-)

Kaua'i has the most stringent shoreline setback requirement in the nation. The ordinance regulates all land within the County that abuts the shoreline or are located within five-hundred feet of the shoreline.

The setback is based on the average erosion rate, a planning period of seventy to one hundred years, as well as a buffer of forty feet. For structures with a building footprint less than or equal to five-thousand square feet, the setback is forty feet plus seventy times the annual coastal erosion rate. For structures greater than five-thousand square feet, the setback distance is forty feet plus one-hundred times the annual coastal erosion rate. The bill also protects coastal dunes.

Avoidance: **Move Out of the Way**

Building Elevation

COSTS

\$9/ft³

LIFESPAN

30+ years

SITING FACTORS

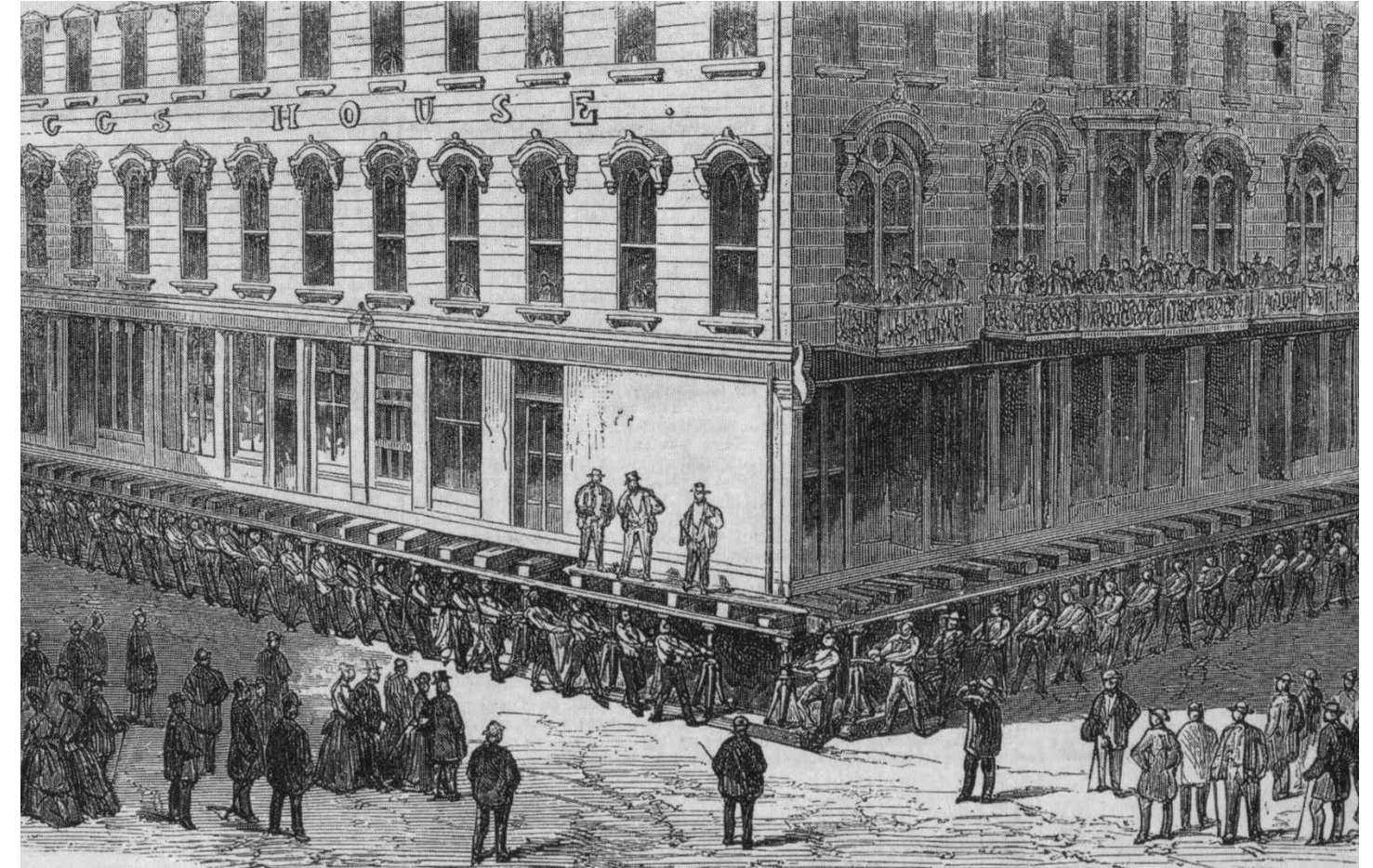
Flood zone, wave energy

DECISION MAKER(S)

State government, US Army Corps of Engineers, property owner, municipal government

Structures may be elevated above base flood levels to protect from inundation. Communities that participate in the National Flood Insurance Program (NFIP) must elevate new residential buildings in a hundred-year floodplain to or above the base flood elevation (BFE).¹⁰²

Buildings in areas with intense wave energy should be elevated on open foundations, such as piers or pilings, to allow water to flow under buildings.



Chicago Historical Society, *Raising of the Briggs House, 1866*

CASE STUDY

Raising of Chicago¹⁰³

Chicago, Illinois, USA (1858–1866)

\$455,000

The City of Chicago was not much higher than the shoreline of Lake Michigan, resulting in significant drainage issues and public health concerns that required installing a stormwater management system. In 1858, a brick masonry building was elevated six feet on jackscrews.

Fifty buildings were raised by the end of 1858, and the process continued through the 1860s. Wooden frame buildings, considered inappropriate for the city's character, were removed on rollers instead of being elevated. The work was funded by private property owners and public funds to regrade streets to meet the buildings.

Avoidance: **Move Out of the Way**

Clustering

COSTS

Clustering involves increasing the permissible development density in the least vulnerable areas within a specific property.¹⁰⁴

LIFESPAN

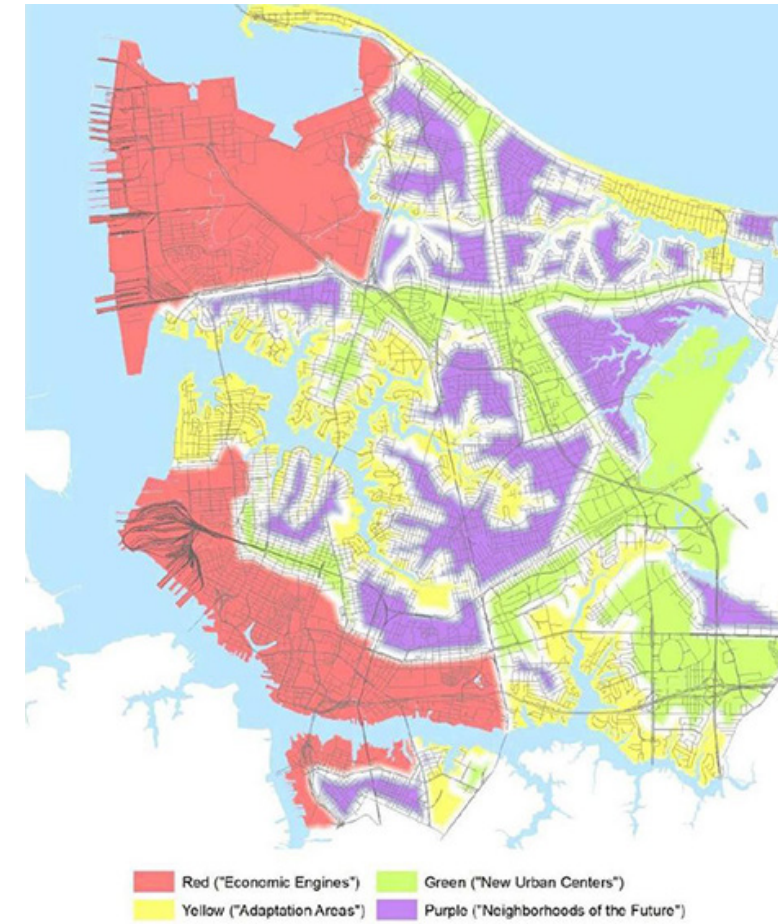
30+ years

SITING FACTORS

Flood zones

DECISION MAKER(S)

Developer, property owner, municipal government



Norfolk City Government, *Vision 2100*, (Norfolk, VA: Norfolk City Government, 2018)

CASE STUDY

A Zoning Ordinance for the 21st Century¹⁰⁵

Norfolk, Virginia, USA (2010–)

The Norfolk zoning ordinance includes innovative practices, including several overlay districts and a resilience quotient system.

The coastal resilience overlay mandates permeable surfaces on new parking spaces in addition to stormwater infiltration requirements. The upland resilience overlay applies to areas outside of flood hazard zones and includes policies that target transit-oriented, walkable, and bike-able neighborhoods.

Developers can earn resilience quotient points by going through a site review process that includes risk reduction by elevating mechanical equipment, stormwater management through site design, and energy resilience by generating electricity on site. Developers are incentivized to transfer development rights from the coastal overlay zone and acquire open space easements in the coastal resilience overlay district.

Demolition

COSTS

Variable

Demolition refers to demolishing structures, mitigating contamination, and returning land to nature in perpetuity.¹⁰⁶

LIFESPAN

In perpetuity

SITING FACTORS

DECISION MAKER(S)

Property owner,
municipal government



John Englander, "Shoreline Adaptation Land Trusts," (St. Petersburg, FL: ISGP Climate Change Arctic Program Conference, October 2-3, 2015)

CASE STUDY

Shoreline Adaptation Land Trusts (SALTs)¹⁰⁷ (2015–)

John Englander proposed the adoption of Shoreline Adaptation Land Trusts (SALTs) in 2015. SALTs are nonprofit public land trusts established pro bono for any defined area to get property into the public sector in anticipation of submergence.

Private and commercial property owners donate coastal real estate that is vulnerable to erosion and sea level rise. The owner is allowed to continue full use for his or her lifetime, subject only to sea level rise and intermittent flooding. The immediate benefit to the donor is to terminate property taxes. A second benefit is a tax-deductible gift donation for the value of the property, including the land, buildings, and infrastructure. The percentage of deductibility would decline 2% every year from the inception of SALT.

Avoidance: **Move Out of the Way**



Maritime History Foundation, Moving a House in Trinity Bay, NL, 1968

CASE STUDY

Newfoundland Resettlement

Newfoundland and Labrador, Canada (1954–)

Small fishing communities were established throughout the coastal region in Newfoundland and Labrador. In the early 1900s, major changes in resource development and a cod moratorium resulted in changing population dynamics and the de-densification of many island settlements.

In 1954, a government-sponsored resettlement program relocated 110 communities to cities with greater populations. The government provided a small amount of assistance for each family and additional cash to assist with moving costs.

Since 2010, the provincial and federal governments in Canada have partnered on a new resettlement program in which requests for resettlement must come from the communities themselves. Essential services, including electricity, are terminated in communities where 90% or more of the community elects to resettle. Each household receives compensation of \$270,000 to relocate. Eight communities have relocated since 2000.

Density Bonuses

COSTS

Variable

LIFESPAN

In perpetuity

SITING FACTORS

Existing zoning regulation

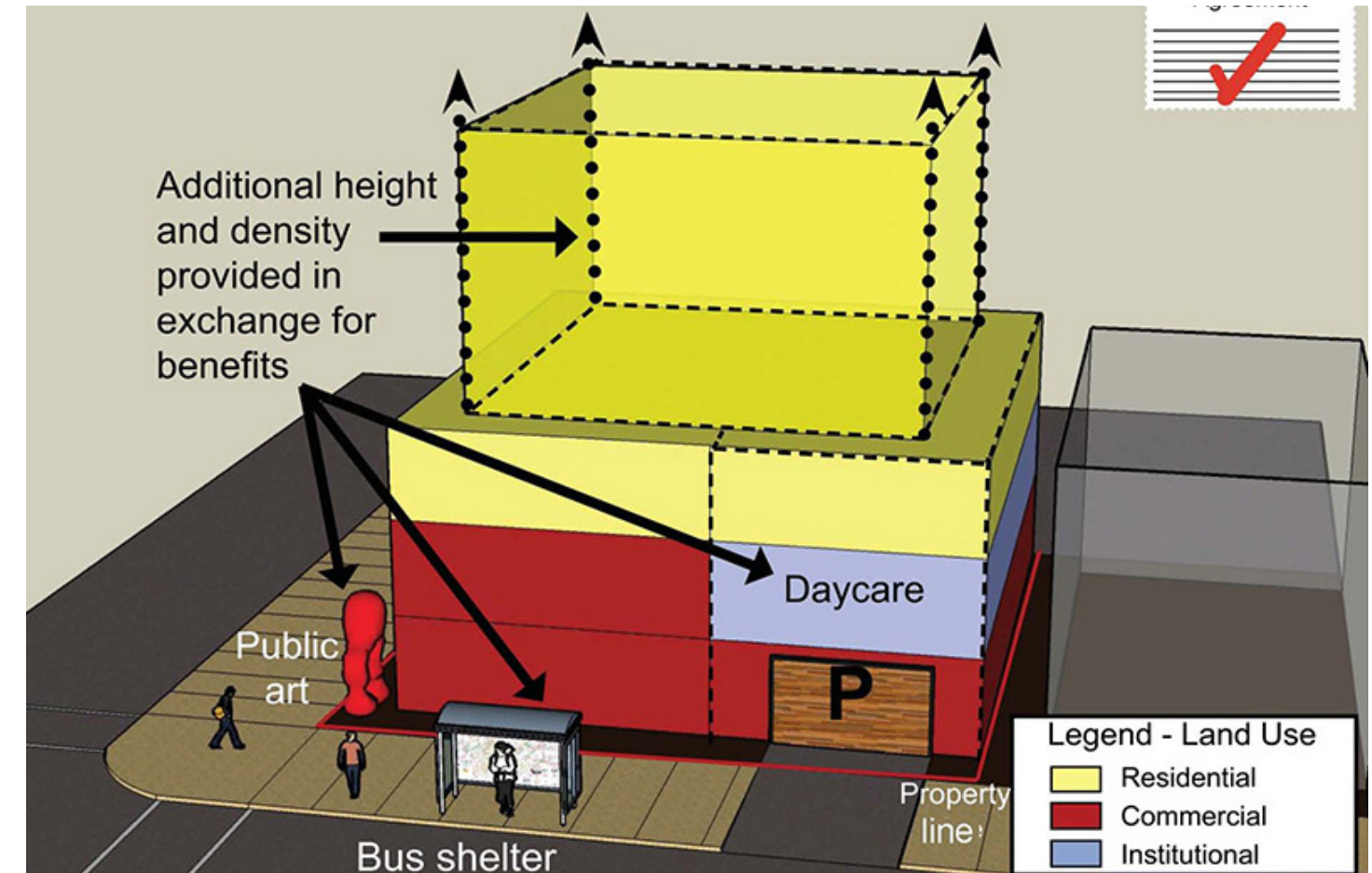
DECISION MAKER(S)

Municipal government, development, property owner

Density bonuses incentivize increased development density by increasing the number of allowable units, the floor area ratio, height restrictions or the minimum lot size and height requirements for specified parcels through a regulatory permitting process. Density bonuses are a form of infill incentive that increase density in underutilized areas within existing urban areas with developed infrastructure. They can be combined with direct financial assistance to developers and expedited permitting processes.¹⁰⁸

Density bonuses can be used to encourage green construction when combined with LEED requirements in residential, commercial, or industrial zones.

Many communities have some form of density bonus, whether to encourage infill, green construction practices, or incentivize developers to build affordable housing.



Friends of the Verde River, *Density bonus tools*, 2012

CASE STUDY

Incentive Zoning in Seattle¹⁰⁹

Seattle, Washington, USA (2006–)

\$18.95–\$23/ft³

Seattle adopted a density bonus policy in 2006 that advances two public goals: green construction and affordable housing. Achieving a LEED Silver rating is a condition for developers to gain entry to a bonus program that subsidizes affordable housing construction.

For residential construction, developers are able to increase the height of their construction between ten to fifteen floors depending on their zone. The money collected goes toward an affordable housing fund managed by the city.

For commercial construction, developers can increase their FAR by 200% from the base FAR by paying into affordable housing, at \$23 per square foot, or provide similar funds for childcare.

Avoidance: **Move Out of the Way**

Elevate Building Utilities

COSTS

Variable

LIFESPAN

30+ years

SITING FACTORS

Sea level rise, storm surge

DECISION MAKER(S)

Municipal government, property owner

Utilities and service equipment, including ductwork, heaters and electrical lines, can be elevated above grade to ensure they are not damaged in the event of flooding. This can be used as an opportunity to upgrade and increase the energy efficiency of a building's systems, leading to a reduction in greenhouse gas emissions and annual utility costs.^{110 111}

Avoidance: **Move Out of the Way**

Floodproof Building Utilities

COSTS	Building utilities, including water heaters, electrical panels, and other critical system, should be floodproofed. Non-residential structures can use dry floodproofing to seal and reinforce the interior surfaces of an entryway to protect building utilities. ^{112 113}
Variable	
LIFESPAN	Regulatory frameworks can be used to ensure that building utilities are floodproofed, including building codes and health and sanitary regulations. As part of the floodproofing process, utilities may be upgraded to adopt new technology and reduce greenhouse gas emissions and annual utility costs.
30+ years	
SITING FACTORS	
Building code, floodplain	
DECISION MAKER(S)	
Municipal government, developer, property owner	

Flotation

COSTS

\$35,000-\$1 million

LIFESPAN

10+ years

SITING FACTORS

Flood frequency and intensity, wave energy, existing infrastructure

DECISION MAKER(S)

Property owner, developer

Flotation is a building technique that floats structures on water in perpetuity or during storm events. Flotation allows development in risky areas and therefore must be carefully considered because it requires the continuous function of infrastructure along the coast.¹¹⁴

Floating development is not new: the Dutch, for example, have designed floating settlements since the 1600s. Such houses are designed for permanent wet conditions. Amphibious housing is proactive and designed to operate on dry land conditions and during flood events.

Floating houses are proposed for dense urban areas of industrial decline, urban and rural fluvial floodplains, and coastal zones with low wave energy.



"Amphibious House", *Baca Architects*, Buckinghamshire, 2017

CASE STUDY

Amphibious House¹¹⁵

Buckinghamshire, United Kingdom (2018-)

\$500,000+

The houses in the middle catchment of the River Thames were built in the 1950s with one-meter timber pilings to endure regular flooding rather than extreme flooding.

The amphibious house rests on the ground when dry and rises up on a dock and floats during floods. The dock can float up to eight feet high while maintaining utility function using elephant cables.

The landscape around the house is set into terraces that flood incrementally to specific levels. The landscape is planted with wetland species, including reeds and other shrubs, and is designed to alert residents to rising floodwaters. The terraces also improve recovery by providing dry areas as water levels drop.

Freeboard

COSTS

\$890–\$4,470/ft²

LIFESPAN

10-30 years

SITING FACTORS

Sea level rise, storm surge, wave energy, National Flood Insurance Program eligibility

DECISION MAKER(S)

State government, municipal government

Freeboard requirements elevate structures to an additional height above base flood elevation. The freeboard requirement provides an extra margin of protection that accounts for wave debris, changing future weather conditions, and new development as well as a general lack of accurate data.¹¹⁶

Freeboard requirements can be costly and difficult if the structure is a slab-on-grade design, but these costs are usually offset over time. Communities that adopt freeboard generally save \$800,000 annually in community-wide flood losses annually. Freeboard is considered the most effective of all mitigation strategies in avoiding flood losses to residential structures. They can also lower home insurance costs and offer indirect benefits, including added value at the time of sale due to lower risk and lower insurance costs.



Kira Clingen, *Portsmouth Freeboard*, 2020

CASE STUDY

Portsmouth, VA District Provisions¹¹⁷

Portsmouth, Virginia, USA (2012–)

Portsmouth includes a freeboard requirement for buildings within the floodplain and zoning ordinance. The ordinance requires three feet of freeboard for all construction. The additional freeboard does not count toward the total height of the structure.

From the ordinance: “the following provisions shall apply for the VE or V Zones (Coastal High Hazard areas). a. All new construction and substantial improvements in Zones V and VE (V if no BFE is available) shall be elevated on pilings or columns so that: 1) The bottom of the lowest horizontal structural member of the lowest floor (including all HVAC and duct work but excluding the pilings or columns) is elevated above the base flood level by at least three feet; and 2) The pile or column foundation and structure attached thereto is anchored to resist flotation, collapse, and lateral movement due to the effects of wind and water loads acting simultaneously on all building components. Wind and water loading values shall each have a one percent chance of being equaled or exceeded in any given year.”

Avoidance: **Move Out of the Way**

Infill

COSTS

\$130-\$290/ft²

LIFESPAN

In perpetuity

SITING FACTORS

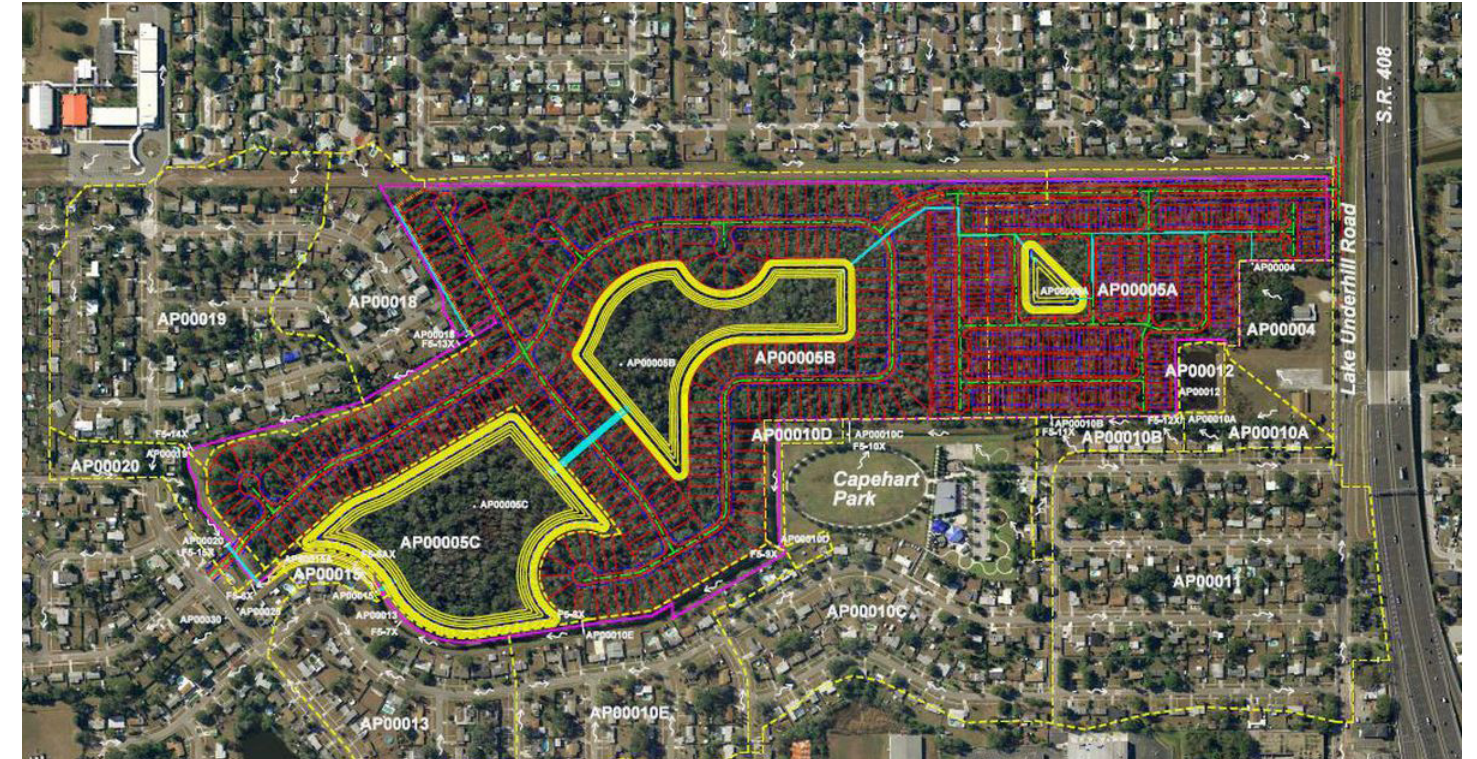
Existing zoning regulations and development

DECISION MAKER(S)

Municipal government, developer

Infill is the practice of increasing density in underutilized urban areas with developed infrastructure. It can be combined with direct financial assistance to developers and expedited permitting processes.¹¹⁸

Infill can be used to move people out of high risk coastal areas into upland zones with additional infrastructural capacity.



Orange County, Florida Government, *Infill Masterplan*, (Orange County, FL: Municipal Government, 2006)

CASE STUDY

Orange County Infill Master Plan¹¹⁹

Orange County, Florida, USA (2006–)

The Orange County infill master plan provides incentives for infilling, including recommendations for density bonuses for residential and mixed use housing developers.

The plan promotes infill development, rehabilitation, and reuse that contribute to specific infill goals. It also contributes to socioeconomic and conservation goals by including improving the rate of home ownership and conserving sensitive environmental areas.

Avoidance: **Move Out of the Way**

Land Swap

COSTS

Variable

LIFESPAN

In perpetuity

SITING FACTORS

Wetlands, existing property ownership

DECISION MAKER(S)

Property owner, developer, corporation, municipal government, state government, federal government

Land swaps involve trading land between property owners in perpetuity. This can be part of a public-private partnership, in which a municipally owned site is traded with a privately owned site, or between public agencies or private owners.¹²⁰



Spidalieri, Katie, *Managed Retreat Toolkit*, 2020

CASE STUDY

Los Cerritos Wetlands Oil Consolidation and Restoration Project

Long Beach, California, USA (2018–)

There are only a few hundred acres remaining of a former 2,400 acre wetlands site in Los Cerritos, California. These acres are privately owned by oil companies, which use the wetlands for operations.

The proposed land swap transfers 154 acres of privately owned wetlands to public ownership for five acres of wetlands currently owned by the public Los Cerritos Wetlands Authority. The land swap restores a major portion of the wetlands via a mitigation bank and increases public access while reducing the oil production footprint and consolidating operations for fossil fuel activity. The land swap has significant tradeoffs, including an expanded lifespan for oil production facilities and greater risk for oil spills.

Avoidance: **Move Out of the Way**

Low Impact Development

COSTS

Variable

LIFESPAN

5+ years

SITING FACTORS

DECISION MAKER(S)

Municipal
government,
developer

Low impact development standards and techniques are designed to work with ecological functions to manage stormwater as close to its source as possible (bioswales, rain gardens, permeable pavement).¹²¹



Karres en Brands, *Connected City*, 2018

CASE STUDY

Connected City (Oberbillwerder)¹²²
Hamburg, Germany (2018–2019)

The Connected City plan is a 124-hectare development proposed by Karres en Brands in Hamburg that links the central district to the surrounding agricultural landscape.

The development brings together residential, retail, and commercial development with affordable housing alongside recreation areas. A series of green arteries prioritizes pedestrians and cyclists and links them to the city at large.

The project emphasizes energy production through passive solar by heliomorphic design, and each neighborhood includes adaptive techniques such as wide canals, bioswales and rain beds to absorb flow, linear trenches on the side of streets, and concavely graded street profiles to protect buildings from floods.

Avoidance: Move Out of the Way

Overlay Districts

COSTS

LIFESPAN

In perpetuity

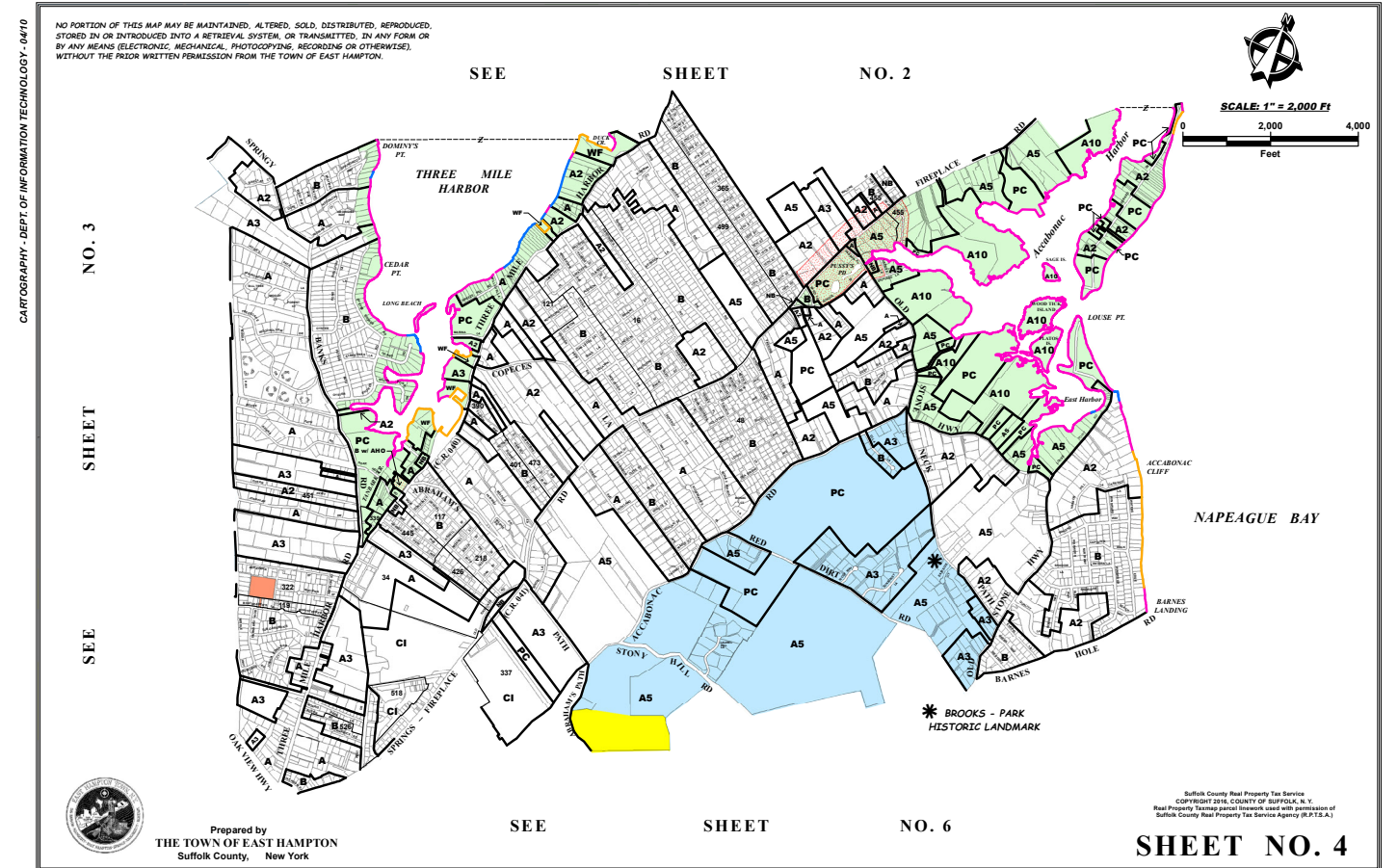
SITING FACTORS

DECISION MAKER(S)

Municipal government

Overlay districts are a regulatory tool that creates a special zoning district, placed over an existing base zone, which identifies special provisions in addition to those in the underlying base zone. Overlay districts can share common boundaries with a base zone or cut across base zone boundaries. They are used to protect a specific resource or guide development within an area. The purpose of the district must be clearly defined, with the distinct boundaries mapped and specific rules identified that apply to the district.¹²³

Communities such as Boston have proposed zoning overlay districts that include design guidelines to raise awareness of future coastal flooding risks and provide consistent standards for review for projects within the resilient overlay district. The Boston overlay district, called the Coastal Flood Resilience Zoning Overlay District, identifies areas with a projected 1% annual chance of flooding in the year 2070 with forty inches of sea level rise.



Town of East Hampton, *Coastal Erosion Overlay District on East Hampton Zoning Map*, (East Hampton: Town of East Hampton, 2007).

CASE STUDY

East Hampton Coastal Erosion Overlay District¹²⁴

East Hampton, New York, USA (2007–)

The Coastal Erosion Overlay District was established around the coast of East Hampton to protect the town's coastline and nature shoreline. These resources are considered particularly important because of their flooding and erosion prevention functions, scenic qualities, value for public recreation and water access, and their value as wildlife habitat. The district is divided into four coastal zones based on their similar features and storm exposures. The districts establish rules and standards for erosion-control structures and projects, which differ across zones.

The District is separated into four zones: the ocean coastal zone, bay coastal zone, bay coastal zone with isolated erosion control measures, and bay coastal zone with significant erosion control measures.

Parcel Fill

COSTS

\$1/ft³

LIFESPAN

30+ years

SITING FACTORS

DECISION MAKER(S)

Municipal
government, state
government, property
owner, developer

Parcel fill involves elevating landscapes with compacted soil or dirt before construction of buildings to prevent inundation. Fill is placed for an individual parcel or a series of parcels in a new subdivision before the building is put in place. The technique has been used in the United States since the 1980s.¹²⁵

Avoidance: **Move Out of the Way**

Protected Areas/Open Space

COSTS

\$1-\$150/ft²

LIFESPAN

In perpetuity

SITING FACTORS

Land value, land use

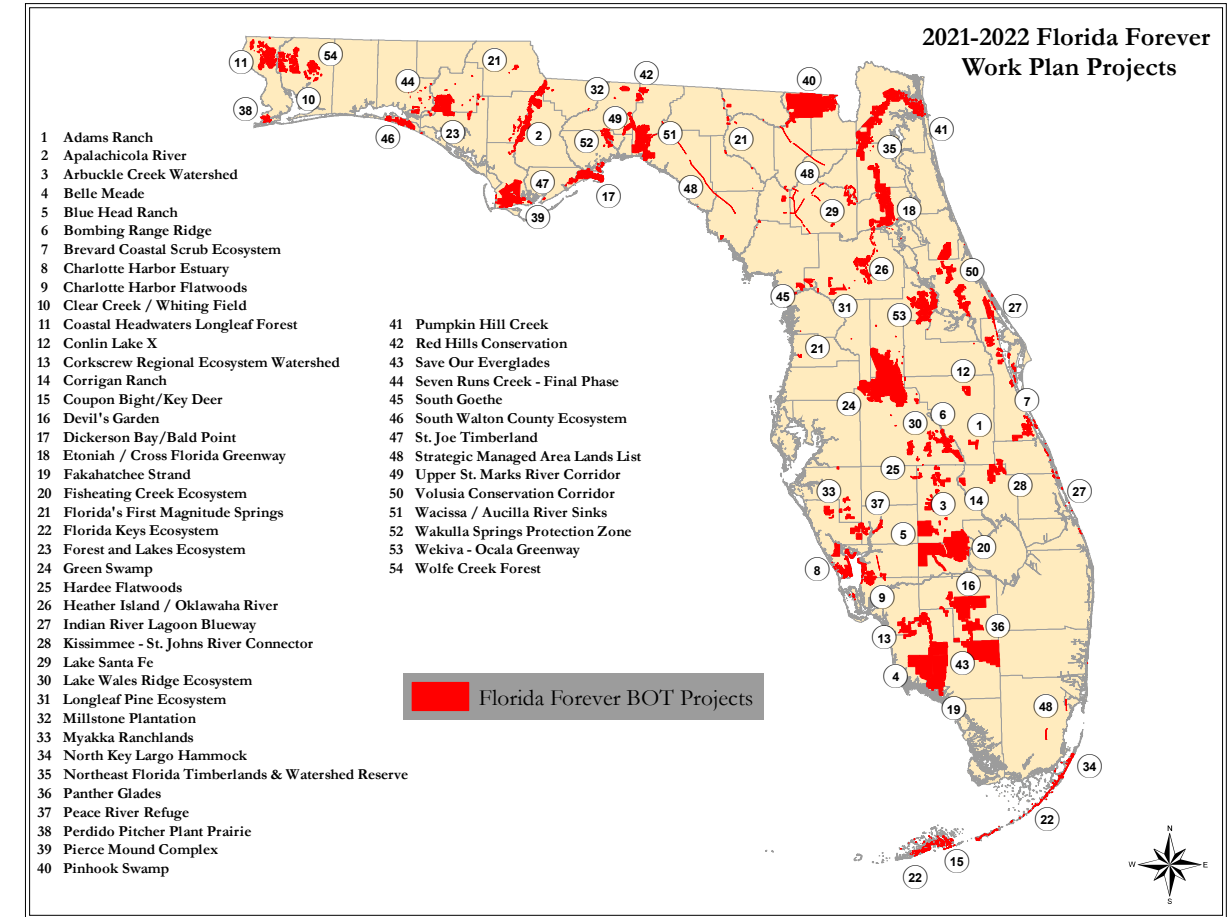
DECISION MAKER(S)

Municipal government, state government, NGOs

Designating one or multiple parcels as protected open space may be done for flood mitigation purposes. This can be achieved through different planning, regulatory and market-based means. Climate projections should be used to make informed decisions about which parcels are most important to conserve or acquire with limited funds.¹²⁶

Conservation easements are voluntary but legally binding agreements between property owners and landholding entities in which development rights are limited in perpetuity to preserve ecological functions. Conservation easements can be held by land trusts, land banks and local governments.

The economic benefits of open space is estimated at \$7,853/acre; for riparian space at \$37,493/acre.



Florida Forever Program, 2021-2022 Florida Forever Work Plan Projects, (Miami: Florida Department of Environmental Protection, 2021)

CASE STUDY

Florida Forever Program¹²⁷

Florida, USA (2001-)

The Florida Forever Act requires the Florida Department of Environmental Protection Division of State Lands to evaluate lands for acquisition based on their potential benefits to sequester carbon or adapt to climate change impacts.

The state acquires land by purchasing fee titles or interests in land through conservation easements to protect environmentally significant lands, including land for water resource protection, and historical properties.

Projects are ranked from high to low in various categories, and the projects are negotiated and purchased by the state. This process is supported by the Florida Natural Area Inventory tool, which ranks parcels with significant natural attributes based on scientific review and the program's conservation priorities.

Avoidance: **Move Out of the Way**



Texas State Historical Association, *TSHA | Greens Bayou (Harris County)*, 2020

CASE STUDY

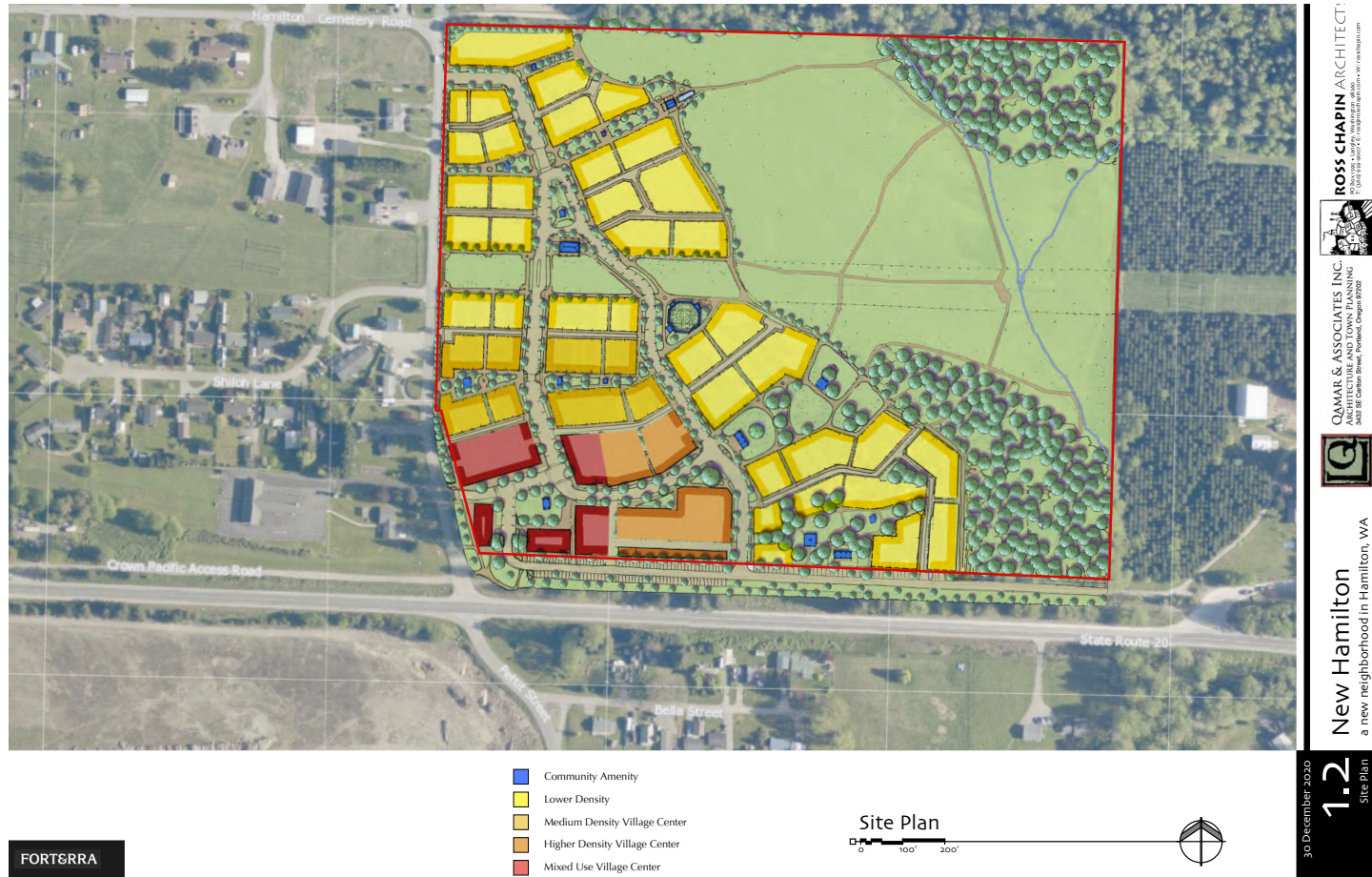
Green Bayou Mitigation Bank (Greens WetBank)¹²⁸

Houston, Texas, USA (1995–)

The Greens WetBank was first created in 1995 and includes 961 acres of ponds, marshes and forests that are protected as open space in perpetuity. Developers that build projects affecting the wetlands pay a one-time fee to the wetlands bank as compensating credits for affected wetlands, and the funds are used to implement projects to offset the loss of wetlands on sites around Harris County.

The WetBank is therefore a funding source that meets the legal requirements to mitigate the net loss of wetlands while simultaneously providing a fee-generated source of revenue to restore the environment, which results in reduced costs for Harris County.

Avoidance: **Move Out of the Way**



Forterra, *New Hamilton Masterplan*, 2019

CASE STUDY

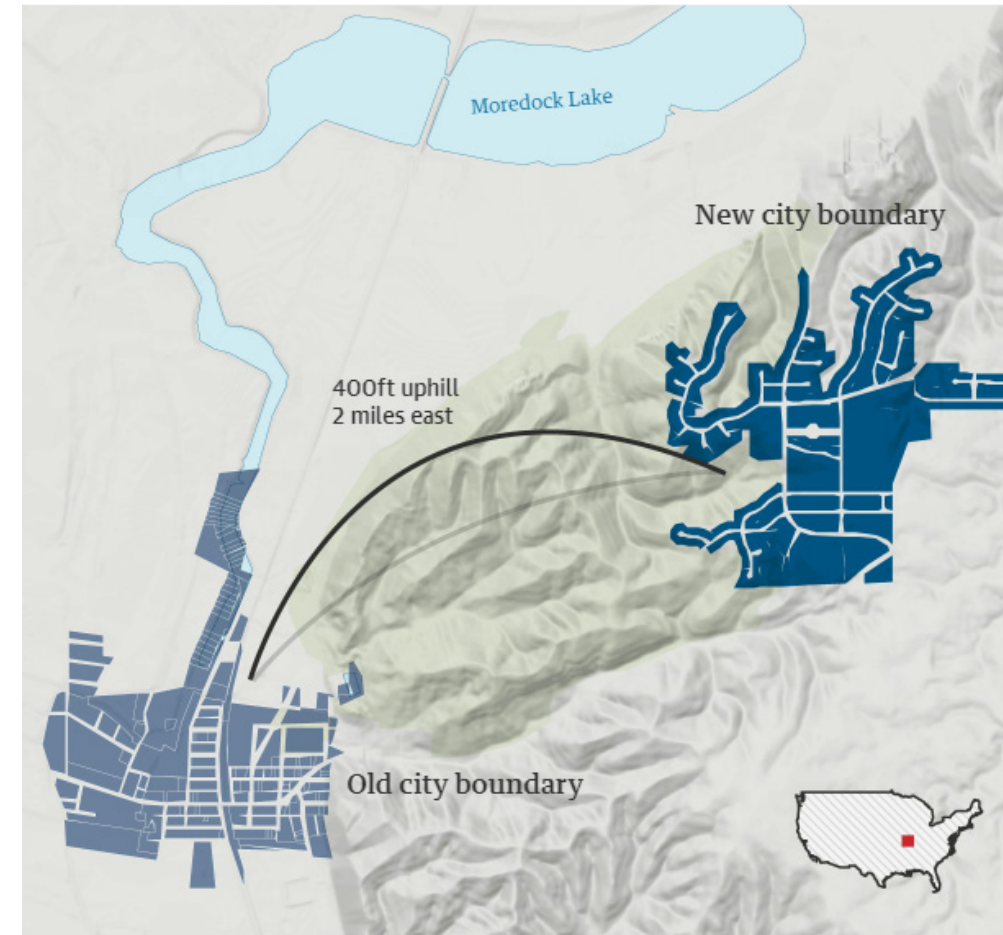
Annexing and Preparing High Ground Receiving Areas in Hamilton¹³¹

Hamilton, Washington, USA (2019–)

\$1 million

In 2019, the town of Hamilton in Skagit County formed a public-private partnership with Forterra, a local land conservancy and non-profit. The partnership annexed a forty-eight-acre parcel of land outside of the town's hundred-year floodplain. The development will be primarily residential with some commercial spaces, and includes an advanced wastewater and sewage treatment system, ample green space, and net zero housing.

The homes will be sold to current Hamilton residents interested in moving outside of the floodplain, with grants to subsidize down-payments and forty-year fixed rate mortgages. Homes in the development that are not sold to Hamilton residents will be sold at market rate to non-Hamilton residents to subsidize the affordability of homes for Hamilton residents.



Marcello Rossi, "The Illinois town that got up and left," *The Guardian*, March 14, 2022

CASE STUDY

New Valmeyer¹³²

Valmeyer, Illinois, USA (1993–)

\$35 million

After a devastating flood in 1993, the community of Valmeyer moved two miles east and four-hundred feet up. The community is small, with nine-hundred residents, and only three-hundred houses. After the 1993 flood, ninety percent of properties were deemed uninhabitable and beyond repair.

The town purchased land from a local farmer. Residents made down payments on plots of land for their new homes, generating \$500,000 for the initial payment for the land and infrastructure, including roads and a new water system.

A key factor in the success of the project was the demographics of the community: Valmeyer is a wealthy bedroom community, and residents could afford to wait to relocate.

Avoidance: **Move Out of the Way**



Louisiana Land Trust, *The New Isle*, 2019

CASE STUDY

Isle de Jean Charles¹³³

Isle de Jean Charles, Louisiana, USA (2016–)

\$48.3 million

The Isle de Jean Charles is a low-lying barrier island located in coastal Louisiana and is the home of members of the Biloxi-Chitimacha-Choctaw tribe. The island's land mass has shrunk from fifty-five square miles to eight square miles due to natural and human-made causes. The sole road connecting the island to the mainland, the Island Road, is often impassable due to high winds and tides.

In 2002, the USACE began exploring options to relocate the community, but they were met with intense opposition of tribal members.

In 2016, Louisiana was awarded \$48.3 million in Community Development Block Grants to fund work for residents to implement a structured and voluntary retreat from the island. The project includes a new development called New Isle, forty miles north of Isle de Jean Charles, that includes five-hundred homes, a community center, and commercial and retail space.

Rolling Easements

COSTS

Variable

LIFESPAN

In perpetuity

SITING FACTORS

Topography, flood zones

DECISION MAKER(S)

State government, US Army Corps of Engineers, property owner, municipal government

Easements are property interests that enable someone other than the owner of a property to use the land in a specific way. Rolling easements are a broad group of approaches for migrating inland, including removing buildings, roads, and other structures from land as it becomes submerged. The easement “rolls” upland as sea level rise and coastal erosion cause coastline encroachment.

Rolling easements do not restrict land use but prevent shore protection of coastal lands through regulation, or by transferring any right to armor the coast from owners inclined to do so to organizations that will not.^{134 135}

This approach enables ecosystems to migrate inland and avoids the costs and hazards of protecting low lands. This strategy includes local zoning that restricts shore protection, regulations that prohibit shore protection or require removal of structures on beaches and in wetlands. These strategies can be paired with property rights approaches including affirmative easements, conservation easements, restrictive covenants, migrating property lines that move as the shore erodes, and transferable development rights.

Rolling easements can preserve beaches and other eroding shores, preserve public access along the shore, help wetlands to migrate inland, and facilitate the landward relocation of roads and other infrastructures.



Peter A. Slovinsky and Stephen M. Dickson, *Coastal Sand Dune Geology*, (Augusta: Maine Geological Survey, 2011)

CASE STUDY

Maine Sand Dune Rules¹³⁶

Maine, USA (1983–)

Maine's sand dune rules combine limits on upland development with prohibitions against sea walls to create a rolling coastal management statute. The Rules provide that a project may not be permitted if, within 100 years, the property may reasonably be expected to be eroded as a result of changes in the shoreline such that the project is likely to be severely damaged after allowing for a two-foot rise in sea level over 100 years. To obtain development permits, project applicants must provide data to show how the project will be impacted by sea level rise, and new sea walls are prohibited in areas expected to suffer severe damage within 100 years. Existing sea walls may be repaired or modified only if they are relocated landward, or if they are made less damaging to dune systems. Structures that come to be located on an intertidal zone for a period of six consecutive months must be removed.

Avoidance: **Move Out of the Way**

Targeted Public Infrastructure

COSTS

Variable

LIFESPAN

30+ years

SITING FACTORS

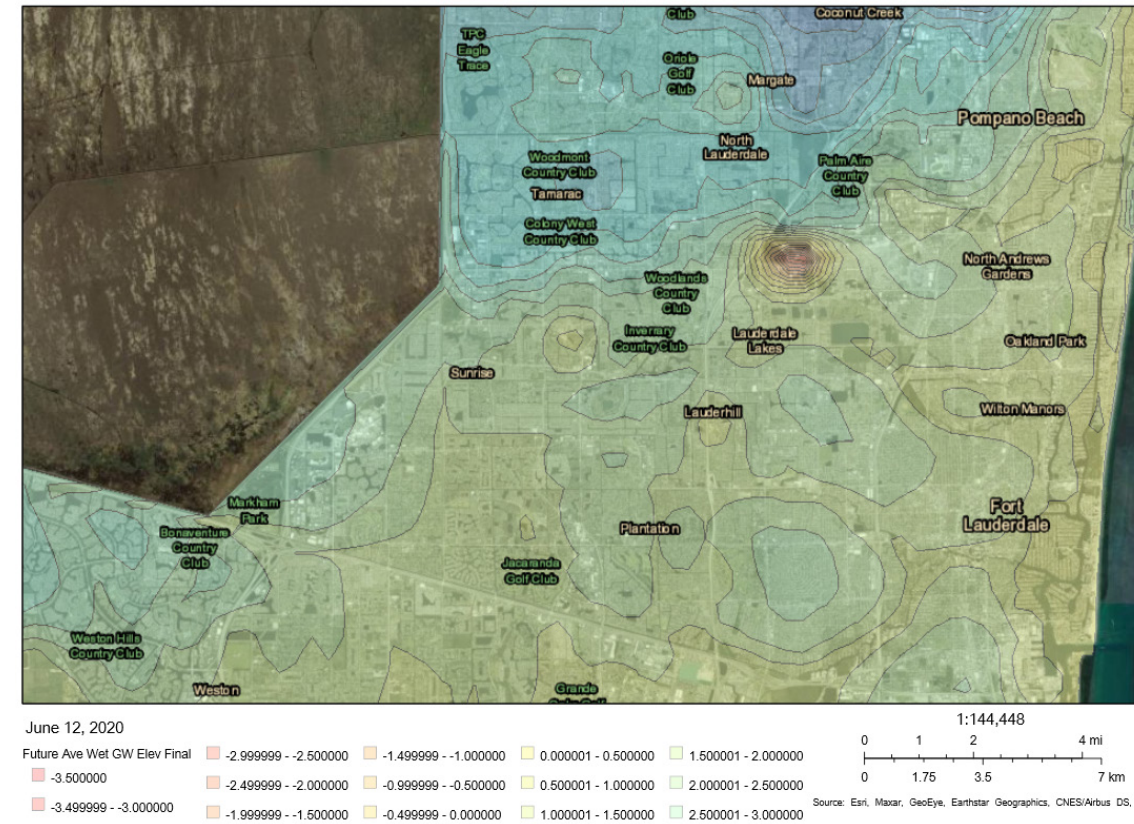
Flood zones, hazard zones

DECISION MAKER(S)

Municipal government, state government, developer

Targeted public infrastructure involves investing in public utilities and other infrastructures in the least vulnerable areas.¹³⁷

Future Conditions Average Wet Season Groundwater Elevation Map



Broward County Board of Commissioners, *2060 Future Conditions Average Wet Seasons Groundwater Elevation Map*, (Broward County: Broward County Board of Commissioners, 2017)

CASE STUDY

Future Conditions Map¹³⁸

Broward County, Florida, USA (2017-)

The zoning ordinance looks at the resiliency of current and future infrastructure investments and creates a Future Conditions Average Wet Season Water Level Map that addresses conditions predicted for the years 2060-2069.

These conditions must be accounted for in the design and construction of surface water management systems to ensure they deliver the necessary level of flood protection and water quality treatment during their expected lifespan.

Transfer of Development Rights (TDRs)

COSTS

Variable

LIFESPAN

In perpetuity

SITING FACTORS

Existing zoning regulations and development, flood zones

DECISION MAKER(S)

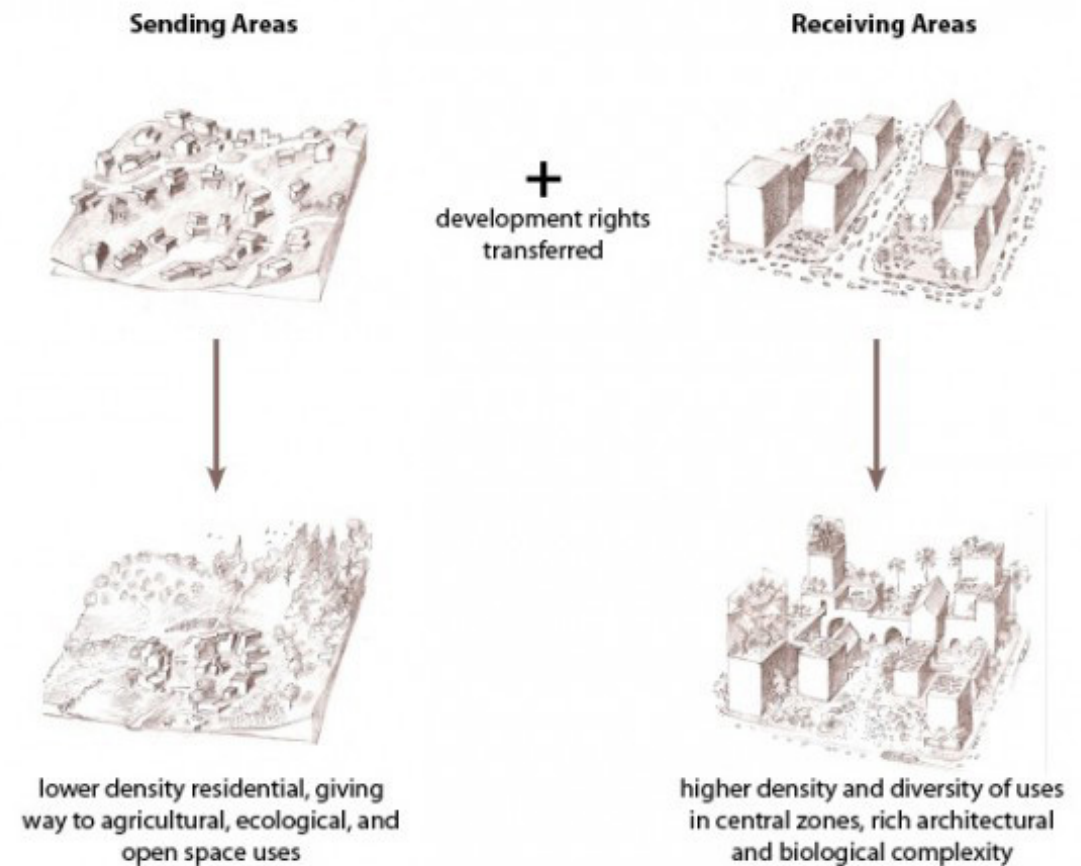
Municipal government, developer, property owner

Transfer of development rights (TDRs) move rights from a vulnerable area to a less vulnerable or sensitive area. TDRs limit potential development in vulnerable areas and compensate property owners for the reduction in property values.¹³⁹

Municipal governments can identify “sending” areas where development intensity remains low; as well as upland “receiving” areas where higher density development is more suitable.

A market can be established where landowners in the sending area are compensated for the transfer of some of their development rights to property owners in the receiving areas. The municipal government can establish a development rights land bank to acquire and retain rights within the sending district.

Governments can use TDR programs to create disincentives for development in coastal areas. They can sell TDR rights by transferring TDR credits to increase density in low-risk inland or higher ground receiving areas, and sell TDR credits to encourage property owners with high-risk developed lots to remove or relocate structures that could act as barriers for habitat migration.



Friends of the Verde River, *Transfer of development rights tools*, 2012

CASE STUDY

State of New York Senate Bill S6424A: Identifying Lands at Risk from Sea Level Rise or Flooding as Eligible Sending Districts for Transfer of Development Rights (TDR) Programs

New York, USA (2019–)

In 2019, the State of New York passed a bill that amends the State’s enable statute for TDR programs to allow local governments to create a TDR program to mitigate risks from sea level rise, storm surge, and flooding.

The language explicitly allows local governments to designate sending areas in districts that consist of “natural, scenic, recreational, agricultural or open land or sites of special historical, cultural, aesthetic or economic values sought to be protected or lands at risk from sea level rise, storm surge or flooding.”

This language allows governments to use TDR programs as a managed retreat strategy for coastal adaptation by discouraging development in high-risk sending areas and encouraging the sale of TDR credits in lower-risk receiving areas. This language can be replicated across states or written into municipal ordinances through land use and zoning regulations.

Capacity Building

Strategies to build leadership and resources



Detroit Publishing Co., *A Glimpse of Magnolia Harbor*, 1900, Photograph, Gloucester, Massachusetts

Academic Partnerships

COSTS Variable	Universities and research centers are making contributions to understand the science of climate change, coastal storms, and rising seas. There has been less attention to laying the intellectual foundation to support the expensive and socially complex measures that are needed to address these problems. ¹⁴⁰
LIFESPAN Variable	
SITING FACTORS	
DECISION MAKER(S) Academic institution	

Chief Resilience Officer (CRO)

COSTS

Variable

LIFESPAN

Variable

SITING FACTORS

DECISION MAKER(S)

Municipal
government, regional
coalition

The Chief Resilience Officer position establishes a figure to help communities develop, plan, maintain, and implement continuity and disaster mitigation and recovery plans. The officer can work in a single municipality or at the region or state level to coordinate climate planning across scales.¹⁴¹

Community Buy-In

COSTS

Variable

Engaged citizens, organized-issue-publics and advocacy coalitions can build public and political will for climate change action.¹⁴²

LIFESPAN

Variable

These groups are vital to achieving strong and sustained climate change policies. It is necessary for organizations to find, recruit, train, and deploy active citizens to build a coalition with strong community buy-in to support climate policy.

SITING FACTORS

DECISION MAKER(S)

Citizens

Amplifying citizen voices and power is crucial for building a collective sense of efficacy and sustain the movement.

Corporate Engagement

COSTS

Variable

LIFESPAN

Variable

Corporations can form mutually beneficial relationships with communities that focus on solving environmental or social objectives with significant, long-lasting, and measurable support.¹⁴³

SITING FACTORS

DECISION MAKER(S)

Corporation,
municipal government

Green Bonds/Climate Bonds

COSTS Variable	"Green" or "climate" bonds are fixed-income financial instruments used to fund projects that have positive environmental or climate benefits. Sustainability bonds must include a positive social impact in addition to positive environmental impacts. ¹⁴⁴
LIFESPAN Variable	
SITING FACTORS	
DECISION MAKER(S) Climate Bonds Standard and Certification Scheme, bank, municipal government	The Climate Bonds Initiative is an international non-profit that has spearheaded the development of green bonds. The group is a non-profit that developed the Climate Bonds Standard and Certification Scheme, a policy engagement and market intelligence network. It promotes investment in green projects and assets as part of a broader aim of transitioning to a low-carbon and carbon-resilient economy.

Green New Deal

COSTS
Variable

LIFESPAN
Variable

SITING FACTORS

DECISION MAKER(S)
Federal legislative
branch

The Green New Deal (H.Res 109) is a congressional resolution introduced in 2019 by Massachusetts Senator Edward J. Markey and New York Representative Alexandria Ocasio-Cortez that lays out a ground plan for tackling climate change. The proposal calls on the federal government to wean the United States from fossil fuels and curb planet-warming greenhouse gas emissions across the economy.¹⁴⁵

The resolution is nonbinding and builds on previous variations for climate change proposals. The resolution calls for a ten-year mobilization to reduce carbon emissions and includes funding for zero-emissions power, electric vehicles, high-speed rail, and job training. The total costs of the deal is unclear, but it would release funding to federal, state and municipal governments and agencies for climate adaptation.

Hazard Mitigation Grant Program

COSTS Variable	All states and over 20,000 local jurisdictions have Hazard Mitigation Plans, which are required to receive federal disaster assistance. ¹⁴⁶
LIFESPAN Variable	FEMA provides hazard mitigation grants to state, local, tribal, and territorial governments to rebuild after disasters in a way that reduces future disaster losses. This funding is only available after presidentially-declared disasters.
SITING FACTORS	
DECISION MAKER(S) FEMA, federal government, President, municipal government, state government	Homeowners and businesses cannot apply for grants, but local communities can apply for funding on their behalf.

Infrastructure Investment and Jobs Act

COSTS Variable	The Bipartisan Infrastructure Law is a national bill allocating \$1.2 trillion for American infrastructure, focusing on rebuilding roads and bridges, providing high speed internet access across rural and urban America, creating high speed rail and other public transit improvements, upgrading the power grid, and building resilient infrastructure. ¹⁴⁷
LIFESPAN Variable	
SITING FACTORS	
DECISION MAKER(S) FEMA, federal government, President, municipal government, state government	<p>The bill will add hundreds of thousands of jobs and release funding to state and municipal governments for infrastructural improvements.</p> <p>The bill was paired with the Build Back Better Act, which was tabled for reconsideration.</p>

Land and Water Conservation Fund

COSTS	The Land and Water Conservation Fund is supported by royalties from offshore drilling leases. Congress releases roughly \$350 million of \$900 million in funding each year, most of which are used by the federal government to purchase land based on priorities set by the Department of Interior. Some funds have been used to expand coastal parks and wetlands. The fund also matches state grants to meet their acquisition priorities. ¹⁴⁸
Variable	
LIFESPAN	
Variable	
SITING FACTORS	
DECISION MAKER(S)	
Federal government, Department of Interior	

Limit Spending

COSTS Variable	Financial disincentives can redirect state and municipal spending away from high-risk areas. ¹⁴⁹
LIFESPAN Variable	Municipal governments can limit local spending on resilience measures like beach nourishment and publicly funded investment in seawalls or protection structures, which can discourage new development or redevelopment in coastal hazard areas.
SITING FACTORS	
DECISION MAKER(S) Municipal government, state government	

Municipal Services Fee

COSTS
Variable

LIFESPAN
Variable

SITING FACTORS

DECISION MAKER(S)
Municipal government

In North Carolina, the Charlotte-Mecklenburg’s regional plan for climate adaptation includes a storm water services fee. The fee is based on a property’s impervious surface area, including rooftops and concrete driveways. It is billed in tiers based on the number of square feet of impervious surfaces, which are measured through aerial photography.¹⁵⁰

Municipal Vulnerability Preparedness Action Grant

COSTS	The Municipal Vulnerability Preparedness Action Grant offers financial resources to municipalities that are seeking to advance priority climate adaptation actions to address climate change impacts resulting from extreme weather, sea level rise, inland and coastal flooding, severe heat, and other climate impacts. These grant requests can be submitted by municipalities who have received designation from the Executive Office of Energy and Environmental Affairs as MVP Communities. Each project must be partially funded by the municipality using cash or in-kind contributions. ¹⁵¹
Variable	
LIFESPAN	
Variable	
SITING FACTORS	
DECISION MAKER(S)	
Municipal government, Executive Office of Energy and Environmental Affairs	

National Coastal Resilience Fund

COSTS

Variable

LIFESPAN

Variable

SITING FACTORS

Natural features

DECISION MAKER(S)

National Fish and Wildlife Foundation, NOAA, Shell Oil, TransRe, municipal government

The National Coastal Resilience Fund is managed by the National Fish and Wildlife Foundation with support from NOAA, Shell Oil, and TransRe reinsurance company. The fund is authorized in the National Oceans and Coastal Security Act and supports projects that that restore or expand natural features (such as marshes, wetlands, and dune and beach systems) that minimize the impacts of storms on nearby communities.¹⁵²

The program is widespread but significantly underfunded. In 2019 it dispersed \$29 million in grants across the country.

National Flood Insurance Program

COSTS Variable	FEMA manages the National Flood Insurance Program (NFIP), which is delivered to the public by a network of fifty private insurance companies and NFIP Direct. Most homeowner insurance policies do not cover flood damage, so flood insurance is usually a separate policy. The NFIP provides flood insurance to property owners, renters, and businesses and works with communities to adopt and enforce floodplain management regulations in order to mitigate flooding effects. ¹⁵³
LIFESPAN Variable	
SITING FACTORS FEMA flood zones	
DECISION MAKER(S) FEMA, NFIP, municipal government	

Individuals are eligible to purchase insurance through NFIP only if they live in one of 23,000 participating communities. Communities can lower their flood insurance premiums paid by local policyholders by voluntarily adopting a range of additional flood mitigation measures through the Community Rating System.

National Sea Grant Program

COSTS Variable	Sea Grant is a network of thirty-four university-based programs and the National Sea Grant Library. The program supports coastal and Great Lakes communities through research, extension programs, and education. Sea Grant employs thousands of scientists and employs on-the-ground extension specialists who broker scientific information for communities. ¹⁵⁴
LIFESPAN Variable	
SITING FACTORS	
DECISION MAKER(S) NOAA, Sea Grant, municipal government	Sea Grant also provides instruction and tools to teachers, students, working professionals, and the public on topics related to healthy coastal ecosystems, sustainable fisheries and aquaculture, resilient communities and economies, and environmental literacy and workforce development.

Philanthropy/Foundations

COSTS
Variable

LIFESPAN
Variable

SITING FACTORS

Foundation funding for climate change can provide cash grants, technical support, build organizational capacity, and offer other forms of assistance for communities affected by sea level rise. Less than two percent of all philanthropic dollars currently go toward climate change efforts, but this number will increase in the near future.¹⁵⁵

DECISION MAKER(S)
Philanthropic organizations, NGOs, municipal government

The Rockefeller Foundation's 100 Resilient Cities Program assists cities in building more sustainable communities. The program selected one hundred cities around the world and provides them with financial and logistical guidance. It focuses particularly on helping establish a Chief Resilience Officer to lead each city's adaptation efforts. The cities have access to the solutions, service providers and partners from private, public and NGO sectors to help them develop and implement resilience strategies.¹⁵⁶

Political Leadership

COSTS

Variable

Political leadership at the municipal, state and federal levels is required to enact meaningful change, yet there is a lack of political will for climate action.

LIFESPAN

Variable

SITING FACTORS

Due to the complexity of the climate problem and the significant trade-offs involved in all forms of adaptation, it is difficult for leaders to make value judgments that necessarily benefit some stakeholders more than others.

DECISION MAKER(S)

Municipal leaders, state leaders, federal leaders, government agencies

It is critical to establish a Chief Resiliency Officer or other political leadership position with the resources and governmental support to lead climate action. Strong political leadership for climate is often fragmented across different groups or organizations or government agencies, making it difficult to effect change.

Professional Organizations

COSTS	Professional organizations have members widely distributed across the country and can contribute insights needed to help craft informed solutions to coastal flood and inundation challenges. These groups include the American Institute of Architects (AIA), American Society of Landscape Architects (ASLA), the American Society of Civil Engineers (ASCE), and American Planning Association (APA), among others. ¹⁵⁷
Variable	
LIFESPAN	
Variable	
SITING FACTORS	
DECISION MAKER(S)	
Professional associations	

Public-Private Leasing Arrangements

COSTS	Gloucester, Massachusetts and several communities in Rhode Island lease public land to private companies to establish renewable energy technologies. The three wind turbines in Gloucester's Blackburn Industrial Park are part of one such private-public partnership. In Rhode Island, underutilized conservation land is leased for large-scale solar installations. The funds from these public leases are put into a climate adaptation fund for the community.
Variable	
LIFESPAN	
Variable	
SITING FACTORS	
Publicly owned underdeveloped land	
DECISION MAKER(S)	
Municipal governments, businesses	

Risk Inundation Tax

COSTS	First proposed by environmental lawyer Joseph Sax, a risk inundation tax requires property owners facing inundation to be taxed to contribute to a fund. Once inundation occurs and ownership is transferred to the public, this fund makes a payment (with interest) back to the original owner. Around the time of inundation and de facto transfer of ownership of the property to public ownership, the fund will make a payment to the original owner based on the owner's payments to the fund, plus interest. ¹⁵⁸
Variable	
LIFESPAN	
Variable	
SITING FACTORS	
Flood zones	
DECISION MAKER(S)	
Municipal government, property owner	

Sea Level Purchasing Options (SLPOs)

COSTS

Variable

LIFESPAN

Variable

SITING FACTORS

Flood zones

DECISION MAKER(S)

Land trusts, municipal government, property owner

SLPOs are a real estate option that does not vest until sea level rise materially affects the property at issue.¹⁵⁹ A land trust or similar entity purchases a SLPO on a threatened coastal property. Once sea level rise has certain effects on that property, the SLPO vests, providing the land trust the right to purchase the property for a specified price. SLPOs initiate retreat while delaying actual withdrawal.

Service Tax Funds

COSTS

Variable

Municipal governments tax AirBnB like hotel rooms, which incur an occupancy fee. These funds can be applied to a climate adaptation fund.

LIFESPAN

Variable

SITING FACTORS

DECISION MAKER(S)

Municipal government

Shoreline Adaptation Land Trusts (SALTs)

COSTS Variable	SALTs are nonprofit public land trusts established pro bono for any defined area to transfer property into the public sector in anticipation of submergence. ¹⁶⁰
LIFESPAN Variable	
SITING FACTORS Flood zones	Private and commercial property owners donate coastal real estate that is vulnerable to erosion and sea level rise and the owner is allowed to continue full use for his or her lifetime, subject only to sea level rise and intermittent flooding. The immediate benefit to the donor would be to terminate property taxes. A second benefit is a tax-deductible gift donation for the value of the property, including the land, buildings and infrastructure. The percentage of deductability would decline 2% every year from the inception of SALT.
DECISION MAKER(S) Municipal government, property owner, land trust	

Special Taxing Districts

COSTS	Local governments can collect additional taxes that reflect the costs that communities expect to pay to safely remove private structure and support public infrastructure damaged by storms or inundation.
Variable	
LIFESPAN	A community can set up a special taxing district to impose a surcharge on annual property taxes in the amount needed to support a dedicated fund used to pay for the costs of storm damage and/or adaptation measures. ¹⁶¹
Variable	
SITING FACTORS	
DECISION MAKER(S)	
Municipal government	Des Moines, Iowa, for example, levies a one cent sales tax that funds water quality and mental health programs.

State Grant Programs

COSTS	In 2021, Rhode Island established the Ocean State Climate Adaptation and Resilience Fund. Cities, towns, and the state can apply to this fund for grants to pursue projects that restore and improve vulnerable coastal habitats. The fund gives priority to projects that improve community resilience and public safety.
Variable	
LIFESPAN	
Variable	
SITING FACTORS	
DECISION MAKER(S)	
State government	

Technical Assistance

COSTS Variable	Technical assistance involves providing targeted support to an organization with a development need or problem. Engineering and consulting firms can provide data and modeling on climate impacts, build platforms to communicate with citizens, and solve other novel needs.
LIFESPAN Variable	
SITING FACTORS	
DECISION MAKER(S) Engineering firms, NGOs, consulting firms, academic institutions	Various such efforts exist across the Northeast. MAPPR Tool, developed by the Massachusetts Audubon Society, The Nature Conservancy, and LandVest allows land conservationists to identify parcels within an area of interest based on habitat quality, climate change resilience, and other metrics, including parcel size and the adjacency to existing protected parcels. ¹⁶²

Town Meeting

COSTS
Variable A town meeting is an event or entity that serves as a gathering of a town’s eligible voters and the legislative body for towns in Massachusetts.

LIFESPAN
Variable While town meetings are open to eligible voters, they tend to bias policy discussions in favor of an unrepresentative group of overwhelmingly older, male longtime residents and homeowners.

SITING FACTORS
DECISION MAKER(S)
Municipal government, citizens Such participatory inequalities have far-reaching implications for climate action.¹⁶³

Notes

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