DESIGNING WITH WATER

CREATIVE SOLUTIONS FROM AROUND THE GLOBE

The Boston Harbor Association
A Voice for the Harbor

SASAKI

PREPARING FOR THE RISING TIDE SERIES
VOLUME 2 | AUGUST 2014

Preparing for the Rising Tide (2013) provided an initial assessment of Boston's vulnerability to coastal flooding due to storm surges and sea level rise.

This second volume in the *Preparing for the Rising Tide* series focuses on the concept of Designing with Water flood management. This concept considers coastal flooding not only a threat, but an opportunity to address multiple goals while making necessary new investments in our buildings, communities, and infrastructure.

This report provides 12 case studies describing how cities around the world are using Designing with Water strategies to decrease potential flood damage without losing the vibrancy and livability of their communities.

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DESIGNING WITH WATER: CREATIVE SOLUTIONS FROM AROUND THE GLOBE

This report is the second in The Boston Harbor Association's (TBHA) *Preparing for the Rising Tide* series. For the series, TBHA has partnered with recognized content experts—in this case Sasaki Associates—to offer policy recommendations to help Boston prepare for increased coastal flooding.

Preparing for the Rising Tide (2013) provided an initial assessment of Boston's vulnerability to coastal flooding due to storm surges and sea level rise. The report also described how to do a basic site-specific vulnerability assessment and a time-phased preparedness plan.

This second volume in the *Preparing for the Rising Tide* series focuses on the concept of Designing with Water flood management. This concept considers coastal flooding not only a threat, but an opportunity to address multiple goals while making necessary new investments in our buildings, communities, and infrastructure.

This report provides 12 case studies describing how cities around the world are using Designing with Water strategies to decrease their potential flood damage without losing the vibrancy and livability of their communities. Appendix 2 lists dozens more. We hope to inform and inspire decision makers at all scales — from individual property owners to community leaders, regional planners and elected officials -- in Boston and other communities facing coastal flooding.

The document is organized into five parts:

1) BOSTON'S WET FUTURE
describes Boston's anticipated exposure to coastal flooding.

2) DESIGNING WITH WATER
defines the idea of Designing with Water.

3) CASE STUDIES
includes twelve Designing with Water case studies.

4) RECOMMENDATIONS AND CONCLUSIONS
offers findings and recommendations for Boston, based on the case study research.

5) RESOURCES
reprints Boston's coastal flooding maps, defines key terms, and offers supplemental case studies.

CONTENTS

BOSTON'S WET FUTURE

© Sasaki Associates (depicts high tide during a 100-year storm in the year 2050 with 2 feet of projected sea level rise)

BOSTON HARBOR IS NATURALLY PROTECTIVE

Originally founded on the narrow Shawmut Peninsula, Boston was established and expanded behind the protective landforms of what are today Winthrop, Hull, and the 34 Boston Harbor Islands.

Our ancestors sited Boston well. In addition to historically providing protection against sea-based military attacks, the coastal landscape breaks up wind and waves, decreasing storm energy within the inner harbor.

Boston Harbor's protective capacity is shown dramatically in a graphic produced by GZA (Figure 1) using the Swan2D model. The model predicts that a 30-foot wave produced in the open ocean during a 100-year storm would decrease in height to less than 2 feet by the time it reached Boston's inner harbor (note: Figure 1 is in meters).[i]

In fact, Boston Harbor's shape, volume, and islands are far more effective at buffering the city against storms than New York Harbor. As a result, Boston's 1,000-year storm surge is considerably lower than New York City's 100-year storm surge (see Figure 2).[1]

i. Note: a storm surge is an increase in overall water level due to wind and low air pressure; waves are wind-generated fluctuations in surface water height.

100-YEAR WAVE CONDITION APPLIED AT WAVE BOUNDARY

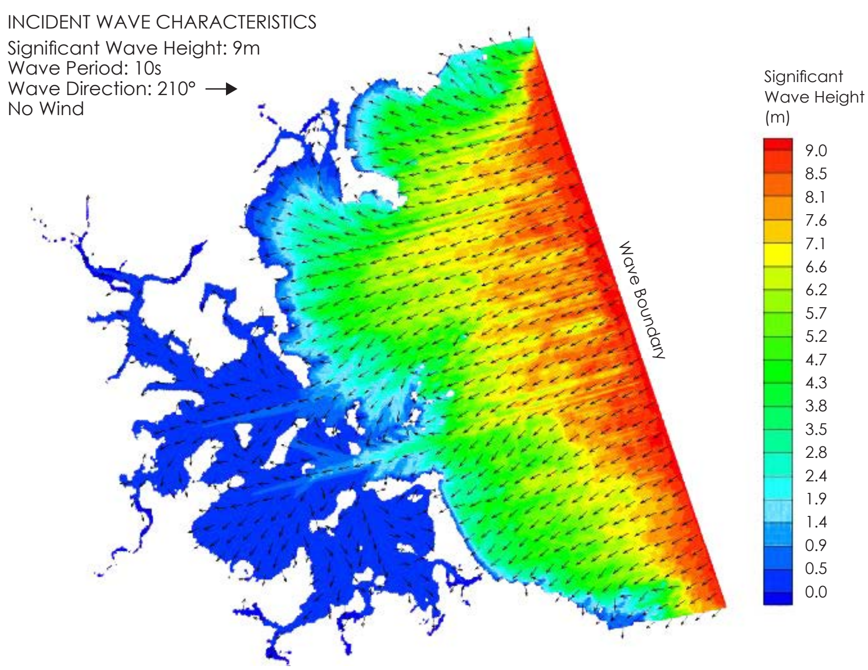

Figure 1. Results of GZA Swan 2D wave model. © GZA

100-, 500-, AND 1,000-YEAR STORM SURGE COMPARISION BETWEEN NEW YORK HARBOR AND BOSTON HARBOR

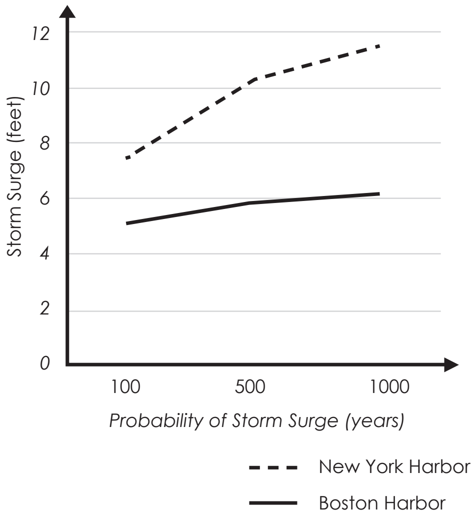

Figure 2. Relative storm surge projections for NY and Boston Harbors (photos © Google Earth, data © Dr. Ellen Douglas.)

PAST DEVELOPMENT DECISIONS HAVE INCREASED FUTURE FLOOD RISK

Over the course of three centuries, Boston's planners and developers confidently filled-in marshes and tidelands to increase the city's footprint by over 50 percent.[2] Most of the filled-in land and the subsequent neighborhoods lie between 2 and 8 feet above today's high tide.[3] Not surprisingly, these are the neighborhoods that will flood first as sea level rises.

COASTAL FLOODING WILL INCREASE DUE TO HIGHER SEAS AND STRONGER STORMS

Over the last century, sea level in Boston Harbor has increased by approximately one foot.[4] Low lying areas of Boston, including Long Wharf and Morrissey Boulevard, already flood multiple times each year during astronomical high tides (known locally as wicked high tides).

What's more, storms in the Northeastern US are getting significantly worse. According to the National Climate Assessment,[5] the amount of rainfall in the most extreme one percent of storms increased by over 70 percent between 1985 and 2010. In addition, warmer oceans are expected to increase the intensity of coastal storms.[6] With increases in sea levels anticipated to rise an additional 1 to 2 feet by 2050 and 3 to 6 feet by 2100, the extent of today's 100-year storm flood waters could become an annual storm around midcentury and the twice-daily high tide by 2100 (see Appendix 1).[7]

TIDE HEIGHT COULD BE THE DIFFERENCE BETWEEN SAFETY AND DISASTER

The timing of high or low tide makes a huge difference in the amount of coastal flooding that occurs. Tide heights fluctuate twice daily, with extra-high tides occurring around full and new moons. Maximum coastal flooding occurs when a peak storm surge coincides with an astronomical high tide (see "What Causes Coastal Flooding in Boston Harbor" sidebar).

During the Blizzard of February 1978, astronomical high tide coincided with the storm's peak storm surge. Nearly 80 MPH winds were recorded in Boston,[8] while the high water was

Figure 3. The sidewinder Peter Stuyvesant during the Blizzard of 1978. Photo property of The Boston Globe.

WHAT CAUSES COASTAL FLOODING IN BOSTON HARBOR?

Coastal flooding happens when one or more of the following conditions occur:

High tide: Wicked or astronomical high tides can add up to 2.5 feet to normal high tides.

Storm surges: New England's storms come from the east, pushing surface waters onto land. A 100-year storm can temporarily increase sea level by 5 feet.

Sea level rise: Boston has experienced 1 foot of sea level rise since the late 1800s and is expected to see up to 6 feet more by 2100.

enough to lift the sidewinder *Peter Stuyvesant* — part of Anthony's Pier Four Restaurant in South Boston — right out of its concrete and steel cradle (see Figure 3). Across New England, damage estimates topped $1 billion, with over 10,000 people displaced and 2,000 homes destroyed.[9]

BOSTON HAS A HISTORY OF NEAR MISSES

On October 29, 2012, Superstorm Sandy slammed East Coast communities from the Mid-Atlantic through the Northeast, most severely in New York and New Jersey. What was an unprecedented flood event in New York (see Figure 4), however, caused only minor flooding 200 miles to the north in Boston.

Superstorm Sandy's peak storm surge of 9.4 feet hit New York City during a full-moon at high tide, flooding the city with seas nearly 10 feet above average high tide[10] (see Figures 4 and 5).[11] In Boston, Superstorm Sandy peaked near low tide with a 4.6-foot storm surge, causing only minor flooding.[12] Because of this, Boston's maximum sea level during Sandy was only 2.5 feet above average high tide (see Figure 5).[13] Had Superstorm Sandy's storm surge peaked at high tide 5.5 hours earlier, Boston would have experienced a 100-year flood event (i.e., high tide plus 5 feet).[ii]

Less widely recognized is the fact that Boston experienced three additional near-misses in the 18 months after Sandy when storms peaked hours before or after astronomical high tides, narrowly missing 100-year flood events.[14iii] In addition, NOAA's Boston tide gauge recorded 15 instances of wicked high sea levels (high tide plus 2.5 feet) between January 2012 and April 2014.[15iv] For comparison, these sea levels had been observed just 21 times between 1920 and 1990.[16]

LEARNING TO DESIGN WITH WATER

WHAT ARE OUR OPTIONS?

In the face of rising waters and increased storm-related flooding, we cannot ignore the need to make hard

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ii. Maps depicting the areas in Boston expected to flood at high tide plus 2.5 feet, 5 feet, and 7.5 feet are provided in Appendix 1 and described in further detail in Preparing for the Rising Tide.

iii. Blizzard Nemo (February 9, 2013), Nor'easter Saturn (March 8, 2013) and Nor'easter Hercules (January 3, 2014). Names were given by The Weather Channel.

iv. Data were taken from "WL Max/Min List" reports for Boston and converted from "station datum" to MHHW by subtracting 13.8 feet.

THE BATTERY, NY

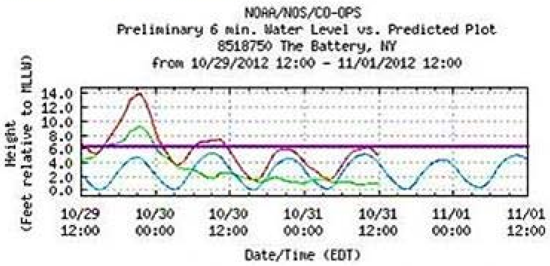

Figure 4. New York Harbor tide gauge observations during Superstorm Sandy, in feet above low tide (MLLW; NOAA, 2012). Lowest (blue) line represents predicted tide, green line is observed storm surge, and top red line is observed storm tide. The horizontal (purple) line marks the level of the highest astronomical tide, known locally in Boston as wicked high tide. At its peak, Sandy's storm tide was 10 feet above average high tide when it hit lower Manhattan.

BOSTON, MA

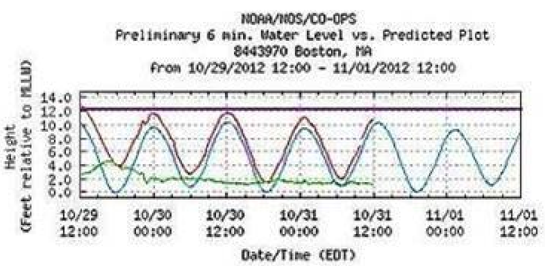

Figure 5. Boston Harbor tide gauge observations during Superstorm Sandy, in feet above low tide (MLLW; NOAA, 2012). Lowest (blue) line represents predicted tide, green line is observed storm surge, and top red line is observed storm tide. The horizontal (purple) line marks the level of the highest astronomical tide, known locally in Boston as wicked high tide. At its peak, Sandy's storm tide was 2.5 feet above average high tide when it hit Boston's inner harbor.

decisions about how to equitably manage flood-prone areas. Repeatedly repairing storm-damaged structures and providing emergency services to vulnerable residents is expensive and disrupteive to people's lives. Policy makers and property owners need to proactively decide on the investments to make in these vulnerable areas.

If we do nothing, up to one-third[17] of the city of Boston (by land area) could flood by 2100. Our challenge is to prepare Boston's people, buildings, and infrastructure to manage increasingly-frequent coastal flooding while maintaining and enhancing the economic and social vitality of this historic city. By taking a proactive approach, triggered by actual changes in coastal flooding, Boston's residents, businesses, and policy makers can better prevent flood damage even as sea levels increase.

Strategies include short-term preparedness as emergency response to severe storms, and long-term flood preparedness as response to sea level rise. Long-term responses could include fortification and adaptation to repeated flooding, or managed retreat when preparedness and rebuilding costs become too high.

SHORT-TERM EMERGENCY RESPONSE

Preventing flood damage from more intense coastal storms and wicked high tides is Boston's immediate concern. Emergency response actions focus on preventing saltwater from reaching vulnerable people and resources and on returning to normal operations as quickly and cheaply as possible after a storm event has passed. Most public and commercial activities typically cease during a storm flood event, except in the case of hospitals or other critical services.

In Boston, today's emergency response to coastal flooding means managers of buildings and infrastructure within the current 100-year flood zone[v] need to develop effective short-term strategies for protecting their properties from saltwater intrusion. With extensive resources on emergency response available elsewhere, this report largely focuses on longer-term preparedness measures.

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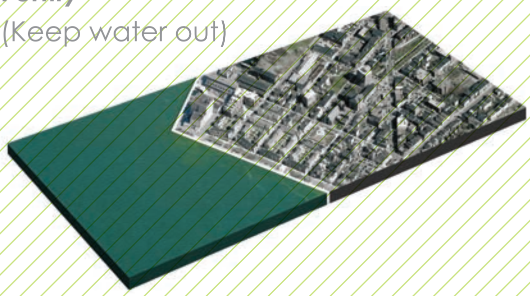
v. i.e., areas that flood when seas are approximately 5 feet above high tide.

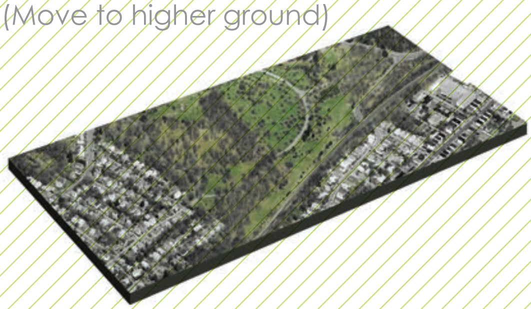
> ## *"IF WE DO NOTHING, UP TO ONE-THIRD OF BOSTON COULD FLOOD BY 2100.*

WHAT ARE THE OPTIONS?

Fortify
(Keep water out)



Retreat
(Move to higher ground)



Adapt
(Design with water)

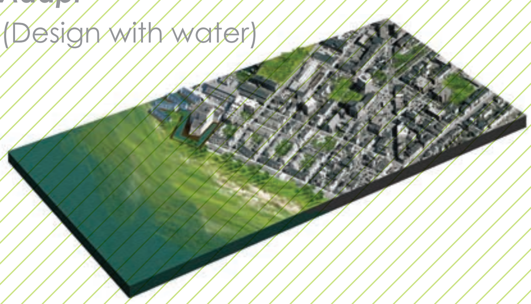


Figure 6. Designing with Water urban design and planning options (© Sasaki Associates)

LONGER-TERM FLOOD PREPAREDNESS RESPONSES

In the past, managing low-probability, high-impact flood events such as Superstorm Sandy or Hurricane Katrina has depended on preventing flooding using grey infrastructure such as sea walls, bulkheads, and barriers. Although effective, fortification requires significant investments in time and capital and can exacerbate flood damage if barriers are breached or overtopped.

As sea levels rise and chronic flooding becomes the new normal, even master dike builders such as the Dutch are moving to more flexible, resilient solutions. The concept of Designing with Water is the strategy of allowing defined areas to flood or contain water in order to prevent damage to other areas.

Popularized by the Dutch, this concept considers water to be a design opportunity to manage chronic flooding while providing other benefits such as new recreation areas, marsh habitat, and more livable communities.[18] Both flood prevention and resilience are needed; socioeconomic goals and available resources will dictate the balance between the two.

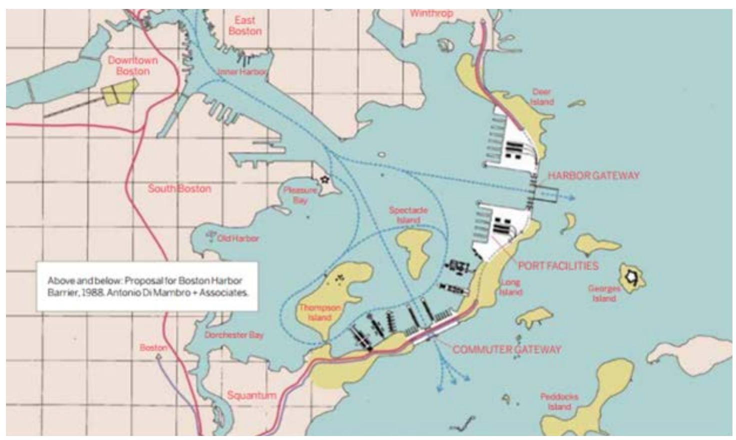
Finally, for low-lying areas that are no longer able to be viably protected from chronic flooding, managed retreat involves moving to higher ground. Two case studies in this report — the Room for the River Waal in the Netherlands and the Cedar River Corridor Redevelopment Plan in Cedar Rapids, Iowa — describe how this strategy was used to improve community resilience and decrease risks of future flood damage. In both cases, managed retreat involved community input and compensating property owners who had to move.

TO DAM OR NOT TO DAM?

One oft-cited strategy to protect Boston from coastal flooding is to construct a storm barrier within Boston Harbor. Although a storm barrier cannot protect the city from higher sea levels one day overtopping our coastline, it can be effective in further protecting harbor communities from waves and storm surges. It is, however, a time- and capital-expensive solution requiring regional support and investment.

Figure 7 shows alternative plausible visions for coastal flood prevention in Boston. The first, an award-winning design by Antonio DiMambro, focuses on flood prevention while including multiple co-benefits. His proposal (top illustration) centers on a regional storm surge barrier across the Boston Harbor Islands that would protect the inner harbor, restore wetlands, increase developable lands, move the Port of Boston offshore, and create an integrated North-South transportation corridor.

The second shows four different barrier configurations. The configurations in blue show three options for barriers that connect the harbor islands. The smaller orange barriers were contemplated by Dr. Paul Kirshen and colleagues as a first phase of a Designing with Water approach. These smaller "first flood" initial investments of sea walls and storm surge barriers focus on low-lying areas where coastal flooding occurs first and are intended to buy time for planning and investment in future flood prevention and resilience strategies as coastal flooding increases.



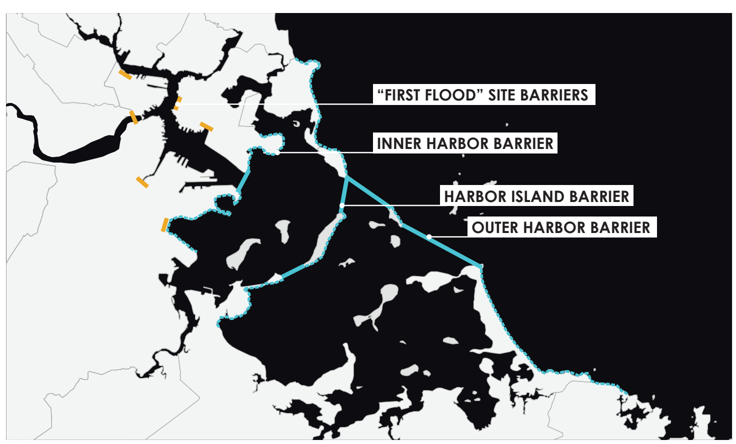


Figure 7. Visions for Boston coastal barriers. (property of DiMambro (top), © Paul Kirshen (bottom, orange), and © Sasaki Associates (bottom, blue).

DESIGNING WITH WATER

Canal, Amsterdam, The Netherlands
© Filip Demuinck www.filipdemuynck-kistelpardon.blogspot.com

> ***"TODAY, THE PARADIGM IS SHIFTING AWAY FROM KEEPING WATER OUT, TO DESIGNING TO LET WATER IN.***

LEARNING FROM THE DUTCH

After devastating coastal flooding in 1953, the Netherlands invested $40 billion into a massive national flood protection system called the Delta Works. Constructed to provide flood protection while allowing the continuation of the fishing industry and protection of important estuaries, Delta Works has so far successfully prevented major flood damage.[19]

As sea level projections continued to rise, however, the Dutch determined that continuing to fortify against water was both economically and socially infeasible.

First, they realized that building ever-higher flood dikes while continuing to allow development in low-lying areas actually increased the potential for extensive damage if such barriers ever breached. Second, the Dutch wished to maintain an aesthetically pleasing connection with their waterways.

Dutch planners and designers coined the phrase "Leven met Water"[20] — translated as "Living with Water"[vi] — to describe their shift in focus (see Figure 8). Today they are planning and implementing flood resiliency projects that are making room for flood waters in urban settings, designing extensive floating neighborhoods, and putting nature to work by mimicking resilient natural coastal ecosystems.

DESIGNING WITH WATER PRINCIPLES

Although the Dutch are recognized leaders of the "Living with Water" strategy, they are by no means alone in its adoption. Communities across the globe have begun to implement strategies that integrate risk mitigation, placemaking, and sustainable design to promote solutions that enhance not only flood control but socioeconomic

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vi The phrase "Living with Water" is trademarked by Waggonner & Ball Architects

NEDERLAND LEEFT MET WATER

Figure 8. Dutch Living with Water logo

vitality. This document highlights 12 excellent examples of Desiging with Water, but there are many more, including dozens of examples listed in Appendix 2.

In 2013, *Preparing for the Rising Tide* mentioned the concept of "Living with Water" in the context of Boston's flood preparations. Since then, we have compiled over 100 examples of successful flood adaptation measures from around the world. During this research process, five key Designing with Water principles emerged and informed the final selection of the 12 case studies presented in this document.

DESIGNING WITH WATER PRINCIPLES

DESIGN FOR RESILIENCE
Resilience implies adapting to or bouncing back from a disturbance quickly. Resilient planning and design incorporates redundancy and anticipates change over time.

CREATE DOUBLE-DUTY SOLUTIONS
Double-duty solutions provide multiple benefits to maximize economic, ecologic, and cultural gain.

STRENGTHEN COMMUNITY RESILIENCE
Community resilience maintains and enhances the cultural identity that defines a city through resiliency networks and social support systems. Strategies that strengthen social resilience can both cost less and provide meaningful benefits to participants.

INCENTIVIZE AND INSTITUTIONALIZE PREPAREDNESS
Citywide and regional adaptation plans are necessary to guide resiliency efforts. Insurance standards, zoning laws, construction codes, and policy are tools that local and state governments should consider to encourage adaptation within their communities.

PHASE PLANS OVER TIME
Designing with Water requires design and planning for flexibility and adaptability over time. Planning efforts that address sea level rise should be phased and have the ability to change based on external conditions.

CASE STUDIES

Floating Houses, IJburg, The Netherlands
© Luuk Kramer | Marlies Rohmer Architects and Planners

LEARNING FROM OTHERS

Designers and engineers around the world are developing flexible, adaptable, resilient solutions in response to coastal flooding. We hope to see more of these principles put into place in Boston to help us recover more quickly from storms and prepare for higher sea levels.

These 12 case studies illustrate a range of relevant solutions at multiple scales to increase Boston's resiliency to coastal flooding. All are strategies that increase the social and economic vibrancy of their communities. Examples include floodable and floating buildings, neighborhood-scale infrastructure, social resilience, and regional plans.

HOW TO APPROACH THE CASE STUDIES

Our intent in providing 12 case studies — as well as many additional examples in Appendix 2 — is to provide decision makers at all levels with a range of creative solutions that can serve as inspiration for their particular design challenges. Each case study illustrates one or more Designing with Water principle, as signified by the colored icons throughout this section.

The case studies are organized by three levels of decision making.

1) INDIVIDUAL SITE SCALE strategies can be designed and implemented by individual property owners, residents, or building managers.

2) NEIGHBORHOOD SCALE solutions offer protection for multiple properties and/or mobilize resources to assist vulnerable populations at a community level.

3) REGIONAL SCALE interventions generally require public sector actions to protect multiple neighborhoods or cities with large-scale infrastructure investments, policies, and/or market incentives.

NOT ALL FLOODING IS CREATED EQUAL

Readers must be careful in translating flood resilient strategies from one location to another. Some freshwater examples are relevant to coastal flood management, though differences between the two should be considered. Saltwater is far more corrosive than fresh water. Fresh water flooding — even from extreme snowmelt and/or precipitation — is finite. Once average sea levels rise higher than coastal barriers, the volume of seawater flooding becomes essentially infinite, making solutions such as underground seawater storage of limited value.

Stormwater management is still very relevant to meeting coastal water quality goals. Because Boston has a combined sewer system, untreated sewage can enter our rivers and ocean under extreme precipitation events. Examples such as the Alewife Stormwater Wetland case can therefore help mitigate both inland flooding and coastal water pollution.

Storm flooding can also pose different sets of problems than tidal flooding. Even after storm floods recede, they can leave behind longer-term problems with waterborne pathogens, mold, and/or sewage backup in plumbing and basements.

Tidal flooding caused by sea level rise is slower and more predictable, providing protected communities such as Boston more time to adapt. Once sea levels reach a certain height, however, flooding becomes permanent and may require managed retreat.

SCALE	CASE STUDY	DESIGING WITH WATER PRINCIPLES: Design for Resilience	Create Double-duty Solutions	Strengthen Community Resilience	Incentivize and Institutionalize Preparedness	Phase Plans Over Time
INDIVIDUAL SITE	Cuisinart Center for Culinary Excellence *(Providence, RI, US)*	●				
	Burnham Hall *(Lincoln, VT, US)*	●		●		●
	Alewife Reservation Stormwater Wetland *(Cambridge, MA, US)*	●	●			
	The Citadel *(Naaldwijk, NLD)*	●				
NEIGHBORHOOD	Village Agents *(Gloucestershire, ENG)*		●	●	●	●
	HafenCity Master Plan *(Hamburg, GER)*	●	●		●	●
	Cheonggyecheon Stream Restoration (Seoul, KR)	●	●			
	Strategic Plan for the United Houma Nation *(United Houma Nation, LA, USA)*	●		●		●
REGION	Greater New Orleans Urban Water Plan *(New Orleans, LA, USA)*	●			●	●
	The Thames Estuary 2100 Plan *(London, ENG)*	●			●	●
	Room for the River Waal *(Nijmegen, NLD)*	●	●		●	●
	Cedar Rapids River Corridor Redevelopment (Cedar Rapids, IA, US)	●	●	●	●	●

Design for Resilience

Create Double-duty Solutions

Strengthen Community Resilience

Incentivize and Institutionalize Preparedness

Phase Plans Over Time

INDIVIDUAL SITE SCALE CASE STUDIES

Spaulding Rehabilitation Hospital, Boston, Massachusetts
© Anton Grassl/ESTO | Perkins+Will

CUISINART CENTER FOR CULINARY EXCELLENCE

JOHNSON & WALES UNIVERSITY, PROVIDENCE, RHODE ISLAND

© Jeffrey Totaro | Tsoi/Kobus & Associates | Cuisinart Center for Culinary Excellence at Johnson & Wales University

CUISINART CENTER FOR CULINARY EXCELLENCE

JOHNSON & WALES UNIVERSITY, PROVIDENCE, RHODE ISLAND

APPLICATION TO BOSTON: FLOODABLE FIRST FLOOR

The Cuisinart Center's sacrificial first floor strategy seeks to prevent flood damage to both the building itself and its fragile, expensive equipment. Its resilient design and construction are relevant to Boston, especially to new buildings in the Seaport District and in East Boston.

Sacrificial (or less dramatically, floodable) first floors make sense, especially in areas in downtown Boston where vibrant public streetscapes are desired. Techniques include using submergible materials such as tile and concrete, prohibiting first-floor residential housing, relocating heating, electrical, and other vulnerable equipment to higher floors, and elevating electrical outlets and wiring to above anticipated flood levels.

THE CHALLENGE

When the Johnson & Wales' culinary arts program started in 1973, its 141 students studied and practiced in a converted industrial building.[21] After only 10 years of operation, enrollment jumped to 3,000 students and the program outgrew its space. [22]

Faculty input helped guide Tsoi/Kobus & Associates to design to meet the culinary industry's demands, but the site — a polluted brownfield in a coastal floodplain — offered an additional set of challenges. State and federal regulations required that new flood plain development must design for future storm surges.

THE PROCESS

Architects initially considered using the first floor for parking, but the structure's layout made driving underneath difficult and parking was plentiful nearby.

Instead, designers turned to methods more typical of beach homes. "We basically built the building up on stilts," said Chris Placco, vice president of facilities. Blake Jackson, of Tsoi/Kobus & Associates, described his firm's design approach as "fail fast, fail cheap." [24] The first floor was looked at as a sacrificial layer.

THE RESULTS

The LEED® Gold-certified 82,000 square foot building opened in 2009. Its 30 classrooms, 11 specialty labs, and 9 kitchens enjoy stunning views of Narragansett Bay and cutting-edge technology.[25] It additionally employs green building materials and energy- and water-saving measures throughout the building.

The final design incorporated a first floor lobby and loading dock with technology-packed classrooms and kitchens on higher levels. The lobby and loading dock are enclosed with special glass and brick panels designed to break away if hit by storm surges. The design strategy maintains structural integrity by relieving pressure on the primary columns and walls.

BURNHAM HALL

LINCOLN, VERMONT

© Mark G. Benz

BURNHAM HALL

LINCOLN, VERMONT

APPLICATION TO BOSTON: RESILIENT RETROFIT

Burnham Hall offers an excellent example of retrofitting a historic existing building to Design with Water in emergency flooding conditions. Similar flood prevention techniques could be applied to existing structures across Boston's neighborhoods.

This strategy requires active maintenance and real-time interventions by dedicated individuals. To be effective, people need training, practice, and oversight ahead of time so emergency preparedness plans are carried out quickly and effectively throughout the building's lifespan. Similar to volunteer firefighting, these strategies both require and support strong community ties.

THE CHALLENGE

Burnham Hall was built in the early 1920s as a community space. Located on the bank of the New Haven River, it experiences flooding about once every 12 years.[26,27]

In 1998, a storm flooded the first floor of Burnham Hall with 5 feet of water. Following the storm, longtime resident Harriet Brown rallied community support to prevent future damage to Burnham Hall.

THE PROCESS

A volunteer committee secured state funding to determine what changes were needed to "live with the river for the next 100 years." The group weighed two options — relocate the entire structure or retrofit it using a host of flood-proofing measures. Ultimately the committee decided to retrofit and used hazard mitigation grants to complete the adaptive measures over the course of three years as part of Burnham Hall's maintenance plan.

Flood prevention techniques included temporary watertight window and door barriers; sealed electrical, telephone, and fuel line wall penetrations; septic line backflow prevention valves; sump pumps and discharge pumps to help remove water during a flood; and alternative electrical lines from the discharge pump to an external generator connection.

THE RESULTS

The new barrier system was designed to handle freshwater floodwaters up to 7 feet deep. Within two years it was tested by Tropical Storm Irene. After forecasts warned of heavy rains and flash flooding, volunteers gathered to set up the building's flood protections. Within thirty minutes the team installed 15-pound steel planks over the doors and windows. The New Haven River flooded its banks, pushing water levels to 4 feet above the floor. The barriers held.

Hydrostatic pressure pop-up valves responded to outside water pressure and prevented the floor from buckling upward. While the valves were designed to allow in a small amount of sand-filtered water, sump pumps quickly cleared it out. The next day the waters receded and the building needed minor cleanup. Burnham Hall had weathered the storm without sustaining interior damage.

ALEWIFE RESERVATION STORMWATER WETLAND

CAMBRIDGE, MASSACHUSETTS

© Friends of Alewife Reservation | www.friendsofalewifereservation.org

ALEWIFE RESERVATION STORMWATER WETLAND

CAMBRIDGE, MASSACHUSETTS

APPLICATION TO BOSTON: NATURALIZED STORMWATER MANAGEMENT

Located in close proximity to Boston, the Alewife Reservation Stormwater Wetland serves as an example of successful green infrastructure in an urban setting. Maximizing limited (and valuable) land, the stormwater wetland model could be replicated in similarly dense neighborhoods that have a history of CSOs and stormwater flooding. However, in some places Boston's high water table and urban soils could make onsite retention or percolation difficult and/or undesirable.

THE CHALLENGE

In the late 1990s, Cambridge planners sought to prevent combined sewer overflows (CSOs) from polluting Alewife Brook during heavy storms. The city is densely populated with little open space. Some of the only available land was owned by the Massachusetts Department of Conservation and Recreation (DCR). The challenge was to engineer a cost-effective stormwater management system that also met DCR's open space goals.

THE PROCESS

The project was a collaboration of several engineering firms — Kleinfelder, MWH Americas, and Bioengineering Group — with the client, the City of Cambridge Department of Public Works (DPW); the parcel owner, DCR; and the Massachusetts Water Resources Authority (MWRA), as part of the federally mandated Boston Harbor cleanup. Working with DCR offered the opportunity to weave educational and recreational amenities into a new model for urban stormwater management. The stormwater model calculated that a green infrastructure solution, designed to mimic natural wetland systems, would be more cost-effective than traditional grey infrastructure techniques (e.g., pipes, cisterns).

Other environmental and cultural benefits quickly became key drivers. The wetland incorporated several passive management strategies to slow stormwater and increase water absorption, including bending weirs, vegetated swales, polishing wetlands, and flap gates. Designers worked closely with the engineering team to create recreational and educational amenities and improve wildlife habitat.

THE RESULTS

The result was the 3.5-acre Alewife Reservation Stormwater Wetland, the largest such project in New England. It is projected to reduce annual CSO discharges by over 80 percent.[28] Other co-benefits include carbon sequestration, enhanced wildlife habitat, recreational trails and boardwalks, a stone amphitheater, and educational signage. The wetland can expand in the future to accommodate expanded stormwater volumes.

THE CITADEL

NAALDWIJK, THE NETHERLANDS

© Architect Koen Olthuis — Waterstudio.NL | developer: ONW/BNG GO

THE CITADEL

NAALDWIJK, THE NETHERLANDS

APPLICATION TO BOSTON: HIGH DENSITY FLOATING HOUSING

With Boston's sheltered harbor, floating apartments could play a role in preparing for Boston's wet future. A caveat, however, is that Massachusetts currently has strict wetland regulations that could make building beyond the current harbor edge difficult.

With waterfront development at a premium, nearly all new housing in Boston's Seaport District has been beyond the budget of many middle- and working-class residents. Floating high-density housing could be designed to better accommodate residents of varying income levels.

THE CHALLENGE

As an old Dutch saying goes, "God created the earth, but the Dutch created the Netherlands." For several millennia the Dutch fought against the sea, expanding their cities, neighborhoods, and farms on land reclaimed from tidelands and inland marshes. Today 27 percent of the Netherlands is below sea level[29] and there are over 3,000 polders[30] — filled wetlands — across the country.

Dikes and pumps must constantly protect polders from outside flooding. Polders historically served as agricultural land, but more recently have been developed, especially in the Randstad region of Amsterdam, Rotterdam, The Hague, Utrecht, and smaller cities.

THE PROCESS

More than 40 percent of Holland's population lives in the Randstad, despite flood risks.[31] Dutch architect Ken Olthuis sees the potential in designing buildings that can withstand flooding; "It's just evolution — the elevator made vertical cities of skyscrapers… water is the next step for letting cities… become more dense."[32] His firm, Waterstudio, is designing the Citadel, Europe's first floating apartment complex. The Citadel is one of six projects[33] in Het Nieuwe Water ("Project New Water"), a residential development across nearly 200 acres of marshlands in the Randstad.[34]

THE RESULTS

Construction of the Citadel is set for completion in December 2014, with 60 high-density luxury apartments (30 units/acre of water). The units rest on a massive concrete caisson, which prevents the building from noticeably rocking. Most residents have both a car parking space within the foundation and a small berth for boat access. Once completed, the polder will be allowed to flood, floating the Citadel. Residents will be far less flood prone while being physically and aesthetically much closer to water.

NEIGHBORHOOD SCALE CASE STUDIES

Boston, Massachusetts
"View from BWM's room" on Flickr by emivel2003 is licensed under CC BY-NC-ND 2.0

VILLAGE AGENTS

GLOUCESTERSHIRE, ENGLAND

Photo property of Gloucestershire Rural Community Council

VILLAGE AGENTS

GLOUCESTERSHIRE, ENGLAND

APPLICATION TO BOSTON: CULTURAL RESILIENCE

Strengthening and supporting existing social networks can greatly enhance Boston's ability to prepare for increased flooding while improving other socioeconomic goals. Such networks connect neighbors to each other and to policy makers and service providers. They can also help engage community members in the development and implementation of flood preparedness plans and provide a conduit for emergency response information and support.

THE CHALLENGE

Gloucestershire is a rural county in southwest England. The Bristol Channel and the Rivers Severn, Thames, and Don and their tributaries flow through the region, and extreme storm events are causing these waterways to flood more often and more intensely. A 2006 estimate puts approximately 8,700 homes and 20,000 people at risk.[35]

In addition, nearly 20 percent of floodplain residents are 65 years old or older.[36] A majority of these residents live alone in dispersed housing with poor access to local services.

THE PROCESS

In 2006, The UK Department of Work and Pensions sponsored a pilot project in Gloucestershire to better connect older residents to public services. Local community members were trained as Village Agents to work one-on-one with seniors, with the goal of improving public health outcomes.[37]

Each agent served clusters of three to five of the county's most isolated parishes. They connected vulnerable seniors to public health services. By visiting neighbors in their homes, Village Agents increased seniors' positive connections with their own communities.[38]

THE RESULTS

Climate change preparedness was not the impetus for the creation of the Village Agents, but the project was powerfully effective during the summer floods of 2007. River levels reached record highs and flooded homes, businesses, and infrastructure.

Although parts of the county were left without services for days, Village Agents were already in place to assist vulnerable seniors. They provided an emergency hotline number, brought seniors clean water and food, and checked in daily. During the pilot phase evaluation, one individual commented, "Village Agents were the glue that kept things together."[39] In 2008, the program was made permanent, and expanded to support residents of color. Their success attracted national attention as an example of building social resilience in dispersed communities.

HAFENCITY MASTER PLAN

HAMBURG, GERMANY

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HAFENCITY MASTER PLAN

HAMBURG, GERMANY

APPLICATION TO BOSTON: INDUSTRIAL FLOODPLAIN REUSE

HafenCity provides an innovative example of how to accommodate chronic flooding while creating or redeveloping a new neighborhood. Boston is undergoing a post-industrial waterfront renaissance similar to Hamburg.

In neighborhoods such as East Boston, Charlestown, and the Seaport District, reuse of industrial land is occurring along the waterfront. Notably, the Seaport District offers opportunities to pair elevated structures with floodable public spaces to mitigate flood risk. The dense, transit-oriented development that defines HafenCity would also help relieve traffic congestion in Boston's rapidly expanding neighborhoods.

THE CHALLENGE

During the 1990s, industrial activities in the Port of Hamburg declined. The city recognized the opportunity to reuse the industrial ports to expand development inside the city instead of developing outlying agricultural land. Since then, HafenCity ("Harbor City") has become the largest single development project (by acreage) in Europe.

As HafenCity is located on the banks of the Elbe River outside the protection of Hamburg's dike system, developers saw the risk of severe flooding as a design opportunity. The challenge was to design HafenCity as a model for post-industrial development within a floodplain.

THE PROCESS

HafenCity's developers wanted to emphasize flood-resilient design and sustainable architecture. The design team considered constructing a new dike to manage flood risks, but determined that associated time and costs were prohibitive. People also hoped to maintain the district's proximity and visual connection to the Elbe River. Instead of a dike, existing land was elevated with large constructed mounds called warften. Buildings and roads were strategically constructed on the high points out of the floodplain, allowing other areas to flood periodically.

THE RESULTS

Currently under construction, HafenCity represents an example of dense, transit-oriented, flood resilient development. Buildings and passageways are elevated up to 30 feet, while plazas and promenades remain at 15 feet, closer to the river.[40] Small floodgates guard the connection between HafenCity and older portions of Hamburg.

Unstable riparian soils required all development to be built on structural piles. These piles offered the opportunity to create ample parking within the warften, relieving surface parking and vehicular congestion. In addition, dense, transit-oriented development increases the district's walkability and decreases overall carbon dioxide emissions. Permitting requirements ensure new development meets rigorous design standards and socioeconomic goals.

CHEONGGYECHEON STREAM RESTORATION

SEOUL, SOUTH KOREA

©Robert Koehler

CHEONGGYECHEON STREAM RESTORATION

SEOUL, SOUTH KOREA

APPLICATION TO BOSTON: MULTI-FUNCTIONAL INFRASTRUCTURE

The Cheonggeycheon channel represents an example of infrastructure that serves multiple functions: flood control, habitat creation, economic growth, and recreational amenities.

Coastal flood control channels connected to Boston Harbor are feasible, though they would need to be constructed more like tidal marshes, with water levels rising and falling twice daily. Such channels — sited perpendicular to the harbor on pedestrian side streets — could provide many functions, including beautiful water features, cultural amenities, and below-grade areas to manage periodic storm floods.

THE CHALLENGE

Seoul, South Korea was settled thousands of years ago along the banks of the Han River and its tributaries. The waterways regularly flooded their banks during the rainy season. As early as the 1400s, city rulers ordered the first flood management projects on the river.[41]

By the early 1900s, the Cheonggyecheon ("clear water stream") tributary became so fouled by sewage and pollution it earned the moniker Takgyecheon ("dirty water stream").[42] In 1955, the city undertook a massive redevelopment project that capped the polluted river and constructed a four-lane elevated highway above it.[43] This transformed the neighborhood into what planners intended to be an industrial district. The area's revitalization was short-lived. The subterranean river reeked, and the noisy elevated highway depressed the economic and social vitality of the surrounding district.

THE PROCESS

In 2002, Lee Myung-bak ran a successful campaign for mayor in part by proposing to demolish the highway and redevelop the area in order to drive tourism and international investment.[44] His proposal called for replacing the highway with a seven-mile-long urban park that evoked the city's historic riverfront, improved water quality, and mitigated flood risk.[45]

Mikyoung Kim, a Korean-American landscape architect, won an international design competition with her design that created an extraordinary public social space during dry periods while safely containing periodic floodwaters during rainy periods.

THE RESULTS

The Cheonggyecheon project has become a must-see attraction for visitors and residents. Since its opening in October 2005, the park has been wildly popular.[46] Surrounding neighborhoods experienced a development boom with vibrant new social and business activity, increasing land value by 30 to 50 percent. The restoration project incorporated 3.6 miles of continuous green space and was designed to provide protection for up to a 200-year flood event. [48]

STRATEGIC PLAN FOR THE UNITED HOUMA NATION

UNITED HOUMA NATION, LOUISIANA

© Miscellaneous Tactics

STRATEGIC PLAN FOR THE UNITED HOUMA NATION

UNITED HOUMA NATION, LOUISIANA

APPLICATION TO BOSTON: INCREASED SOCIAL RESILIENCE

Some of Boston's lowest-lying coastal neighborhoods, including East Boston and Dorchester, are also geographically and at times politically distant from city and state decision makers.

As with the United Houma Nation (UHN) process, effective community engagement is essential to ensure adaptation plans account for the values and traditions unique to a particular neighborhood or culture. Such processes, done well, also build trust, understanding, and buy-in for plan outcomes.

In 2014, the City of Boston is updating its citywide climate action plan, focused on climate preparedness. As a follow up, public agencies and community leaders need to work with neighborhood residents and businesses to adapt the citywide plan to their needs and values.

THE CHALLENGE

Coastal Louisiana has lost over 1,880 square miles of wetland since the 1930s due to a combination of human-caused and natural factors, leaving coastal communities vulnerable to more frequent and intense saltwater flooding. The United Houma Nation (UHN) is Louisiana's largest tribal nation with deep cultural ties to Louisiana's wetlands. Over the centuries, they observed their land disappear as new development destroyed the once-protective natural barriers.

Between 2005 and 2008, the UHN was hit by four major hurricanes: Katrina, Rita, Gustav, and Ike. In the days following Gustav's landfall, the media reported New Orleans had "dodged a bullet;" however, nearby the Houma people suffered. The tribe's history of displacement, along with news reports following Gustav, supported their perception that the US government would not come to their aid.

THE PROCESS

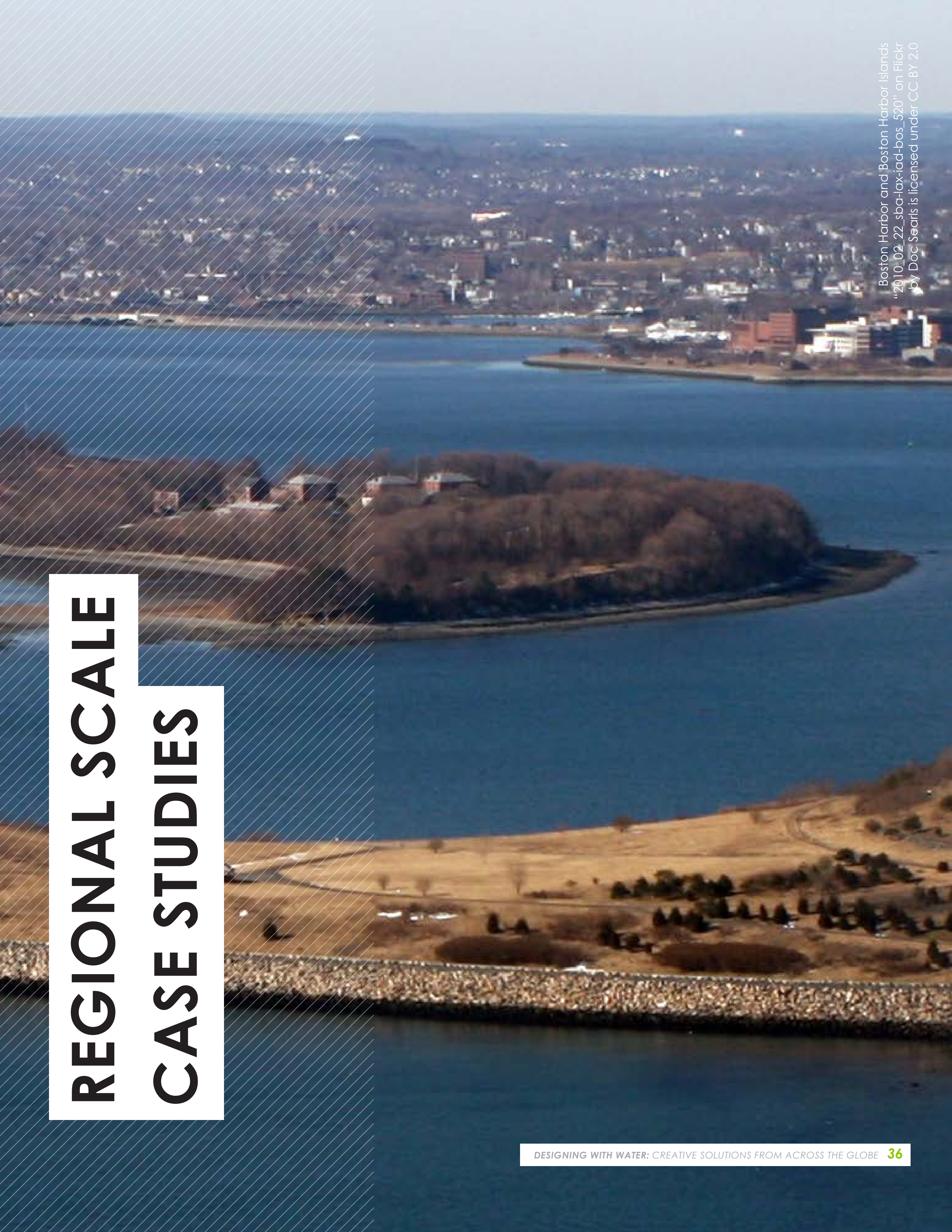
In 2008,[49] the UHN undertook its own planning process with the help of a team from Tulane Law School, Environmental Defense Fund, and the University of New Orleans Center for Hazards Assessment, Response & Technology. They began developing an emergency evacuation, mitigation, and stabilization plan through a series of public forums.

Although younger members of the tribe were open to relocating to safer land, many elders were especially reluctant to give up land. "It's not for me, as a tribal leader or person to say, you need to get out of here. This is not a good future for you. That's everybody's own personal decision," said Brenda Dardar Robichaux, Principal Chief of the UHN.[50]

THE RESULTS

Together, the UHN team created a document called The Three Part Plan. The plan focuses on relocating people out of the path of danger, assisting tribal citizens in preparing existing communities for future storms, and helping the UHN reclaim higher ground. The plan lays out evacuation plans and safe havens secured through formal agreements negotiated with neighboring tribal nations.

REGIONAL SCALE CASE STUDIES



Boston Harbor and Boston Harbor Islands
“2010_02_22_sba-lax-iad-bos_520” on Flickr
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GREATER NEW ORLEANS URBAN WATER PLAN

NEW ORLEANS, LOUISIANA

© LSU Coastal Sustainability Studio | The Greater New Orleans Urban Water Plan

GREATER NEW ORLEANS URBAN WATER PLAN

NEW ORLEANS, LOUISIANA

APPLICATION TO BOSTON: WATER-FOCUSED REGIONAL PLANNING

The Greater New Orleans Urban Water Plan addresses the need to plan across political boundaries. Large-scale issues such as sea level rise call for regional decision making. Boston and surrounding communities will need to plan regionally to address flood risks without making them worse for others. In addition, land subsidence, although less dramatic in Boston than in Louisiana, is a real issue for Boston, especially for neighborhoods built on former tidelands.

THE CHALLENGE

New Orleans' current flood control strategy relies on highly-engineered infrastructure that moves water out of the city as quickly as possible. This system allows extensive development within a below-grade floodplain and prevents groundwater replenishment, leading to increased subsidence of land and exacerbating the city's risk of flooding.

Levees currently around the city separate residents from the surrounding water bodies — including Lake Pontchartrain, Lake Borgne, the Mississippi River, and the Gulf of Mexico. Most stormwater is managed via unseen underground pumps. In order to protect from future devastating floods, New Orleans' challenge is to make room for water physically and culturally.

THE PROCESS

The Greater New Orleans Urban Water Plan, released in September 2013, identifies a 50-year, phased regional strategy incorporating intelligent retrofits and urban design strategies for flood resilience.[51] It was the product of a two-year collaboration among the City of New Orleans, the State of Louisiana, Waggonner & Ball Architects, and the Royal Netherlands Embassy. The Urban Water Plan strives to be a regional planning example for other coastal cities.

The plan shifts the city's focus from hard, engineered stormwater management strategies to dynamic, adaptive solutions that address the relationship between flooding and subsidence. It calls for making space for water within the greater region using bio-swales, retrofitted canals, new canals, and ponds to hold and absorb water. Absorbent landscapes and natural systems control the first wave of stormwater. Pumping stations are activated as a last resort.

THE RESULTS

The plan advocates for regional cooperation to support both the economic and cultural future of Greater New Orleans. It will be integrated with the Louisiana 2012 Coastal Master Plan and the existing levee system to create a greener, more resilient New Orleans region.

THE THAMES ESTUARY 2100 PLAN

LONDON, ENGLAND

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THE THAMES ESTUARY 2100 PLAN

LONDON, ENGLAND

APPLICATION TO BOSTON: PHASED PLANNING

Large-scale issues such as coastal and inland flooding call for regional decision-making. However, the issue of climate change is often paired with unpredictable change. The TE2100 plan is an example of a regional plan that addresses this uncertainty and plans for adaptability.

MetroFuture, developed by the Metropolitan Area Planning Council (MAPC), is the regional plan for the Greater Boston area between now and 2030. While MetroFuture is robust in planning for the region's future, flooding and sea level rise are not the plan's main focus. We will need a regional organization such as MAPC to help develop sea level rise solutions that cross political boundaries. Such a regional forum can help bring together political leaders, scientists, economists, and the broader public to take on tough tradeoffs.

THE CHALLENGE

The Thames Estuary is located at the junction of the North Sea and the River Thames, with tidal fluctuations as high as 22 feet.[52] Like so many other coastal communities, for centuries London has relied on flood barriers. In addition to sea level rise, the region faces aging flood defenses, land subsidence, changing socio-economics, and low public awareness of flood risks.

THE PROCESS

In 2002, the UK Environment Agency began its work on the Thames Estuary 2100 Plan (TE2100). The plan sought to manage coastal flooding risks through "technically-realistic, adaptable, environmentally-sustainable, economically-feasible, and socially- and politically- acceptable" means.[52] The TE2100 plan was the first flood management plan in the United Kingdom to be defined by climate change instead of economic goals and political boundaries. It is a process-based plan with area boundaries defined by flood risks, not municipal borders.

The plan defines 23 policy units (locations) in the estuary that share common flood characteristics.[52] Risk assessments and recommendations were developed for three time horizons: short-term (2010–2035), medium-term (2035–2050), and long-term (2050–2100). The plan builds on the best science today and integrates a recurring process of decision-making based on new information. It calls for monitoring 10 key indicators to alert decision-makers to changing conditions. Significant changes in these indicators trigger further action.[52] The plan will be updated every decade, or more often if water levels rise more quickly than expected.

THE RESULTS

TE2100 is a national flood management strategy for the Thames Estuary. It directs future floodplain management, provides key information to local governments, and helps build knowledge and capacity within the region. The Environment Agency's leadership on the TE2100 plan institutionalized the planning process and elevated the platform of flooding risk to a national level.

ROOM FOR THE RIVER WAAL

NIJMEGEN, THE NETHERLANDS

© City of Nijmegen

ROOM FOR THE RIVER WAAL

NIJMEGEN, THE NETHERLANDS

APPLICATION TO BOSTON: ALLOCATED SPACE FOR WATER

Room for the River Waal anticipates future flooding and provides adequate space for the flood water in an urban setting. In Boston, the Bay Back Fens historically served a similar purpose, allowing the Charles River to have space in the city. What are the possibilities of making more room for water? Could Boston make room for a Sapphire Necklace to complement our Emerald Necklace?

THE CHALLENGE

In the Netherlands, many major rivers are contained by high dikes while residents live on sinking, but habitable, land behind the dikes.

Nijmegen, the oldest city in Holland,[53] celebrated its 2,000th anniversary in 2005.[54] It is located next to a sharp bend in the Waal River that creates a dangerous bottleneck in the river and makes the city particularly susceptible to flooding. In 1993 and again in 1995, extreme rainfall events forced approximately 250,000[55] Dutch residents to evacuate riverside communities, including Nijmegen.[56]

Although the dikes held floodwaters back, the close calls alarmed the Dutch government. They realized if existing dikes failed, resulting damage would be worsened by water filling the sunken land behind the dikes.

THE PROCESS

The Dutch government initiated the Ruimte voor de Rivier ("Room for the River") program, targeting almost 40 locations across the country.[57] The program looks to expand rivers' capacity to hold increased volumes of water during intense storm events. In Nijmegen, Room for the River Waal involves relocating the Waal dike in Lent and constructing a secondary channel within the floodplain. These measures create a new elevated island in the Waal that includes residential, recreational, and cultural development.

THE RESULTS

Room for the River Waal started in 2013. The dike relocation and island and channel construction are set for completion by 2016.[58] Because the project involves demolishing homes, the government is compensating displaced residents. The new island is expected to attract more development to the city's center. Social benefits include new bridges connecting residential neighborhoods, a green dike for pedestrians and cyclists, and new restaurants and shops along the waterfront. When plans are completed, the ancient city of Nijmegen will span the new channel.

CEDAR RAPIDS RIVER CORRIDOR REDEVELOPMENT

CEDAR RAPIDS, IOWA

© Sasaki Associates

CEDAR RAPIDS RIVER CORRIDOR REDEVELOPMENT

CEDAR RAPIDS, IOWA

APPLICATION TO BOSTON: PUBLIC ENGAGEMENT

The Cedar Rapids flood recovery plan depicts an aggressive civic strategy to invest in flood recovery at a regional scale. It included extensive community buy-in throughout the process. Structural improvements to protect the downtown paired with voluntary buyouts of destroyed properties. Other measures included improved evacuation planning, interim flood protection, flood-proofing, flood warning systems, and a larger civic initiative to address upstream Cedar River watershed issues.

As the City of Boston begins to contend with rising sea levels and chronic flooding, it will need to continue and deepen its engagement with private and non-profit sector leaders, residents, other municipalities, and state and federal agencies.

THE CHALLENGE

The City of Cedar Rapids crowned 2008 the Year of the River, to reinforce its connection with the Cedar River running through its center. Unfortunately, it took on a new meaning in June 2008 when a major flood forced thousands of evacuations and caused roughly $7 billion in damage.[59] Prior to the flood, Sasaki Associates was slated to generate a riverfront master plan. The team quickly mobilized to facilitate the development of a recovery plan. Together, Sasaki and the city developed recovery through an extensive public engagement process that directs reinvestment in the city and the region for the next 15 years.

THE PROCESS

The recovery plan is a two-phase process. Phase I minimizes future flood risk while improving the city's relationship to the river. Phase II provides a reinvestment framework for the city's nine flood-affected neighborhoods, including downtown.

Once the plan was complete, additional public processes included prioritizing the replacement of flood-damaged city facilities, voluntary property acquisition in vulnerable neighborhoods, integrating the 220-acre floodable greenway into the existing park system, and addressing the need for a consistently high-quality urban realm as the city rebuilds.

THE RESULTS

Since the flood, the city and its residents have completed several phases of reinvestment planning. The planning process continues to nurture a partnership among community members, multiple city departments, the City Council, and various agencies. The city completed voluntary property acquisitions of 1,400 properties damaged beyond repair and are starting planning for creation of a 220-acre greenway.[59]

The city and the US Army Corps of Engineers are seeking funding for a flood protection system that will include a riverwalk and temporary flood walls that can be deployed during a flood. By the flood's fifth anniversary, $235 million had been invested in over 1,300 new housing units and over 2,350 rehabs.[59]

RECOMMENDATIONS AND CONCLUSIONS

© Sasaki Associates

RECOMMENDATIONS

The goal of this document is to describe a range of Designing with Water concepts and examples relevant to Boston and other coastal cities. Although coastal flooding is a new challenge for Boston, other major cities such as London, Rotterdam, and Seoul have centuries of experience upon which we can draw. We believe that ultimately Boston will need to implement multiple creative solutions to prevent costly damage.

The City of Boston is in the process of updating its Climate Action Plan to increase the city's resilience to climate change. Its plan appropriately addresses not only coastal flooding but also extreme precipitation and heat waves. Below are additional private and public sector recommendations focused only on preparing for flooding.

PRIVATE SECTOR ACTIONS

1. Decrease structures' vulnerability to coastal flooding through new construction and retrofits (see Cuisinart Center, Burnham Hall cases).

2. Develop redundant, flexible strategies to decrease damage and recovery time from flooding (see Room for the River Waal, Greater New Orleans cases).

3. Create time-phased preparedness plans based on environmental triggers such as sea level or storm intensity to maintain or even reduce risk of flood damage over time (see Thames 2100 case). As possible, incorporate flood preparedness into capital maintenance schedules to minimize additional costs.

4. Look for opportunities to combine flood control with other business and institutional goals such as energy efficiency, sustainability, and livability (see Cuisinart Center case). Coordinate such strategies with neighboring properties to provide more effective, less costly solutions (see HafenCity case).

5. Anticipate future preparedness actions (e.g., floodable first floors) in new building construction to minimize expensive retrofits. The 2013 report *Building Resilience in Boston* is an excellent resource for such ideas (see Cuisinart Center case).

6. Develop and teach curricula focused on Designing with Water and other flood preparedness concepts. Local design schools could be a resource.
7. Lay the groundwork for effective emergency response to protect vulnerable community members (see Village Agents; Strategic Plan for the Unite Houma Nation cases). Neighborhood organizations could be a resource.

PUBLIC SECTOR ACTIONS

1. In order to limit costly delays, dead-end investments, and exacerbated social inequalities, we strongly recommend the City of Boston and surrounding communities develop a phased master plan that protects our people and places over time as the tide rises (see Hafencity, Thames 2100 cases).
2. Integrate the citywide master plan with other city plans (e.g., plans associated with economies, housing, neighborhood development, public health) to identify and pursue co-benefits as much as possible (see Cedar Rapids case).
3. Secure significant new public and private investment to implement the master plan and accelerate private actions. Identify an appropriate coordinating body to manage these resources most effectively to address multiple goals (see Cedar Rapids, Thames 2100, Room for the River Waal cases).
4. Work with surrounding municipalities — especially those closely connected through transportation, power, water, and sewage — to develop the political will, regional planning, and resources needed to prepare for chronic coastal flooding (see Greater New Orleans case).
5. Work with stakeholders to align building codes, zoning regulations, insurance premiums, and other market-based incentives to align flood preparedness activities with profitability.
6. Continue to provide the data, technical support, leadership, and policy guidance needed to help public and private property owners decrease their risk of flood damage and recover quickly in case preparations are insufficient (see Cedar Rapids case).

CONCLUSION

In the 18 months after Superstorm Sandy hit New York City and surrounding communities, Boston's public, private, and non-profit sectors have mobilized to try to prevent similar damage from occurring in Boston. In summer 2013, the Green Ribbon Commission released *Building Resilience in Boston*, an extensive report providing information on how to decrease flood damage.[60]

On the storm's first anniversary, then-Mayor Menino released *Climate Ready Boston*, a vulnerability assessment with recommendations for municipal actions they intend to take. Now-Mayor Walsh has continued the city's commitment to climate change mitigation and preparedness by joining the C40 Cities Climate Leadership Group in April 2014.[60]

We are privileged to join hundreds of other professionals in a collective learning community around our shared commitment to our beloved Boston. We hope this report — and the dozens of great examples it references — adds to the efforts here and elsewhere to effectively and creatively prepare for the rising tide.

—Boston, Massachusetts, August 2014

RESOURCES

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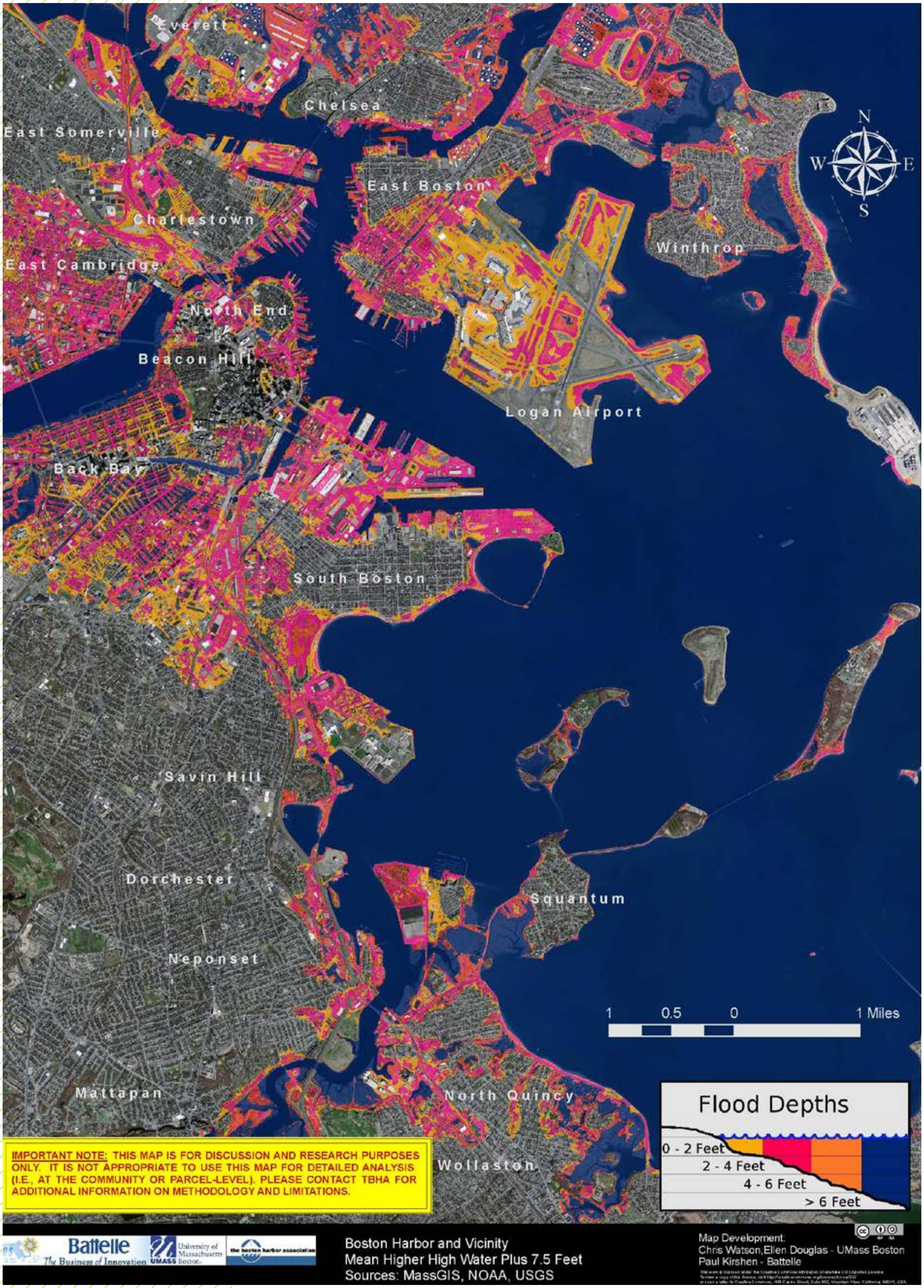
GLOSSARY OF TERMS

100-year flood	A flood that has a 1 percent likelihood of occurring or being exceeded in a given year
500-year flood	A flood that has a 0.2 percent likelihood of occurring or being exceeded in a given year
Adaptation	An ongoing process of successful adjustments to new environmental conditions
Adaptive capacity	Ability of a system or population to adapt to a changing environment
Boston Harbor	The harbor bounded to the north by Winthrop and to the south by Hull; contains 34 harbor islands and multiple municipalities
Boston's Inner Harbor	The narrow, more developed area of Boston Harbor bounded by East Boston's Logan Airport, the Mystic and Charles Rivers, and South Boston's Castle Island
Co-benefit solutions	Solutions that also further other goals
Combined Sewer Overflow	Discharge of wastewater and stormwater from a combined sewer system directly into a water body
Critical elevation	The lowest level at which a property potentially experiences flood damage
Mean Higher High Water (MHHW)	Technical measure of average high tide: "The average level of the higher high water of each tidal day over the course of a 19-year reference period (the National Tidal Datum Epoch)"
Mitigation	The effort to decrease emissions of climate change-causing gases such as carbon dioxide or methane
No-regret solutions	Solutions that provide benefits irrespective of climate change
Preparedness	Precautionary measures taken to prevent damage from coastal flooding
Resilience	The ability to recover quickly and relatively inexpensively from flooding or another stress
Resistance	The ability to prevent flooding
Storm surge	Higher sea levels due to low barometric pressure and high winds
Storm tide	Storm surge plus tide level; flooding is worst when a storm surge peaks at high tide
Subsidence	The gradual sinking of the earth's surface
Vulnerability	The degree to which a system is susceptible to and unable to cope with adverse effects of coastal flooding

APPENDIX 1. BOSTON SEA LEVEL RISE MAPS FROM *PREPARING FOR THE RISING TIDE*

Flooding in Boston at Mean Higher High Water plus 2.5 feet

Flooding in Boston at Mean Higher High Water plus 5 feet



Flooding in Boston at Mean Higher High Water plus 7.5 feet

APPENDIX 2. ADDITIONAL CASE STUDIES

INDIVIDUAL SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Alumnae Valley Restoration	Wellesley College	Michael Van Valkenburgh Associates, Inc.	Wellesley, MA	2005	Create Double-duty solutions
Amphibious House	Private owner	Baca Architects, Techniker, HR Wallingford	Marlow, United Kingdom	Under Construction	Design for Resilience
Duval Beach Club	City of Key West		Key West, FL	1999	Design for Resilience
Floating House	Private owners	MOS Architects	Ontario, Canada	2005	Design for Resilience
Floatyard		Perkins+Will	Charlestown, MA	Conceptual	Design for Resilience
IJburg Floating Houses	Ontwikkelings-combinatie Waterbuurt West v.o.f.	Marlies Rohmer Architects and Planners	Ijburg, Amsterdam	2011	Design for Resilience
Julian D. Steele Building	Melrose Housing Authority	Michael Casavoy	Melrose, MA	2010	Design for Resilience
Lambertville Public School Retrofit	Hunterdon County		Lambertville, NJ	2000	Design for Resilience
Make It Right Foundation, Lower 9th Ward	Private homeowners	Various	New Orleans, LA	Under Construction	Design for Resilience
Makoko Floating School		NLÉ	Lagos, Nigeria	2012	Design for Resilience
MTA Flood Mitigation Street Furniture and Urban Plan	Metropolitan Transit Authority	Rogers Marvel Architects; Di Domenico + Partners	New York, NY	2009	Design for Resilience

INDIVIDUAL SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Museumpark Garage and Underground Water Storage	Museumpark: Ontwikkelingsbedrijf Rotterdam (Rotterdam Development); Erasmus Medisch Centrum (Erasmus Medical Center) Water Storage: Municipality of Rotterdam and Hoogheemraadschap Schieland and Krimpenerwaard (Schieland and Krimpenerwaard Water Board)	Architectenbureau Paul de Ruiter	Rotterdam, The Neatherlands	2010	Create Double-duty solutions
NYC Parks Beach Restoration Modules	NYC DDC Design Excellent Program/NYC Parks Department	Garrison Architects	New York, NY	2013	Design for Resilience
The Turnaround House	RIBA and Norwich Union Flood Design competition, 2008	Nissen Adams	UK	Conceptual	Design for Resilience

NEIGHBORHOOD SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Averne By The Sea	Arverne By the Sea LLC	EE&K	Arverne, NY		Design for Resilience
Benidorm West Beach Promenade	Generalitat Valenciana – Ajuntament De Benidorm	Office of Architecture in Barcelona	Benidorm, Spain	2009	Create Double-duty solutions
The Big U	Rebuild by Design Competition	BIG Team	New York, NY	In Progress	Create Double-duty solutions
Borneo-Sporenberg Residential Waterfront Master Plan	City of Amsterdam	West 8	Borneo-Sporenberg, Germany	2000	Phase Plans Over Time
Brookside Wetland Project	The City of Portland Bureau of Environmental Services		Portland, OR		Create Double-duty solutions
Canting Basin Floating Village	Floating Concepts	Baca Architects, ZM Architecture	Glasgow, Scotland		Design for Resilience
Cedar Grove Mobile Home Park Acquisition	King County		King County, WA	Ongoing	Incentivize and Institutionalize Preparedness
Climate Resilience 2.0	The Nature Conservancy	The Nature Conservancy, the Natural Capital Project, National Oceanic and Atmospheric Administration, University of Southern Mississippi and Association of State Floodplain Managers	Fairfax, VA	2013	Strengthen Community Resilience
Community-based Flood Preparedness and Institutional Coordination Systems	Kutao sub-district	The Songkhla Community Foundation	Hat Yai, Thailand	2013	Strengthen Community Resilience

NEIGHBORHOOD SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Community Disaster Risk Reduction Trust Fund	Department of Foreign Affairs, Trade and Development, Canada (DFATD), the United Kingdom's Department for International Development (DFID)	Caribbean Development Bank	Bangladesh		Strengthen Community Resilience
Community Flood Wardens	Leicester, Leicestershire, and Rutland	Local Resilience Forum	Uniked Kingdom		Strengthen Community Resilience
East Powell Butte Restoration Project	The City of Portland Bureau of Environmental Services		Portland, OR	Ongoing	Create Double-duty solutions
Floating Pavilion	Municipality of Rotterdam	Public Domain Architects, Deltasync	Rotterdam, The Netherlands	2010	Create Double-duty solutions
Flood Forcasting and Warning System	The Project Management Unit including representatives from Semarang Development Planning Board and Environmental Board	Mercy Corps	Semarang, Indonesia	2014	Strengthen Community Resilience
Flood Monitoring and Community Communications System	Chiang Rai Municipality	Thailand Environment Institute	Chiang Rai, Thailand	2012	Strengthen Community Resilience
Hunts Point Lifelines	Rebuild by Design Competition	PennDesign/OLIN	Bronx, NY	In Progress	Create Double-duty solutions
Ma'anshan Cihu River Basin Improvement Project	Anhui Province	Cihu River Integrated Development Co. Ltd.	Ma'anshan, China	Ongoing	Strengthen Community Resilience

NEIGHBORHOOD SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Maasbommel	De Gouden Kust	Factor Architecten, Dura Vermeer	Maasbommel, The Netherlands	2006	Design for Resilience
Marina Barrage	PUB, Singapore's national water agency	Architects Team 3 Pte Ltd	Singapore	2008	Create Double-duty solutions
Mound Plan Overdiepse Polder	Providence of Noord Brabant and Municipality of Waalwijk	Bosch Slabbers Landscape + Urban Design; Onix Architects	the Netherlands	Ongoing	Create Double-duty solutions
National Emergency Child Locator Center		National Center for Missing & Exploited Children	United States	2005	Strengthen Community Resilience
Occupy Sandy	NY and NJ community residents	Occupy Sandy network	New York, NY	Ongoing	Strengthen Community Resilience
Power Rockaways Resilience	residents and businesses	Jennifer Bolstad and Walter Meyer	The Rockaways, NY	2012	Strengthen Community Resilience
RAYdike	Rising Tides Competition 2009	Faulders Studio	San Francisco, CA	Conceptual	Strengthen Community Resilience
Resilience + The Beach	Rebuild by Design Competition	Sasaki/Rutgers/Arup	Jersey Shore, NJ	In Progress	Create Double-duty solutions
San Dieguito Lagoon's Wetland Restoration Project	Southern California Edison	WRA, Inc.	San Dieguito, CA	2011	Create Double-duty solutions
Seoul Floating Islands	Seoul Metropolitan Government	H Architecture, Haeahn Architecture	Seoul, South Korea	2011	Design for Resilience
Shanghai Houtan Park	Shanghai World Expo Land Development Co., Ltd.	Turenscape	Shanghai Houtan Park, China	2010	Create Double-duty solutions

NEIGHBORHOOD SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Storm and Flood Resistant Credit and Housing Scheme	Institute for Social and Environmental Transition	Climate Change Coordination Office	Da Nang, Vietnam	Ongoing (2014)	Incentivize and Institutionalize Preparedness
Super Levee Urban Farm	ONE Prize 2011	AGENCY Architecture		Conceptual	Create Double-duty solutions
Super Levees	Tokyo Metropolitan Government	River Council	Tokyo, Japan	Ongoing	Create Double-duty solutions
The Commercial Corridor Resiliency Project	Rebuild by Design Competition	HR&A Advisors, Inc. with Cooper, Robertson & Partners	Red Hook, Brooklyn, New York; Far Rockaway, Queens, New York; Asbury Park, New Jersey	In Progress	Strengthen Community Resilience
The Hanneys Flood Group		The Hanneys Flood Group	Oxfordshire, United Kingdom	2009	Strengthen Community Resilience
The Life Project	Defra Research	Baca Architects; BRE; Cyril Sweett Fulcrum Consulting; LDA Design; Halcrow	United Kingdom	Ongoing	Create Double-duty solutions
The Local Disaster Risk Reduction and Management Fund	National Disaster Risk Reduction and Management Council	Local Disaster Risk Reduction and Management Council	Phillippines	2012	Strengthen Community Resilience
Urban Mangrove Restoration for Storm Surge Protection and Resilient Land Use Practice	Institute for Social and Environmental Transition	Binh Dinh Climate Change Coordination Office	Quy Nhon, Vietnam	Ongoing (2015)	Create Double-duty solutions
Viet Village Urban Farm	Mary Queen of Viet Nam Community Development Corporation	Mossop + Michaels; Tulane City Center; and Louisiana State University (LSU) School of Landscape Architecture	New Orleans, LA	Ongoing	Strengthen Community Resilience

NEIGHBORHOOD SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Water Proving Ground	Rising Currents Exhibit 2010	LTL Architects	New York, NY	Conceptual	Create Double-duty solutions
Water-scraper	eVolo 2010 Skyscraper Competition	Sarly Adre Bin Sarkum	Malaysia	Conceptual	Design for Resilience
Watersquare Benthemplein (Benthemplein Waterplein)	Rotterdam Climate Initiative, City of Rotterdam, and Waterboard Schieland & Krimpenerwaard	DE URBANISTEN	the Netherlands	2013	Create Double-duty solutions

REGIONAL SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
100 Year Plan — Rising Tides are a Catalyst to Solve the Water Crisis	Rising Tides Competition 2009	Derek James Hoeferlin, Ian Caine, Michael Heller	San Francisco, CA	Conceptual	Create Double-duty solutions
5 Lagoons Project	Dutch Docklands Maldives	Waterstudio.NL	The Maldives	Under Construction, 2015	Create Double-duty solutions
BAY Arc	Rising Tides Competition 2009	SOM	San Francisco, CA	Conceptual	Develoop Time-phased Flexible Plans
Biggert-Waters Flood Insurance Reform Act of 2012		Federal Emergency Management Agency	United States	2012	Incentivize and Institutionalize Preparedness
Blue Dunes — The Future of Coastal Protection	Rebuild by Design Competition	WXY/West 8	Offshore New York and New Jersey	In Progress	Phase Plans Over Time
Boston 2088	Antonio Di Mambro + Associates, Inc.		Boston, MA	Conceptual	Phase Plans Over Time
Cedar Falls Zoning and Ordinances for 500-year Floodplain		City of Cedar Falls, IA	Cedar Falls, IA	2011	Incentivize and Institutionalize Preparedness
Chesapeake and Atlantic Coastal Bays Critical Area Program	Joint Committee on the Chesapeake and Atlantic Coastal Bays Critical Area	State of Maryland Critical Areas Commission	Maryland	1984	Incentivize and Institutionalize Preparedness
Chesapeake Bay Living Shorelines		Chesapeake Bay Foundation and Maryland Department of Environment	Maryland, Virginia, Louisiana, Chesapeake Bay	Ongoing	Create Double-duty solutions

REGIONAL SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Coastal Blue Acres Program	New Jersey Department of Environmental Protection		New Jersey	Ongoing	Incentivize and Institutionalize Preparedness
Copenhagen Climate Action Plan	The City of Copenhagen		Copenhagen, Denmark	2011	Phase Plans Over Time
CSO-to-go		Local Office Landscape Architecture	New York, NY	Pending	Design for Resilience
Curitiba Parks	City of Curitiba	Jamie Lerner	Curitiba, Brazil		Create Double-duty solutions
Delaware Coastal Management Program — Sea Level Rise Initiative	The State of Delaware	Delaware Department of Natural Resources and Environmental Control	Delaware		Incentivize and Institutionalize Preparedness
Embracing the Rise	Rising Tides Competition 2009	Perkins+Will	San Francisco, CA	Conceptual	Phase Plans Over Time
Evolutionary Recovery	Rising Tides Competition 2009	LANDplus Design	San Francisco, CA	Conceptual	Phase Plans Over Time
Folding Water Ventilated Levees	Rising Tides Competition 2009	Kuth Ranieri Architects	San Francisco, CA	Conceptual	Create Double-duty solutions
Horizontal Levee		The Bay Institute	San Francisco, CA	Conceptual	Create Double-duty solutions
Iowa City Community Development Block Grant Buyouts		City of Iowa City	Iowa City, IA		Strengthen Community Resilience

REGIONAL SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Kingston Tidal Waterfront Flooding Task Force	The City of Kingston	Tidal Waterfront Flooding Task Force	Kingston, NY	2013	Strengthen Community Resilience
Living Breakwaters	Rebuild by Design Competition	SCAPE / Landscape Architecture	Staten Island, NY	In Progress	Create Double-duty solutions
Living with the Bay: A Comprehensive Regional Resiliency Plan for Nassau County's South Shore	Rebuild by Design Competition	Interboro Team	Long Island, NY	In Progress	Phase Plans Over Time
London Britannia Airport		Gensler, Thames Estuary Reseach and Development Company (TESTRAD)	London, UK	Conceptual	Design for Resilience
Malibu Local Coastal Program - Local Implementation Plan		City of Malibu, California	Malibu, CA	Ongoing	Incentivize and Institutionalize Preparedness
Mississippi River Gulf Outlet Ecosystem Restoration	US Federal Government	US Army Corps of Engineers	New Orleans and St. Bernard Parish, LA		Create Double-duty solutions
National Flood Insurance Program's (NFIP) Community Rating System		Federal Emergency Management Agency	united States	1990	Incentivize and Institutionalize Preparedness
National Planning Policy Framework	Department for Communities and Local Government		England, United Kingdom	2012	Phase Plans Over Time

REGIONAL SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
New Aqueous City	MoMA Rising Currents	nArchitects	New York, NY		Phase Plans Over Time
New Meadowlands: Productive City + Regional Park	Rebuild by Design Competition	MIT CAU + ZUS + URBANISTEN	The Meadowlands, NJ	In Progress	Create Double-duty solutions
Ocean Beach Master Plan	State Coastal Conservancy, the San Francisco Public Utilities Commission and the National Park Service	SPUR	San Francisco, CA	Ongoing	Phase Plans Over Time
Pacifica State Beach Managed Retreat, Beach and Estuary Restoration	City of Pacifica	Environmental Service Associates	Pacifica, CA		Phase Plans Over Time
Pine Barrens Credit Program	Central Pine Barrens Commission	Clearinghouse Board of Advisors	Long Island, NY	1995	Incentivize and Institutionalize Preparedness
PlaNYC	The City of New York	Office of Long-Term Planning and Sustainabilty	New York, NY	2009	Phase Plans Over Time
Pontchartrain Coastal Lines of Defense Program		Lake Pontchartrain Basin Foundation	New Orleans, LA	Ongoing	Phase Plans Over Time
Punggol Waterway Project	National Parks Board	Surbana International Consultants PTE LTD	Punggol, Singapore	2011	Create Double-duty solutions
Shenzhen Qianhai Water City	Urban Planning, Land and Resources Commission of Shenzhen Municipality	James Corner Field Operations	Shenzhen, China	Ongoing	Phase Plans Over Time

REGIONAL SITE SCALE

Project Name	Client/Site Owner/Project Beneficiaries	Designer/Project Implementer	Location	Date Opened/ Launched	Designing with Water Concepts
Smart Tunnel	Government of Malaysia	MMC Engineering-Gamuda joint venture	Kuala Lumpur, Malaysia	2007	Create Double-duty solutions
TDR Program & Overlay Zone	Collier County Government	Collier County Government	Collier County, FL	2013	Incentivize and Institutionalize Preparedness
Thames River Barrier	Greater London Council	Rendel, Palmer and Tritton	London, England	1982	Traditional
The Drakes Estero Coastal Watershed Restoration Project		National Park Service	Point Reyes National Seashore, CA	2008	Create Double-duty solutions
The Sand Motor (Zandmotor)	Rijkswaterstaat and the provincial authority of Zuid-Holland		the Netherlands	2011	Create Double-duty solutions
Tidal Floodplain Overlay		Board of Trustees of the Village of Southampton	Southampton, NY	2013	Incentivize and Institutionalize Preparedness
Tillamook County Flood Hazard and Beach and Dune Overlay Zones	Tillamook County	Department of Community Development	Tillamook County, OR	1999	Incentivize and Institutionalize Preparedness
Topographical Shifts at the Urban Waterfront	BCDC — SF Bay Conservation & Development	Wright Huaiche Yang + J. Lee Stickles	San Francisco, CA	Conceptual	Phase Plans Over Time
Working Waterline	Rising Currents Exhibition 2010	Matthew Baird Architects	New York, NY	Conceptual	Create Double-duty solutions

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