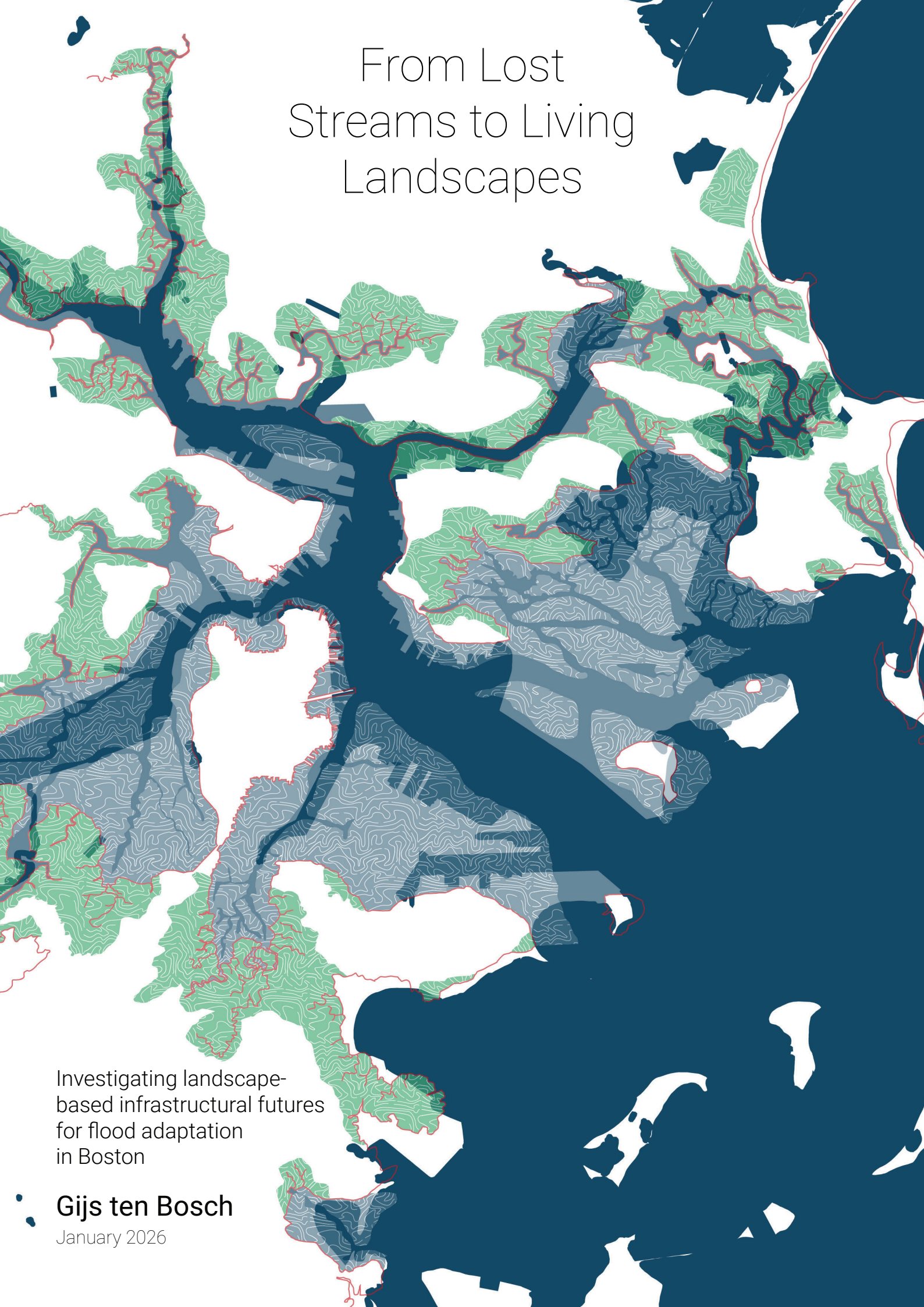
From Lost Streams to Living Landscapes



Investigating landscape-based infrastructural futures for flood adaptation in Boston

Gijs ten Bosch

January 2026

Colophon

From Lost Streams to Living Landscapes

Investigating landscape-based infrastructural futures for flood adaptation in Boston

Master Thesis

Author
Gijs ten Bosch
5081653

January 2026

Supervisors
First mentor - Luca Iuorio - Environmental Technology and Design
Second mentor - Daniele Cannatella - Landscape
Delegate - Eytan Mann Kanowitz

Delft University of Technology

Faculty of Architecture and the Built Environment

MSc Architecture, Urbanism and Building Sciences

Urbanism

With support of:

EFL STICHTING

Urbanism

TU Delft | Architecture and the Built Environment

Acknowledgments

I would like to thank the people without whom this thesis would not have been possible.

To my mentors, Luca and Daniele: thank you for your indispensable support throughout the past year. Your open-minded approach and critical attitude toward the research and design process guided, inspired, and encouraged me to grow as an urbanist.

To Myrthe, Thijs, Nikita, Emma, and Ganesh: thank you for the study sessions, our self-made workshops, and the fun moments along the way. You made this journey genuinely enjoyable.

I am also deeply grateful to everyone who supported me during my time in Boston. Esther, Bob, John, Ksenia, Kelly, and the MWRA: thank you for showing me around and sharing invaluable insights that significantly strengthened this thesis.

A heartfelt thank-you as well to my parents and friends for their continuous support, not only over the past year, but throughout my entire time studying in Delft.

Lastly, I would like to thank the EFL Stichting for supporting the field trip that formed such an important part of this project.

Abstract

‘From Lost Streams to Living Landscapes’ investigates landscape-based infrastructural futures for flood adaptation by diving into American flood management and critiquing the dependence on centralized infrastructural systems that create complex patterns of vulnerability within the Metropolitan Area of Boston.

This thesis approaches landscape as a form of infrastructural ecology, an active system that organizes flows of water, energy, and life. The objective of this thesis is to explore how such a perspective can balance environmental pressures with everyday urban life by integrating ecological processes into the logic of urban systems. This approach aims to strengthen the embedding of the city within its landscape and to explore how hydrology, flood risk, and landscape can generate new urban futures.

The main question: *How can landscape, understood as infrastructure, guide future scenarios of flood adaptation that strengthen the spatial and ecological relationship between water and urban life in Metropolitan Boston?* is answered through critical cartography, ethnographic fieldwork, scenario building, and research-by-design through the following research questions:

- What is the current condition of Boston’s water and landscape infrastructures?

- What are the (spatial) implications of extreme water scenarios, caused by climate change, in Metropolitan Boston?

- How do socio-economic vulnerabilities intersect within Boston’s flood-prone areas?

- What future scenarios can be developed to explore how landscape-based infrastructures could mediate between flood dynamics and urban development?

- How can these scenarios be spatially translated into design strategies that reconnect urban form with its underlying land- and waterscapes?

Through a systematic sectional exploration, the integration of the urban and environmental system is translated into design strategies by combining historical hydrology, soil conditions, water flow patterns, and urban form into a coherent spatial logic. The result is a set of landscape-based strategies that reconnect the city to its underlying land and waterscapes, not by replicating historical conditions, but by using them to guide new forms of flood-resilient urbanism.

By acknowledging the correlation between the urban and environmental (sub)systems, in combination with a flood accommodating approach, landscape-based infrastructures can transform (storm)water from a hazard into a driver that enables the co-evolution of landscape, ecology, and urban life.

Table of Contents

1. INTRODUCTION 8
- 1.1 Motivation 10
- 1.2 Flood management in the United States 12
- 1.3 Land-making history 14

2. LANDSCAPE & WATER SYSTEM ANALYSIS 18
- 2.1 Topography 20
- 2.2 Infrastructural systems 26
- 2.3 Landscape ecologies 40
- 2.4 Environmental degradation 44

3. EXTREME WATER SCENARIOS 46
- 3.1 Climate change weather patterns 48
- 3.2 Coastal storm surge flood events 50
- 3.3 Riverine floods 58
- 3.4 Rising threats 60

4. PATTERNS OF VULNERABILITY 62
- 4.1 Socio-economic vulnerability 64
- 4.2 Vulnerability scorecards 76

5. PROBLEMATIZATION 82
- 5.1 Problem framework 84
- 5.2 Problem statement 87

6. THEORY & CONCEPTS 88
- 6.1 Theoretical framework 90
- 6.2 Conceptual framework 93

7. METHODOLOGY 94
- 7.1 Research questions 96
- 7.2 Aims & Methods 98

8. FIELDWORK 102
- 8.1 Site visits 104
- 8.2 Metropolitan ecologies 106
- 8.3 Downtown & Seaport 116
- 8.4 East Boston 118
- 8.5 Chelsea 126
- 8.6 Biking along the Charles River 128
- 8.7 Biking along the Mystic River 134
- 8.8 Visiting Deer Island - MWRA water treatment plant 142
- 8.9 Observing coastal developments and infrastructure 148
- 8.10 Visiting the Boston Harbor Islands - Spectacle Island 156
- 8.11 Fieldwork reflection 160

9. BUILDING SCENARIOS 164
- 9.1 Clustering design interventions 166
- 9.2 Popular elements of reality 180
- 9.3 Scenarios 182
- 9.4 Synthesis 192

10. DESIGN PROCESS 194
- 10.1 Local scale analysis 196
- 10.2 Analytical synthesis 212
- 10.3 Design framework 218
- 10.4 Systemic sectional exploration 222
- 10.5 Cross-scalar synthesis 258

11. THESIS OUTCOMES 264
- 11.1 Conclusion 266
- 11.2 Discussion 269
- 11.3 Reflection 270

12. BIBLIOGRAPHY 274

13. APPENDIX 282

1. INTRODUCTION

1.1 Motivation
1.2 Flood management in the United States
1.3 Land-making history



1.1 Motivation

Designing with water

As a typical Dutch kid, I spent most of my summers camping across Europe. My parents would take me away from the city life of Rotterdam to enjoy the outdoors, usually in the southwest of France. I would spend my days playing football between the pine trees and swimming in the Atlantic Ocean. As I got older, swimming was replaced by surfing, and to this day, I continue to spend much of my time in the water.

These experiences form the foundation of my fascination with the outdoors and how these land- and waterscapes can be meaningfully integrated into urban environments. Since studying urbanism, however, I have become aware of the complexities and environmental pressures that define cities today, especially in the context of climate change. This awareness has also deepened my desire to leave the city whenever I can, to reconnect with the landscapes that urban life often distances us from.

As an urbanist, I am conscious of my role in shaping the future. Our generation is confronted with the urgent task of redefining spatial planning in response to climate change, urbanization, and social inequality. These intertwined crises demand not only design responses but also a rethinking of our relationship with the environment. My design projects throughout this master's program have consistently revolved around water, its flows, its risks, and its potential as a structuring element in urban design.

With this thesis, I want to take that exploration further. By investigating the implications of floods on cities, I aim to uncover how urban environments can evolve with, rather than resist, the changing dynamics of water. Ultimately, this project is an attempt to bridge my personal connection to water with my professional ambition to combine urbanism and landscape architecture to imagine and blend urban land- and waterscapes that embrace uncertainty and change.

"Those who live by the water are under constant threat from it."

Dorthe Nors (2022)

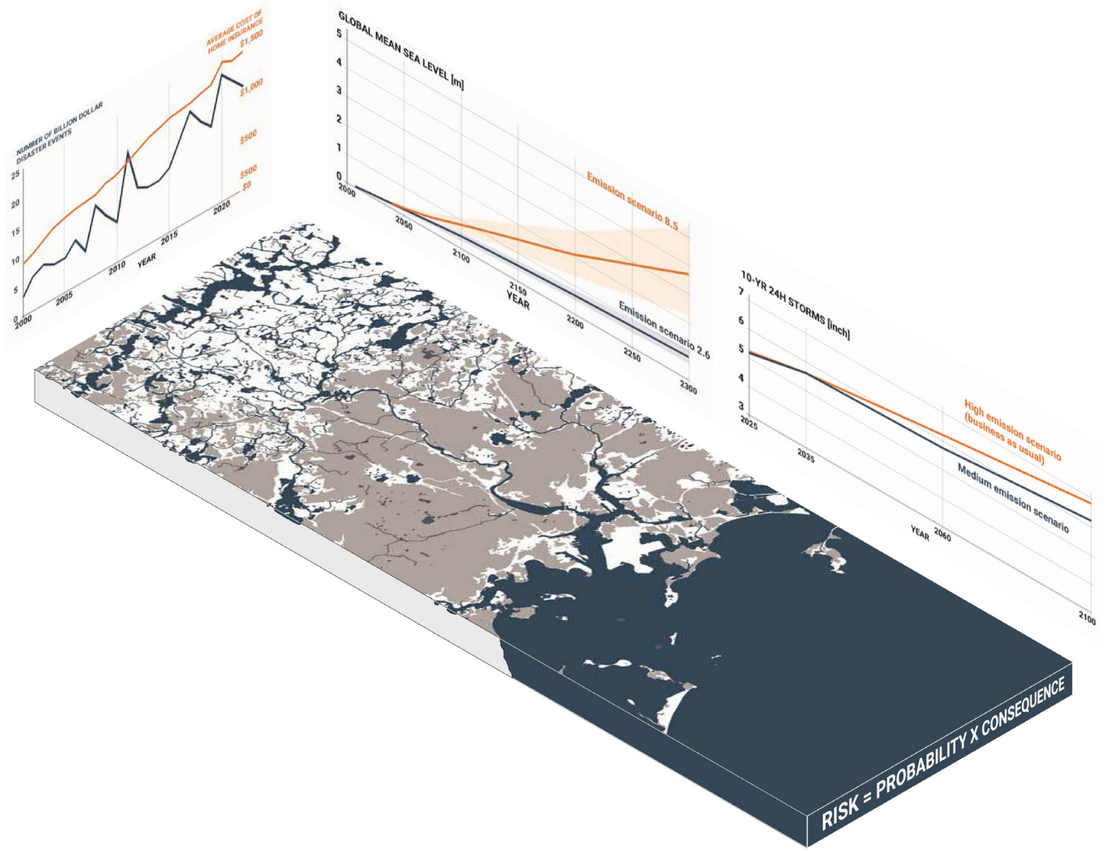
1.2 Flood management in the United States

Contextualization

Worldwide, society faces severe consequences from climate change, which places urban environments under immense pressure. Increased flood risks due to extreme precipitation, heightened river runoff, and rising sea levels threaten the Metropolitan Area of Boston. Although projections of sea level rise depend on global carbon emissions, the IPCC (2019) indicates that the American East Coast is experiencing one of the highest rises. Additionally, Boston ranks 8th globally in terms of average annual economic loss caused by coastal floods (Hallegatte et al., 2013), and the city faces 100% flood exposure if sea levels rise by 1.80 meters (6 feet) (Berger et al., 2020). These are merely coastal flood risks, not to mention the hazards that arise from inland flooding (pluvial & riverine). Furthermore, Boston is particularly vulnerable to floods due to the land making history of the city, which correlates to land subsidence along the coast and areas developed throughout the city's history.

The flood risk management system in the United States differs from that of the Netherlands. Dutch water management relies on physical flood defenses, while in the United States, insurance (and evacuation strategies) are more important (Hooimeijer et al., 2022). Between 1988 and 2017, Davenport et al. (2021) estimate that flood damage accounted for just over 200 billion dollars. The requirement of purchasing insurance to mitigate flood risk, combined with significant inequalities in the United States, creates an unfairness in protection.

Figure 1.1 -
Made by author.
Data: Oppenheimer et al. (2019), BWSC (2017), NCEI et al. (2023)





Ethan Swope (2025)



Halle Parker (2021)

1.3 Land-making history



The City of Boston was founded on the Shawmut Peninsula in 1630 by the Puritans. The Shawmut Peninsula was connected to the mainland through a long 'neck' which was only accessible during low tide. Due to urban expansion and the maritime sector as the main economy of the settlement, it was indispensable to extend to the mainland. Instead the early Bostonians made land, by filling the tidal flats that surrounded the peninsula.

Figure 1.2 - Land making process over time - made by author (Map Works, Inc., 1999)

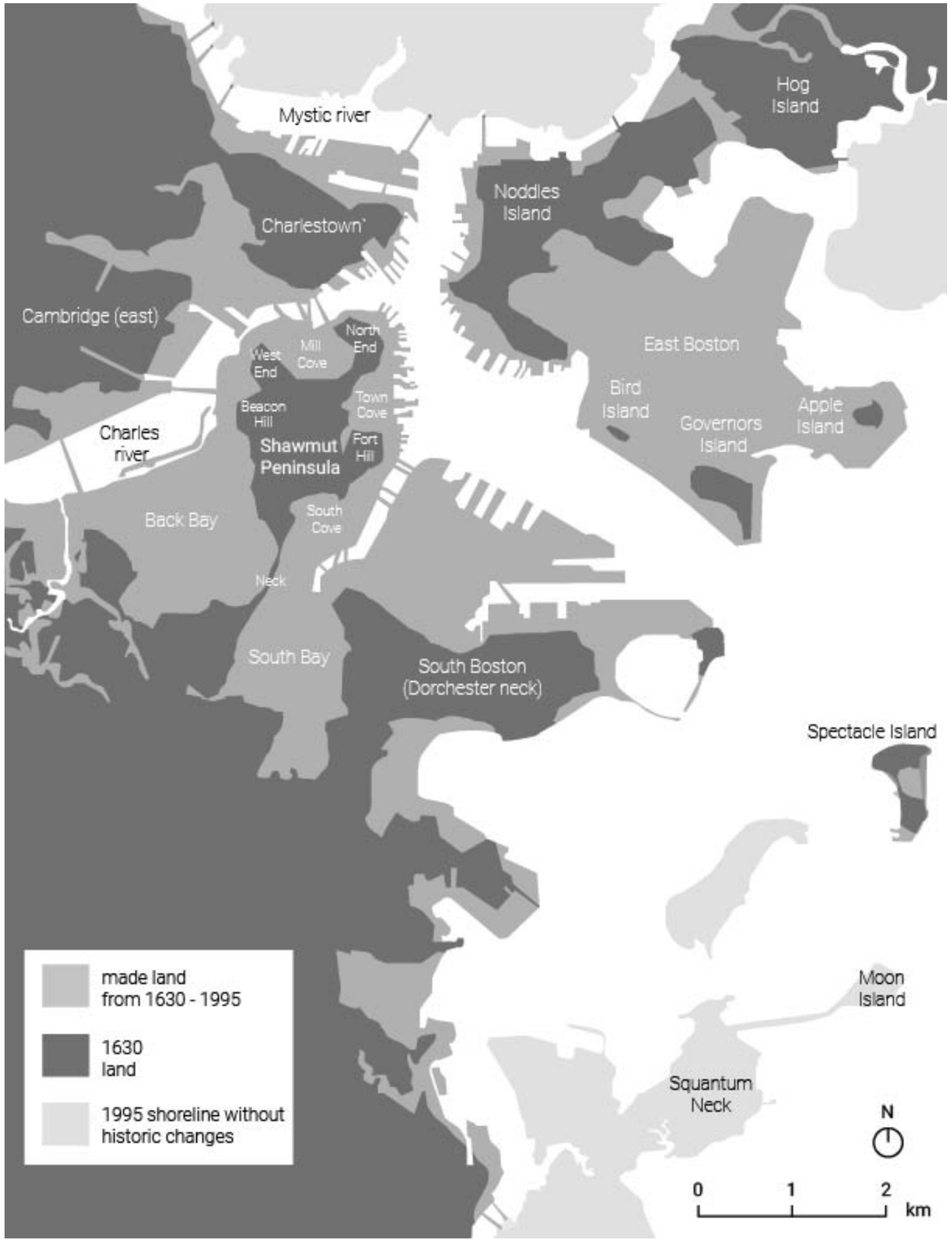


Figure 1.3 - Summary of land making history Made by author (Seasholes, 2003)

Around 30,000 acres of land have been created over time in Boston (Seasholes, 2003). The maritime sector, as a primary industry, explains the wharf structure that Boston adopted through the harbor's expansion caused by economic development. The population doubled in size by 1790, driven by a boost in trade with China, which created significant demand for new land. In 1830, the newly introduced railroads generated the need for new land to accommodate this infrastructure. This served as an important connection from the heart of the maritime industry to the mainland

Later, Boston's wastewater was dumped into Massachusetts Bay near the shore, polluting coastal waters and raising health concerns. Around 1860, there was a growing necessity for public parks. This demand stemmed from the best practices established by Central Park in New York, which Boston aimed to recreate. Newly created land would be designated for these new public parks. Other developments leading to newly created land included large infrastructural projects such as new highway systems and the construction of Logan International Airport (Seasholes, 2003).

Land was created by building a perimeter structure around the soon-to-be-made land on the tidal flats adjacent to the existing land. The new area would be filled with materials like gravel, dirt, or dredge until it rose above the high tide water level. This technique had already been used to build wharves, making it a relatively easy and well-known method for Bostonians (Seasholes, 2003).

Different types of perimeter structures and fill materials have been utilized over time. These ranged from timber structures, which were also employed in the construction of wharves, to large seawalls. Later, stone bulkheads and dikes were utilized as perimeter structures.

Originally, trash was used as fill material. This practice was quite controversial, as people believed that the smell of trash could infect individuals with diseases. Trash fill was covered with dirt. After multiple epidemics, trash became unacceptable as fill material, leading to the predominant use of gravel and dirt, as well as mud from the tidal flats. In the nineteenth century, dredged material from waterways was also utilized as fill (Seasholes, 2003).

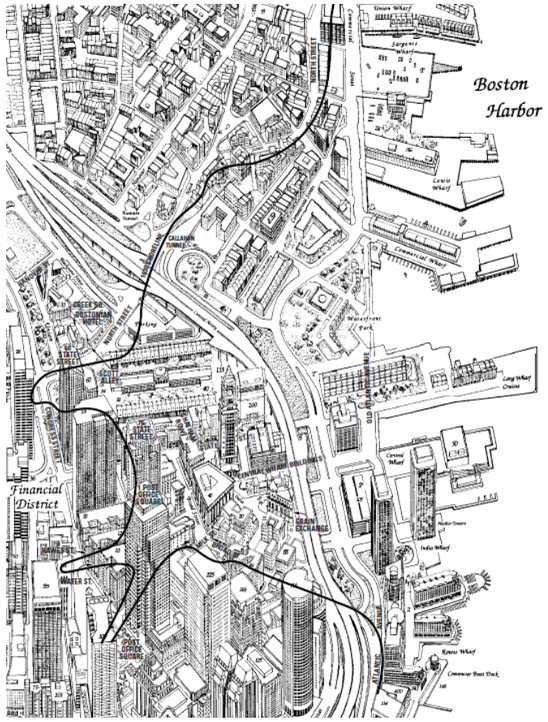


Figure 1.4 - Birds eye view with 1630 shoreline [out of Seasholes, 2003] (Boston Olde South Publishing Company, 1992)



Figure 1.5 - Loading gravel train in Needham [out of Seasholes, 2003] (Society for the Preservation of New England Antiquities, 1858)



Figure 1.6 - Acquiring fill from Fort Hill [out of Seasholes, 2003] (The Bostonian Society/Old State House, 1870)



Figure 1.7 - Dredging process in Back Bay [out of Seasholes, 2003] (Trustees of the Boston Public Library, 1882)

2. LANDSCAPE & WATER SYSTEM ANALYSIS

2.1 Topography
2.2 Infrastructural systems
2.3 Landscape ecologies
2.4 Environmental degradation



2.1 Topography

The Metropolitan Area of Boston is surrounded by higher grounds and the ocean. The low-lying area where Boston is located is called the Boston Basin. The Boston Basin Topographical Model has been made to represent the geological depression in which the city grew over time. During the Ice Age, the glaciers created a layer of clay when they receded. On top of this layer, glacial till and gravel created hills, so-called drumlins (Seasholes, 2003). The small island in the Boston Harbor were connected to the mainland when the sea did not reach its current level. Due to rising sea levels, a layer of muddy silt was deposited on top of the clay.



Figure 2.1 - Renovating the Boston Basin Topographical Model - Source: MWRA (2012)

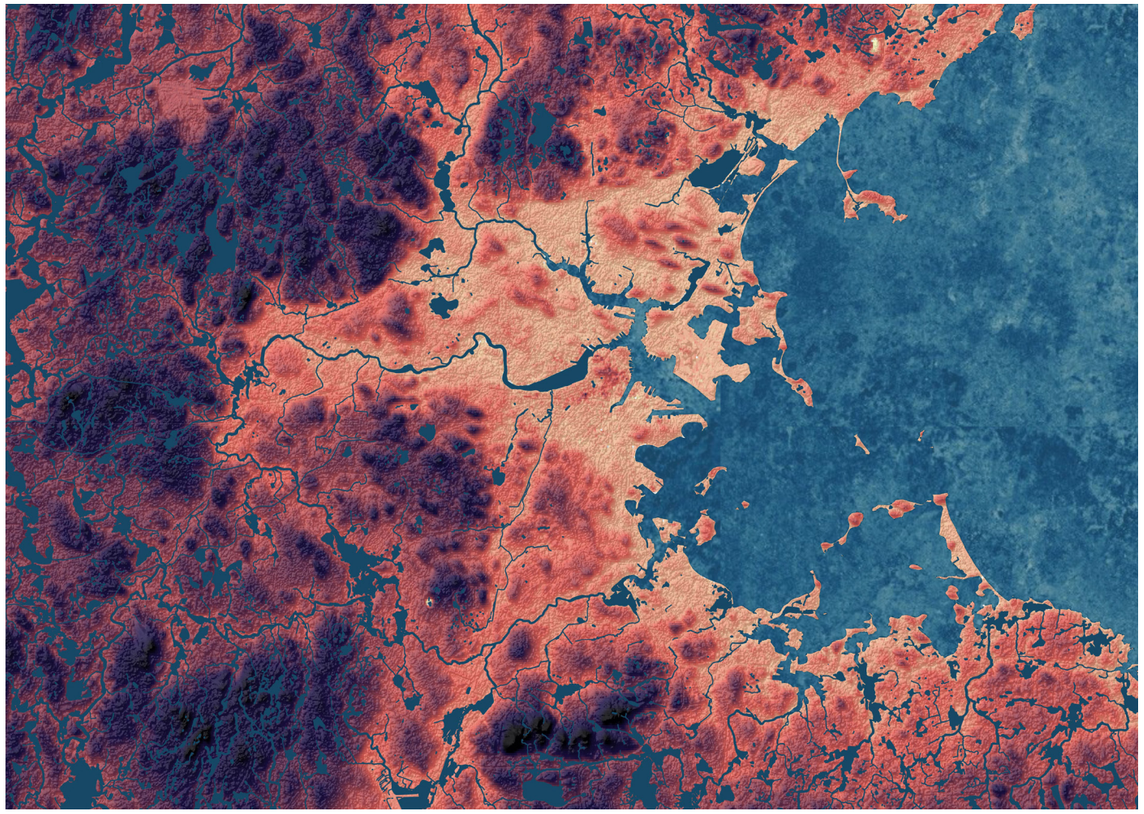


Figure 2.2 - Digital Elevation Model Metropolitan area of Boston
Made by author
Data: European Space Agency (2024)

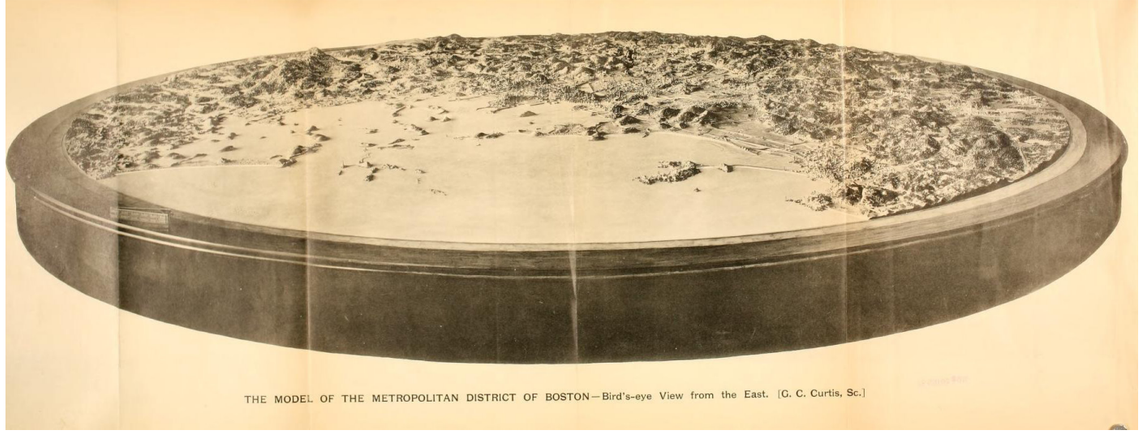


Figure 2.3 - The model of the metropolitan district of Boston
Source: G.C. Curtis & Board of Paris Exposition Managers (1900)

Soil types

"At 5:15 A.M. on December 18, 1986, the residents of a townhouse on Otis Place, on the Beacon Hill Flat in Boston, were suddenly awakened by a loud rumbling and the house shaking... Structural engineers soon ascertained that the house had sunk several inches." (Seasholes, 2003).

Soil is the foundation of the landscape and the built environment. From soil typologies, important characteristics such as stability, water drainage & retention capacity, history, and land use are able to be understood.

Given the historical context of land-making processes in Boston, the areas around the original Shawmut Peninsula are mixed soils with trash, gravel, dirt, mud, dredge material, and many others, called udorthents, that have been altered by human interventions (such as land-making processes). These soils do not have a natural structure and are prone to subsidence (USDA, 1999).

Other predominant soil types in the region are combinations of sand and loam: sandy loam, loamy sand, sand, and loam. Sand is relatively stable and has good water drainage properties. Loam, being a mix of clay, sand, and silt, is very dependent on the ratios between contents and could be subject to subsidence.

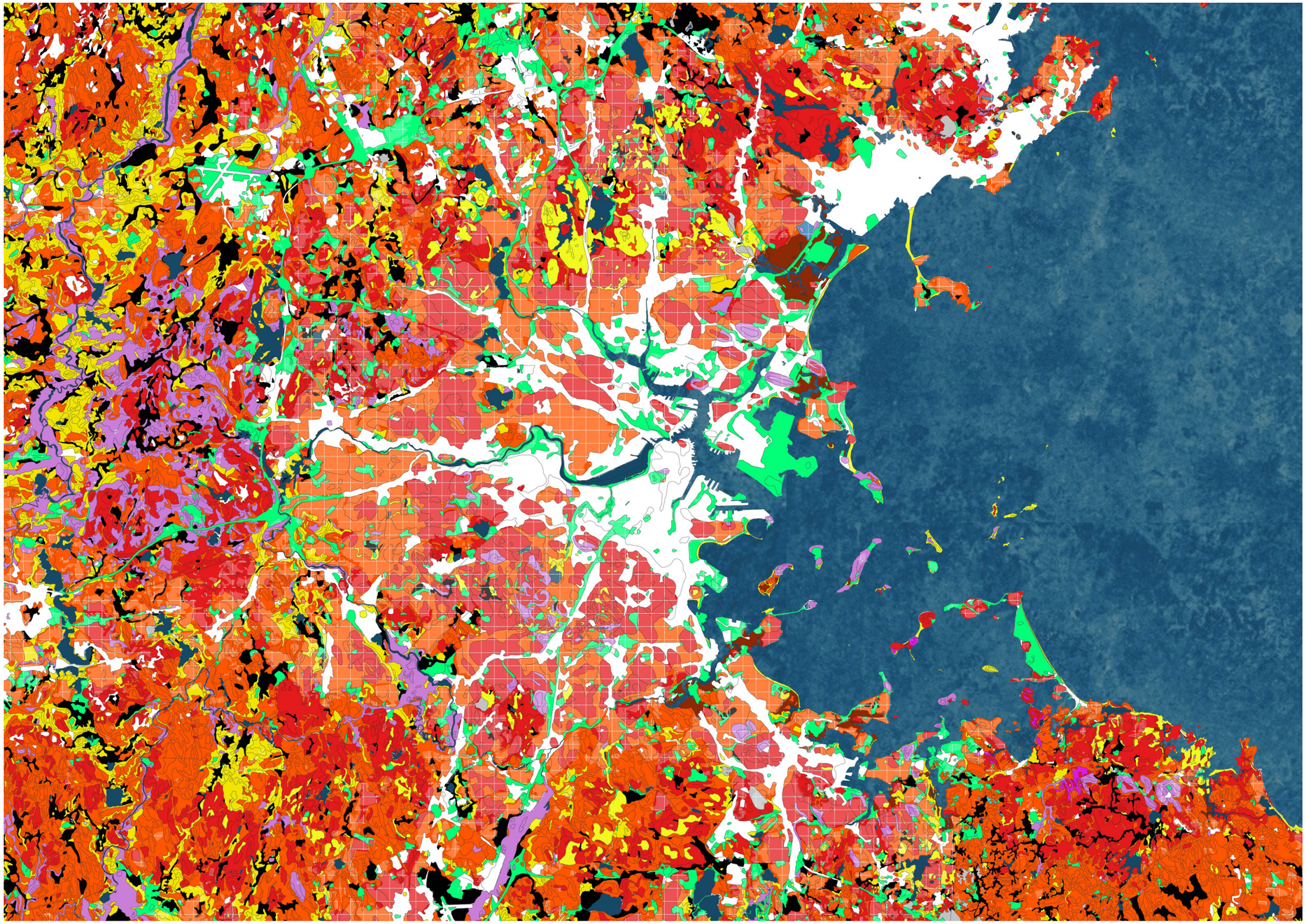


Figure 2.4 - Simplified soil types
Made by author
Data: U.S. Department of Agriculture, Natural Resources Conservation Service (2021)

Land moves

This map shows the vertical land motion in the Metropolitan Area of Boston (Ohenhen et al., 2024). The land subsidence data is overlaid with the historic shoreline of 1630. Most of the negative vertical land motion is present along the newly made land and along the coast. Land subsidence is a hidden threat to Boston. The vertical land motion rates are damaging buildings and infrastructures, creating higher maintenance or rebuilding costs and increasing the risk of collapsing buildings and infrastructures. In the context of climate change, land subsidence negatively contributes to relative sea level rise, which increases flood risk. On top of that, subsiding land impacts elevation, which can create problems for water supply and sewage infrastructures where elevation plays an important role in the flow and capacity of the system. This can also be said for crucial ecosystems in the area that will be impacted by land subsidence. It can cause changes in the system and lead to possible environmental degradation (e.g. saltwater intrusion in freshwater ecosystems).

Recent studies show that Boston's subsidence is part of a broader pattern along the U.S. Atlantic coast, where rates exceeding 3 mm per year affect many coastal cities, including Boston (Ohenhen et al., 2023). Using high-resolution InSAR data, the authors reveal that nearly all coastal areas are subsiding, particularly wetlands, developed land, and reclaimed areas. This suggests that current flood models may underestimate local sea level rise, as subsidence accelerates ecological degradation and limits the capacity of coastal landscapes to adapt. In Boston, this means that low-lying districts and formerly reclaimed marshland are likely to face compounding risks from both subsidence and sea level rise in the years ahead.

Complementary research by Ohenhen et al. (2024) further indicates that this gradual vertical movement poses a direct threat to people and infrastructure along the East Coast. Their findings estimate that between 1.2 and 14 million residents, along with more than half of major urban infrastructures, are situated in areas subsiding between 1 and 2 mm per year.

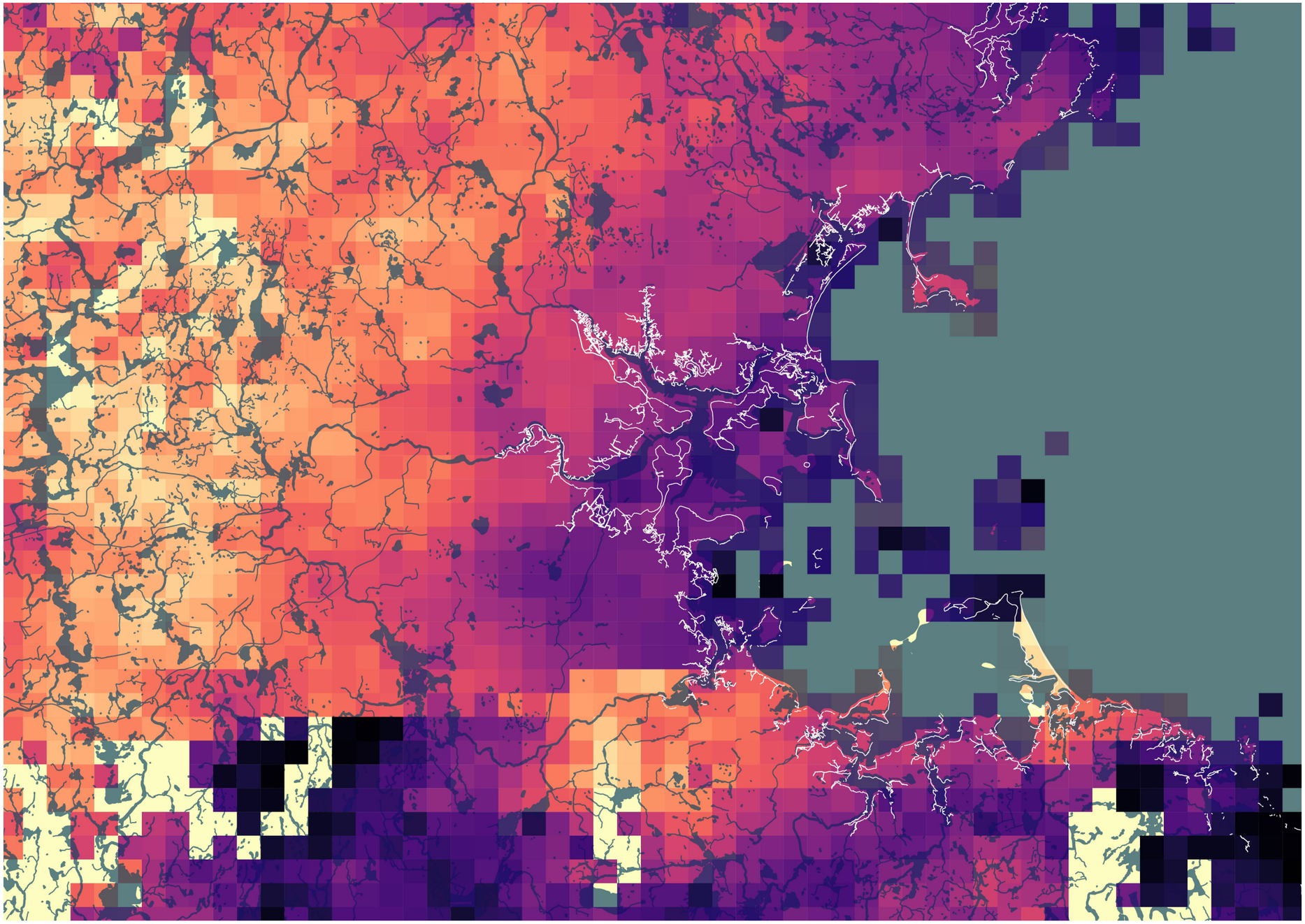


Figure 2.5 - Vertical Land Motion Rates for the Boston Metropolitan Area overlaid with historic shoreline of Boston [mm/year]
Made by author
Data: Ohenhen et al. (2024)

2.2 Infrastructural systems

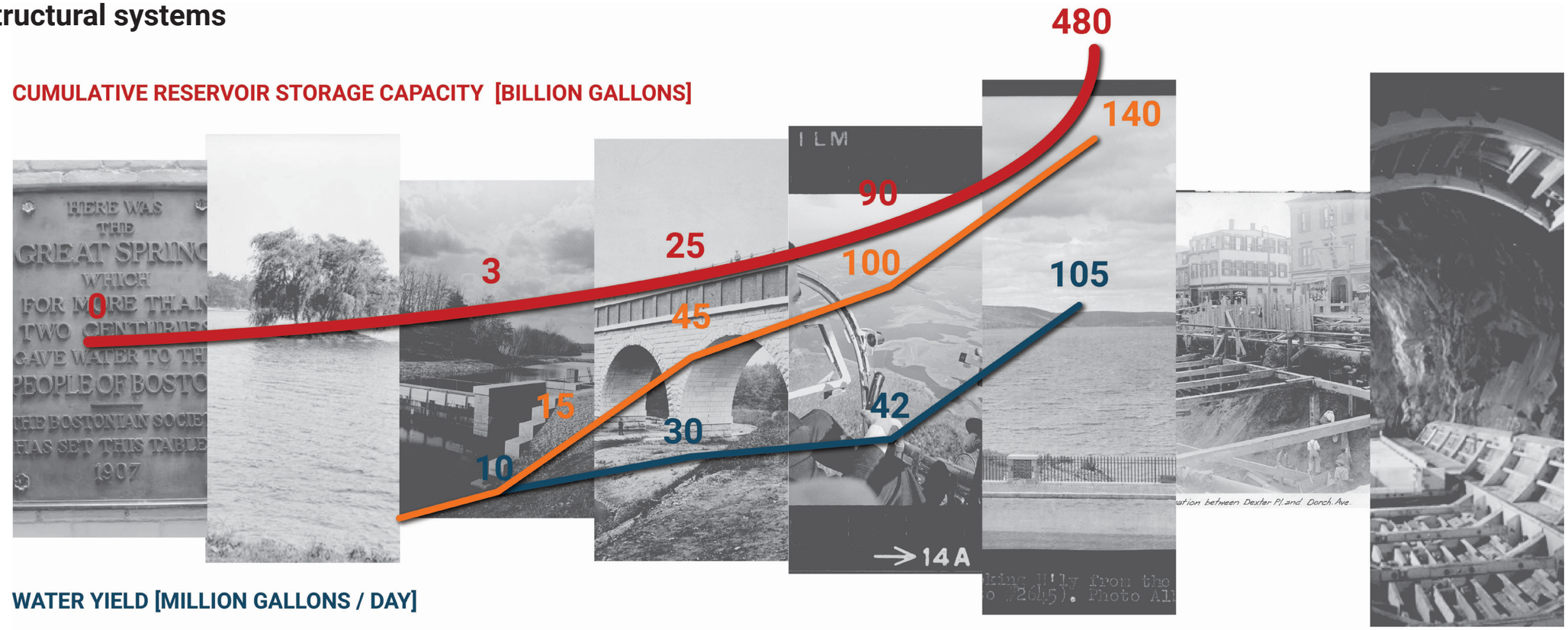


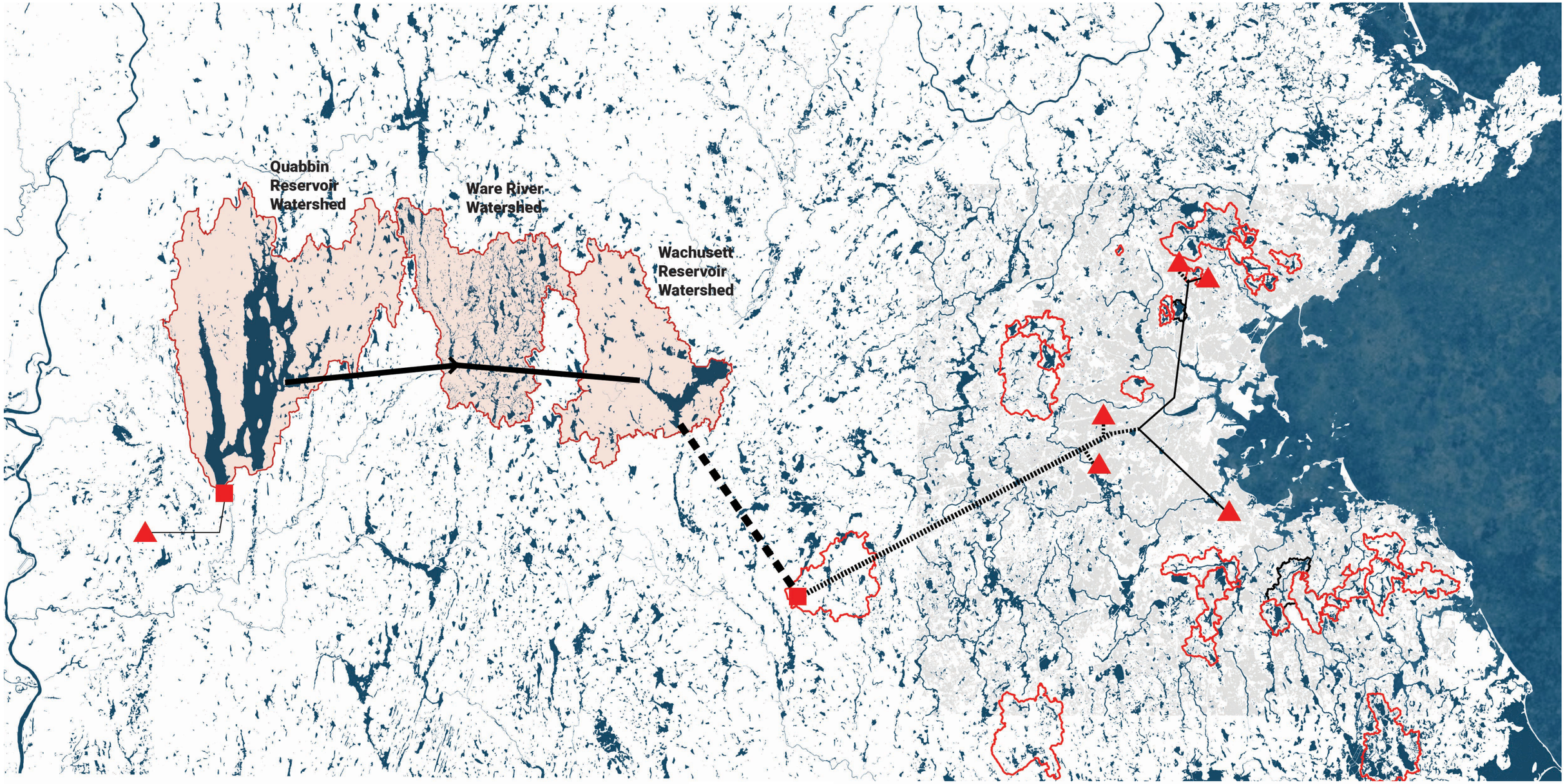
Figure 2.6 - Historic development of freshwater supply infrastructure
Made by author - Data: Wallace, Floyd Associates & MWRA

The New England region possessed a significant number of ponds and lakes, combined with sufficient natural elevation change that would create water flow to the rivers (Kempe, 2006). The first settlers arrived in 1623 and settled along the Great Spring to get access to freshwater (Laskey, 2014). Boston started building its public water supply system in 1652, one of the oldest freshwater supply infrastructures in the United States. Also, the water supply infrastructure expanded to a metropolitan system as one of the first in the country, created by the Water Division of the Metropolitan District Commission (MCD) (Wallace Floyd Associates, 1984). The historical water supply of Boston started with limited local springs and wells. Wooden tanks (cisterns) were used to store freshwater. The development of the water supply system is closely related to the growth of the city, which has caused the demand for freshwater to exceed the available supply of local sources multiple times. On top of that, accessibility to water was important for fire protection, since many houses were made of wood (Kempe, 2006).

The first expansion created a wooden infrastructure pipe system from the Shawmut Peninsula to Jamaica Pond in 1795. The Jamaica Pond was suitable because of its higher elevation above sea level, which allowed gravity to transport the water to the city. This was done by private companies that only supplied water to those who paid and were living in the lower areas of the Shawmut Peninsula (Laskey, 2014). The discussion of private versus public supply of freshwater, combined with the contamination and pollution of drinking water, stimulated the process of creating an infrastructural connection to Lake Cochituate in 1846 (Wallace Floyd Associates, 1984). However, the population of Boston tripled, which meant that the supply of Lake Cochituate would not meet demand. On top of that, supply problems due to drought and damage to the structure caused the urgency for a new reservoir: the Sudbury River and the Chestnut Hill Reservoir in 1878 (Laskey, 2014). In 1898, the shared water demand in 13 communities in and around Boston joined forces and created the Metropolitan Water District, creating a metropolitan pipe network. Around the 1900s, the Wachusett Reservoir was the largest water reservoir in the world made by humans. However, to connect the Wachusett reservoir with the Metropolitan area of Boston, the communities in Clinton were displaced, and large infrastructures took over the landscape. Finally, in 1920, the metropolitan district exceeded supply again, and the connection from the Wachusett Reservoir was extended towards the Quabbin Reservoir in the West. This gravity-based connection allowed for a freshwater supply without filtration (MWRA, n.d.).

The connection of the Quabbin and Wachusett Reservoirs to the freshwater supply of the Metropolitan area of Boston greatly increased the water supply capacity, with currently around 412 billion and 65 billion gallons respectively (MWRA, n.d.). However, this increase in water capacity did not happen without a fight. According to Laskey (2014), 26 people died during construction, 1000 buildings got destroyed, double the number of people had to move elsewhere, 39 square miles were flooded, and 4 towns got removed.

After the connection of the Quabbin Reservoir, the Pressure Aqueduct System was introduced in 1936 to transport water to the city to reduce the reliance on pumps and increase gravity-based transportation flows. Around 1970, the state of the freshwater infrastructure worsened. Overdue maintenance caused leaks and lowered water pressure in Boston (BWSC, n.d.), and redundant water supply infrastructures are still present in Massachusetts.



The current water supply system is dependent on water sources that are relatively far away. On top of that, extensive pipe infrastructure is needed for water transportation, which is prone to leaks and has a limited lifespan. The gravity-based characteristic of the supply system is threatened by land subsidence, which could create differences in elevation, disrupting flow and capacity.

Figure 2.7 - Freshwater supply infrastructure of the metropolitan area of Boston
Made by author
Data: Mass.gov & MWRA

Centralized systems - sewer infrastructure

Rapid urbanization caused the water supply system to expand. However, these developments led to the indispensable construction of a sewer system. The first actual sewer infrastructure, the Boston Main Drainage System, was ready for use in 1884 and led wastewater to Moon Island in the Boston Harbor (MWRA, n.d.). Shortly after, the Metropolitan Sewerage District was established to expand the sewer infrastructure regionally. This system only displaced the water to discharge into the open water without treatment. Due to significant water pollution, shellfish from the harbor had to be treated to prepare for consumption. Water quality worsened, and two sewer treatment plants were built: Nut Island (1952) and Deer Island (1962). The combined capacity of the treatment plants was too little to make up for the increased sewage volumes. In 1972, national regulations were made and required primary and secondary treatment. Later, technological advancements caused the sludge dumping to stop in the Boston Harbor. Simultaneously, the regional sewer system was optimized, which caused Nut Island's closure and sewage centralization to the Deer Island Treatment Plant. In 2000, the Outfall Tunnel was constructed to dump treated wastewater deep into the Massachusetts Bay instead of the Boston Harbor (MWRA, n.d.).



Figure 2.8 - Limited capacity of the water treatment plants caused harbor pollution Plant (MWRA, n.d.)

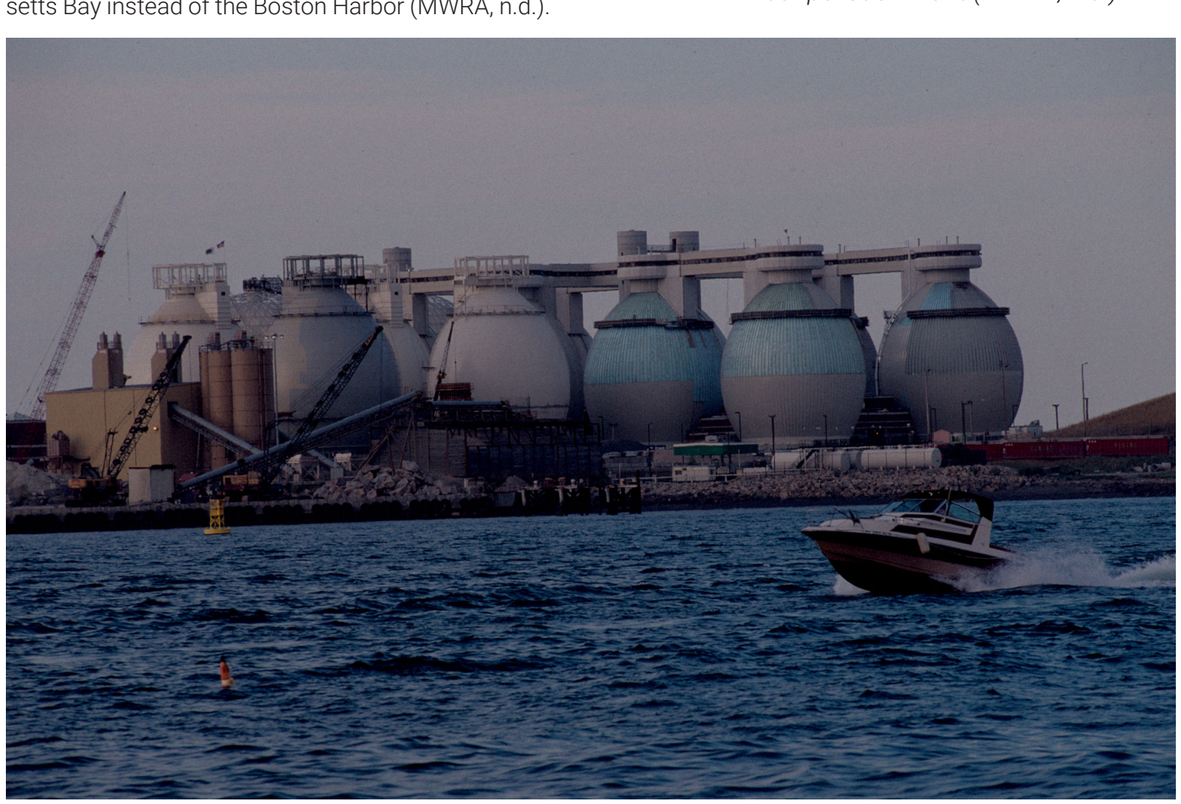
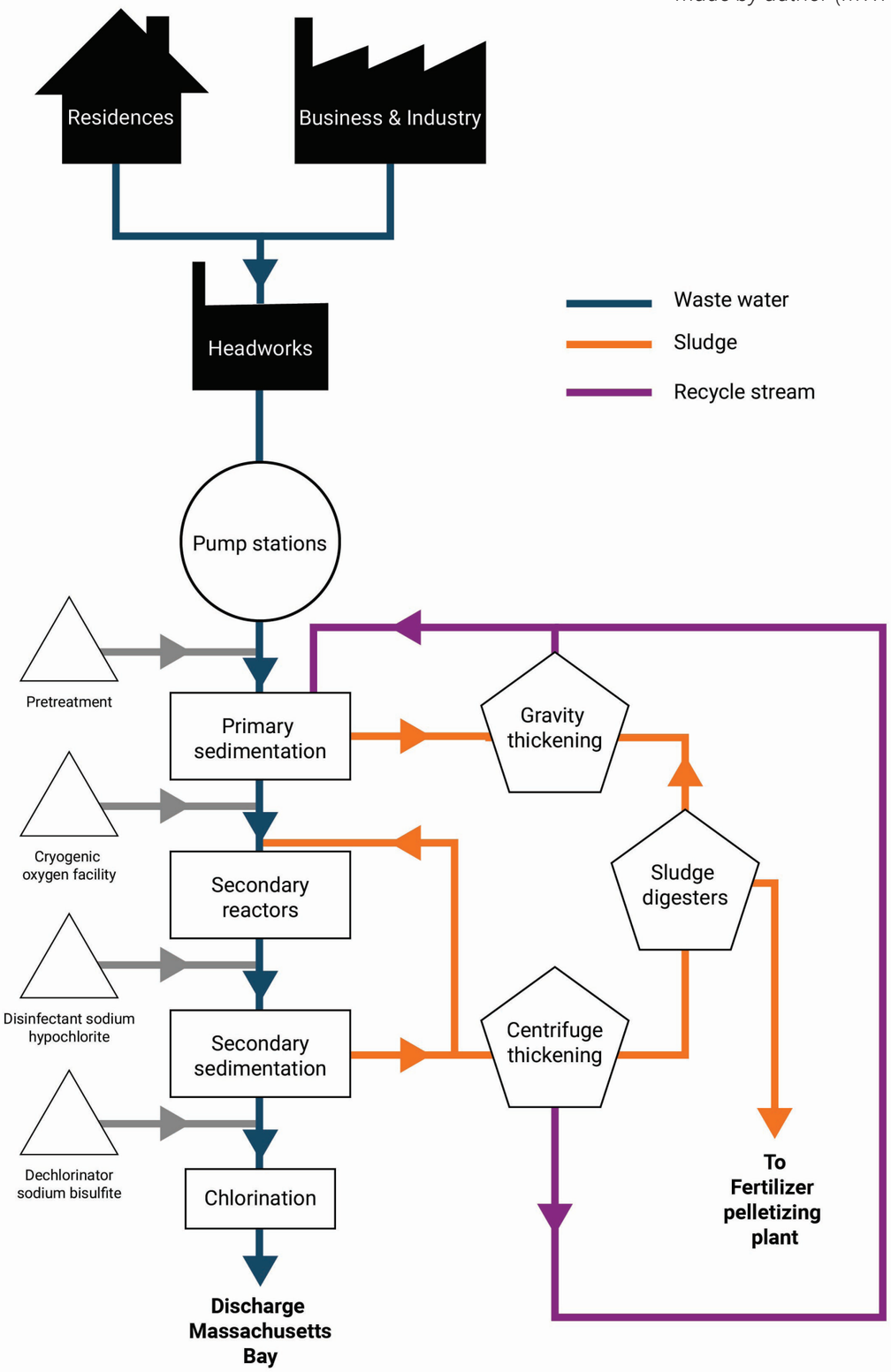


Figure 2.9 - Deer Island Water Treatment Plant (Jones, 1995)

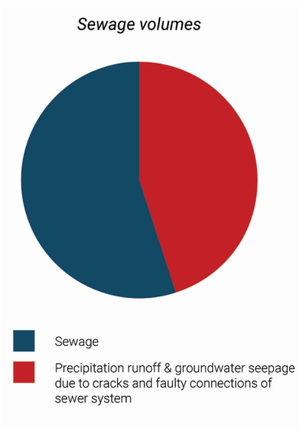
Figure 2.10 - Waste water treatment process
Made by author (MWRA, n.d.)



Sewage infrastructure transports all wastewater to the water treatment plant on Deer Island. This process is mostly gravity-based with additional pumps in the low-lying areas. There are 5,100 miles of local sewer pipe infrastructure, according to the MWRA, and around fifty percent of the sewer flow is caused by precipitation, street runoff, and malfunctioning openings and sewer connections that allow groundwater to infiltrate. The Boston Water & Sewer Commission (2024) displayed multiple combined sewer overflow (CSO) locations in the Boston Metropolitan area. This shows that the current state of this system is poor. On top of that, it creates increased volume to be treated, which does not benefit the longevity of the water treatment plant, as well as energy use, with "an annual energy demand of 18 MW and yearly electric bill of about $16 million" (MWRA, 2012).

The Massachusetts Infrastructure Investment Coalition (MIIC) was already pledging more funding to improve wastewater treatment plants in 2007, especially focusing on smaller communities and towns. The MIIC was especially worried about the longevity of smaller treatment plants and their smaller components. Moreover, they argue that the maximum lifespan of sewage pipes is between 50 and 75 years. However, they state that some pipes are already more than 100 years old (MIIC, 2007). Presently, the Massachusetts Department of Environmental Protection (MassDEP) (2025) is funding $890.8 million on total wastewater projects. The investments in the sewer and wastewater infrastructural systems are significant. These financial burdens could be reduced by looking into the reduction of urban runoff, thus lowering the amount of precipitation and groundwater that infiltrates this system, which will decrease the pressure on the sewer system.

Besides this, the entire sewer system is centralized and comes together on Deer Island. This degree of centralization creates a significant risk in case of failure of the water treatment system, during a power outage, for example.



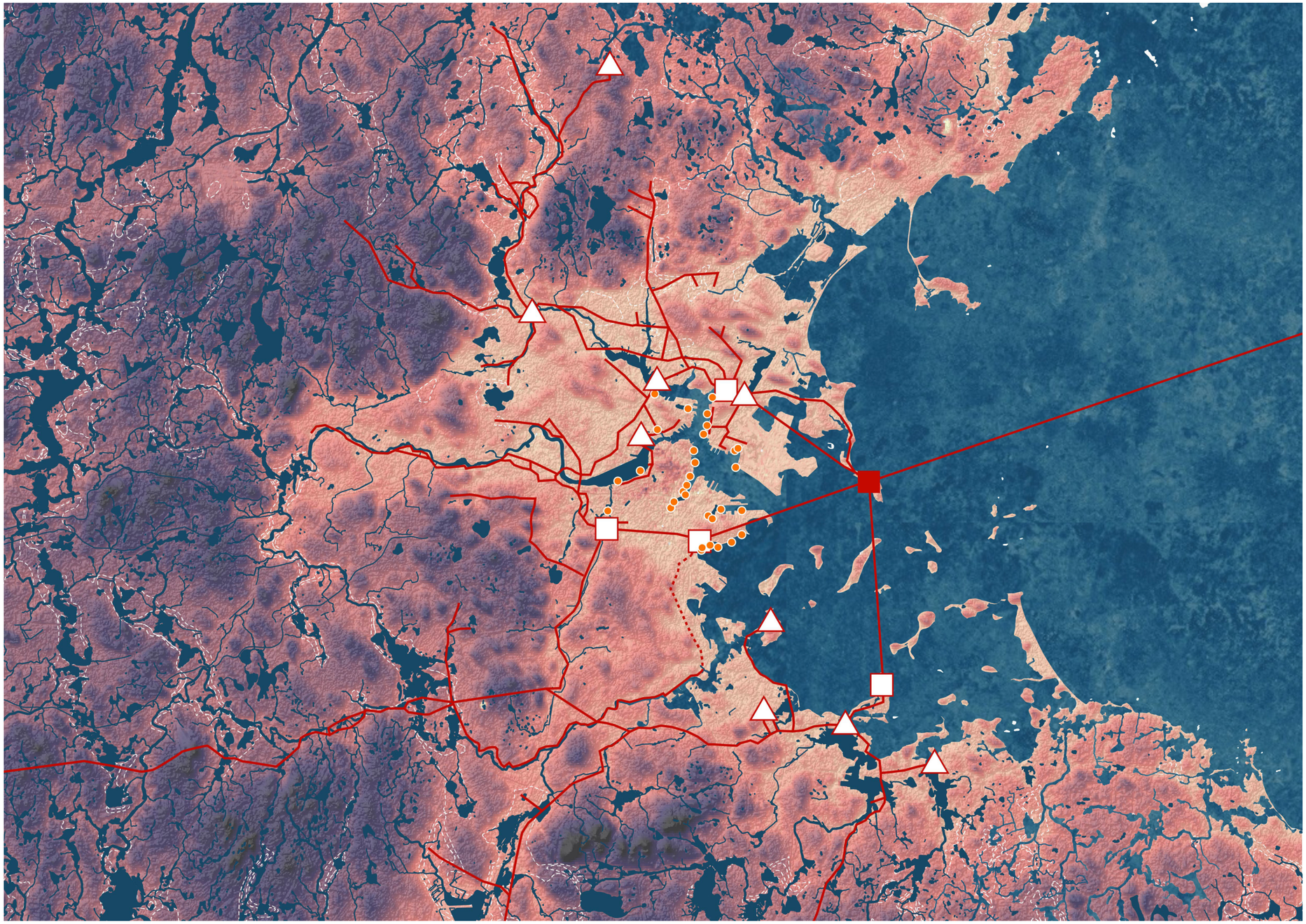


Figure 2.11 & 2.12 - Sewer infrastructure of the metropolitan area of Boston
Made by author
Data: MWRA Sewerage Division (1994), Boston Water & Sewer Commission (2024)

Centralized systems - energy infrastructure

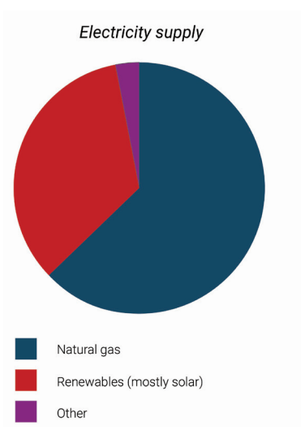
The Metropolitan Area of Boston and the state of Massachusetts in general use 25 times more energy than they generate (U.S. Energy Information Administration, 2024). More than half (63%) of the total electricity supply comes from natural gas. Renewable energy sources, mostly solar energy, account for 34 percent (U.S. Energy Information Administration, 2024).

The state does not produce natural gas, and is dependent on pipeline infrastructure that transports gas from the New York area, Canada, and other parts of the United States (U.S. Energy Information Administration 2024).

The dependency on external energy supply (and infrastructure) outside the state of Massachusetts puts the Metropolitan Area of Boston at risk. If a limited energy supply is available, centralized systems can collapse. The Deer Island water treatment plant is a good example of a highly centralized infrastructural system. According to Fiore et al. (2023), the treatment plant consumed 102 GWh of electricity and 686,429 gallons of diesel in 2021. This electricity use is comparable to the yearly use of 18,000 households.

On the other hand, the MWRA has introduced multiple 'energy consumption reduction projects' that focus on increasing the share of renewable energy supply and reducing overall energy demand. In 2021, 28% of total electricity use was renewable and self-created, using PV panels, wind turbines, and anaerobic digester gas (Fiore et al., 2023).

However, the primary concern lies within the dependency of external sources and the structural centralization of large, important infrastructures, and the potential hazard it creates.



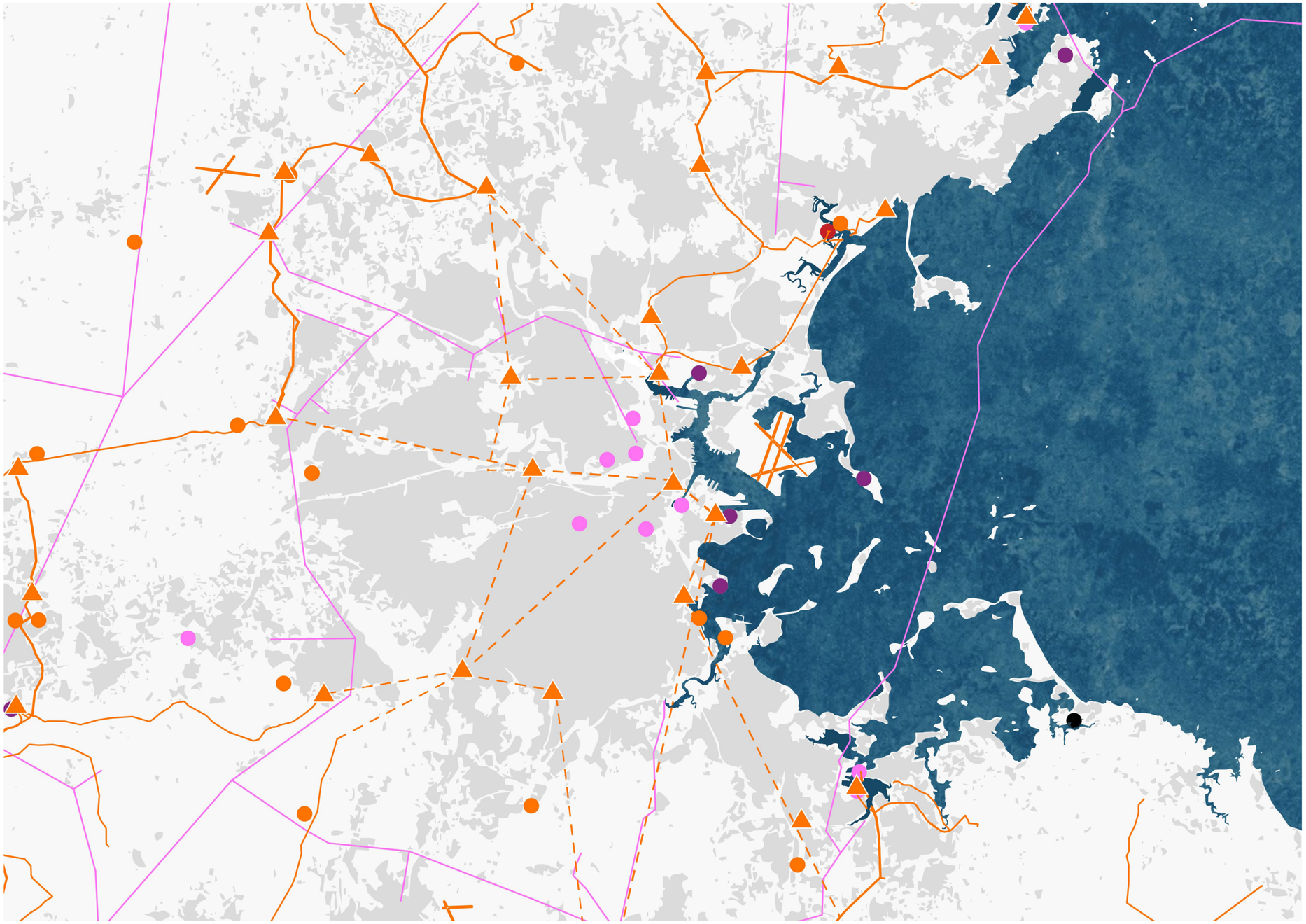


Figure 2.13 & 2.14 - Energy infrastructure of the metropolitan area of Boston
Made by author
Data: U.S. Energy Information Administration (2024).

Obsolete dams

Dams served an important role in the freshwater supply history of the Metropolitan Area of Boston. Dams were utilized to create water reservoirs that supplied water to the city. Over time, the water demand grew and these reservoirs did not have sufficient capacity.

Nowadays, some dammed water reservoirs serve as emergency water supply. However, most of the old dammed water supplies are not in use anymore. Most of these dams do not serve their main purpose anymore, but do still affect the landscape in a certain way. Numerous dams have a high or significant hazard code level, which means that the effects in the event of dam failure may cause death and significant damage to homes, infrastructures, industrial, and commercial facilities (Massachusetts Office of Dam Safety, 2012), especially dams that are located within the same drainage basin of the large Metropolitan Area of Boston. “More than 1/3 of all dam failures or near-failures since 1874 have happened in just the last decade” (Bélanger, 2016).

Technical, engineered water infrastructures like dams have ending lifespans. On the map, it is visible that numerous dams are over 100 years old and that the majority of dams are over 50 years old. According to Bélanger (2016), large dams have a lifespan of just over 100 years old and small dams reach the end of their lifespan just over 50 years. Although some dams last many years beyond their lifespan, it is crucial to see that these infrastructures are not permanent. A false sense of security is created by building these centralized and colossal infrastructures, which led to development in flood prone areas.

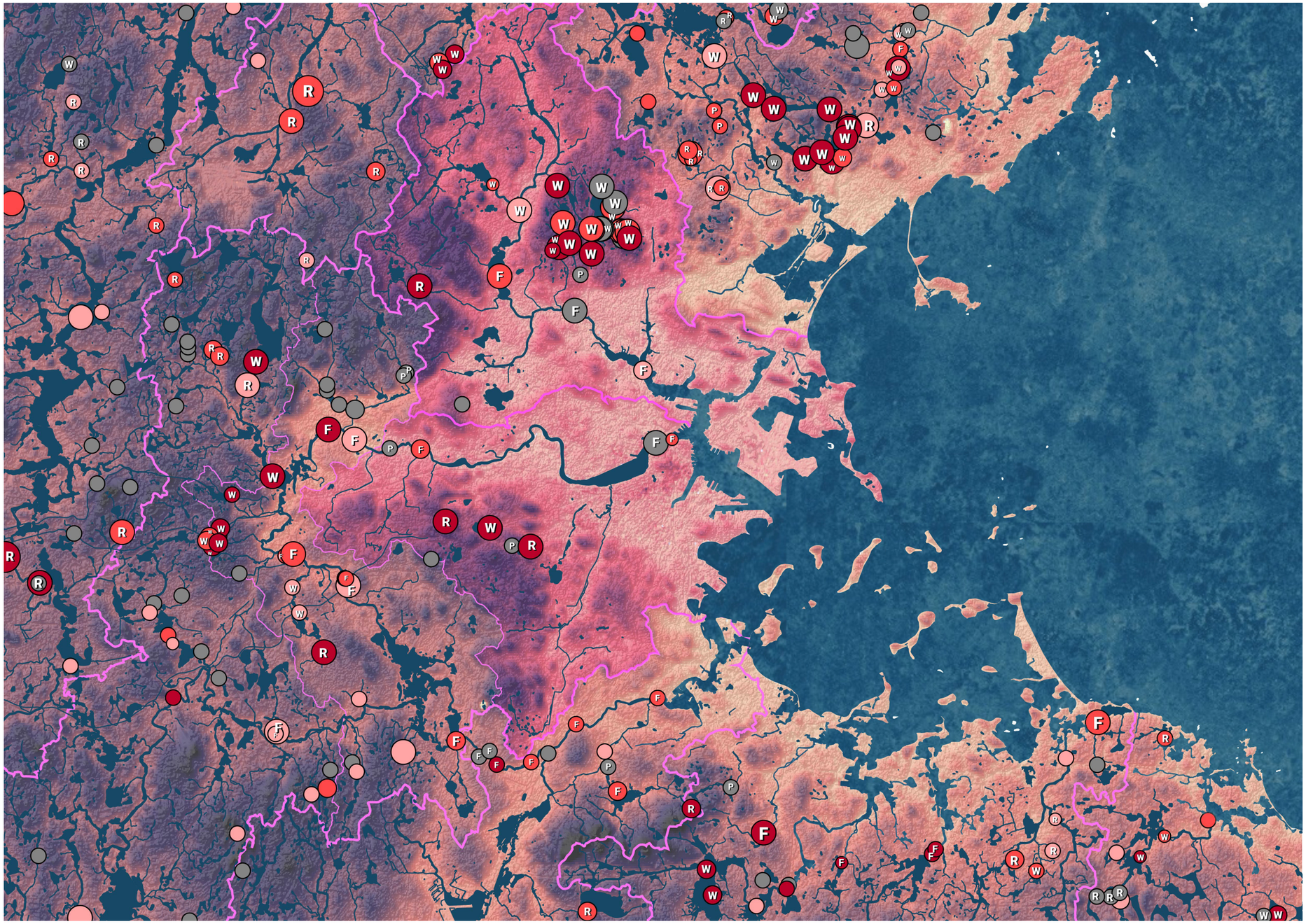


Figure 2.15 - Categorization of dams by age, hazard code and purpose Made by author Data: U.S. Army Corps of Engineers (n.d.) & Massachusetts Office of Dam Safety (2012)

Dam effects

On the other hand, dams disrupt fish habitats and influence ecosystems by cutting of water flow. This can be crucial in estuary systems, where fresh and salt water meet. An example of environmental degradation in the area is the vanishing of the American Eel and the river Herring. The absence of these species is significant since it impacts the entire food chain in these estuarine ecosystems. These diadromous fish, which live between fresh and salt waters, are impaired in their flow.

Dam infrastructures play a big role in the impairment of diadromous fish. Water quality, habitats, and sediment flows and quality are under pressure as a consequence of dam presence (Charles River Watershed Organization, 2022). The impairments in the Charles River watershed have decreased spawning areas and weigh down on the diadromous fish species.

Small-scale structures like fish ladders seem to serve as a solution to the impairment of fish. However, these structures do not work for all fish species and are not a 'one size fits all' solution (Gahagan & Bailey, 2020; Jensen et al., 2024). Furthermore, the dam acts as a bottleneck, where all fish, if they even get to the other side, are particularly prone to being caught by predators.

Dams can impede not only diadromous fish. According to the Division of Marine Fisheries (2023), excessive slope, vertical rise, water turbulence, low flows, excessive sediment, and plant growth can also obstruct fish flows.

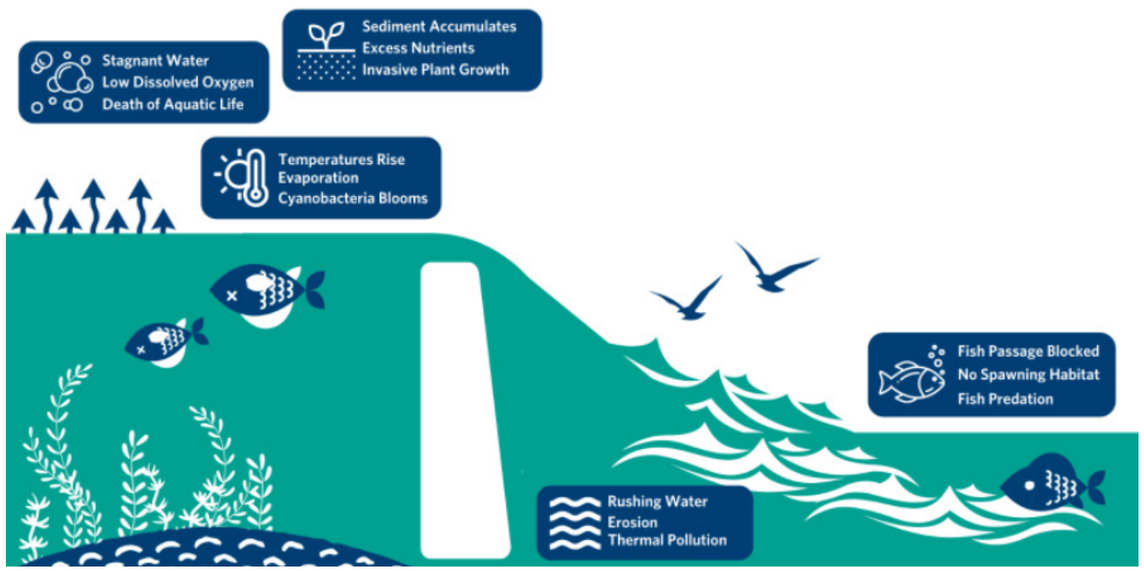


Figure 2.16 - Impacts of Dams on the Charles River Ecosystem (Charles River Watershed Organization, 2022)

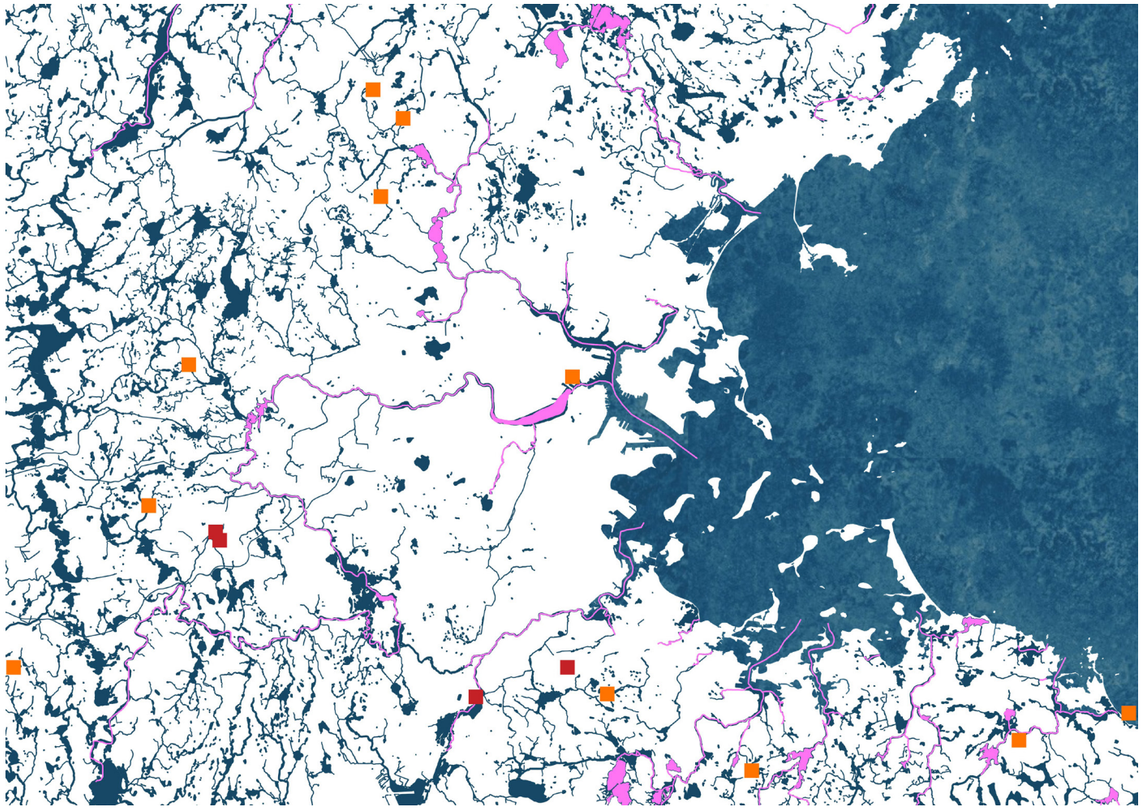


Figure 2.17 - Diadromous fish impairments
Made by author
Data: Division of Marine Fisheries (2023)



Figure 2.18 - Warmer waters & lower stream flow can lead to fish death (CRWA, 1964)

2.3 Landscape ecologies

Wetlands, rivers, and other core habitats form the ecological foundation of the Boston Metropolitan Area. These systems play a key role in regulating water, filtering pollutants, and providing habitat for many species. However, centuries of land reclamation, industrialization, and urban growth have reshaped this landscape. Wetlands were drained, rivers were channelized, and forests were fragmented to make space for human settlement and infrastructure.

The remaining natural areas can be seen as scattered patches of ecological value within a highly urbanized and engineered region. These fragmented systems still perform important ecological functions but are under increasing pressure. In the lower Charles and Mystic River watersheds, for example, wetlands are surrounded by impermeable surfaces, limiting infiltration and degrading water quality through stormwater runoff. In coastal areas, salt marshes and tidal flats face additional threats from rising sea levels.

The disconnection between water and landscape ecologies has reduced the system's ability to adapt to floods and droughts. What once acted as a connected hydrological landscape has become a disconnected patchwork of isolated habitats and altered flows. This condition contributes to environmental degradation and weakens the region's natural resilience to climate impacts.

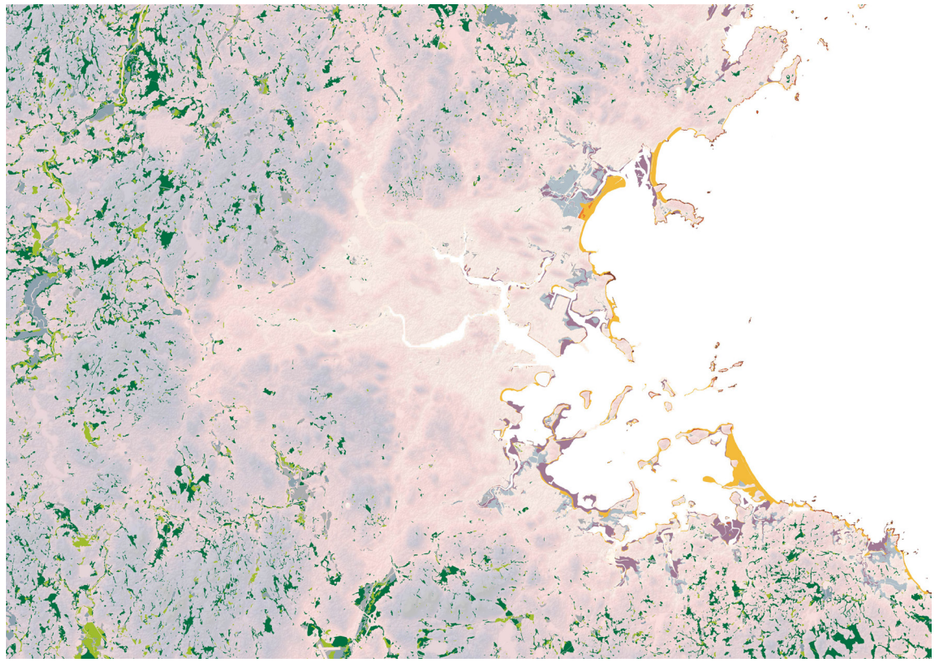


Figure 2.19 - Wetlands
Made by author
Data: The Nature Conservancy (2022)

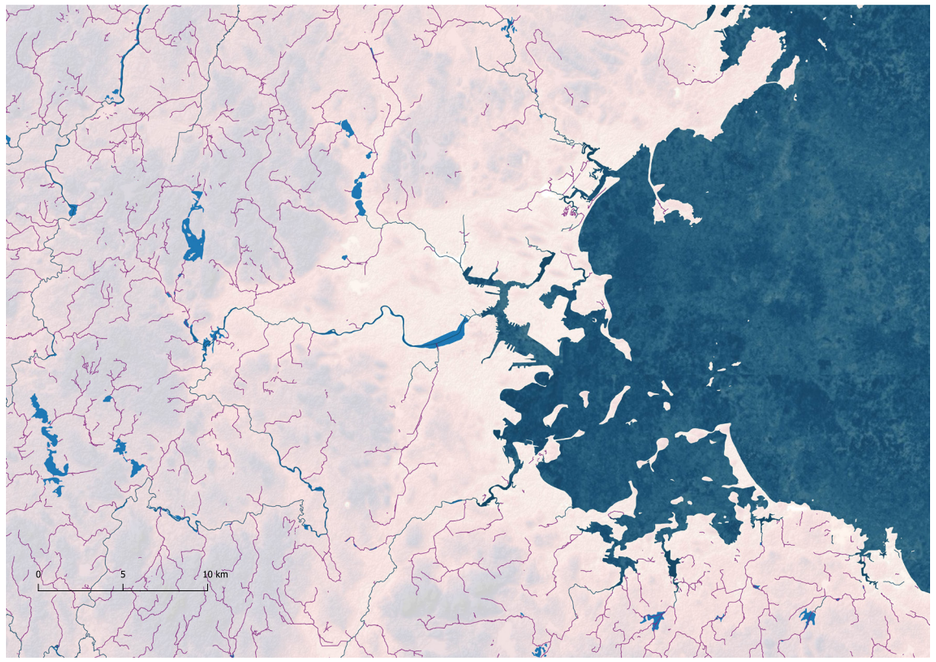


Figure 2.20 - Water
Made by author
Data: The Nature Conservancy (2022)

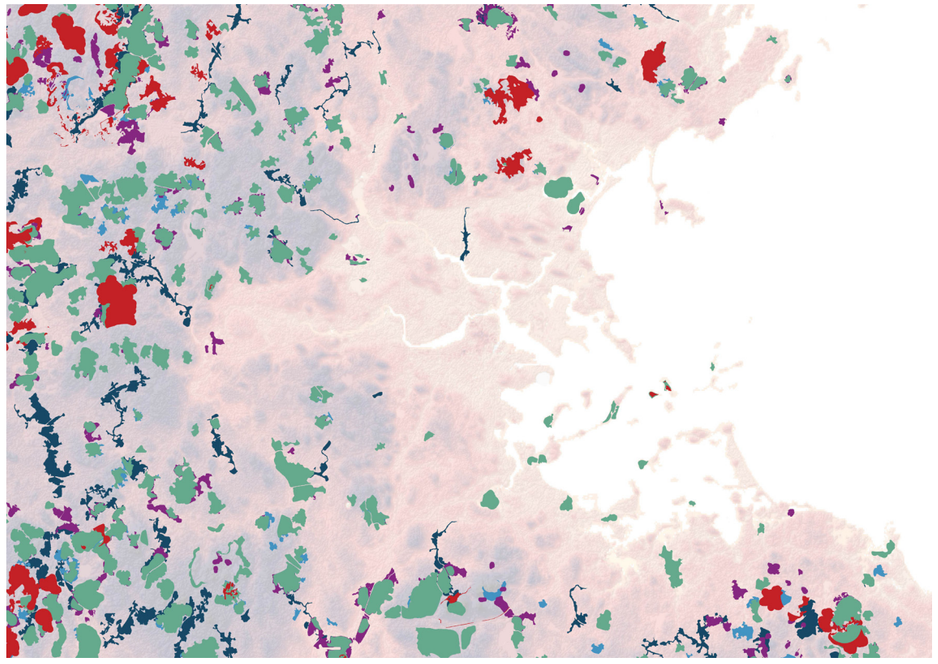


Figure 2.21 - Local landscapes
Made by author
Data: The Nature Conservancy (2022)

The Nature Conservancy (2022) has created a Bio-Map3 dataset in which landscape ecologies are subdivided into two systems: Critical Natural Landscapes and Core Habitats. Critical Natural Landscapes are characterized by large areas that are barely affected by urban development. These landscapes create important ecological connections on the regional scale and are complementary to the Core Habitats, which are essential to rare species. Together, these systems are crucial in conserving and improving ecosystems in the Boston region.

The isometric diagram shows the composition of Critical Natural Landscapes & Core Habitats, respectively. Both systems are subdivided into the following categories:

Critical Natural Landscapes
Aquatic buffer - supports connectivity between habitats and water habitats

Landscape blocks - predominantly unaffected forest areas.

Tern foraging - areas where Terns (and other birds) are looking for food and feeding

Wetland buffers - supporting wetland cores and improving wetland connectivity

Coastal adaptation areas - bordering salt marshes and have the potential to host species, taking the sea level rise into account

Core Habitats
Aquatic cores - important lakes, rivers, streams, ponds, and other water bodies with numerous species

Forest cores - the least impacted and most intact forests in the area

Rare species cores - essential areas for the preservation and existence of vulnerable rare species

Wetland cores - wetlands that are minimally impacted by urban development and pollution

Vernal pool cores - significant because of ecological diversity

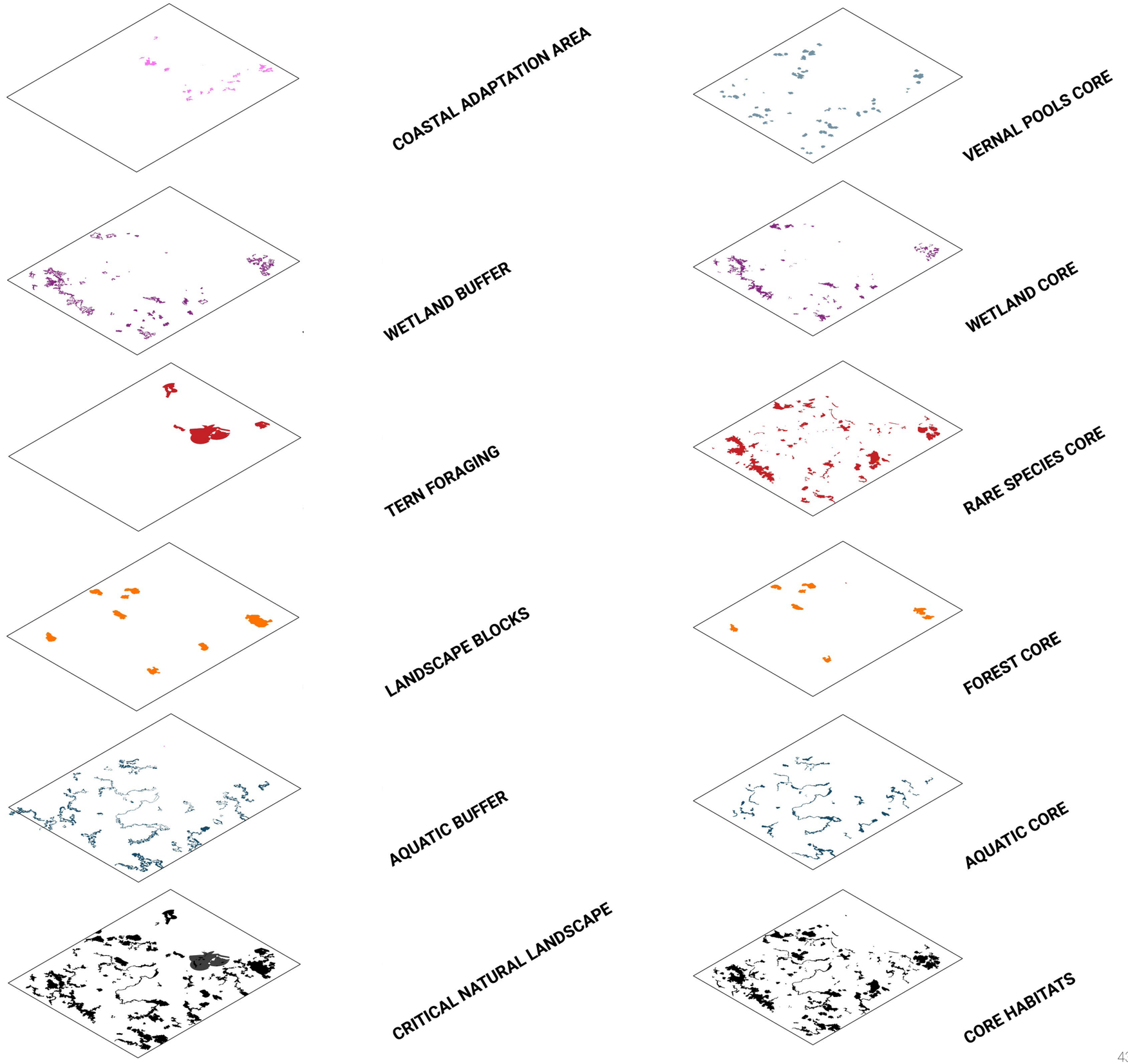


Figure 2.22 - Subdivision of the regional Critical Natural Landscapes and Core Habitats
Made by author
Data: The Nature Conservancy (2022)

2.4 Environmental degradation

The presence and historical development of infrastructural systems in the Metropolitan Area of Boston place increasing pressure on existing landscape ecologies, including Critical Natural Landscapes and Core Habitats. This condition is rooted in the rapid metropolitan expansion that has occurred over the past centuries. Transport, energy, and water infrastructures cut through ecologically valuable areas, fragmenting habitats and interrupting natural processes.

These disruptions not only obstruct the stimulation of biodiversity but also diminish the capacity of the landscape to regulate climate and water. The interconnected systems that once sustained ecological balance have been replaced by rigid infrastructural networks, prioritizing efficiency over environmental function. This demonstrates that large-scale infrastructures themselves are key contributors to environmental degradation in the region.

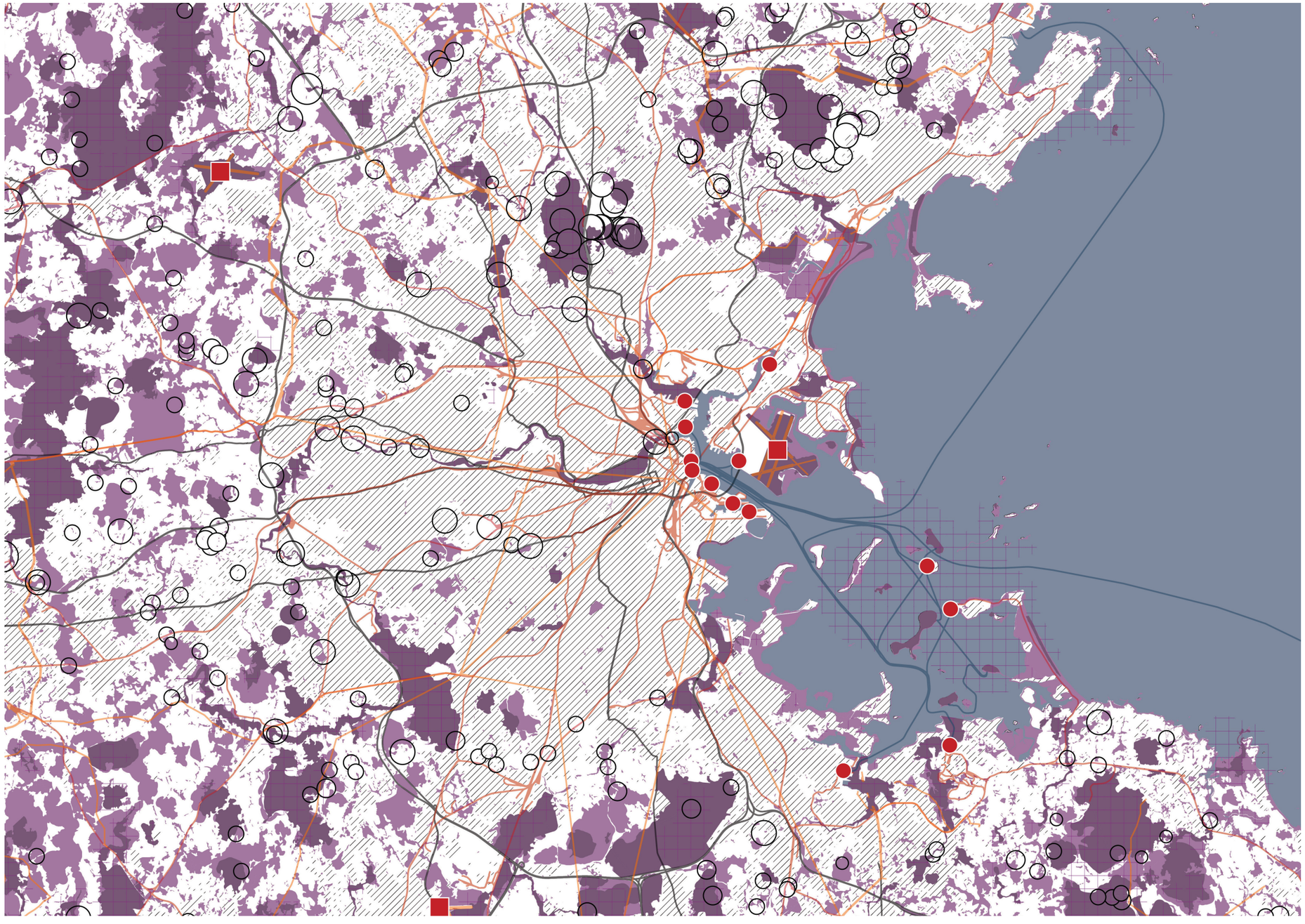


Figure 2.23 - Spatial clash between critical natural landscapes and man-made infrastructures

Made by author

Data: The Nature Conservancy (2022), Central Transportation Planning Staff (2023), Massachusetts Office of Dam Safety, U.S. Energy Information Administration (2024)

3. EXTREME WATER SCENARIOS

3.1 Climate change weather patterns
3.2 Coastal floods
3.3 Riverine floods
3.4 Pluvial floods



3.1 Climate change weather patterns

Besides the state and organization of infrastructural systems in the United States, climate change also contributes to increasing flood vulnerability of the Metropolitan Area of Boston in the future. A changing climate impacts the frequency and intensity of weather-related hazards. The increasing number of climatological and hydrological events over recent decades confirms this (Figure 3.1). Extreme participation, storm surges, and coastal storms are putting increasingly more pressure on the urban fabric. This is caused by rising temperatures, which are intensifying the hydrological cycle, causing longer storms, larger volumes, and also longer periods of drought. In the event of prolonged drought, an intense storm has more dire consequences, since the soil is too dry to be able to take up stormwater.

In the context of the Northeastern coast of the United States, climate change is expected to increase flood hazards through the combined effects of sea-level rise, stronger storm surges, and more intense precipitation events to create compound flood events.

The spatial implications of these developments become clear when flood risk is understood through the relationship between hazard, exposure, and vulnerability. Places where flood hazards increase evenly, flood risk does not. County-level flood risk patterns across the United States demonstrate how areas with high exposure, such as coastal counties and low-lying urban areas, like Boston, experience disproportionately higher expected annual losses (Wang et al., 2022). These patterns reveal that flood risk is not only a function of climate-driven hazards, but is also influenced by their interaction with land-use patterns, socio-economic vulnerability, and infrastructural capacity.

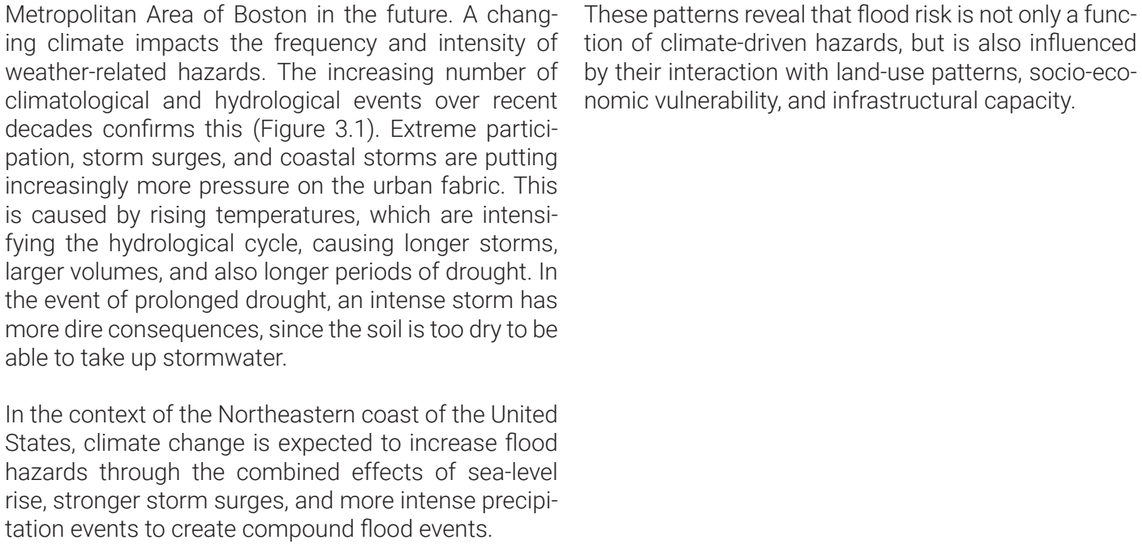


Figure 3.1 - Climate change catastrophic events through time (National Geographic, n.d.)

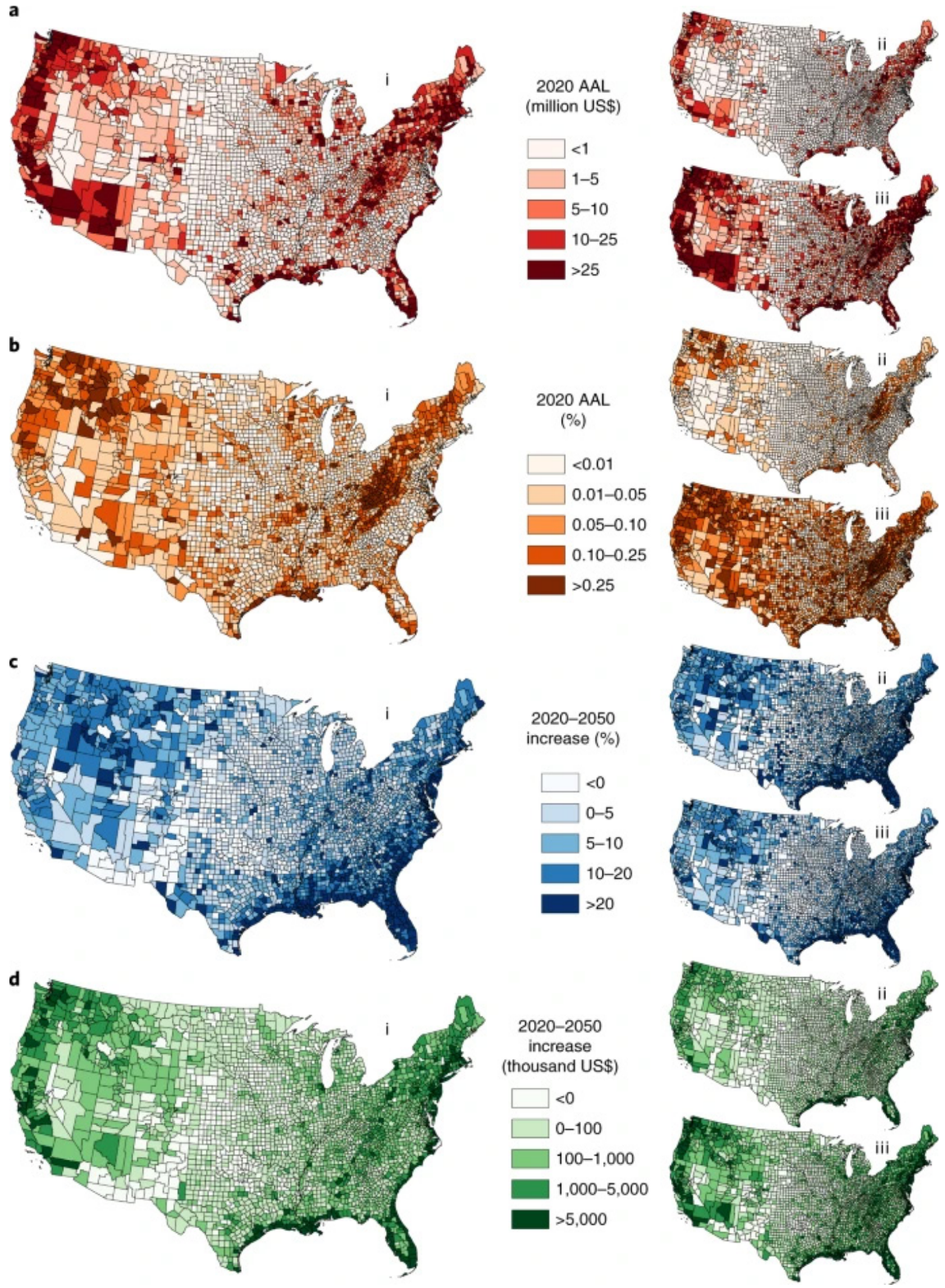


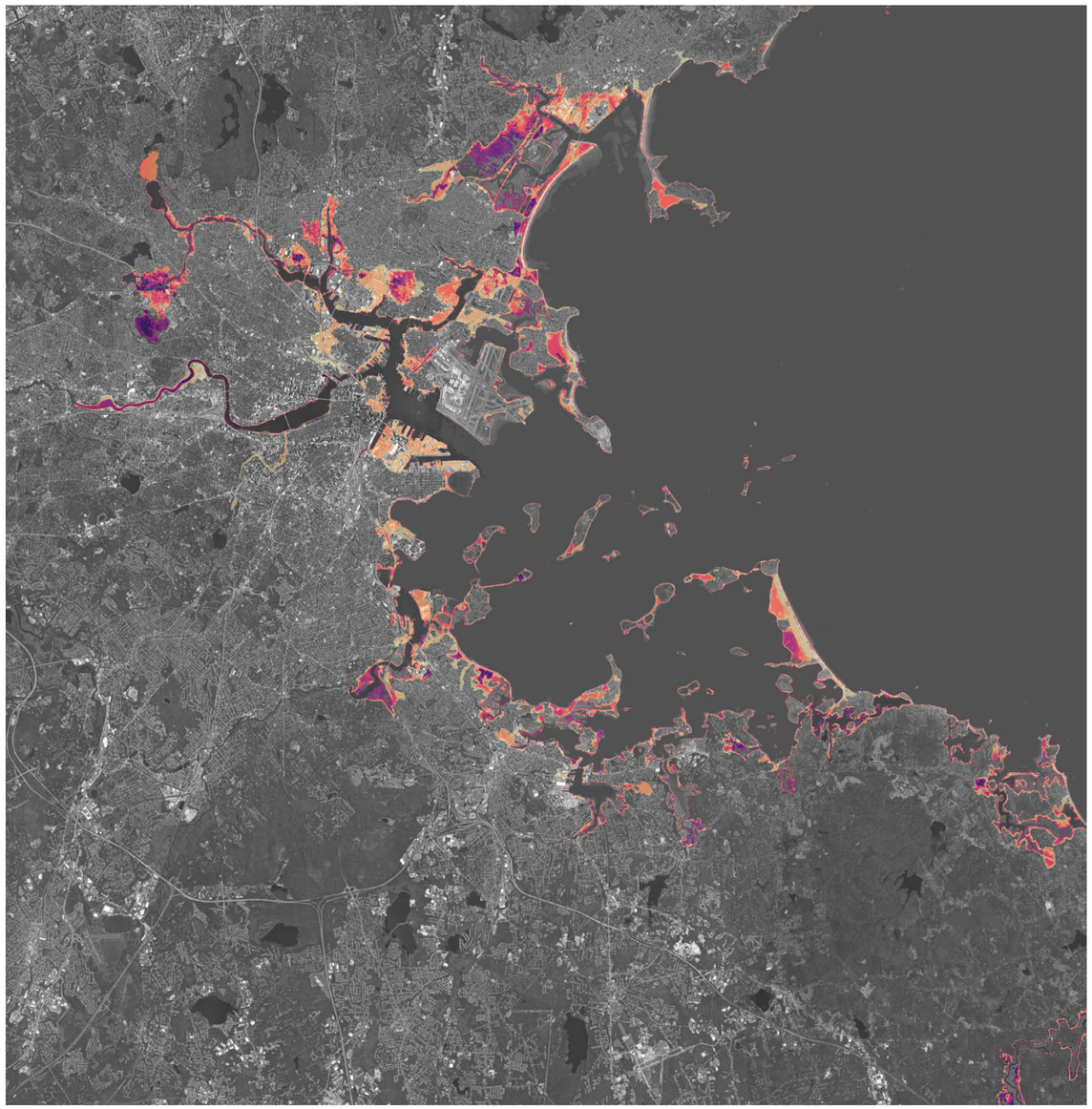
Figure 3.2 - Present and future flood risk by US county (Wing et al., 2022)

3.2 Coastal storm surge flood events

Woods Hole Group (2023) developed a highly accurate, dynamic coastal storm surge flood model that takes sea level rise in combination with storm surges (Nor'easters) into account. The data has been spatialized to show flood probability of the land in relation to the annual exceedence levels; 1% representing 100 years, and 0.1% 1000 years.

2030 - 1%
In this stage, a relatively small chance of flooding is limited to waterfront areas, specifically around the Mystic river and Atlantic Ocean.

Figure 3.3 - 2030 1% Scenario
Made by author
Data: Woods Hole Group (2023)



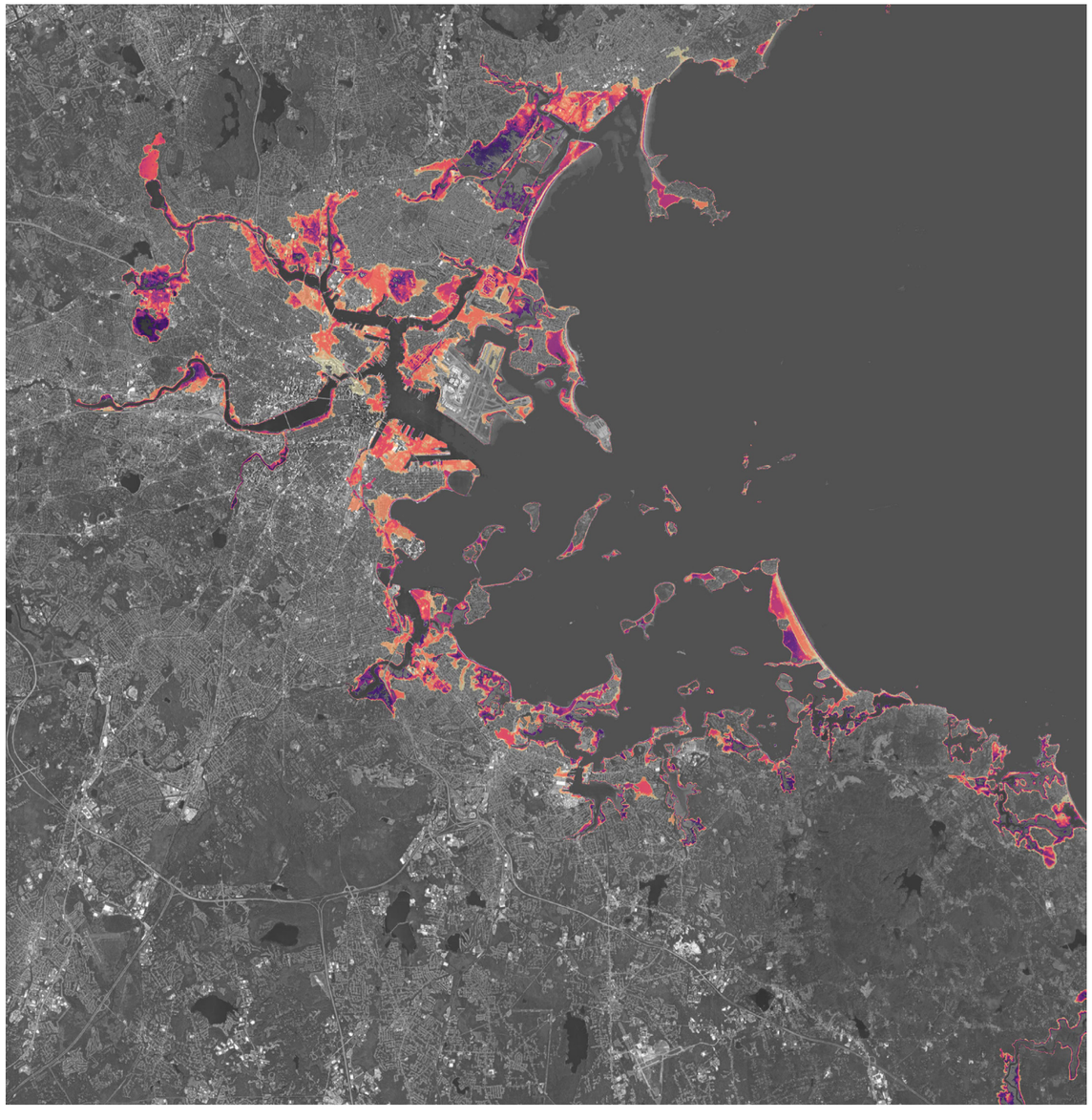
2030 - 0.1%
In the 0.1% scenario, flood probability intensifies and moves more inland, causing waterfront vulnerability as well as inland areas in Chelsea and East-Boston predominantly.

Figure 3.4 - 2030 0.1% Scenario
Made by author
Data: Woods Hole Group (2023)



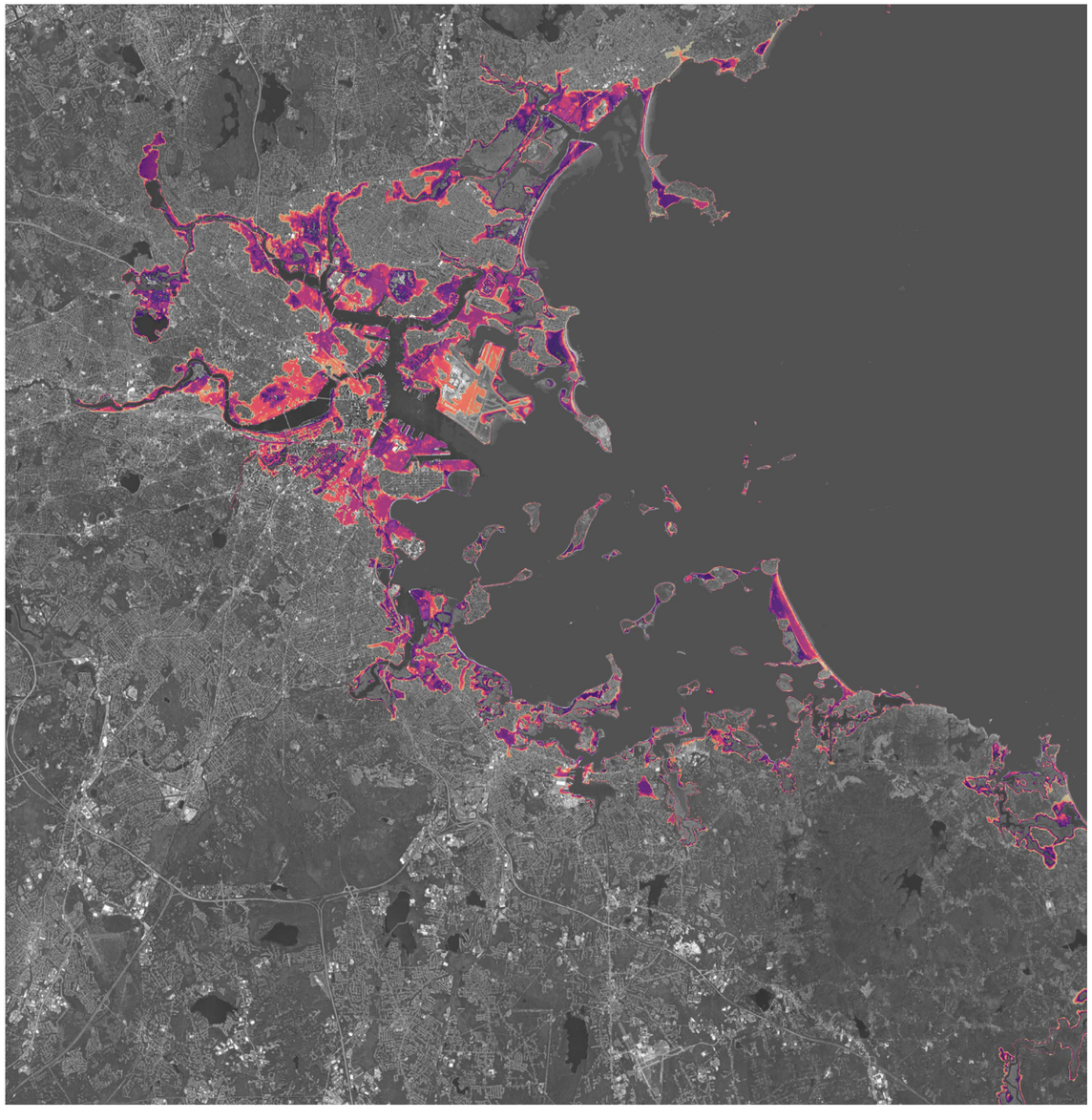
2050 - 1%
The flood probable areas of the most extreme scenario in 2030 are similar to the 1% scenario of 2050, with a lower probability.

Figure 3.5 - 2050 1% Scenario
Made by author
Data: Woods Hole Group (2023)



2050 - 0.1%
However, in the most extreme scenario, the probability significantly increases and shows that almost all artificially filled land areas are highly likely to flood. This is the first time the land returns back to its historical state, before land making operations. On top of that, the area of Cambridge is also prone to floods.

Figure 3.6 - 2050 0.1% Scenario
Made by author
Data: Woods Hole Group (2023)



2070 - 1%
The Shawmut Peninsula returns to its original land outline and the areas of Dorchester and South Boston are also flood prone.

Figure 3.7 - 2070 1% Scenario
Made by author
Data: Woods Hole Group (2023)



2070 - 0.1%
In the worst case scenario of 2070, almost the entire Metropolitan Area of Boston is completely flooded.

Figure 3.8 - 2070 0.1% Scenario
Made by author
Data: Woods Hole Group (2023)



Coastal barrier typologies

The increase in future flood probability puts increasing pressure on the urban environment of Boston, particularly along its coastline, with technical flood protection infrastructure. Existing coastal barriers function as the primary line of flood protection.

As these coastal barriers are reaching the end of their lifespan, combined with the increasing flood pressures, potentially result in the flood barriers being insufficient in the future. This combination makes their capacity to cope with future flood events uncertain. The different coastal barrier typologies result in a fragmented system with different levels of capacity. This is not only in terms of spatial distribution, but also in the temporal dimension, since different typologies break down at different times. Understanding coastal barriers as part of an interconnected infrastructural landscape reveals that future flood resilience cannot rely solely on reinforcing existing hard defenses.

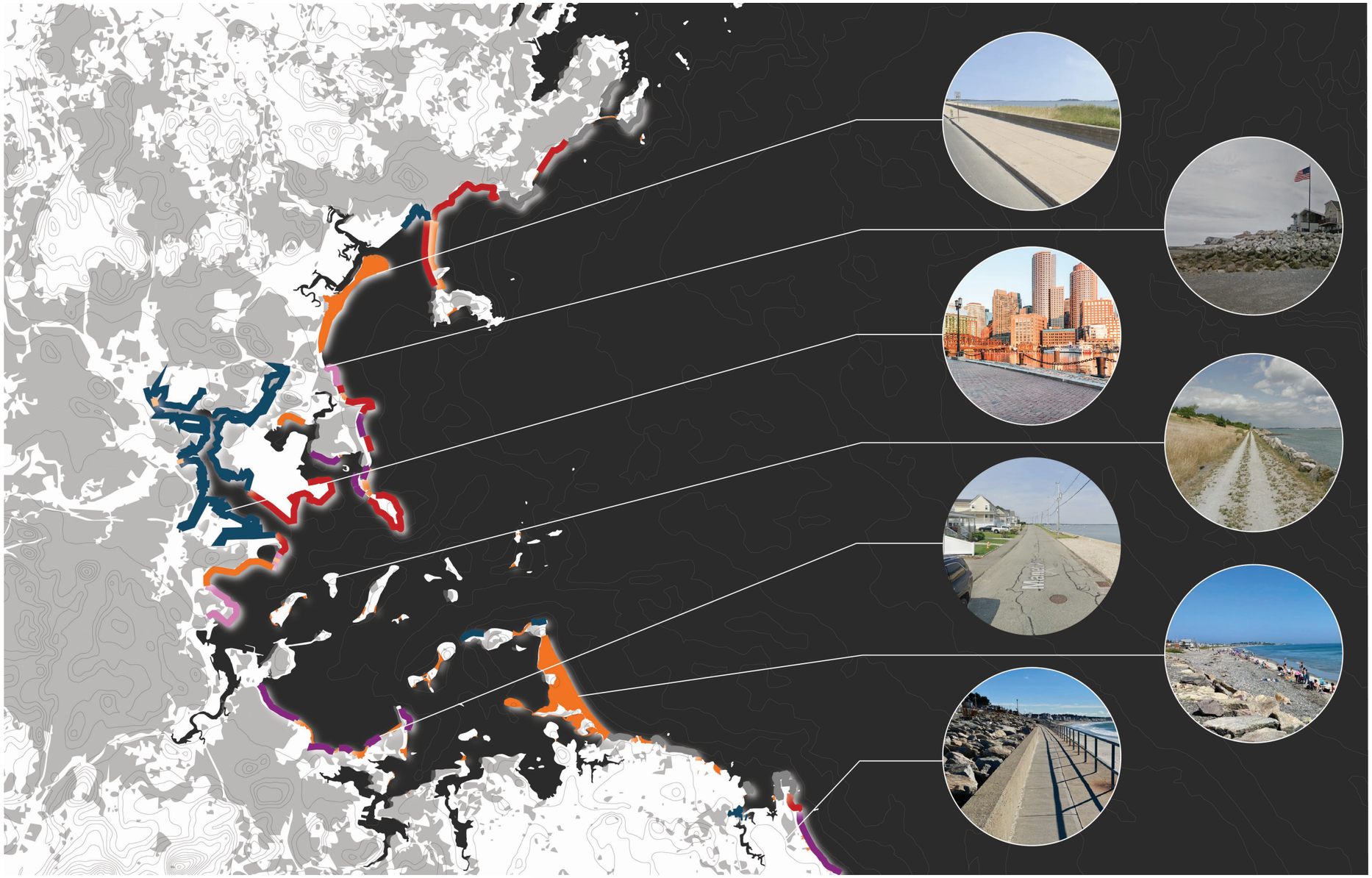


Figure 3.9 - Coastal barrier typologies & Urban settlements.
Made by author
Observed through Google Maps

3.3 Riverine floods

The Charles and Mystic rivers flow through the Metropolitan area of Boston before they culminate in the Atlantic Ocean. In terms of riverine floods, flood vulnerability is mitigated through a cooperation between the environmental system and the flood protection infrastructures.

The Charles River flows through a significant area of wetlands in the upper and middle parts of the river. The Natural Valley Storage provide extensive wetland flood storage that alleviate flood pressures on the downstream Metro Boston area. The urban fabric of Boston is also protected by the (new) Charles River Dam, which is capable of moving 15 million liters of water from the river into the Boston Harbor per minute. The six diesel pumps that are responsible for this movement of water have been upgraded by the Department of Conservation and Recreation around 8 years ago (Zimmerman, 2025).

The Mystic River works in a similar way, where the Mystic Lakes and the Alewife Stormwater wetland protect downstream urban areas in combination with the flood protective Amelia Earheart Dam.



Figure 3.10 - Charles River Natural Valley Storage - Wetland flood storage (Hopkins, 2021)



Figure 3.11 - Diesel pumps of the Charles River Dam
Taken by author



Figure 3.12 - Mystic Lakes Dam
Taken by author



Figure 3.13 - Alewife Stormwater Wetland
Taken by author



Figure 3.14 - Amelia Earheart Dam
Taken by author

3.4 Rising threats

Pluvial floods are a significant hazard to the urban fabric of Boston. Unlike coastal and riverine floods, pluvial floods are not bound to specific floodplains, as precipitation can occur everywhere in the urban environment. Extreme rainfall events can create a burden on the drainage capacity of impermeable surfaces as well as (centralized) sewer systems. This leads to surface floods in places that were not originally part of traditional floodplain zones. In the event of a compound flood, due to an extreme coastal storm, it is more difficult to manage pluvial and coastal floods if water cannot be discharged into the Boston Harbor.

This increased flood risk is closely related to the transformation of the natural water cycle into an engineered one through urban development. In the natural water cycle, rainfall is locally infiltrated, absorbed, and delayed. In contrast, the engineered water cycle does not allow for local infiltration due to the impermeable paving. Pipes are installed to remove water and discharge it elsewhere. In times of drought, the lack of soil moisture impedes natural infiltration, leading to large volumes of runoff that exceed drainage systems' capacity during extreme rainfall events.

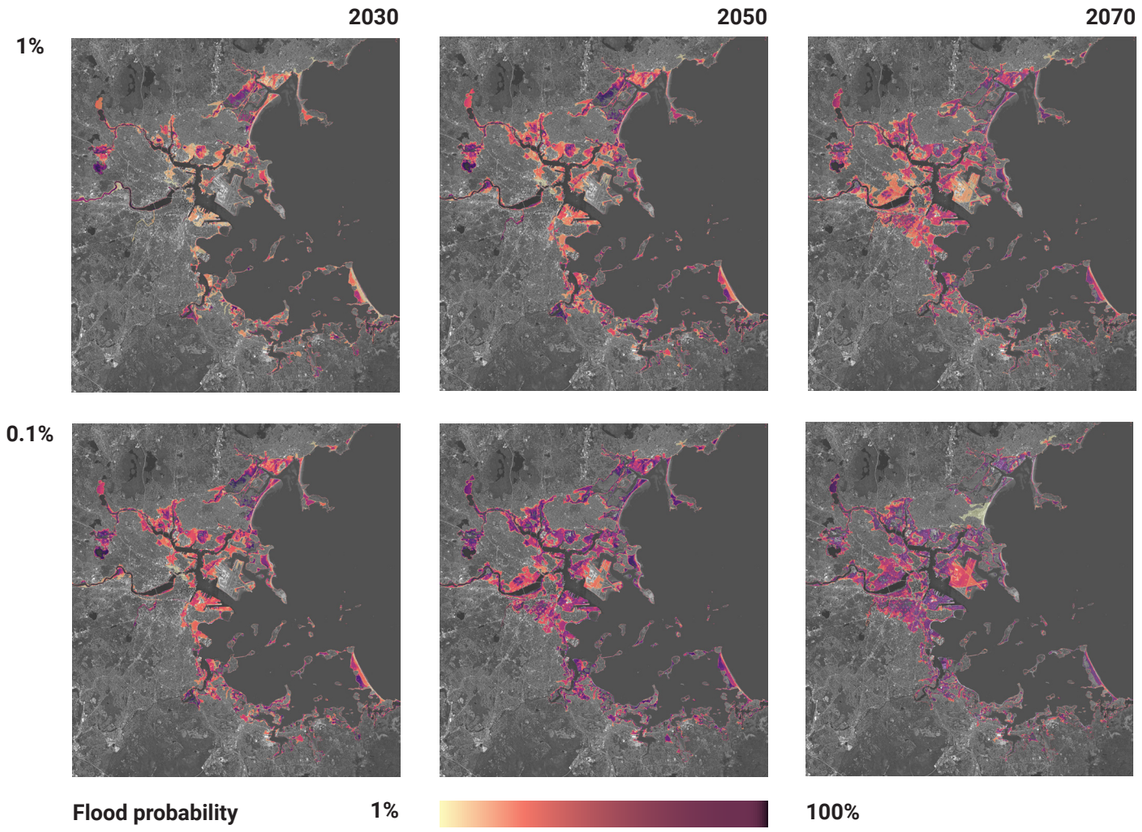
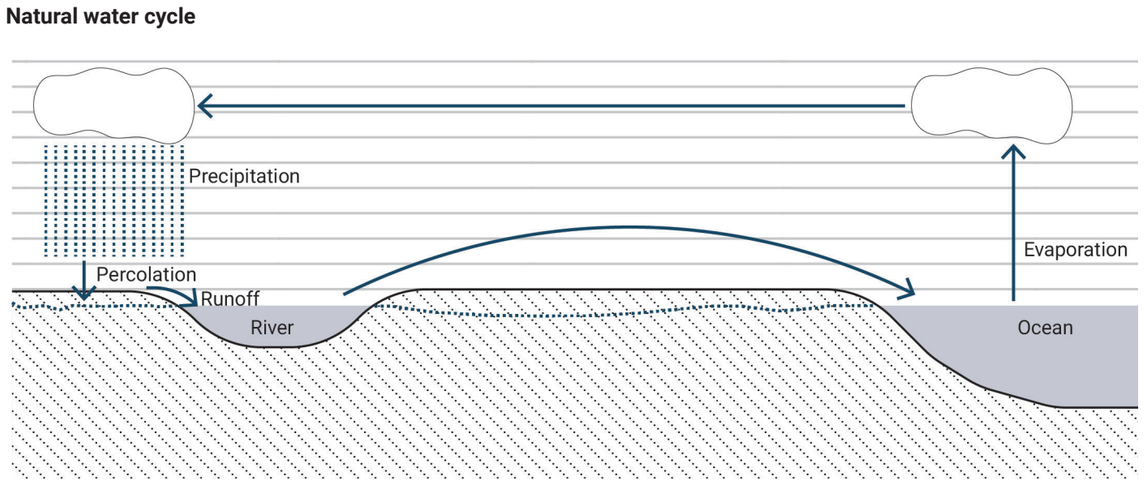


Figure 3.15 - Flood probability over time
Made by author (Woods Hole Group, 2023)



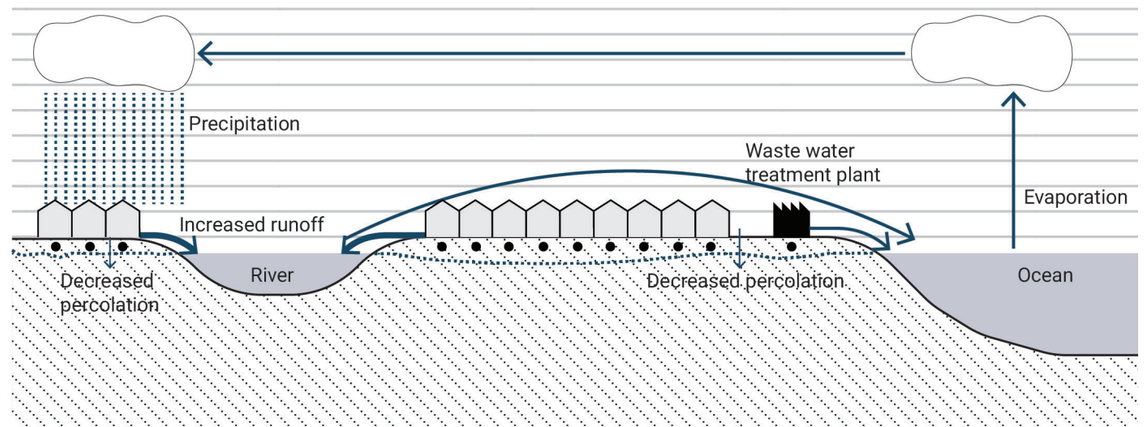


Figure 3.16 - Natural & engineered water cycles
Made by Author - (Zimmerman, 2025)

4. PATTERNS OF VULNERABILITY

4.1 Socio-economic vulnerability
4.2 Vulnerability scorecards



Jessica Rinaldi (2018)
Boston Globe

4.1 Socio-economic vulnerability

Risk is generally defined as the product of probability and consequence (Albers & Evers, 2024). In the flood risk discourse, consequences are typically based on financial indicators, such as economic damage. This practice results in an over-prioritization of urban areas with high economic value. As a consequence, these places usually receive better flood protection, which causes flood injustice through unequal levels of protection in areas with lower economic development.

The difference in protection through the urban fabric relates to the socio-economic state of vulnerable groups. In the event of a flood, these groups are more exposed and are at a disadvantage concerning preparation, response, and recovery. Within the context of metropolitan areas in the United States, flood vulnerabilities are tied to patterns of inequality. This chapter investigates the connection between socio-economic and flood vulnerability through a census-based mapping analysis.

This map shows the spatial distribution of census tracts with a low median household income relative to the metropolitan average. Lower-income areas are strongly concentrated in the North-South direction of the center, particularly in historically industrial and waterfront-adjacent neighborhoods. In the traditional flood risk framework, these economically 'underdeveloped' areas are usually the victim of uneven levels of flood protection, which could worsen socio-economic inequalities in Metro Boston.

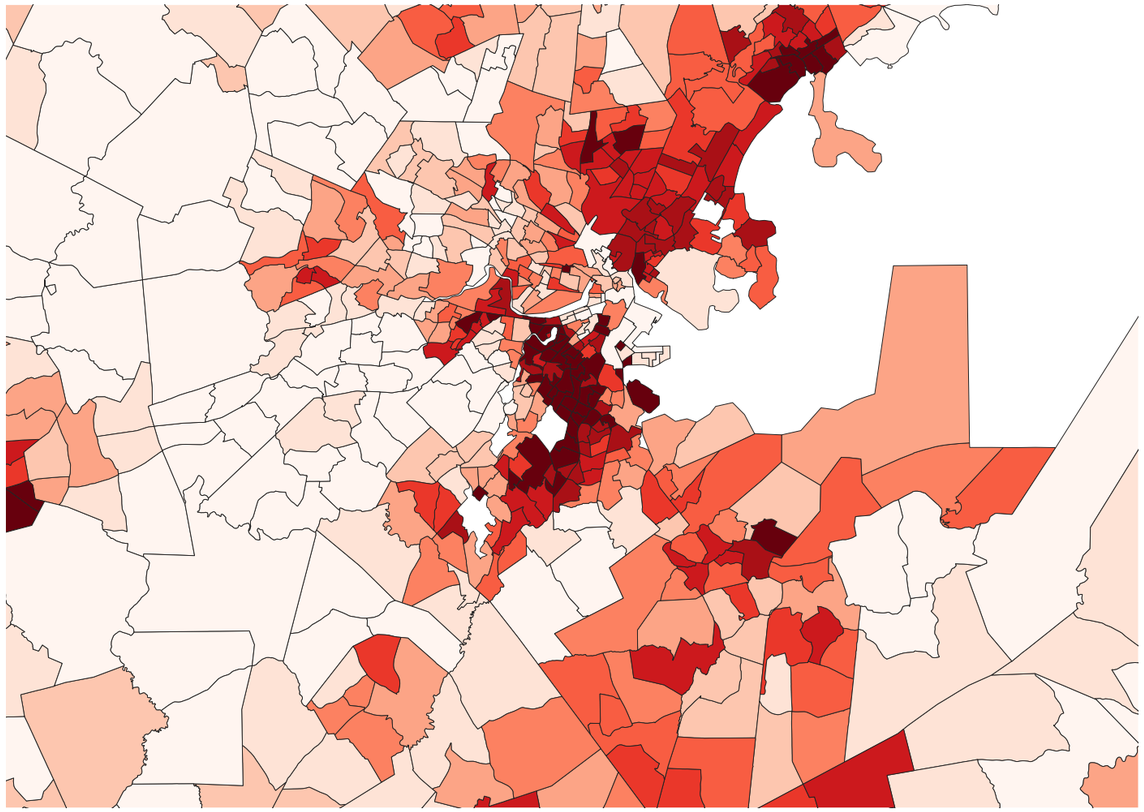


Figure 4.1 - Low median income as a percentage of the area's median income
Made by author
Data: American Community Survey (2019)

The spatial pattern of individuals living below the federal poverty line closely overlaps with the areas identified as having low median incomes. In a logical sense, these two indicators reinforce each other and also show the limited coping capacity to prepare, endure, and recover from a flood event.

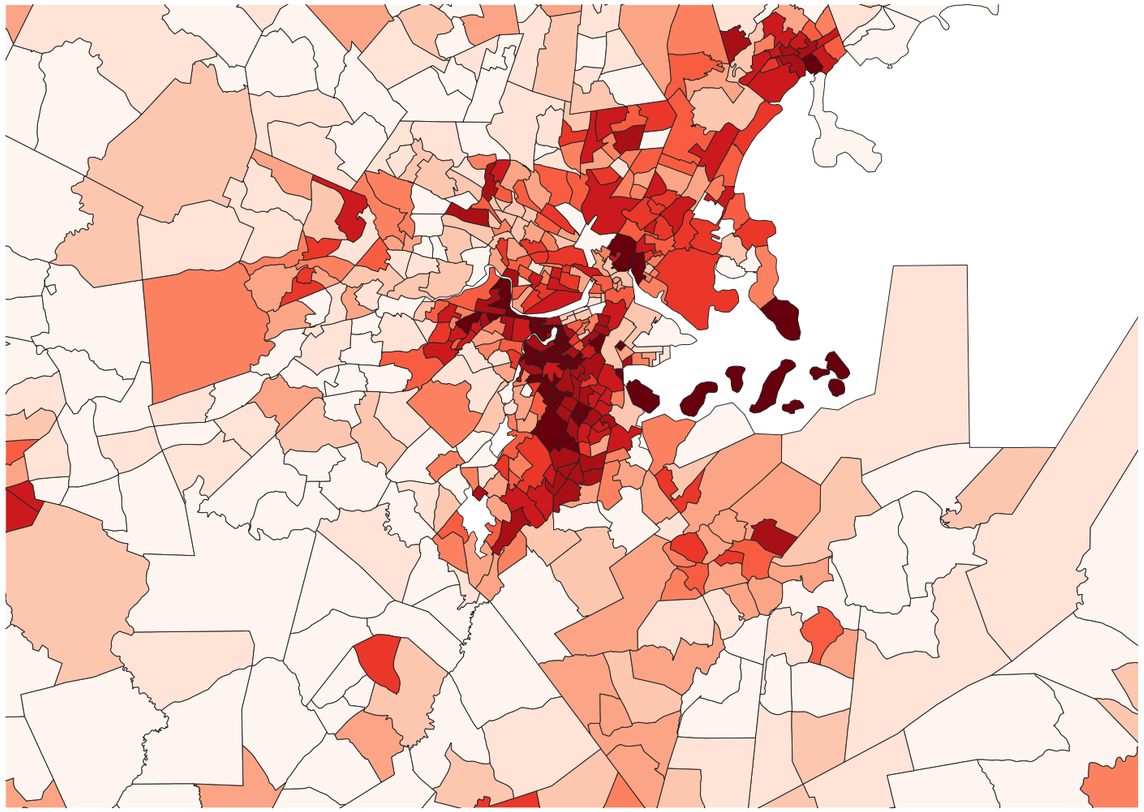


Figure 4.2 - The percentage of individuals who fall under the federal poverty line
Made by author
Data: Decennial Census (2020)

Higher unemployment rates are visible in several of the same census tracts identified as socio-economically vulnerable in previous maps. Unemployment rates in socio-economically vulnerable areas can be linked to limited opportunities because of a lack of education or mobility.

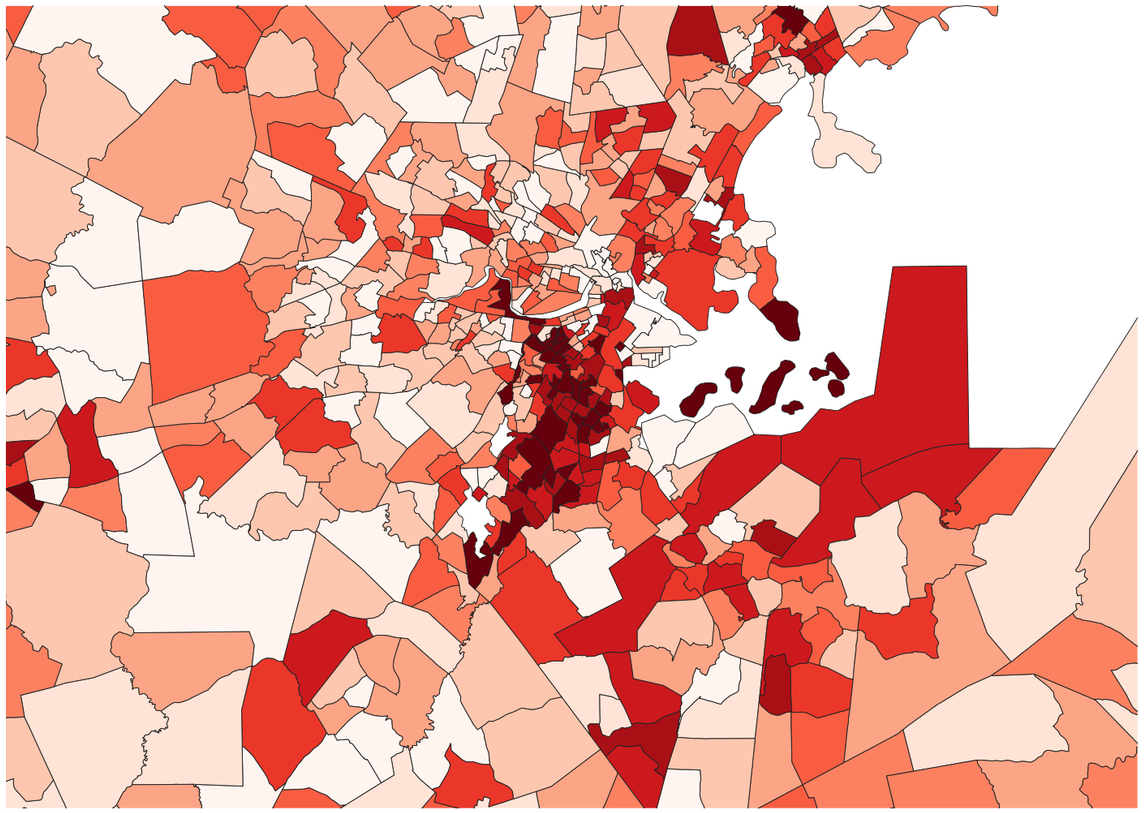


Figure 4.3 - Unemployment rate
Made by author
Data: Decennial Census (2020)

Linguistic isolation is particularly present in areas with high concentrations of immigrant populations. Language barriers can limit access to risk communication, emergency warnings, and public participation in planning and decision-making processes. Historically, many immigrant communities settled in lower-cost, flood-prone areas near industrial zones and waterfronts, resulting in environmental justice groups.

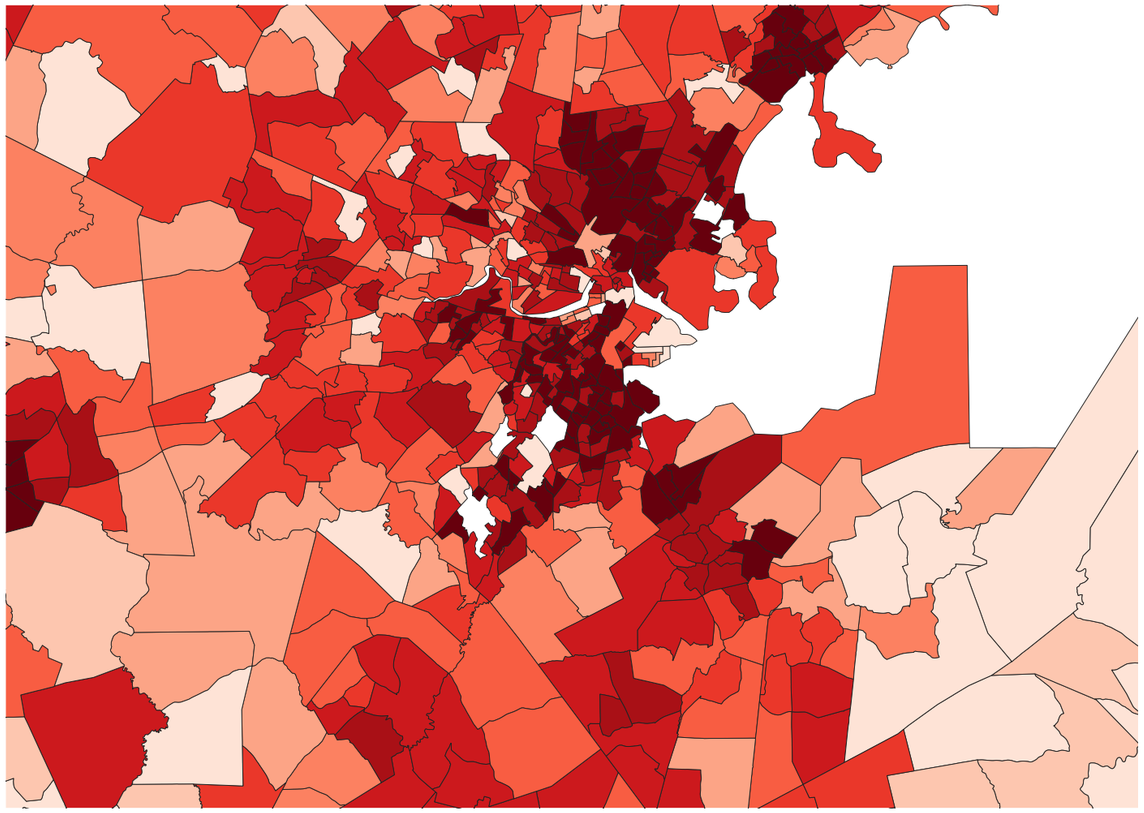


Figure 4.4 - Linguistic Isolation
Made by author
Data: Decennial Census (2020)

This map illustrates census tracts that have been subject to historic underinvestment, largely shaped by discriminatory planning and housing policies such as redlining. This disadvantage can still be observed through environmental and infrastructural degradation, which correlates with flood vulnerability.

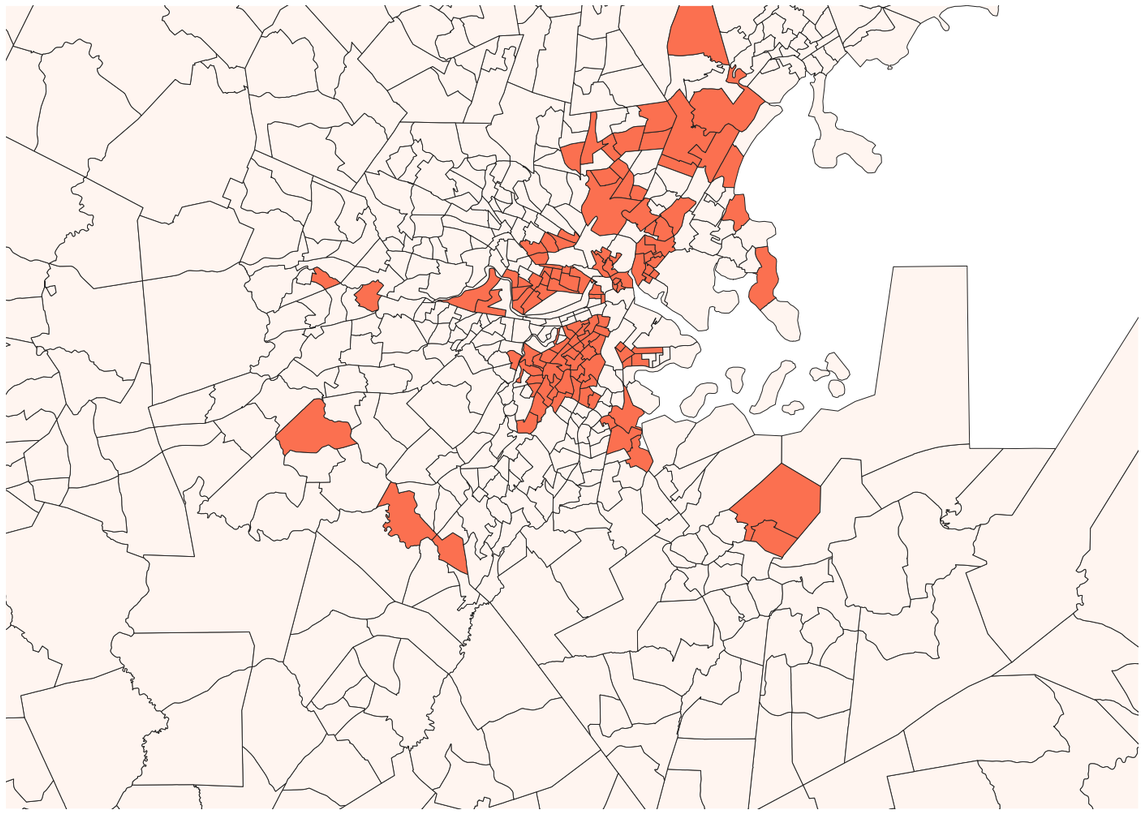


Figure 4.5 - Tracts that experienced historic underinvestment
Made by author
Data: Home Owners' Loan Corporation (2021)

Communities that are facing transportation barriers are socio-economically disadvantaged. Limited accessibility to public transport decreases job opportunities and becomes crucial during flood events, through limited evacuation routes and access to emergency services during and post-disaster, worsening vulnerability through flood-prone isolation.

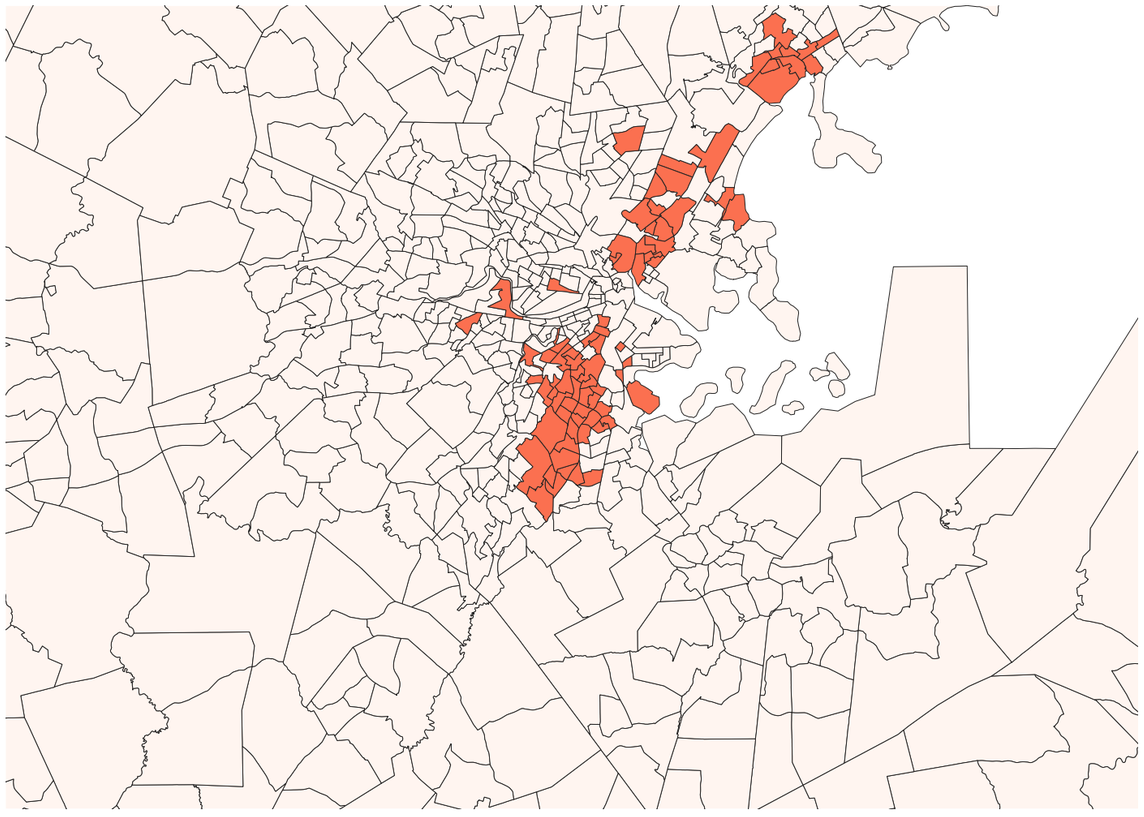


Figure 4.6 - Transportation barriers
Made by author
Data: Department of Transportation (DOT) (2022)

Lower levels of educational attainment are concentrated in similar areas identified as socio-economically vulnerable in previous analyses. Lack of education correlates with employment opportunities and could lead to reduced awareness with regard to flood events.

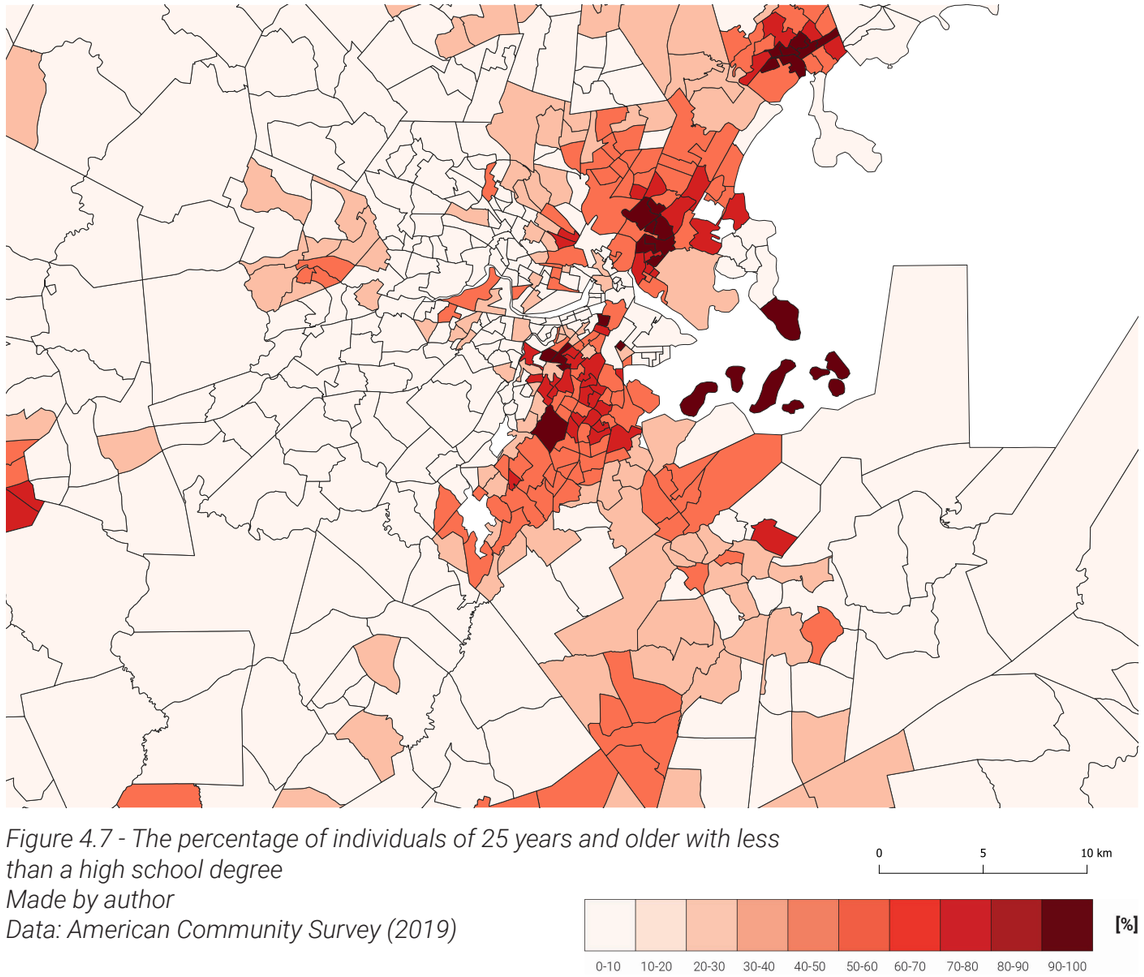


Figure 4.7 - The percentage of individuals of 25 years and older with less than a high school degree
Made by author
Data: American Community Survey (2019)

This map shows the synthesis of disadvantaged communities based on the socio-economic indicators in the maps before. Areas like South Boston, Roxbury, Chelsea, and East Boston are main zones of disadvantaged communities.

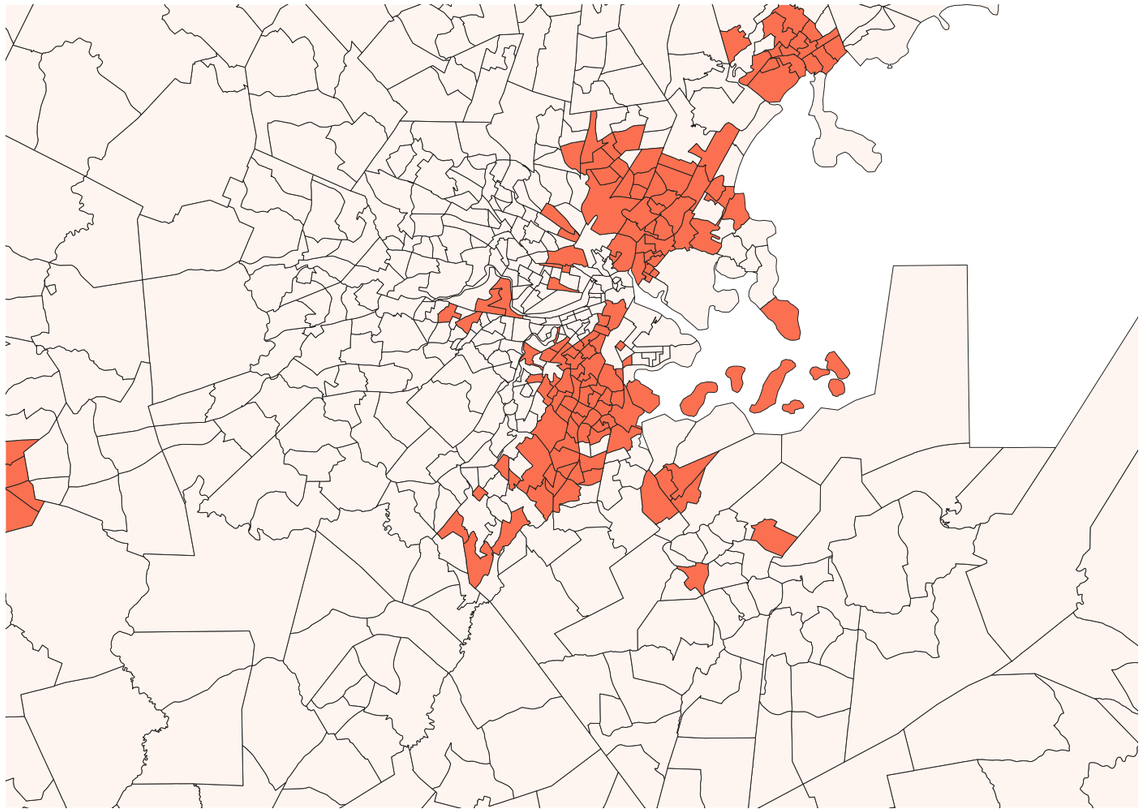


Figure 4.8 - Disadvantaged Communities
Made by author
Data: American Community Survey (2019)

By comparing the socio-economic indicators to the spatial distribution of race through the Metropolitan Area of Boston, it is confirmed that patterns of segregation contribute to (racial) patterns of inequality. The following figures show how ethnic groups are segregated and how mostly Black, African American, Hispanic, and Latino ethnic groups are concentrated in areas with high(er) socio-economic vulnerability.

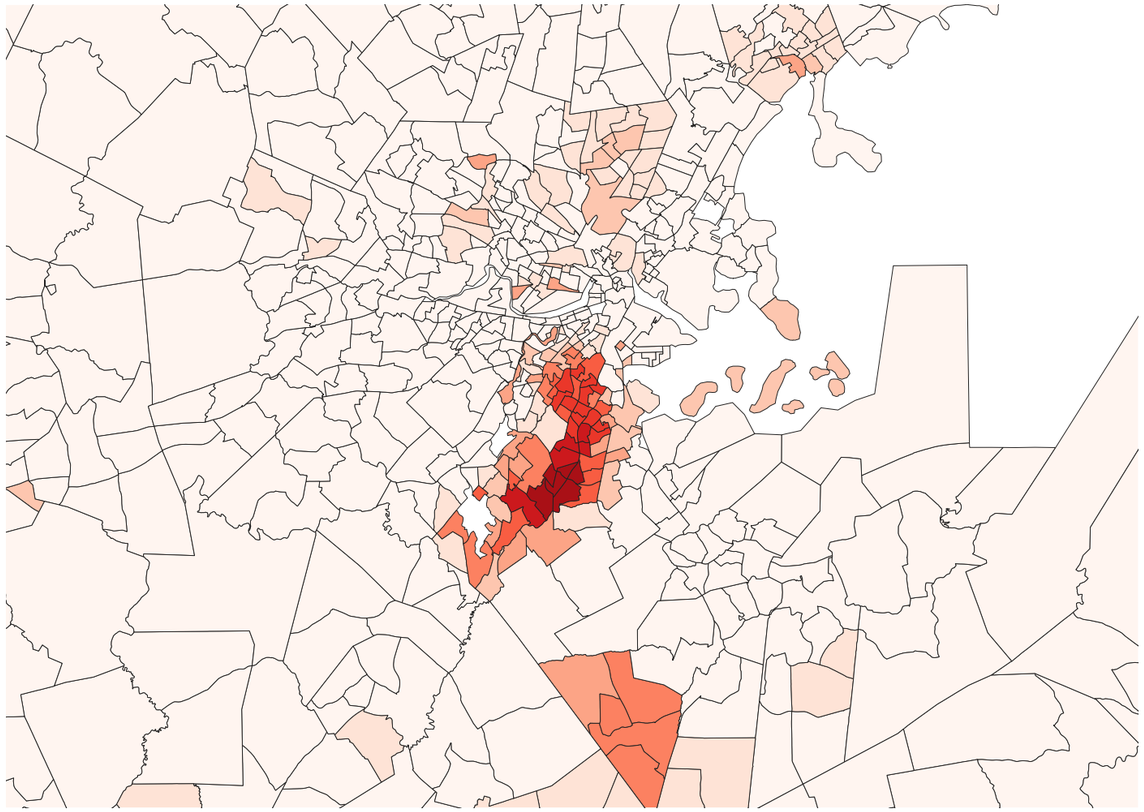


Figure 4.9 - Percentage of the population with Black or African American ethnic background
Made by author
Data: American Community Survey (2019)

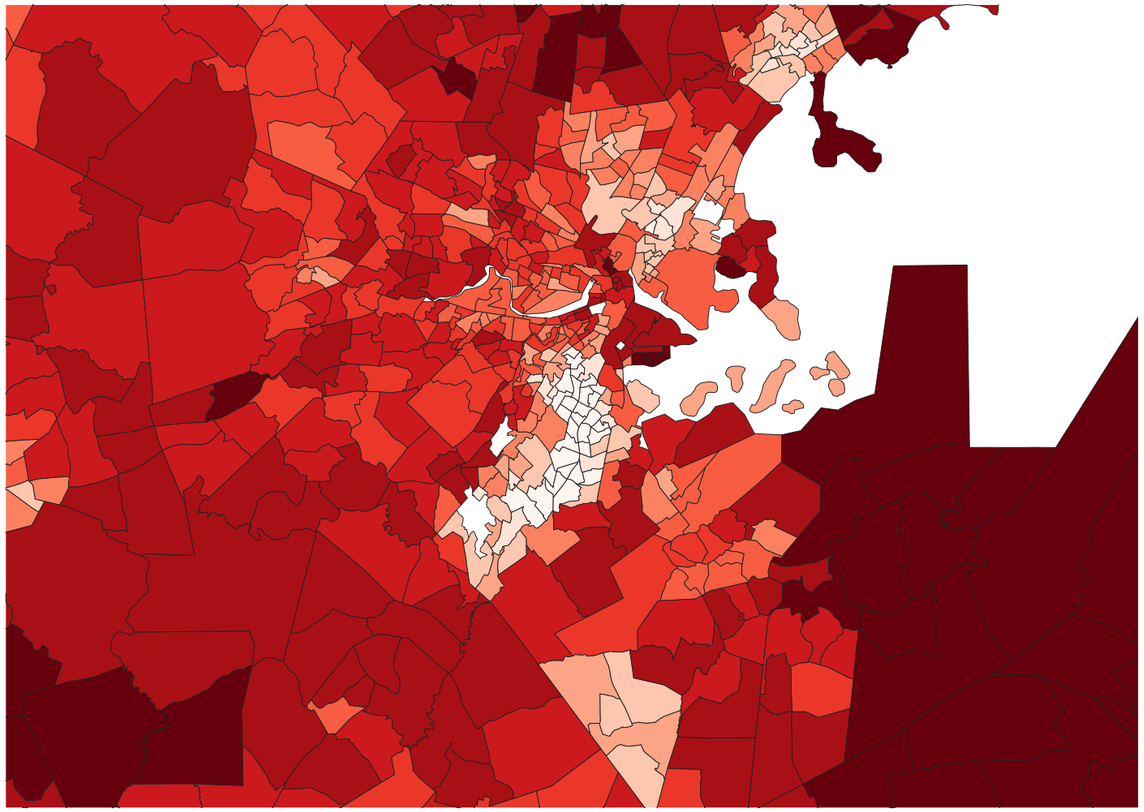


Figure 4.10 - Percentage of the population with White ethnic background
Made by author
Data: American Community Survey (2019)

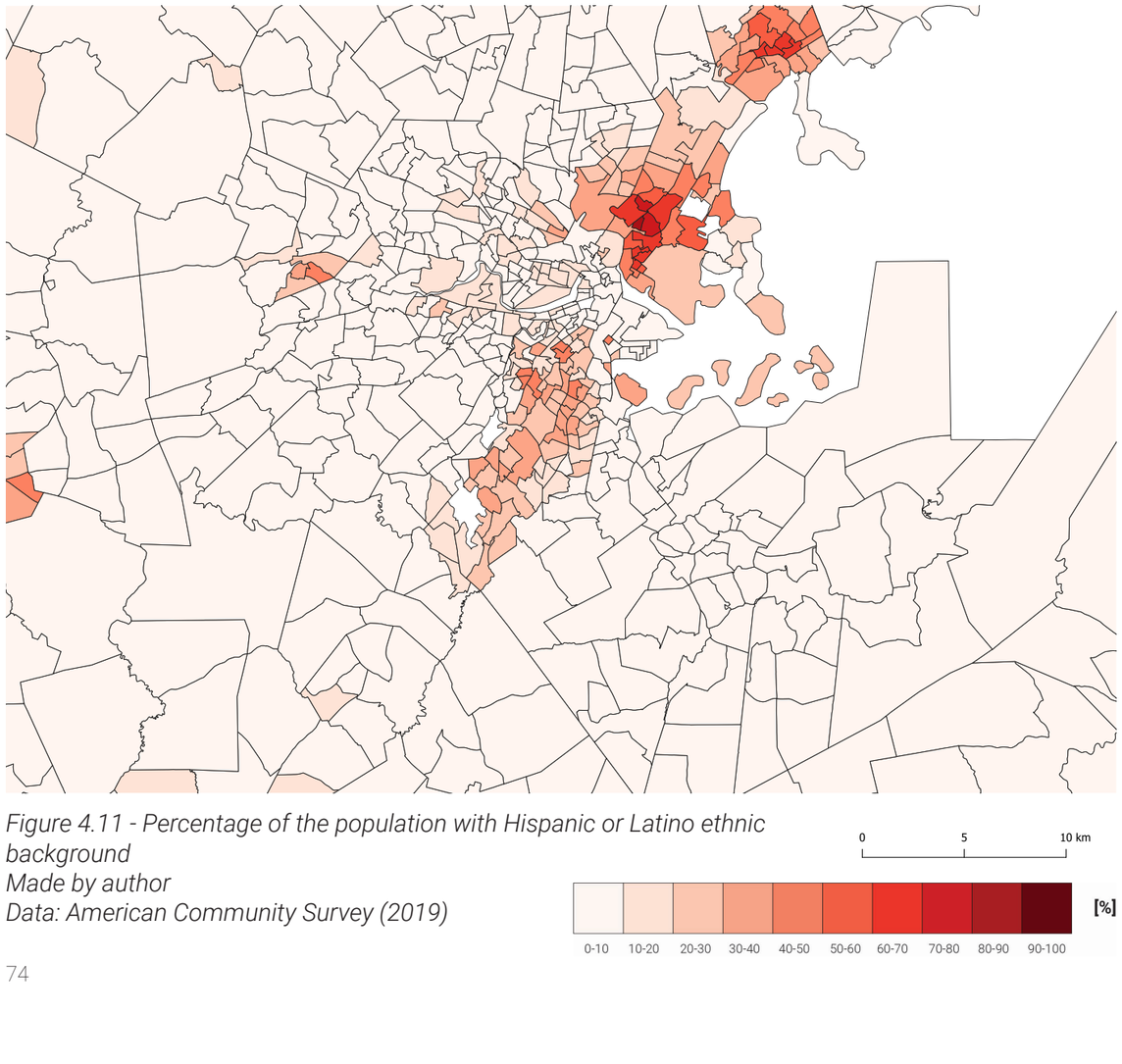


Figure 4.11 - Percentage of the population with Hispanic or Latino ethnic background
Made by author
Data: American Community Survey (2019)

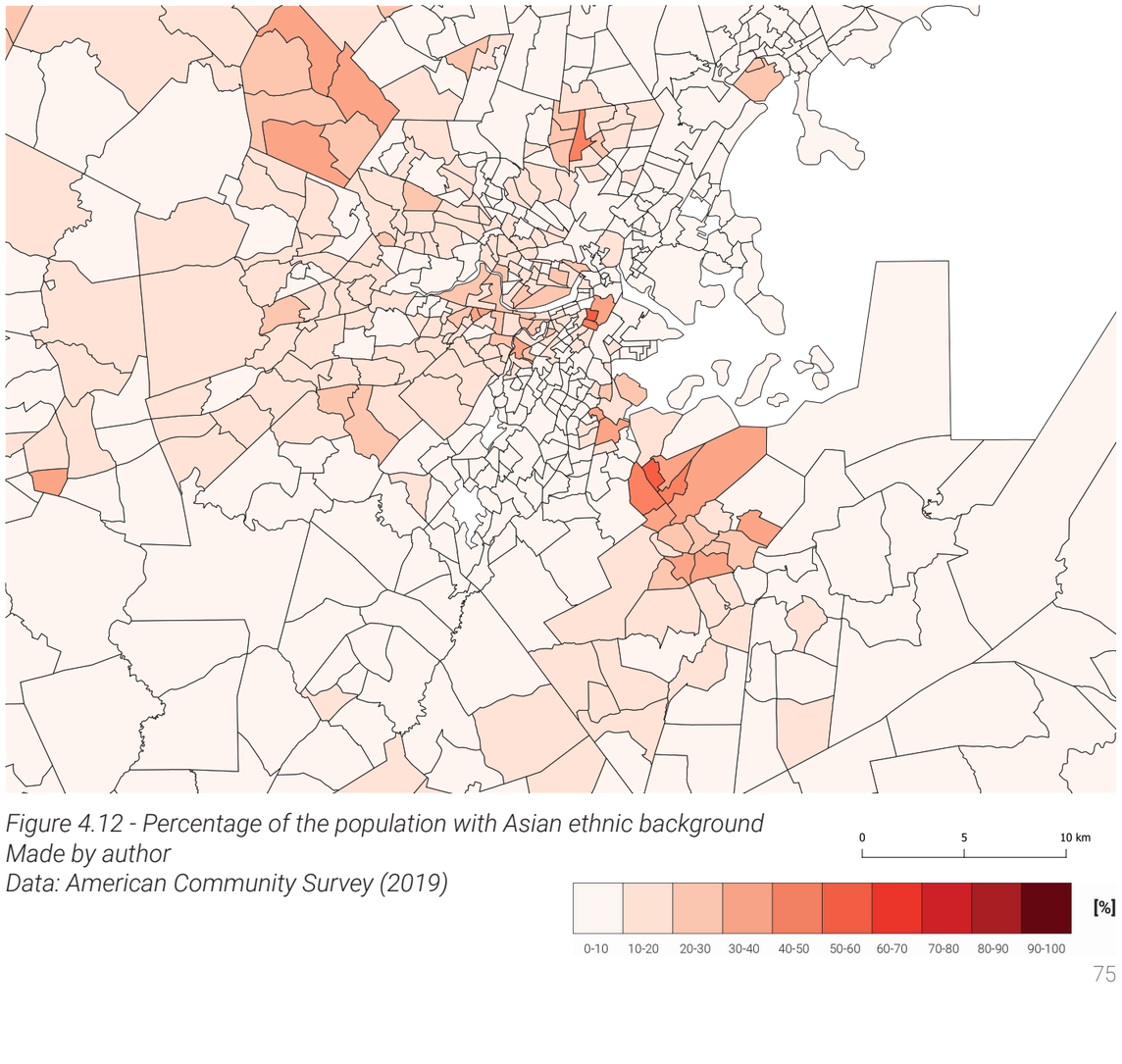


Figure 4.12 - Percentage of the population with Asian ethnic background
Made by author
Data: American Community Survey (2019)

4.2 Vulnerability scorecards

To make the connection between socio-economic indicators and flood vulnerability, the Metro Boston Community Resilience Scorecard (Trust for Public Land, 2025) is used. In this scorecard, grades are given to census tracts in the metropolitan area to assess their resilience performance to inland & coastal floods, and a social vulnerability index.

Inland flood vulnerability highlights areas exposed to pluvial and fluvial floods, primarily caused by impermeable surfaces, topography, and drainage capacity. Almost all census tracts in the metropolitan region have a low score.

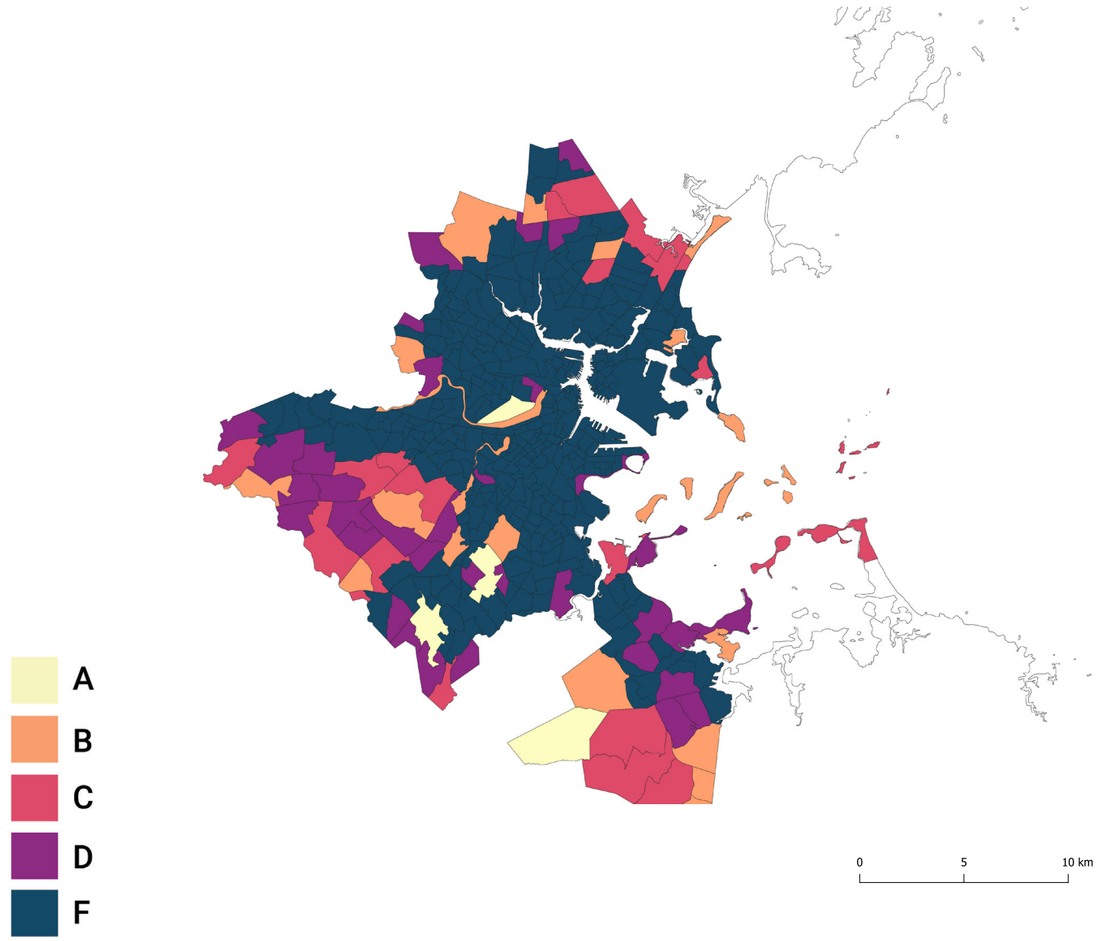


Figure 4.13 - Inland flood vulnerability
Made by author
Data: Trust for Public Land (2023)

The social vulnerability index confirms similar patterns as the socio-economic analysis carried out in the last sub chapter. This acknowledges the compound effects of socio-economic and inland flood vulnerability if compared to the last map.

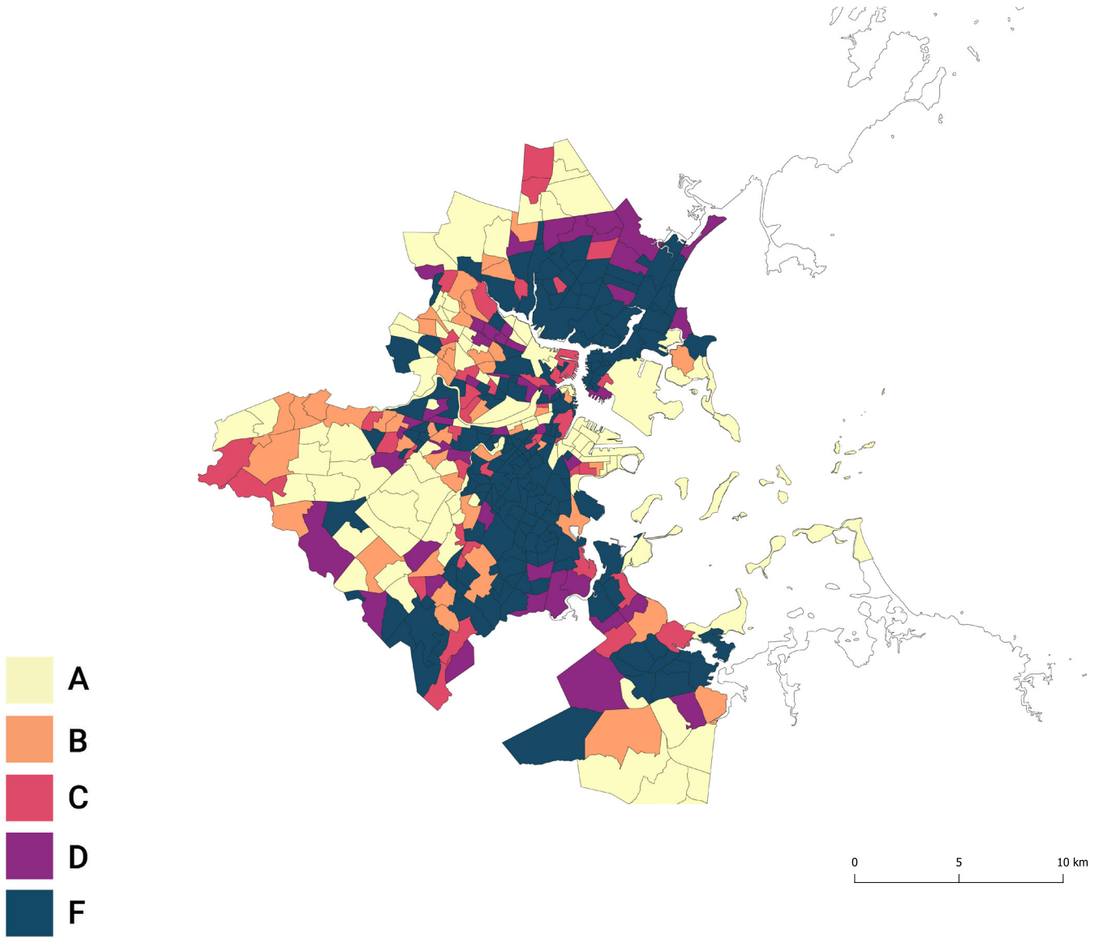


Figure 4.14 - Social vulnerability
Made by author
Data: Trust for Public Land (2023)

Coastal flood vulnerability is concentrated along the coastline edges and artificially filled lands. A significant part of the areas that are vulnerable to coastal floods are also categorized as socio-economically disadvantaged communities.

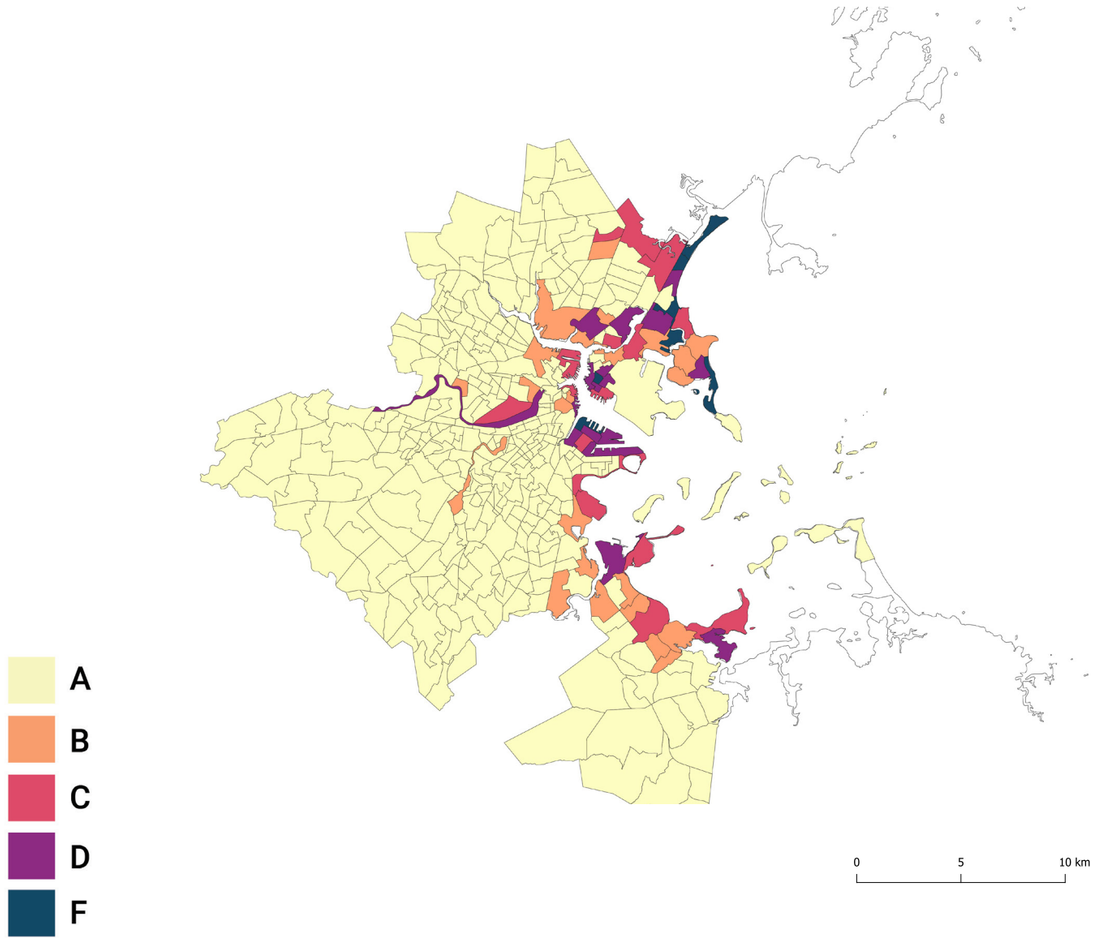


Figure 4.15 - Coastal flood vulnerability
Made by author
Data: Trust for Public Land (2023)

If all worst scoring census tracts (F-score) are synthesized and put over each other, the tracts that experience most compound vulnerability are visible.

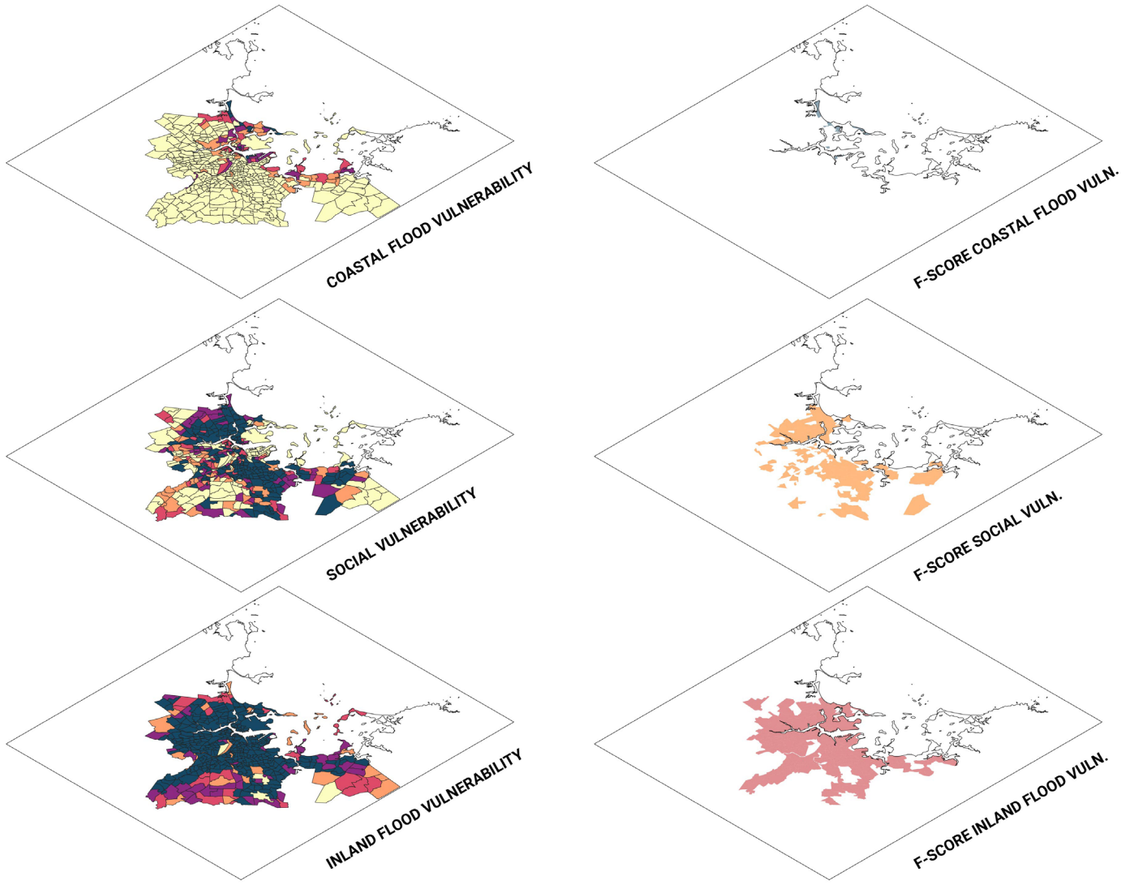


Figure 4.16 - F-score axo
Made by author
Data: Trust for Public Land (2023)

By overlaying the worst-scoring census tracts, this synthesis map reveals the connection between socio-economic vulnerability and flood risk. Limited capacity to cope with and adapt to floods is putting pressure on already stressed communities, reflecting uneven levels of protection. This sub chapter shows that the process of striving towards flood resilience is not merely a technical debate and that flood resilience strategies should take the socio-economic dimension into account in the process of urban (flood) design.

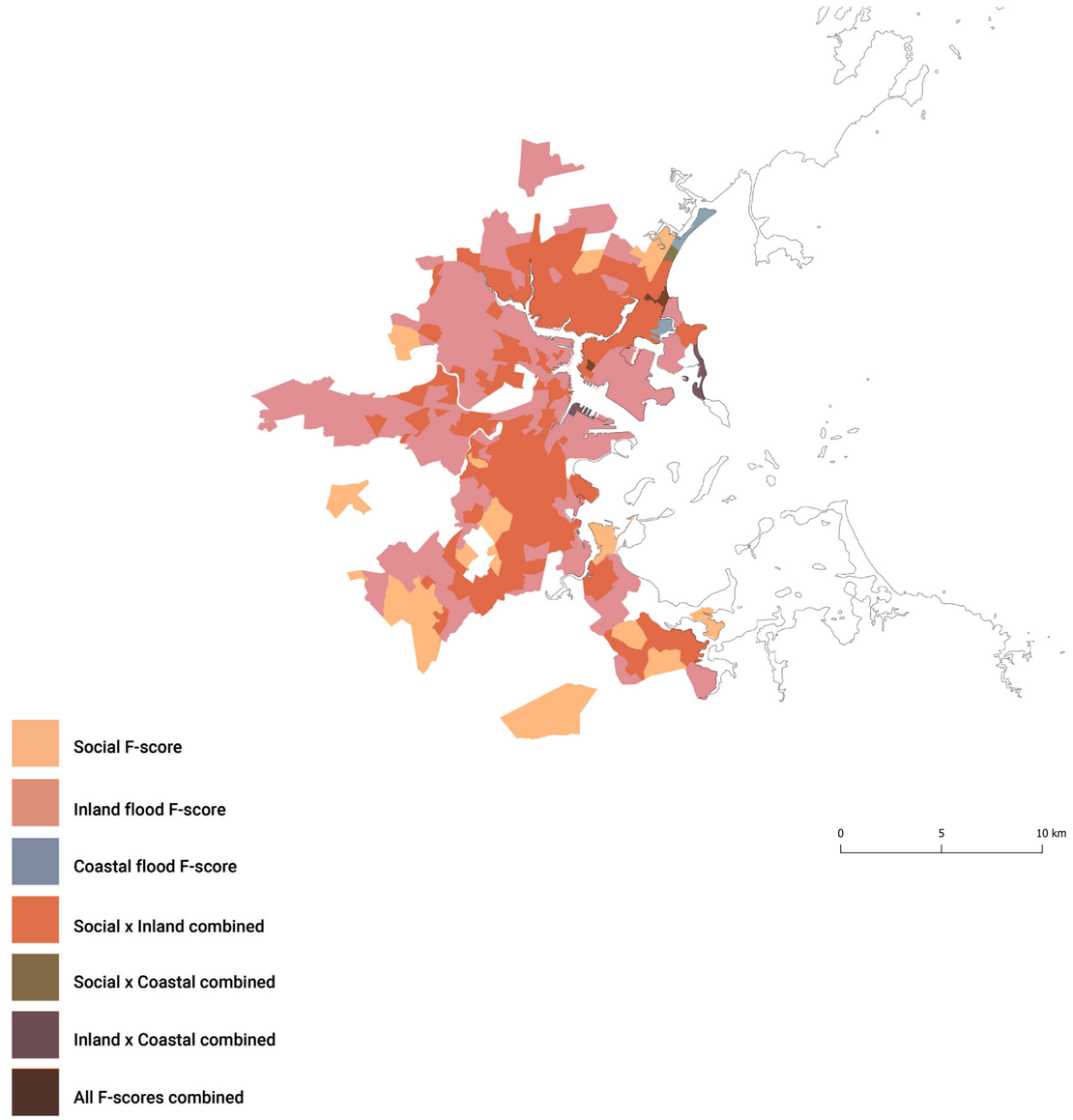
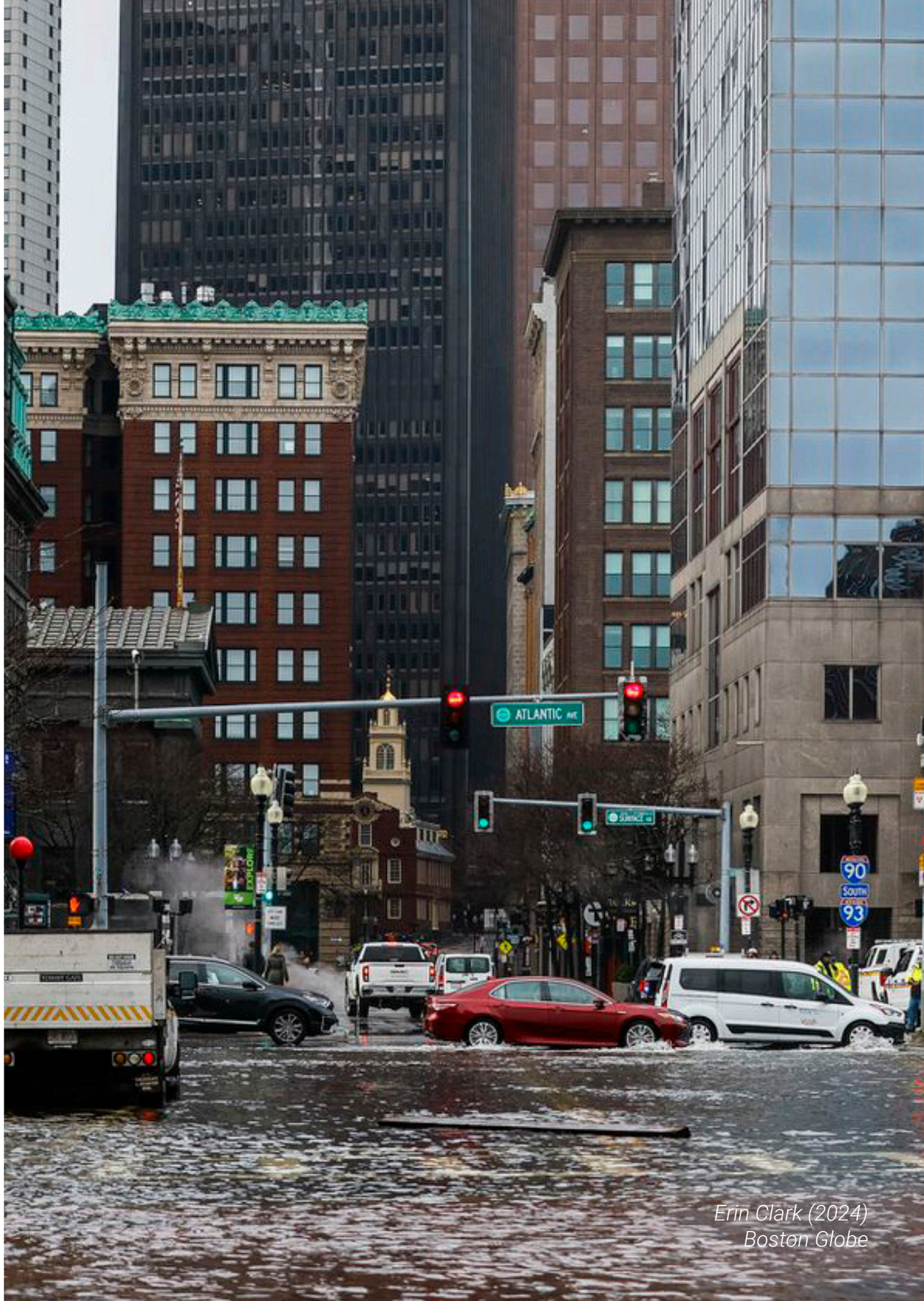


Figure 4.17 - Synthesis map
Made by author
Data: Trust for Public Land (2023)

5. PROBLEMATIZATION

5.1 Problem framework
5.2 Problem statement



Erin Clark (2024)
Boston Globe

5.1 Problem framework

Worldwide, society faces severe consequences from climate change, which places urban environments under immense pressure. Increased flood risks due to extreme precipitation, heightened river runoff, and rising sea levels threaten the Metropolitan Area of Boston. Although projections of sea level rise depend on global carbon emissions, the IPCC (2019) indicates that the American East Coast is experiencing one of the highest rises. Additionally, Boston ranks 8th globally in terms of average annual economic loss caused by coastal floods (Hallegatte et al., 2013), and the city faces 100% flood exposure if sea levels rise by 1.80 meters (6 feet) (Berger et al., 2020). These are merely coastal flood risks, not to mention the hazards that arise from inland (riverine) and pluvial floods. Furthermore, Boston is particularly vulnerable to floods due to the land making history of the city, which correlates to land subsidence along the coast and areas developed throughout the city's history.

The flood risk management system in the United States differs from that of the Netherlands. Dutch water management relies on physical flood defenses, while in the United States, insurance (and evacuation strategies) are more important (Hooimeijer et al., 2022). Between 1988 and 2017, Davenport et al. (2021) estimate that flood damage accounted for just over 200 billion dollars. The requirement of purchasing insurance to mitigate flood risk, combined with significant inequalities in the United States, creates an unfairness in protection.

Increasing flood risks are not only threatening the Metropolitan Area of Boston, but the infrastructural systems that support the urban environment are also nearing the end of their life cycles. This issue of longevity places pressure on the system's functionality, as the urban environment depends on these infrastructures. Furthermore, systems like the sewage network are operating beyond capacity and are likely to fail, with combined sewer overflows occurring regularly.

Additionally, centralizing large engineered infrastructures, such as wastewater treatment plants and dams, creates a false sense of security. The reliance on an external energy supply, combined with the centralization of the wastewater plant, places the system at significant risk of collapse. The construction of dams in the area has led to increased development in (historical) floodplains. However, these outdated dams also have limited lifespans and pose heightened hazards in the event of dam failure.

The condition of the infrastructure is not the only issue. Simply the presence of infrastructural systems in combination with the supported urban system, disrupts vital natural landscapes and core habitats in the area, obstructing ecologies and rare species. Dams obstructing fish migration, urban runoff, and combined sewer overflows are contributing to environmental degradation.

The combination of flood hazards and the current state and effects of existing infrastructural systems shape vulnerable people, animals, and areas. Environmental degradation, historical land making-induced land subsidence, and socio-economic inequalities contribute to unfair levels of protection and disparities in the accessibility of essential resources and infrastructures, particularly in the context of the insurance paradigm in the United States.

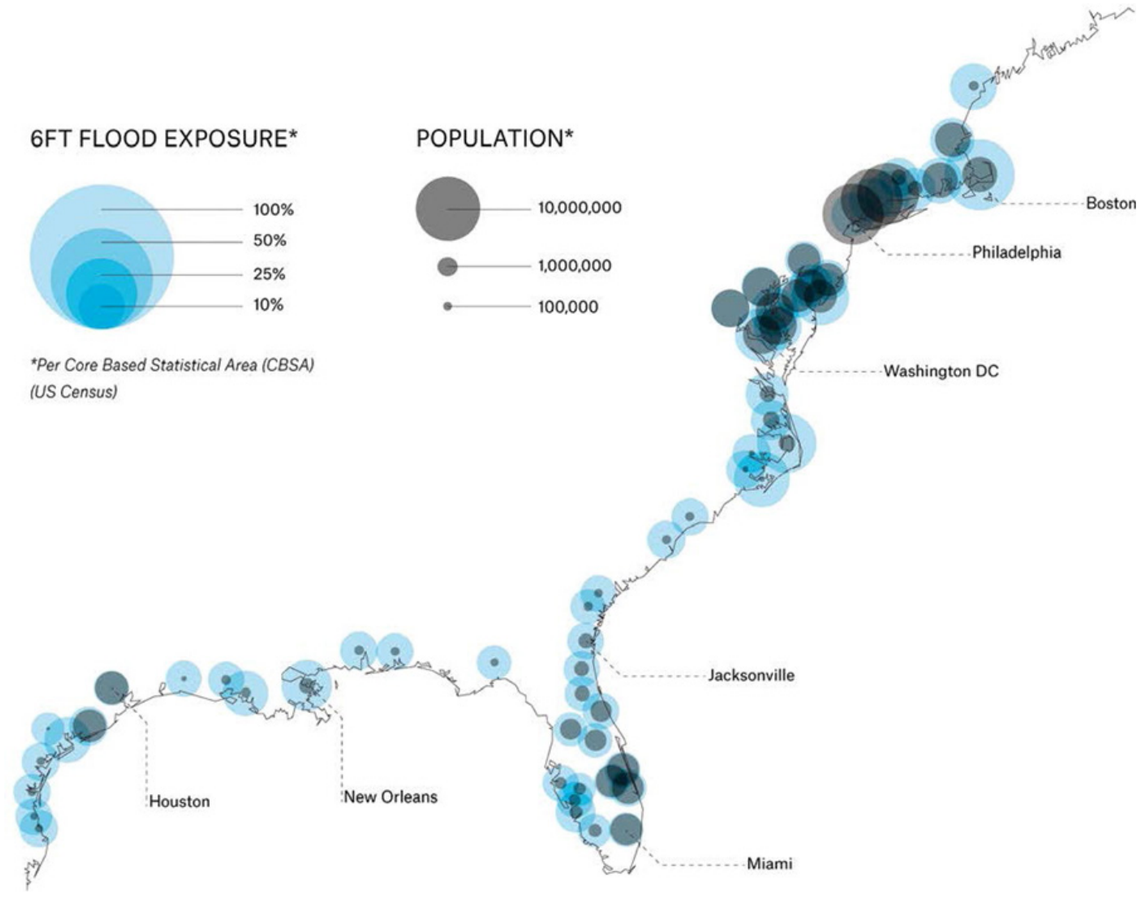


Figure 5.1 - Flooding of the Atlantic and Gulf coasts with 6 feet (1.8 m) of sea level rise Source: (Berger et al., 2020)

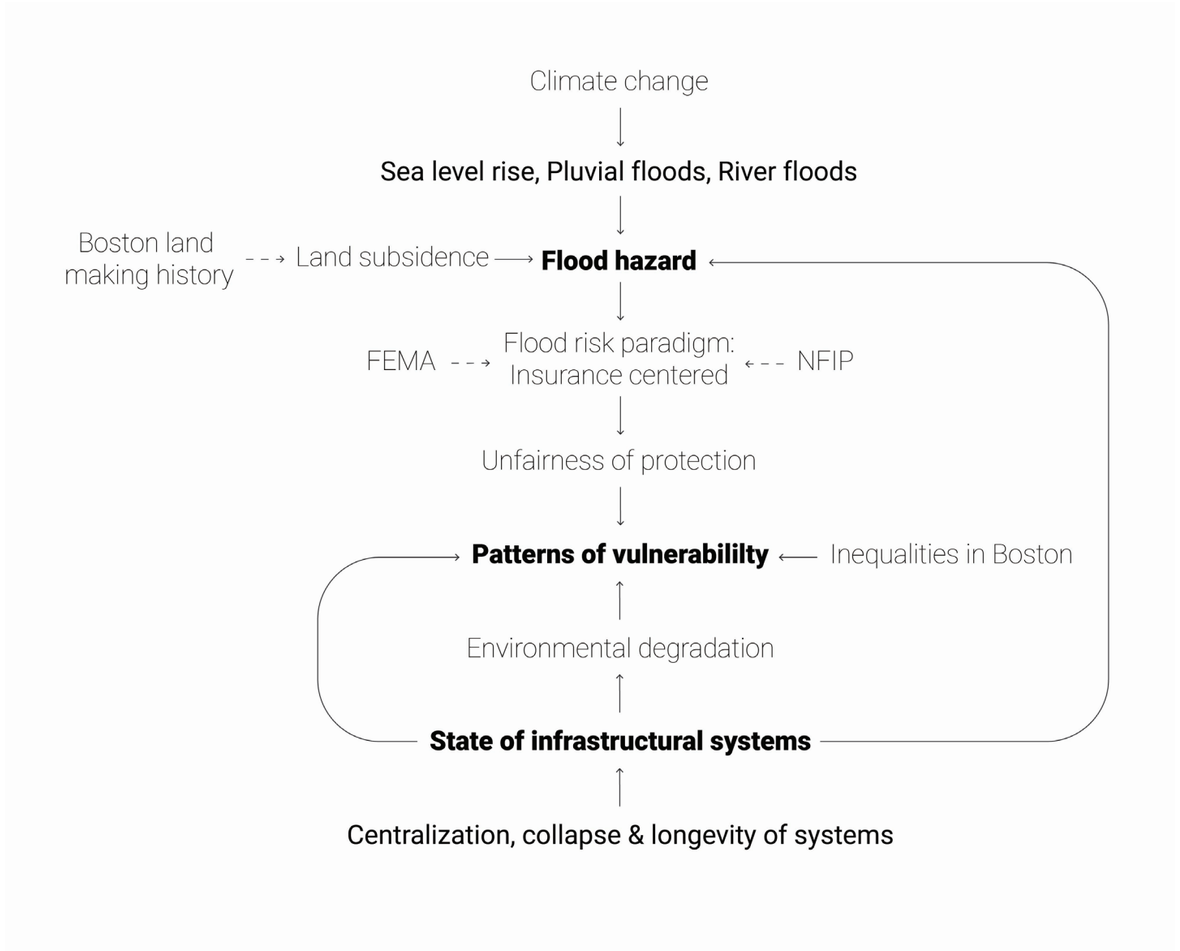


Figure 5.2 - Problematization diagram
Made by author

5.2 Problem statement

Flood hazards, combined with the U.S. **insurance system**, and the current **state** and **effects** of existing **infrastructural systems** shape vulnerable people, animals, and landscapes. **Environmental degradation**, historical land making-induced **land subsidence**, and **socio-economic inequalities** contribute to **unfair levels of protection** and **disparities** in the accessibility of essential resources and infrastructures. As urban development continues to expand without **strengthening** its **relationship** to **environmental systems**, increasing pressure is placed on already stressed landscapes, ensuring an even more vulnerable metropolitan region.

6. THEORY & CONCEPTS

6.1 Theoretical framework
6.2 Conceptual framework



6.1 Theoretical framework

The theoretical framework supports the analytical component of the project's problematization. By creating a subdivision of theories and concepts, the various aspects of the problematization will be examined to create a stronger connection between the project and the existing body of knowledge. Finally, the theoretical framework provides an overview of how the key literature can be applied to this project. Three distinct groups of theoretical concepts are identified and examined: landscape infrastructure design, flood resilience design, and vulnerability & adaptive capacity.

Landscape infrastructure design

The consequences of disasters on the urban fabric is dependent on its risk management and the composition of the urban environment (Iuorio & Kanj, 2025). The land-making history of Boston, in combination with the significant flood-vulnerable areas, show the limitations of human control, and its technological interventions that should protect the urban environment from, in this case, hydrological disasters.

Currently, especially in the American context, urban environments are heavily dependent on large, ultra-engineered infrastructural systems. These systems are built to last for a certain period. However, times are changing, and due to climate change, these infrastructures might not be able to cope with the added pressure of intensifying flood threats. In addition, the analysis shows that certain infrastructural systems are already at bound to fail. Landscape infrastructure design is based on the concept of utilizing landscape and water properties by integrating ecological systems into the urban fabric. The uncertainties over time make landscape infrastructure design a strategy with the potential to adapt to future water conditions.

Landscape is a dynamic system that displays the connection to culture and how it has been altered by nature and humans over time. It is a multi-layered plane that shifts through different physical properties where humans settled and depleted it. The landscape is subject to dynamic processes that span over centuries. Since the twenty-first century, landscape has risen to the light due to deindustrialization and increased environmental awareness. Before, the practice of landscape (architecture) was not connected to architectural or urbanism practices. According to Corner (2006), landscape gained recognition in planning theory and was seen as a tool for urban and architectural planning. This led to the creation of 'Landscape Urbanism'. The city is a fast-paced, dynamic system that constantly evolves. As a consequence of this rapid urbanization process, negative byproducts like pollution are present. Landscape systems allow citizens to escape from the overwhelming dynamics of the city. On top of that, these systems play a significant role in ecological and environmental conservation in the urban environment. The Back Bay Fens, as part of the Emerald Necklace structure in Boston, is not merely a park, but also a hydrological and stormwater management system.

Ian McHarg was responsible for the integration of ecological principles into urban planning and design processes. First, this was only related to the natural and landscape components in this planning process. Later, the fluid dynamics of the landscape and ecology were connected to urban systems. "The designation terra firma (firm, not changing; fixed and definite) gives way in favor of the shifting processes coursing through and across the urban field: terra fluxus." (Corner, 2006). This notion is relevant to the intervention of landscape (urbanism) into urban infrastructure.

Infrastructures support urban flows most critically; thus, they are indispensable in the urban system. In fact, they play the main role in the urban system. Not all infrastructural systems are prominently visible. Many pipes and cables are laid underground, and large structures are usually positioned outside of busy urban centers. However, failures – caused by floods, for example - in the infrastructural systems that support urban environments remind us that they are not indestructible. Industrialization led to the centralization of large infrastructural systems. According to Bélanger (2010), the privatization of public services, due to a doubling in the U.S. population and a stagnating economy, has resulted in deteriorated urban infrastructures. Bélanger states that the privatization of infrastructure has led to underinvestment and overdue maintenance. This "will require an investment of $2.2 trillion over the next five years" (Bélanger, 2010).

Bélanger (2017) critiques the over reliance on civil engineering and pledges to integrate multiple disciplines into the design of infrastructural systems. With this in mind, he questions the equation that defines infrastructure as equal to economy and proposes a new equation where economy equals ecology, making ecology synonymous with infrastructure. He also addresses the increasing failures of ultra-engineered gray infrastructural systems, such as pipes, dams, and highways. These structures are layered across the landscape. Instead, Bélanger argues for the integration of these infrastructures within the landscape, as the landscape itself also supports urban life. The centralized infrastructures are nearing the end of their lifespan. Sooner or later, they will collapse, revealing the false sense of security in urban areas that relied on these structures.

These developments, which lead to the alarming state of infrastructural systems in the United States, raise the question of how to move forward. Essentially, how can infrastructural systems support urban life in the future? According to Bélanger (2010), ecological and environmental concerns are inseparable from the state of infrastructural systems in today's context. The system flows are interconnected with their environmental consequences, bridging ecology and economy. The concept of infrastructure as landscape demands an interdisciplinary and flexible approach in the construction and management of infrastructural systems, as well as the (re)integration of the landscape.

Nijhuis & Jauslin (2015) deduce from the definitions of infrastructure and landscape that infrastructure modifies the natural environment, thus inevitably affecting the landscape. They indicate that combining both systems allows for optimization and integration, creating landscape as infrastructure systems that serve both purposes. The multidisciplinary nature of this combination highlights the importance of collaborative design. In this design process, they emphasize the significance of the multi-scalar dimension and 'longue durée,' reflecting dynamics over an extended period. Nijhuis & Jauslin also note that the design process of urban landscape infrastructures would benefit from a research-by-design approach.

The landscape as infrastructure approach does not oppose the existence of infrastructure. In fact, urban areas cannot function without it (e.g., transport, electricity, water, sewer, communication systems). However, the organization of infrastructural systems established during the industrial era requires reassessment. Alehashemi et al. (2017) have analyzed methods for adapting these infrastructures in the post-industrial era. They state that a "multi-dimensional and holistic approach" is necessary, where the social, ecological, and economic domains of the urban fabric intersect with the landscape as infrastructure approach to achieve more flexible systems.

Flood resilience design

The theoretical framework of flood resilience design focuses on water management methods that differ from traditional land protection approaches. These older methods involve large, physical barriers, while newer designs embrace water through more open interventions, promoting flexibility and adaptability. Flood design regards not only sea level rise and storm surges but also pluvial and fluvial floods.

Currently, flood risk management is predominantly focusing on the primary defense line and reducing the likelihood of flood events. However, Iuorio & Bortolotti (2021) assert that this engineering-focused risk reduction approach may not always result in a design that aligns coherently with the landscape. This challenge can be addressed by integrating design into flood management, involving the (urban) area, and reintegrating ecological systems behind the primary defense line, a concept referred to as 'integrated (urban) flood design.' According to Hooimeijer et al. (2022), this idea "is still underdeveloped."

Moreover, it is crucial to frame the concept of flood resilience. Laidlaw & Percival (2023) have identified a shift in the flood risk management approach. Initially, flood management focused on risk, but it is now transitioning toward resilience-based approaches. However, they note that there is no coherent, overarching definition of flood resilience. The concept of resilience originates from engineering, describing the capacity of a system to return to a normal, balanced state after a disruption. Davoudi et al. (2012) proposed a conceptual framework based on three dimensions of resilience: engineering, ecological, and evolutionary. The ecological resilience perspective emphasizes a system's ability to withstand and absorb external shocks (Holling, 1996).

Nonetheless, the notion of shock absorption and returning to a previous state, central to ecological and engineering resilience, has been challenged by the emergence of the socio-ecological approach known as evolutionary resilience (Davoudi et al., 2012). This perspective acknowledges the differences between human and natural systems, contesting the idea of an unchanging, balanced state over time (Davoudi et al., 2012). Evolutionary resilience focuses on shock absorption, followed by adaptation, transformation, and evolution into a new, improved state. A comparison between flood resistance and flood resilience illustrates that while flood resistance aims to prevent water intrusion, flood resilience prepares the system to adapt to flooded conditions and ensures that the system functions as quickly as possible (Davoudi et al., 2012).

The concepts of integrated (urban) flood design and evolutionary resilience are interconnected. Liao (2012) advocates for a resilience-based management approach for river cities instead of a risk-based one. Relying solely on physical structures like levees and dams does not account for uncertainties over time. In light of extreme, intensified water scenarios brought on by climate change, this approach has become outdated. Liao's urban resilience theory regarding floods asserts that urban areas should be designed to ac-

commodate floods, with the percentage of floodable area serving as a key performance indicator. In this context, the degree of flood control is replaced by the degree of flood adaptation to reduce flood hazards.

Jha et al. (2012) categorize flood management measures into structural and non-structural types. Structural measures focus on controlling water flow, while non-structural measures target flood risk reduction through urban planning and management. Examples of non-structural measures include emergency planning, risk awareness, and flood risk avoidance via land use strategies. Effective non-structural measures require a comprehensive stakeholder engagement plan. The principles and goals of integrated urban flood design, evolutionary resilience, and landscape infrastructure design overlap and synergize with one another. While it may appear that similar principles can be applied universally, Jha et al. (2012) emphasize that each location and flood type necessitates a tailored, context-specific flood management plan.

Vulnerability & adaptive capacity

The complexity of urban environments, coupled with flood hazards, places pressure on vulnerable groups, particularly. Understanding vulnerability and adaptive capacity is crucial to assessing risk distribution in urban settings. By integrating the concepts of vulnerability and adaptive capacity, this thesis aims to propose design interventions that benefit everyone, including the most vulnerable groups.

Flood hazards driven by climate change are impacting urban environments worldwide. However, certain groups—even within the same area—face greater risks. According to Thomas et al. (2018), vulnerability often arises from social and economic factors. The extent of vulnerability at the local level is heavily influenced by the availability of essential resources for at-risk populations. These findings indicate that both local and larger governance scales significantly affect vulnerability patterns. As previously mentioned, vulnerability is directly linked to the differences in exposure to flood threats across communities and their respective adaptive capacities (Smit & Wandel, 2006). Research suggests that adaptive capacity is typically associated with the community scale, whereas the reason to increase the adaptive capacity arises from issues at the city, regional, or even global levels. This leads to complex adaptation strategies. Mortreux & Barnett (2017) emphasize that the challenges of implementing adaptation are tied to research that builds on “a one-size-fits-all assets-based theory” equating adaptation with capital. Mortreux & Barnett (2017) identified several influential drivers of adaptation actions: “risk attitudes, personal experience, trust and expectations of authorities, place attachment, and competing concerns.” The integration of urban flood design with the landscape as infrastructure concept presents an opportunity to bridge the gap created by the multi-scalar complexity between adaptive capacity and adaptation. Furthermore, the social and governance aspects of flood hazard management play a vital role in ensuring local-scale integration within larger systems.

6.2 Conceptual framework

Building on the theoretical framework and my personal and educational experiences, my perspective as an urbanist focuses on the integration of landscape and urbanism. Through my studies and internship, I have come to understand that these two disciplines are interdependent: neither can sustain itself without the other. Yet, urban development has often evolved in ways that undermine the natural systems it depends on, by building in floodplains, channeling rivers, or sealing the ground. Such practices reveal a significant disconnection between urban and ecological processes, caused by the technological engineering innovations of the past centuries. I believe, however, that cities are not separate from their landscapes but are deeply embedded within them.

The water challenges we face, caused by climate change, are not only inviting us to reflect on current urban development practices and the ways of dealing with water in cities, but also forcing us to do so. Do we stay or do we move? In reality, this consideration is substantially more complex. However, with this thesis, I aim to explore how we can sustain urban living in these areas without full retreat by investigating the role of landscape and water in the urban fabric. Presently, we face many challenges. We must build, densify, and keep pace with technology. But we also need to reconnect urban environments with the natural system to prepare for a future-proof urban environment. This is why the integration of landscape, environment, and the urban fabric is essential to reduce our dependencies on over-engineered solutions that are based on a false sense of security.

Inspired by Pierre Bélanger’s Landscape as Infrastructure (2016), I approach landscape as a form of infrastructural ecology, an active system that organizes flows of water, energy, and life. The objective of this thesis is to explore how such a perspective can balance environmental pressures with everyday urban life by integrating ecological processes into the logic of urban systems. This approach aims to strengthen the embedding of the city within its landscape and to explore how hydrology, flood risk, and landscape can generate new urban futures.

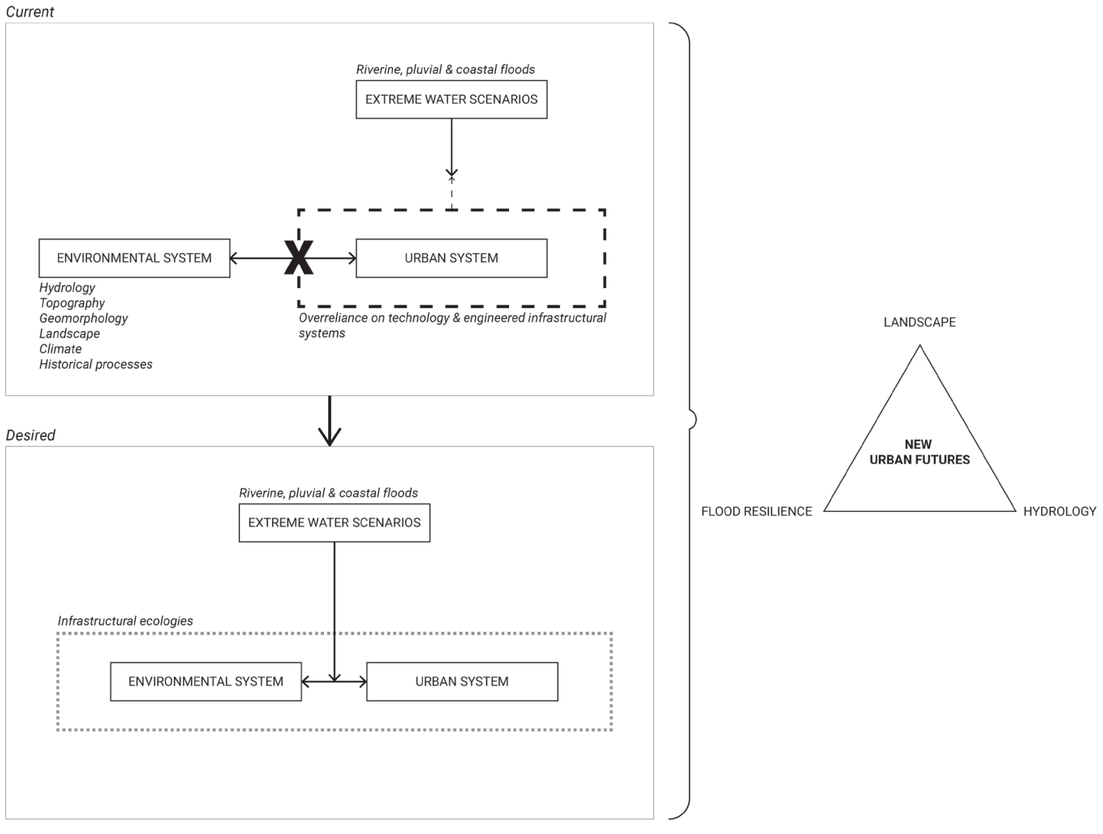


Figure 6.1 - Conceptual framework
Made by author

7. METHODOLOGY

7.1 Research questions
7.2 Research aims
7.3 Methods
7.4 Methodological framework



7.1 Research questions

After researching the condition of water and landscape infrastructures, flood risk, and socio-economic vulnerabilities in the Metropolitan Area of Boston; the main question of the thesis turns toward the role that landscape can play in shaping more adaptive urban futures. Rather than treating water, ecology, and urbanization as separate systems, the question seeks to understand how their integration can open new possibilities for living with increasing flood risks.

Main Question

How can **landscape**, understood as **infrastructure**, guide **future scenarios** of **flood adaptation** that **strengthen** the **spatial** and **ecological relationship** between **water** and **urban life** in Metropolitan **Boston**?

Sub questions

1. What is the **current condition** of Boston's **water** and **landscape infrastructures**?

2. What are the (spatial) **implications** of **extreme water scenarios**, caused by climate change, in Metropolitan Boston?

3. How do **socio-economic vulnerabilities** intersect within Boston's **flood-prone areas**?

4. What **future scenarios** can be developed to **explore** how **landscape-based infrastructures** could **mediate** between **flood dynamics** and **urban development**?

5. How can these scenarios be spatially translated into **design strategies** that **reconnect urban form** with its **underlying land-** and **waterscapes**?

7.2 Aims & Methods

What is the current condition of Boston's water and landscape infrastructures?

↓

The aim of this subquestion is to investigate the state of the systems that serve the urban area of Boston. Their state, interaction, origin, and relationships to the landscape are critically reviewed to get a better understanding of their correlation to flood risk and what other problems are present in the Metropolitan Area of Boston.

What are the (spatial) implications of extreme water scenarios, caused by climate change, in Metropolitan Boston?

↓

By understanding the complexities of the relationships of infrastructural systems out of the first sub question, these can now be connected to the spatialization of extreme water scenarios to see how they relate to each other. This spatialization is required to advance the thesis from a regional perspective, to city and local scale.

How do socio-economic vulnerabilities intersect within Boston's flood-prone areas?

↓

To dive deeper into the complex patterns of vulnerability in Boston, a socio-economic vulnerability analysis reveals the spatialization of communities who are most vulnerable to the combination of environmental degradation, the current state of water and landscape infrastructures, and floods.

What future scenarios can be developed to explore how landscape-based infrastructures could mediate between flood dynamics and urban development?

↓

After completing the first three more analytical-oriented questions, this questions aims to explore the possibilities and 'playing field' based on the research of flood resilience design interventions. Subsequently, these interventions are clustered, and combined with a scenario building exercise that gives an overview of different ways of flood management to dismantle the idea that there is only one way to deal with floods.

How can these scenarios be spatially translated into design strategies that reconnect urban form with its underlying land- and waterscapes?

The objective of the final subquestion is to translate all acquired knowledge into a flood accommodating stormwater park design, where the environmental and urban system come together. The aim is to re-establish the connection between urban form and the ecological processes that structure the site, through prioritizing water & landscape systems. By doing this, a complex interrelated layered approach reveals the relevance and influence of water and landscape to a wider range of subsystems that characterize the prioritization of the urban over the environmental system.

Methods

Critical cartography & Literature review
The first three subquestions of the thesis form the analytical foundation. The methodological character of the analytical phase is formed by the combination of critical cartography, supported by a literature review. Through the layering of hydrology, land-making history, infrastructural networks, ecological systems, and socio-economic vulnerabilities, the analytical phase reconstructs how these systems interact, overlap, and contribute to present-day vulnerabilities.

Ethnographic fieldwork
The transition from the analytical phase to the Research by Design phase was supported by the ethnographic fieldwork component, carried out for two weeks in August 2025. The main method of investigation was site-based observation, documented through photography, whilst cycling through the region. Through this method, the analytical part of the thesis could be critically evaluated and allowed for room to explore small details that could not be covered by desk research.

Besides the observational documentation, academics, practitioners, and community representatives were approached to have an open conversation about the thesis topic and to spar the continuation of the project. These discussions resulted in applicable local knowledge and contextual insight, which were used in the next phase.

Research by Design
The design-oriented sub questions will be investigated through the Research by Design methodology. The wicked problems that are faced in this project do not have a clear timeframe. Research by Design brings creativity to the process, which could uncover unknown potentials or conflicts. The goal of Research by Design is to acquire knowledge and gain a better understanding of the problem or design objective (by creating conceptual strategies). The purpose is not only to produce a final design outcome, but to generate new knowledge and understanding through spatial experimentation (Roggema, 2016; Godin & Zahedi, 2014).

This phase starts with a scenario building exercise. The collection and clustering of existing flood design interventions forms the analytical base of the scenarios, that are used to explore the playing field of options, and to examine how flood management and responsibility intertwine, resulting in potential futures of flood adaptation. This method stresses the importance that there is not merely one way of dealing with floods, but by the integration of different kind of design interventions and how these can elevate each other.

The last part of the Research by Design methodology is the synthesis of all acquired knowledge and to construct an experimental design where interventions are combined to create a symbiosis between the urban and environmental system through the lens of flood adaptation. The section is used as the main tool to reveal how the current and future condition of landscape and water systems, integrated with the new urban development and flood adaptation interventions.

The methodological framework gives an overview of the aims and methods in the context of the entire process of the project. The analytical phase, represented by the three top boxes, are supported by the literature review which is synthesized in the theoretical framework. The Research by Design phase is supported by the conceptual framework and the fieldwork.

The research and design processes in this thesis were not linear. In both phases, iterative loops characterize the abductive process of refining the problematization as well as the spatialization of the Research by Design phase by looping back to the scenario building phase.

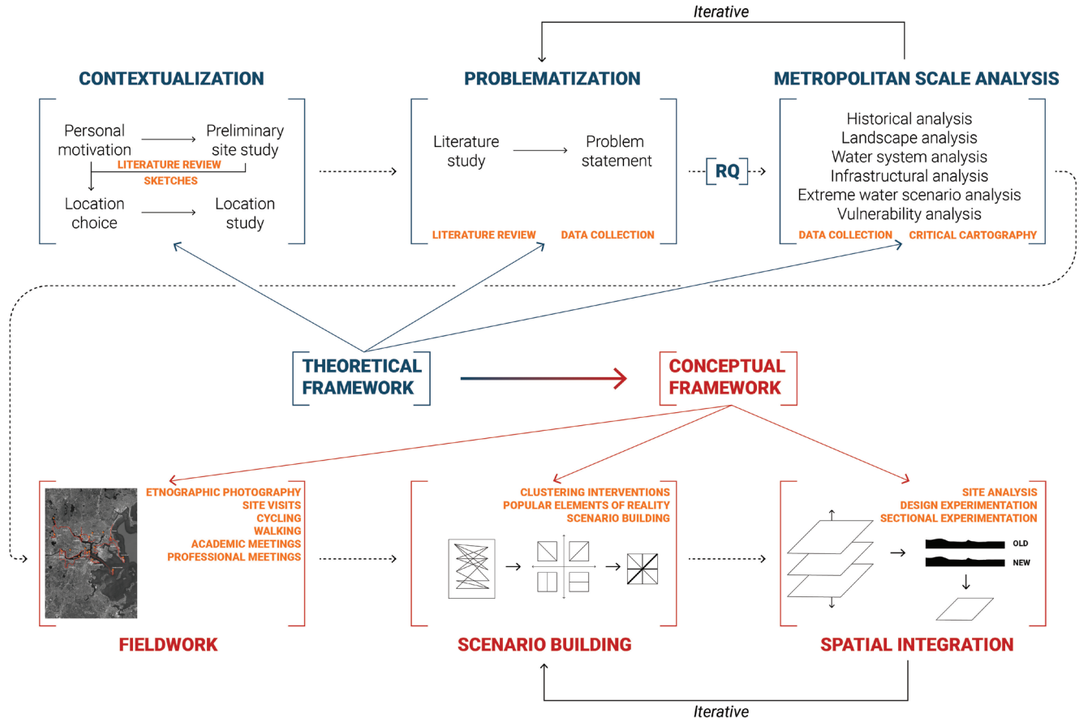


Figure 7.1 - Methodological framework
Made by author

8. FIELDWORK

8.1 Site visits
8.2 Metropolitan ecologies
8.3 Downtown & Seaport
8.4 East Boston
8.5 Chelsea
8.6 Biking along the Charles River
8.7 Biking along the Mystic River
8.8 Visiting Deer Island - MWRA water treatment plant
8.9 Observing coastal developments and infra structure
8.10 Visiting the Boston Harbor Islands - Spectacle Island
8.11 Fieldwork reflection



8.1 Site visits

After completing the analytical foundation of the thesis, I traveled to Boston to interact with the landscapes, infrastructural systems, and people in the Metropolitan Area of Boston through etnographic fieldwork. The main fieldwork objective was to gain more knowledge about the water & landscape systems of the area through observation in a more direct and intuitive way. Besides that, by being on-site, it allowed me to critically evaluate my own 'desk-based' research I have done in the first half of the project.

Throughout the fieldwork, I combined daily on-site exploration, mainly by bicycle, foot, and public transit, with open discussions held with experts from Harvard, GreenRoots, the City of Boston, MWRA, and Buy-In. These conversations allowed me to gain a deeper understanding of the complex relationships between flood risk, landscape, infrastructural capacity, environmental degradation, socio-economic vulnerability, and historic hydrology.

The outcome of this work is a fieldwork journal: a curated, compositional, and observational archive of photographs that tell 'micro-stories'. Every micro-story highlights a different part of the sub-systems that interact in the Metropolitan Area. Together, they show a different side of past and current conditions of infrastructural systems, urban ecologies, water & landscape systems in comparison with maps alone. This journal is a reflection of my time in Boston and helped me to understand the interaction of different urban, landscape, and water systems on a deeper level.



8.2 Metropolitan Ecologies



History


Belle Isle Marsh Reservation
August 18, 2025
Ecology







Ecology



Alewife stormwater wetland - August 19, 2025



42.396310409672665, -71.14782510464356









Urban development pressure

8.3 Downtown & Seaport

Urban

August 13
2025







8.4 East Boston



Urban development pressure







42.368475575631976,
-71.0386073093308



42.37413351446351,
-71.0328299344142





42.36783935868297,
-71.03914975689445



Waterfront gentrification







Flood management approach

August 18
2025



Cause & effect

8.5 Chelsea



Industry

August 20
2025



Historic hydrology



8.6 Biking along the Charles River









Infrastructure

August 11
2025



Charles River Dam (old) (Shattuck, 1908)

42.36776257374647, -71.07099525529372



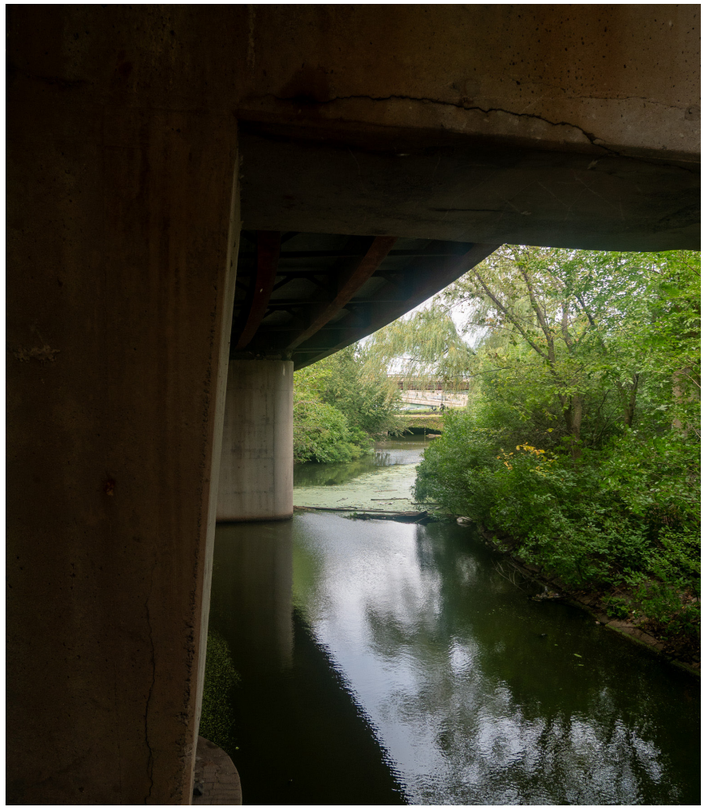
Currently: Museum of Science (2025)



Pollution







Historic hydrology - August 21, 2025



8.7 Biking along the Mystic River











Water

August 19
2025

Protection





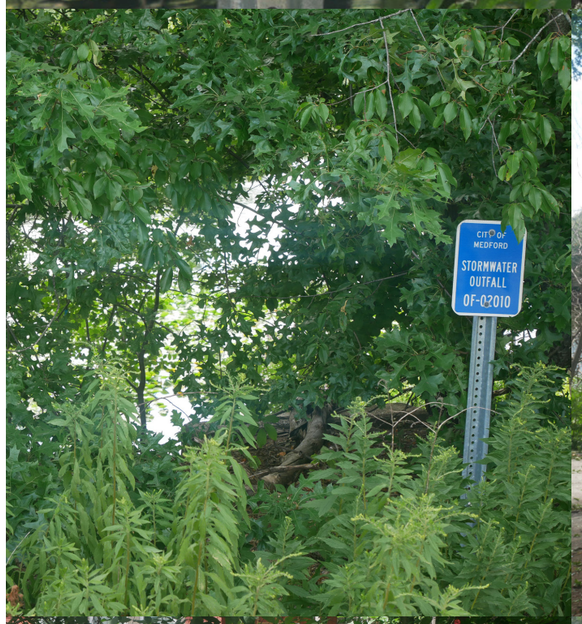




Floodplains


CITY OF
MEDFORD
STORMWATER
OUTFALL
OF-00700


CITY OF
MEDFORD
STORMWATER
OUTFALL
OF-00700


CITY OF
MEDFORD
STORMWATER
OUTFALL
OF-02010


CAUTION
Massachusetts Water Resources Authority | City of Cambridge | City of Somerville
AVOID WATER
ACTIVITIES
DURING OR AFTER
RAINFALL
COMBINED SEWER
OUTFALL NEARBY
MWRA:
Cambridge:
Somerville:


CITY OF
MEDFORD
STORMWATER
OUTFALL
OF-00900


CITY OF
MEDFORD


CITY OF
MEDFORD
STORMWATER
OUTFALL
OF-03000


CITY OF
MEDFORD
STORMWATER
OUTFALL
OF-00900


CITY OF
MEDFORD
STORMWATER
OUTFALL
OF-01300




Pollution


WARNING
WET WEATHER
SEWERAGE DISCHARGE
MWRA OUTFALL
205A

8.8 Visiting Deer Island - MWRA water treatment plant











Infrastructure







(failing) infrastructure



Core habitats



8.9 Observing coastal developments and infrastructure

Protection

August 18 2025

Urban development












NOTICE
NO
ALCOHOL
N BEACH
PLEASE ADHERE
TO WINTHROP'S
CARRY IN/CARRY OUT
POLICY AND KINDLY
REMOVE ALL TRASH
AND PERSONAL ITEMS
UPON DEPARTURE








DUMP NO
WASTE
U
S
A
DRAINS TO
WATERWAYS
MADE IN USA





8.10 Visiting the Boston Harbor Islands - Spectacle Island







Protection



Ecology



Water

8.11 Fieldwork reflection

This map overlays the 1770 historic hydrology of the Boston metropolitan area onto the present-day landscape. During the fieldwork, I discovered this map and brought it with my while I was cycling through the area. Keeping the water- and landscape of 1770 in the back of my mind, it came to me how the natural systems of the past inform the future and how the historic hydrology has been neglected. This reinforces the need to reconnect the environmental system into urban life, which is the foundation of the next part of the thesis.

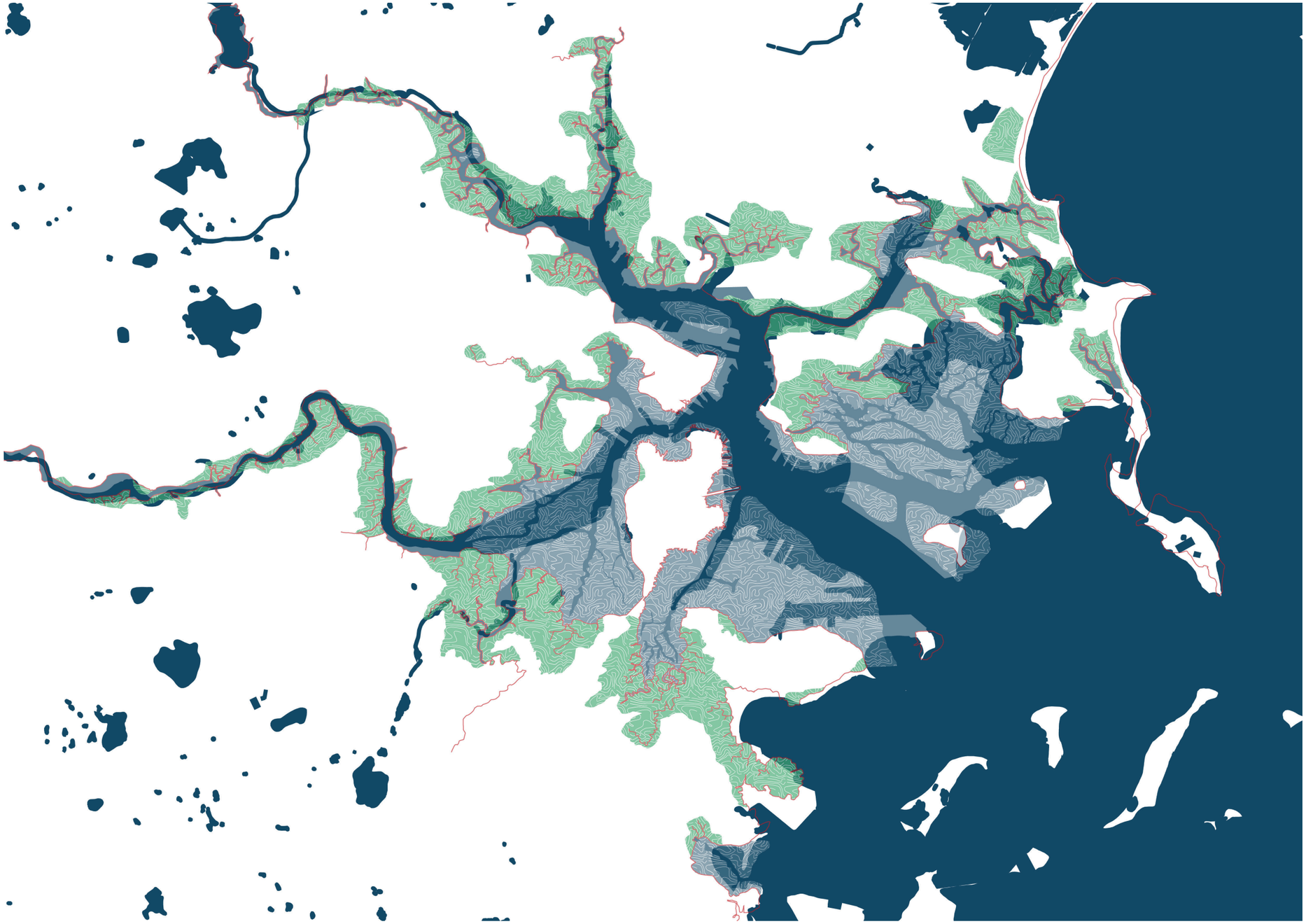


Figure 8.1 - Historic Hydrology
Made by author
Data: Hills (1770-1779)



Future?



9. BUILDING SCENARIOS

9.1 Clustering design interventions
9.2 Popular elements of reality
9.3 Scenarios
9.4 Synthesis



9.1 Clustering design interventions

The scenario building chapter serves as a transition between the analytical subquestions towards the design process. The objective of this chapter is to understand and cluster existing flood design interventions, to explore the 'playing field' of flood management. The analyzed interventions serve as input for the constructed scenarios in the next sub chapter.

Interventions were acquired through literature studies and design precedent analyses (Civil Protection Knowledge Network, 2024) (Environmental Protection Agency, 2014) (Meng et al., 2022) (National Research Council Canada, 2024) (Opperman, 2014) (The Nature Conservancy, 2021) (Harvard Graduate School of Design, 2024) (World Bank, 2021). The acquired flood design interventions all contribute to flood resilience in different ways. Therefore, different clusters (1-8) are composed:

1. Infiltration - Let water enter the ground to recharge and reduce runoff.

2. Absorption - Let vegetation and soil act as sponges.

3. Storage / Retention - Temporarily hold water in place until it can infiltrate, evaporate, or drain.

4. Delay - Slow down movement of water to reduce peak discharge and downstream flooding.

5. Conveyance - Guide water through and around the urban fabric and/or landscape.

6. Protection - Obstruct floodwater from entering critical areas.

7. Accommodation - Adapt land use and design so floods can occur without significant damage (co-exist)

8. Restoration: Restore ecosystems to provide natural flood resilience

Interventions are also classified based on flood type and intervention scale. Besides the clusters above, flood design interventions can also be grouped according to the nature of the intervention and how they work together or are part of other interventions. Therefore, the interventions were also placed in groups (A-G). On the following pages, the interventions per group are spatialized through diagrammatic sections.

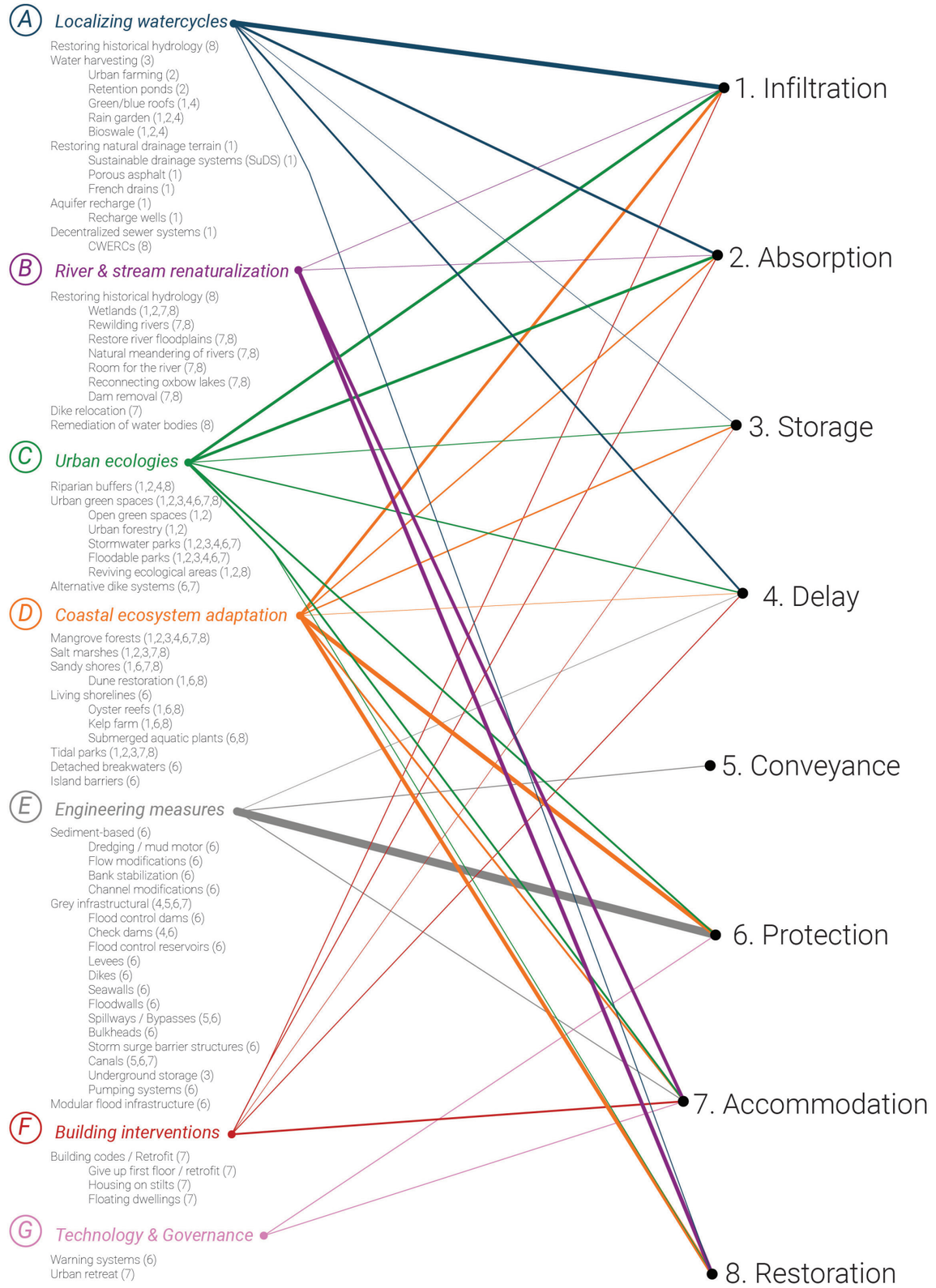
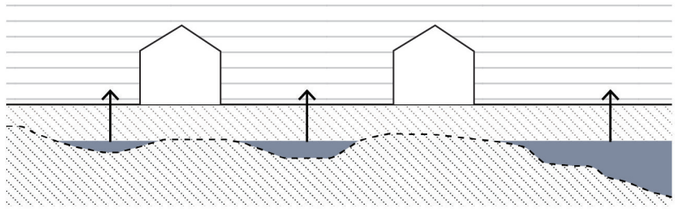


Figure 9.1 - Clustering diagram
Made by author

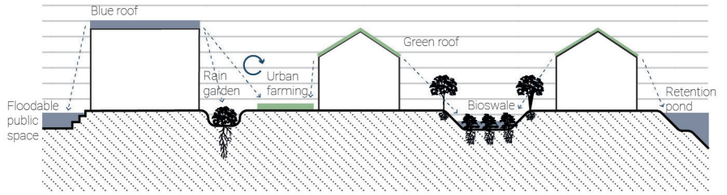
A - Localizing water cycles

This group brings together flood design interventions that aim to localize the urban water cycle, predominantly focusing on infiltration, absorption, storage, delay, and reusing water close to where it falls. Instead of relying on centralized drainage and conveyance systems, these interventions reduce runoff volumes and peak discharge by reconnecting urban surfaces to soil, subsurface, and ecological processes. By restoring elements of historical hydrology and natural drainage patterns, water is redirected from engineered networks back into local landscapes, where it can infiltrate, be stored, or be reused.

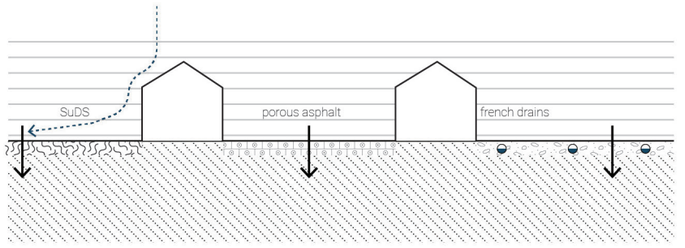
The diagrammatic sections illustrate how localized water cycles operate across scales, from plot and street level to neighborhood systems. Measures such as water harvesting, aquifer recharge, and decentralized sewer systems demonstrate how stormwater, grey water, and wastewater can be integrated into localized water management.



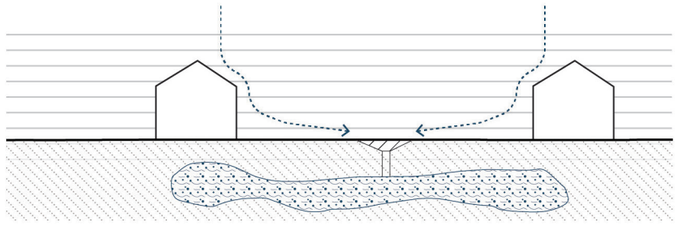
Restoring historical hydrology
Flood type: all
Intervention scale: neighborhood
Potential: high



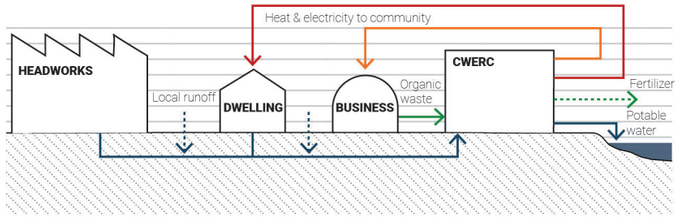
Water harvesting
Flood type: pluvial
Intervention scale: local
Potential: high



Restoring natural drainage terrain
Flood type: pluvial
Intervention scale: local
Potential: medium



Aquifer recharge
Flood type: pluvial
Intervention scale: local/neighborhood
Potential: low



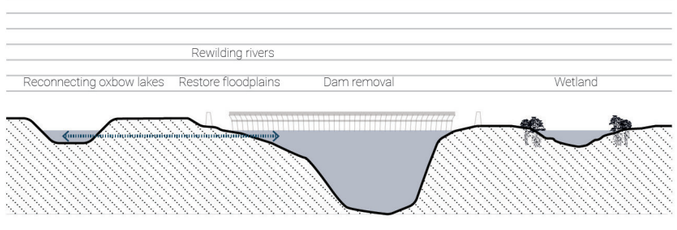
Decentralized sewer systems
Flood type: pluvial (all indirectly)
Intervention scale: system - local - city
Potential: high

Figure 9.2 - Group A
Made by author

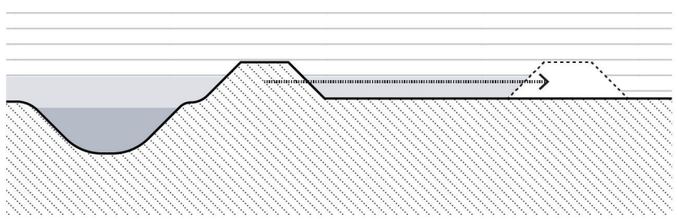
B - River & stream re-naturalization

By restoring historical hydrology and reconnecting floodplains, these interventions increase the capacity of river systems to absorb, store, and convey water when flood pressures increase. The river is re framed as a dynamic landscape that accommodates fluctuating water levels and temporary flooding.

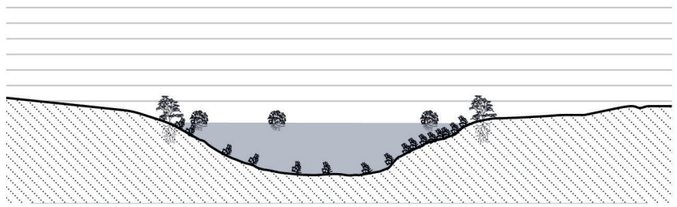
The diagrammatic sections illustrate how re-naturalization operates across local to regional scales, combining measures such as dike relocation and water body remediation. As a bundled strategy, these interventions reduce flood risk by expanding space for water, decreasing flows, and improving ecological performance. Besides flood protection, river and stream re-naturalization contributes to water quality improvement and habitat restoration.



Restoring historical hydrology
Flood type: all
Intervention scale: local - regional
Potential: high



Dike relocation
Flood type: coastal & riverine
Intervention scale: local - city
Potential: high



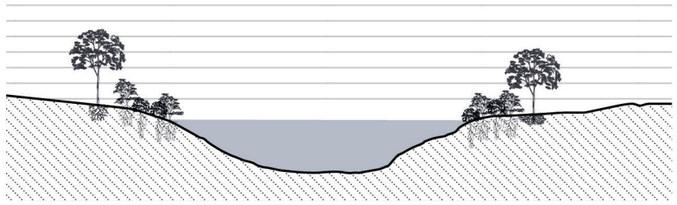
Remediation of water bodies
Flood type: pluvial (stormwater)
Intervention scale: local
Potential: low

Figure 9.3 - Group B
Made by author

C - Urban ecologies

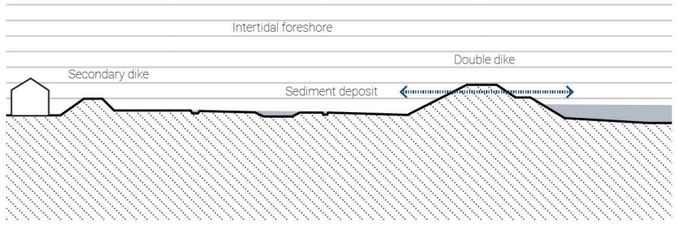
The urban ecologies group focuses on the conservation and integration of landscape and ecology within the urban fabric. Mainly through infiltration, absorption, delay, and accommodation, urban ecologies contribute to flood resilience while maintaining ecological performance.

The diagrammatic sections show how riparian buffers, floodable urban green spaces, and alternative dike systems work together across scales. As a bundled strategy, these interventions address pluvial, riverine, and coastal flooding by combining absorption, storage, and protection with public space and ecological continuity. In doing so, urban ecologies transform flood infrastructure into multifunctional landscapes that enhance biodiversity, improve micro-climate, and strengthen the spatial relationship between water systems and urban life.



Riparian buffers
Flood type: pluvial & riverine
Intervention scale: neighborhood
Potential: medium

(floodable) urban green spaces
Flood type: all
Intervention scale: neighborhood - city
Potential: high



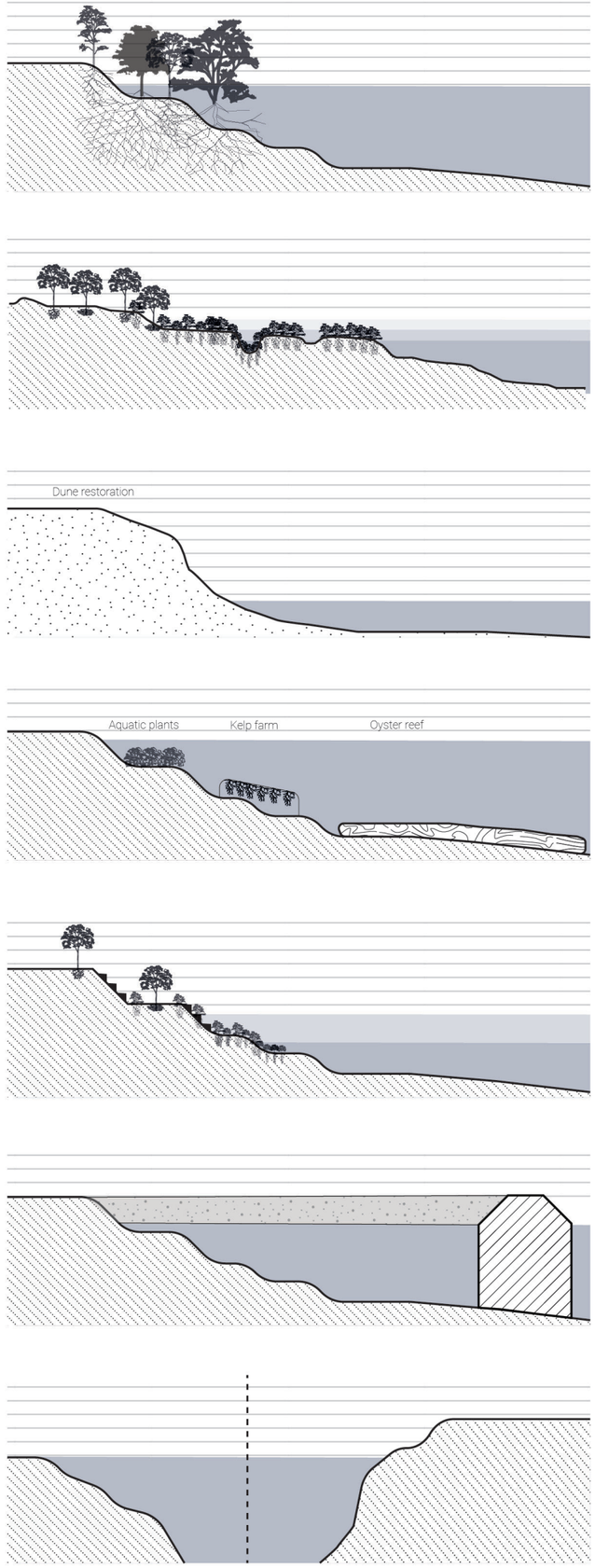
Alternative dike systems
Flood type: riverine & coastal
Intervention scale: local - city
Potential: high

Figure 9.4 - Group C
Made by author

D - Coastal ecosystem adaptation

This group brings together flood design interventions that adapt to coastal flooding by working with coastal ecosystems, rather than relying solely on hard-engineered infrastructures. Through the accommodation of natural shoreline dynamics, these interventions mitigate flood risk through the use of breakwaters, sediment capture, and shoreline transformations.

The diagrammatic sections illustrate how coastal ecosystem adaptation operates across neighborhood to regional scales, combining interventions such as salt marshes, sandy shores, living shorelines, and tidal parks with elements like detached breakwaters and island barriers. These interventions primarily address coastal flooding while also contributing to riverine and pluvial flood resilience where systems overlap.



Mangrove forests
Flood type: coastal
Intervention scale: local - regional
Potential: Not applicable

Salt marshes
Flood type: All
Intervention scale: neighborhood - city
Potential: high

Sandy shores
Flood type: coastal
Intervention scale: neighborhood - region
Potential: high

Living shoreline
Flood type: coastal
Intervention scale: local
Potential: low - medium

Tidal parks
Flood type: coastal & riverine
Intervention scale: neighborhood
Potential: medium

Detached breakwaters
Flood type: coastal
Intervention scale: local
Potential: low

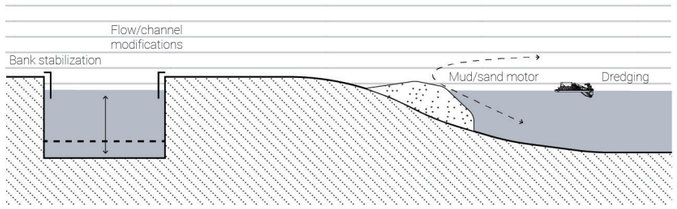
Island barriers
Flood type: coastal
Intervention scale: neighborhood - city
Potential: low

Figure 9.5 - Group D
Made by author

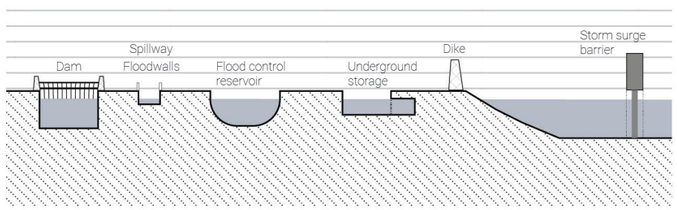
E - Engineering measures

This group bundles flood design interventions that are heavily engineered and fall mainly under the protection cluster. These measures control water flows and are considered the foundation of flood management strategies, especially in the context of the expanding urban fabric in Metropolitan Boston over the years.

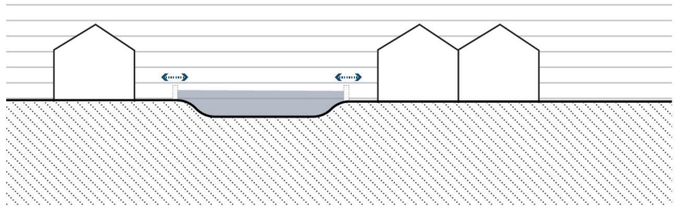
The diagrammatic sections illustrate sediment-based interventions, grey-infrastructural systems, and modular flood protection operating across local to regional scales. As a bundled strategy, these interventions address multiple flood types by stabilizing channels, increasing storage capacity, or providing temporary barriers. However, these types of interventions usually play a role in environmental degradation and, over time, increase risk through their limited lifespan.



Sediment-based
Flood type: riverine & coastal
Intervention scale: local - regional
Potential: low



Grey-infrastructural
Flood type: all
Intervention scale: local - regional
Potential: medium



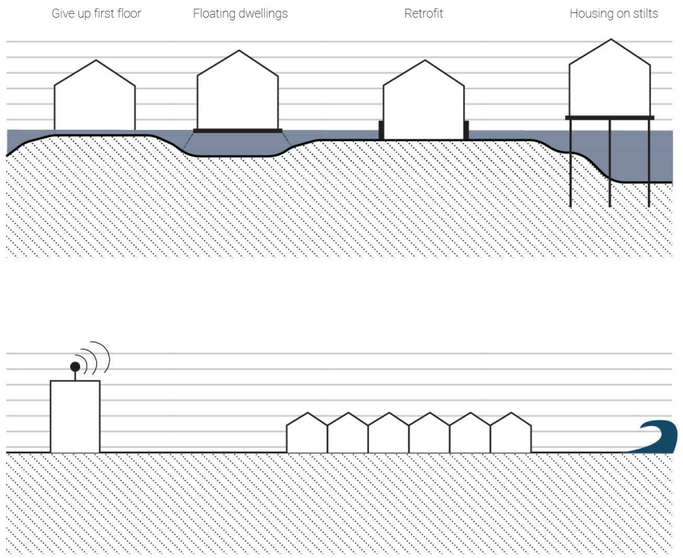
Modular flood protection
Flood type: all
Intervention scale: local
Potential: low

Figure 9.6 - Group E
Made by author

F & G - Building interventions / Technology & Governance

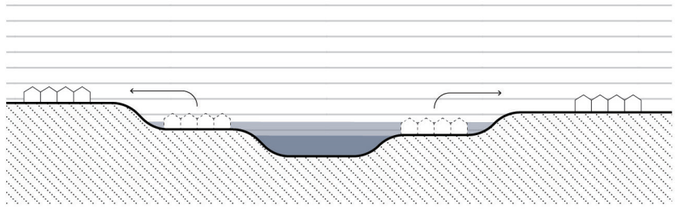
The final two groups bring together flood design interventions at the level of buildings, technology, and governance. These interventions do not directly manage water flows, but instead reduce vulnerability by adapting the built environment, improving preparedness, and reshaping urban planning. As such, they function as enabling conditions that support or condition the effectiveness of spatial flood interventions.

The diagrammatic sections illustrate building adaptations such as retrofitting, flood-adaptive housing typologies, and strategic retreat, alongside system-level measures including warning systems and relocation strategies. Within the playing field of flood management, building interventions and governance mechanisms are therefore positioned as complementary layers that shape how, where, and for whom flood adaptation becomes possible.



Retrofitting buildings
Flood type: all
Intervention scale: local
Potential: medium

Warning systems
Flood type: all
Intervention scale: system
Potential: low



Urban retreat
Flood type: all
Intervention scale: local - regional
Potential: medium

Figure 9.7 - Group F & G
Made by author

9.2 Popular elements of reality

Rather than constructing scenarios based on projected trends, this thesis uses a set of popular elements of reality: observed developments that are already shaping flood management practices today. These elements do not function as forecasts, but as empirical tendencies that influence how flood risk is perceived, governed, and spatially addressed.

The matrix organizes these popular elements into four domains: environmental dynamics, infrastructural conditions, socio-economic processes, and institutional frameworks. Together, they reveal increasing pressures on existing flood management systems, such as sea-level rise and compound flooding, aging infrastructure, growing socio-economic vulnerability, and shifting governance responsibilities.

In combination with the clustering of flood design interventions, the popular elements of reality provide the analytical foundation for constructing the scenario axes in the following sub chapter. Together, they frame the range of potential flood adaptation pathways explored through the scenarios.

ENVIRONMENTAL	INFRASTRUCTURAL	SOCIO-ECONOMIC	INSTITUTIONAL
ENV1 Sea level rise	**INFRA1** Infrastructural systems are aging	**SE1** Unequal risk exposure increases	**INSTI1** The importance of resilience & adaptation in planning is increasing
ENV2 Storm surges increase	**INFRA2** The potential of adaptive and decentralized infrastructure is increasing	**SE2** Segregation/economic vulnerability increases	**INSTI2** Community-driven adaptation is increasing
ENV3 Extreme precipitation increases	**INFRA3** Dam removals are increasing in the USA	**SE3** Trust in federal flood programs is decreasing	**INSTI3** Federal support in post-disaster recovery is decreasing
ENV4 Land subsidence increases	**INFRA4** Technological determinism is increasing	**SE4** Economic & urban expansion is prioritized over environmental importance	**INSTI4** Retreat of flood insurance providers is increasing
ENV5 Compound floods increase	**INFRA5** The transition to green/hybrid infrastructural systems		**INSTI5** Flood insurance is becoming more expensive

Figure 9.8 - Popular elements of reality
Made by author

9.3 Scenarios

Building on the popular elements of reality and the clustering of flood design interventions, the scenario matrix is constructed to explore the 'playing field' of flood management. The scenarios are organized along two axes: the degree of type of responsibility (centralized – decentralized) and the type of flood management focus (infrastructural – environmental). The combination of the type of responsibility and the flood management focus results in four scenarios that should be seen as analytical lenses that showcase the differences and outcomes relative to each other, starting from similar challenges.

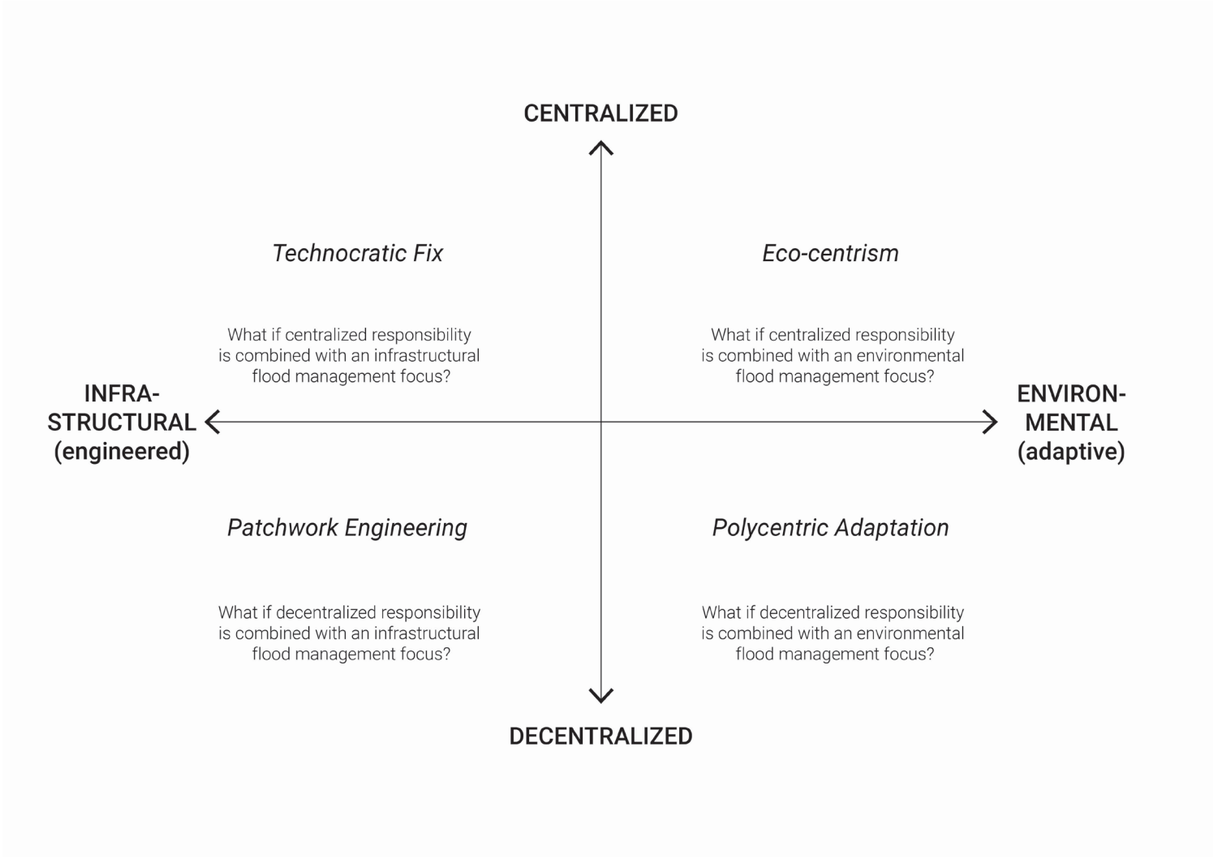


Figure 9.9 - Scenario Matrix
Made by author

Technocratic Fix

The centralized and engineered approach is characterized by a top-down flood management approach, where technological, engineered infrastructural systems are the primary drivers in flood control. This approach aligns with the Command and Control Engineering perspective, which relates to the desire to efficiently control and predict ecosystems to manage natural resources through engineering (Holling & Meffe, 1996). This 'Technocratic Fix', as Hajer & Dassen (2014) call it, represents the prioritization of technical solutions over social or ecological considerations.

While this approach offers reliability and clarity of responsibility, it may also lead to rigid systems, environmental degradation, and reduced adaptive capacity. The central question it raises is: What if centralized responsibility is combined with an infrastructural flood management focus?

The diagram shows the extreme spatialization of the scenario, stressing the importance of protection and control through a top-down, engineered approach. Protective and controlling engineered flood interventions form continuous barriers that obstruct water from entering the urban fabric. When riverine or pluvial floods occur, spillway infrastructure conveys water out of the urban environment. In case of compound flooding, the large, centralized flood control reservoir can be utilized to release flood pressure, and the storm surge barriers that span between the Boston Harbor Islands are closed to protect the city. Along the coast, sediment-based engineering reinforces the shoreline as a pre-designed defense zone.

The spatialization shows a top-down governance structure that prioritizes control and protection over flexibility, and it does not acknowledge the potential of landscape-based approaches where the environment is placed at the center.



Figure 9.10 - Technocratic Fix
Made by author

Patchwork Engineering

This scenario focuses on decentralized engineered approaches with localized technical interventions responding to site-specific flood risk. Zevenbergen et al. (2008) state that urban flood management needs to adopt a multi-scalar approach. They argue that, in order to improve urban flood management and resilience, local-scale experimentation and bottom-up initiatives should be explored.

However, OECD (2019) highlights the fragmentation of flood management in institutional settings. While this fragmentation can encourage adaptive, context-sensitive responses, it also raises concerns about uneven protection and long-term system coherence. The scenario raises the question: What if decentralized responsibility is combined with an engineered flood management focus?

The diagram shows potential interventions on the city scale. This scenario consists of many small scale interventions, such as sustainable drainage systems, that are not shown on this scale. Local aquifers are spatialized to show areas with water harvesting and recharge well potential that can be utilized. On top of that, local sediment-based interventions can benefit a larger shoreline area, through experimentation with dredging and the sand/mud motor concept.

The main intervention that this scenario investigates is the decentralization of infrastructural systems. Through Community Water and Energy Centers (CWERC), the current, centralized sewer network can be distributed to localize water cycles, generate new energy sources, and deal with waste flows in one building. On top of that, the pressure on the existing network is lowered. In case of an emergency, communities are self-reliant and not dependent on the big sewer plant on Deer Island.

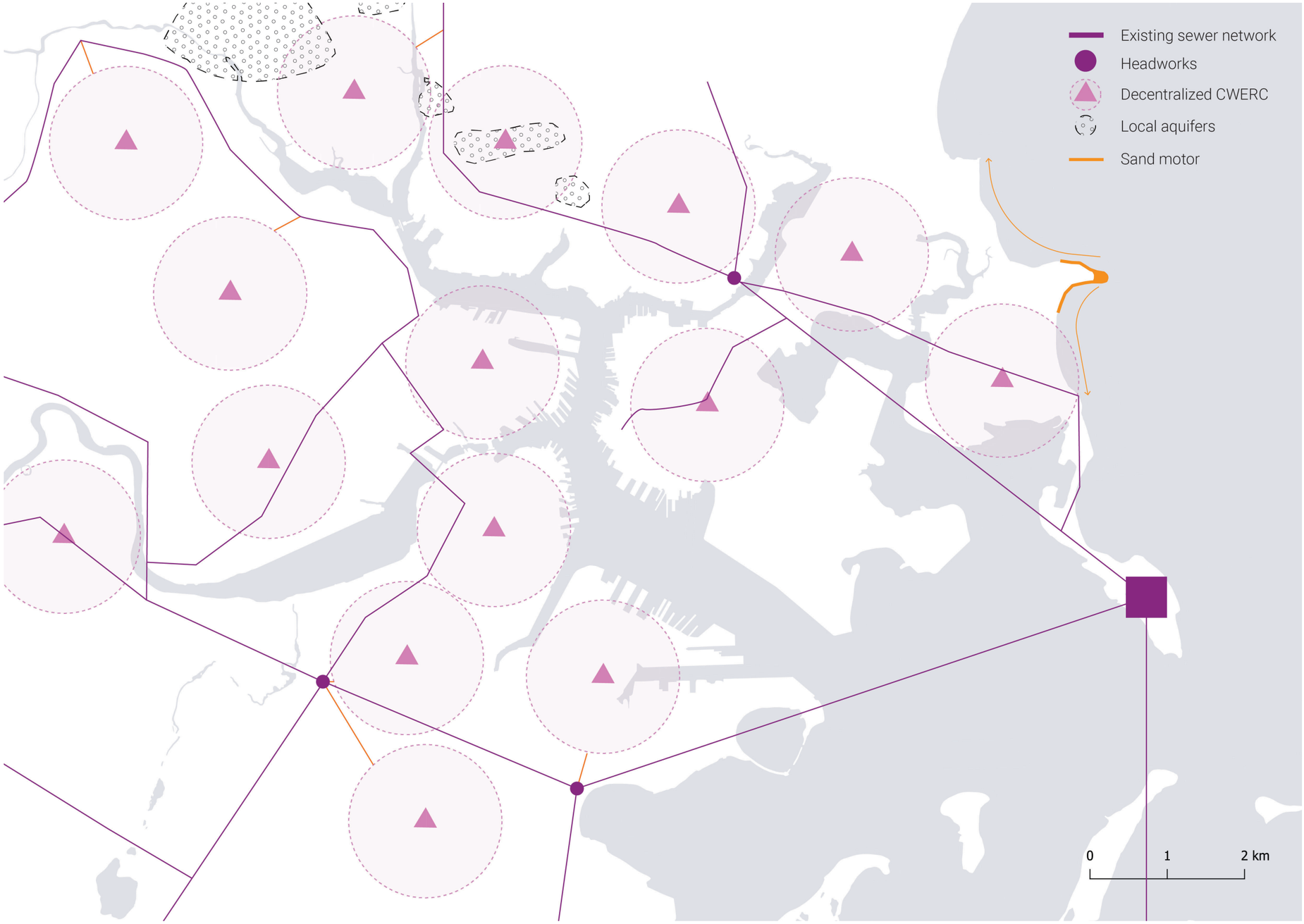


Figure 9.11 - Patchwork Engineering
Made by author

Eco-centrism

In this scenario, the flood management approach remains centralized but integrates ecological principles. It aligns with the concept of Ecological Modernization (Hajer, 1995) in which he advocates for environmental awareness through “technical and procedural innovation” and policy planning. On top of that, the concept of administrative rationalism (Dryzek, 2005) frames the state as an environmental manager, based on the levels of expertise within the state. This centralized approach can be combined with the environmental concept of Aldo Leopold. In 1949, he wrote multiple essays that can be seen as an important pillar in environmental ethics. Through highly descriptive observations of the natural world, he develops the concept of land ethic, where humans are part of a bigger ecological system, which challenges the Anthropocene. His work corresponds with the concepts of ecocentrism, where the natural world has moral values and rights, independent of humans (Lambert, 2024).

While this approach offers system-wide coherence and policy integration, it may risk limited local integration and displacement issues. The scenario raises the question: What if centralized responsibility is combined with an environmental flood management focus?

The diagram expresses a spatial logic that reorganizes the metropolitan region around ecological performance and historic hydrology. Historic floodplains, marshes, and aquifers are mapped as foundational elements of the metropolitan landscape, forming a continuous blue-green connection that runs through the urban system. The arrows represent new corridors to existing landscape cores, from freshwater ecosystems towards the tidal estuarine waterscape. The diagram shows flows that connect river, groundwater, and coastal ecologies into one spatial system.

Spatial interventions concentrate where landscape performance is highest. Belle Isle Marsh and Belle Isle Inlet link north-south salt-marsh expansion westward along Chelsea Creek. The industrial waterfront is not erased but repositioned within this ecological network as an adaptive edge with tidal parks and riparian buffers. The spatial logic scales outward by treating ecological nodes as connectors that integrate protection, remediation, mobility, and habitat continuity across the region.

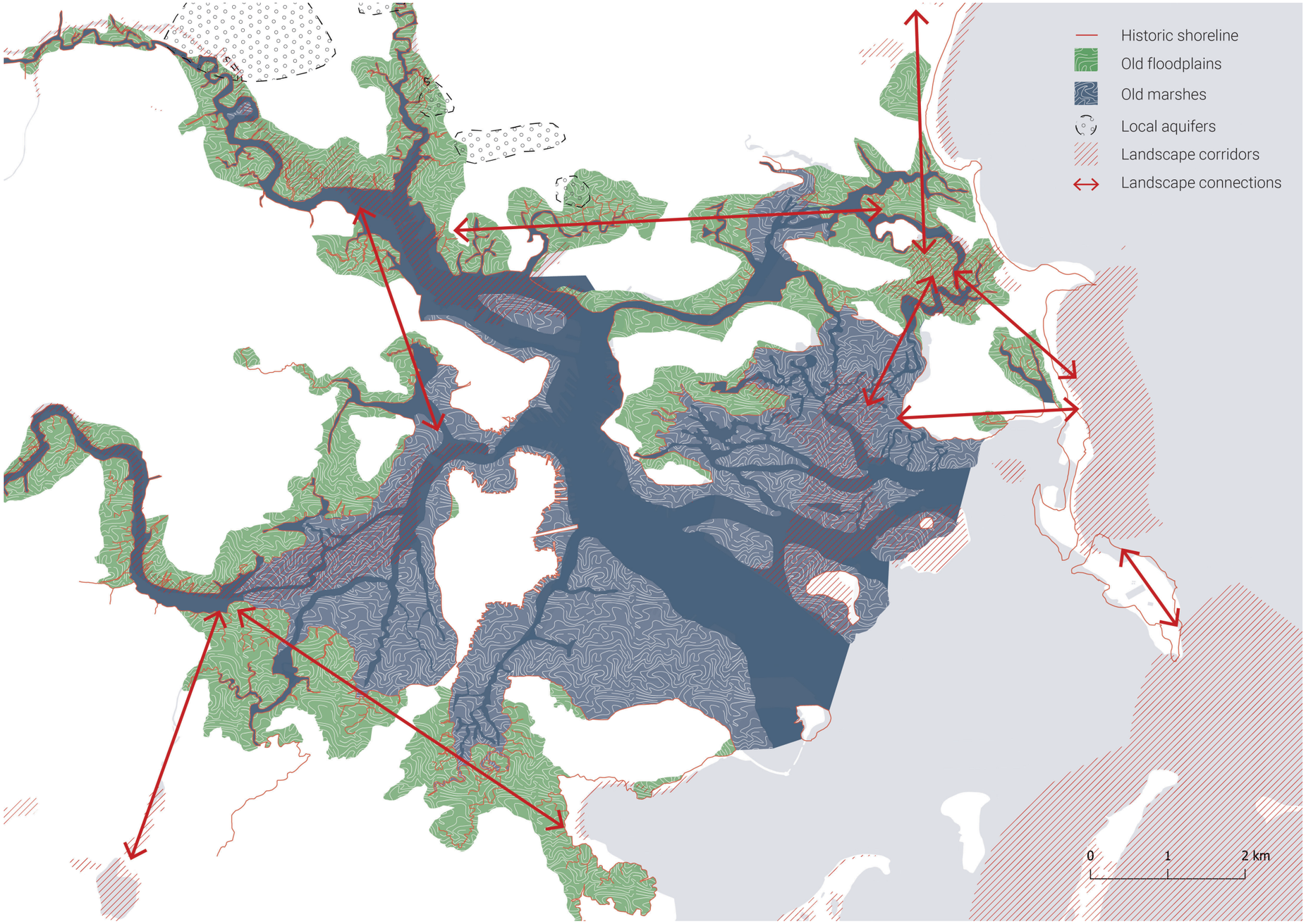


Figure 9.12 - Eco-centrism
Made by author

Poly-centric Adaptation

The decentralized and environmental crossover is characterized by distributed governance and a nature-based flood management approach. This scenario corresponds with the concept of adaptive ecosystem-based governance (Folke et al., 2005), where (local) knowledge is spread via the actors across scales. Olstrom's (2010) concept of poly-centric systems was originally developed in the context of global climate change. However, floods are complex products of climate change and thus require an integrated multi-scalar approach. Poly-centric distribution of flood management and implementation allows for context-specific experimentation on the local scale, promoting innovation.

However, this scenario is not without challenges. Without strong coordination, poly-centric systems may suffer from uneven implementation. The effectiveness of decentralized environmental management depends on local capacity and resources, affecting system-wide coherence. This raises the following question: What if decentralized responsibility is combined with an environmental flood management focus?

The diagram depicts a poly-centric organization of urban cores that will densify in the future, as flood-prone areas are designated to accommodate flooding, which can result in urban retreat. These areas will be repurposed as accommodation zones, new salt-tolerant agricultural areas, and innovation labs focused on aquaculture, such as oyster reefs and seaweed farms.

Urban cores are marked by double dike rings that enhance flood resilience, sedimentation processes, and multifunctional land use, serving as a buffer landscape. Within the cores, a network of stormwater nodes and corridors delivers pluvial flood resilience through environmentally friendly public spaces, such as stormwater and tidal parks.

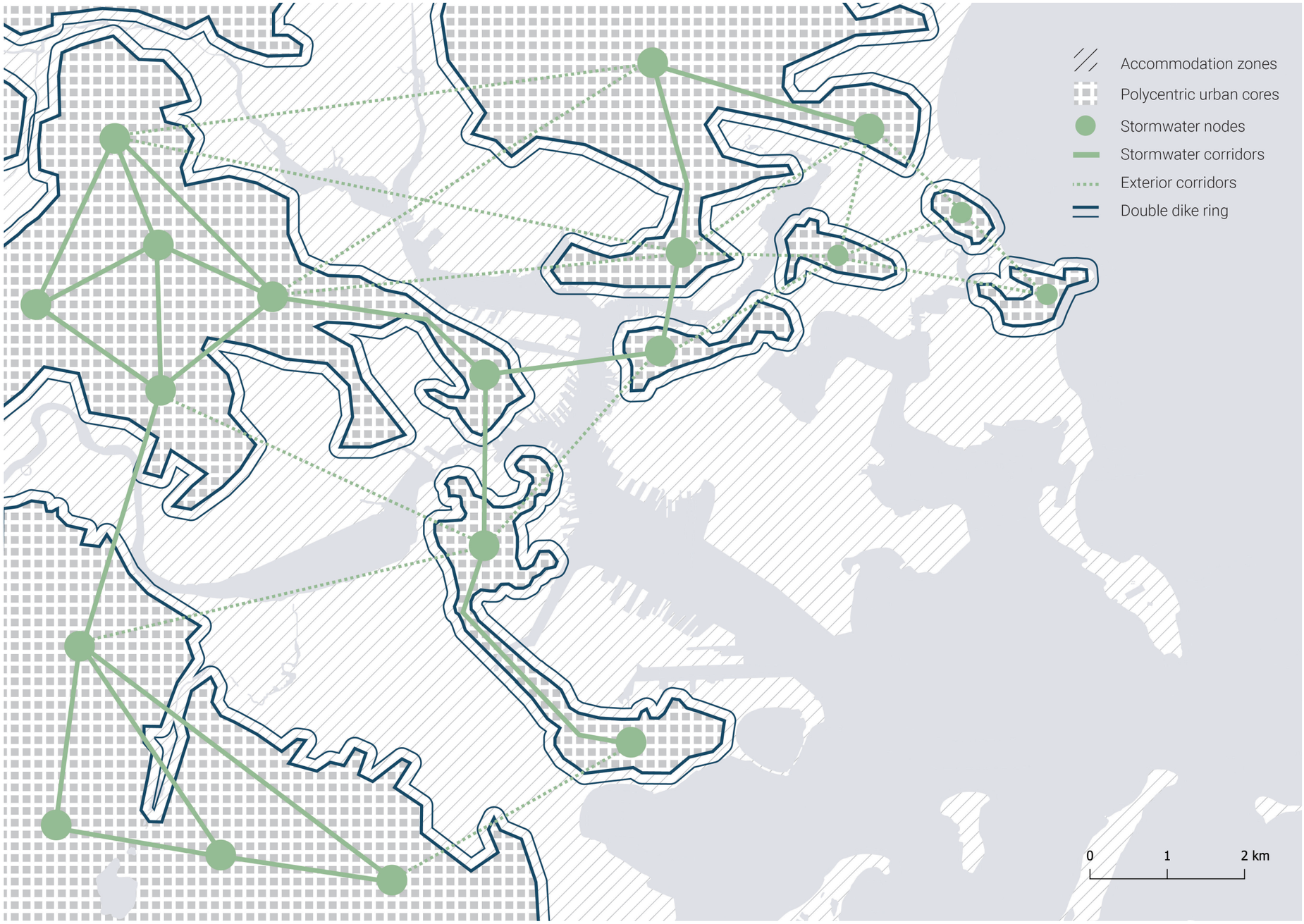


Figure 9.13 - Poly-centric Adaptation
Made by author

9.4 Synthesis

Within this thesis, the scenarios are used as a strategic tool to test and compare flood adaptation pathways across scales. They provide a structured way to reflect on the consequences of centralization versus decentralization, and of engineered versus adaptive approaches, while creating a clear bridge between analysis and design. Rather than selecting a single preferred scenario, the framework supports critical reflection on trade-offs, synergies, and tensions that inform the integrative design strategy developed in the following chapters.

The cluster analysis of existing flood design interventions, combined with popular elements of reality and scenarios, reveals that there is no single approach to flood management. Instead, an open-ended and multi-directional approach is required to advance flood management by combining the best elements from the different scenarios.

The scenario comparison highlights a consistent set of outcomes that shape the thesis' design direction. The project moves away from full dependency on hard, grey engineered interventions, stressing that future flood resilience cannot be achieved through a 'technocratic fix'. Instead, it promotes a distributed network of smaller, engineered structures combined with the decentralization of infrastructural systems to reduce systemic dependency. Ecological integration becomes a primary spatial driver, positioning the environment and the urban as interdependent rather than isolated systems. Finally, the scenarios collectively advocate for local adaptation: accommodating and storing water in places where it naturally wants to go, and only resisting it where it is necessary. This layered approach forms the basis for a scalable, integrative strategy that treats water as a spatial driver in metropolitan adaptation rather than an external threat to be engineered away.

10. DESIGN PROCESS

10.1 Local scale analysis
10.2 Analytical synthesis
10.3 Design framework
10.4 Systemic sectional exploration
10.5 Cross-scalar synthesis



10.1 Local scale analysis

In the design process, the scale transitions from city & regional to local scale. Starting with a local scale analysis that will determine a design site where the integration of the scenarios is used as a foundation to bring the urban and environmental system together in a stormwater park.

The local scale is situated on the border of East Boston, Revere, Chelsea Creek, and the last protected salt marsh of the city: Belle Isle Marsh. The marsh is adjacent to an urban-industrial landscape where future urban development is planned. Combined with the presence of the Irving Oil terminal, this area exemplifies the complexities of the current condition of infrastructural systems, flood risk, environmental degradation, and land-making history. This makes the site a suitable location to research the possibilities of the integration of the urban and environmental system through the lens of floods by design.



Figure 10.1 - Local scale
Data: Google Satellite

Historical analysis

Before the land-making practices took place, the site functioned as a hydrological connector between the present Chelsea Creek and Belle Isle Marsh. The area north of the Orients Heights suburb consisted of flood-plains and marshland that characterized the regions land composition. The land-making operations that serve as the basis of the current urban fabric obstruct original hydrological connectivity of the site, which is related to current flood prone land.

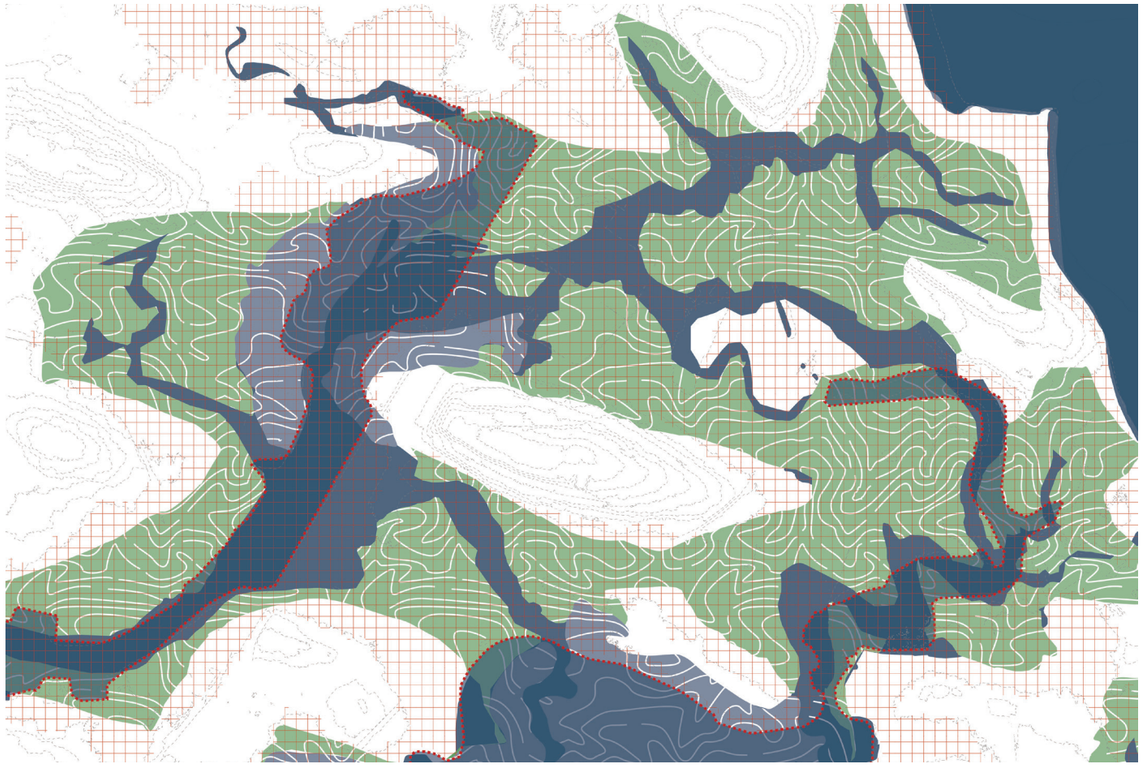


Figure 10.2 - Historic hydrology overlaid with flood zones - Made by author (Hills, 1770-1779)

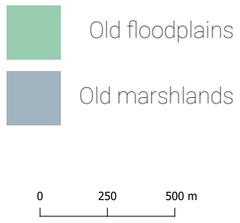




Figure 10.3 - Historic streams (United Coast Survey, 1857)

After the site was artificially filled, it was primarily used as an industrial area, and the Suffolk Downs Racing Track was built. Even though the horse racing venue has a significant historical value, it is confirmed that it will be demolished and a large urban development will take its place. The ‘strategic’ position of the racetrack regarding disconnection in hydrology should be taken into account here.



Figure 10.4 - Historic picture of the race track and Belle Isle Marsh (Aero Scenic Airviews Co., 1939)

Another important element of the site is the presence of Irving Oil. The industrial company fulfills a significant role in the exchange, storage, and distribution of oil and jet (fuel) to Logan Airport. The industrial site used to be bigger, as can be seen on the historical aerial imagery. The remains of the oil tanks and auxiliary structures around the site are still visible in the landscape and it can be assumed that soil and water contamination can be closely linked to these kind of industrial land uses in the site.



Figure 10.5 - Aerial imagery of the design site (MassGIS, 1995)

Water and landscape analysis
The comparison of the historic hydrology and original land- and waterscape with the spatialization of the flood probability model shows the correlation between historic hydrology and flood zones. Almost the entire site between significant hills falls within the flood zone, except for the current location of the Suffolk Downs Racetrack building. This could be the basis for a new urban core.

The subsoil characteristics of the site represent the metropolitan land-making history. Most of the site's area is constructed on artificial fill to accommodate urban expansion. These types of soil are composed of different materials and fill that cannot be seen as one, continuous soil profile, but more as a fragmented soil structure. The soil map reveals a patchwork of artificially made land through the categorization of Map Unit Key IDs (MUKEY) (USDA, 2022).

The categorization of the soil according to the Map Unit Keys reveals a fragmented subsoil consisting of artificial, disturbed, and polluted soils. The analysis can be simplified through grouping the MUKEY IDs into four main groups:

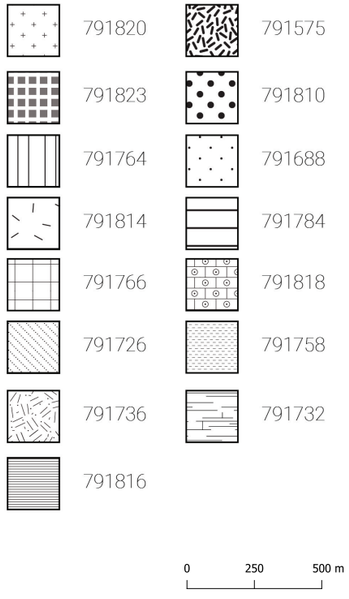
Urban land and miscellaneous fill (791820, 791823, 791766, 791761, 791814)

Dredged or reworked coastal sediments (791726, 791736, 791753, 791732)

Mixed or disturbed fill (791575, 791810, 791688, 791818, 791816, 791784)

The water-guesting properties of these soils are relatively poor because of the mixed composition of the fill. This limits infiltration, (ground)water movement, and causes surface runoff and groundwater accumulation during intense rainfall events. In addition, landfill soils are highly contaminated through industrial land use and urban pollution.

In conclusion, the soil distribution confirms that the site's subsoil is not a neutral foundation but a constructed landscape shaped by land-making history. The dominance of artificial fill explains both the site's limited infiltration capacity and its environmental vulnerability. In the current situation, the subsurface of the site can be seen as a limiting factor instead of contributing as a resilient system. This calls for the application and integration of remediation strategies and a landscape-as-infrastructure approach to water storage, delay, and accommodation.



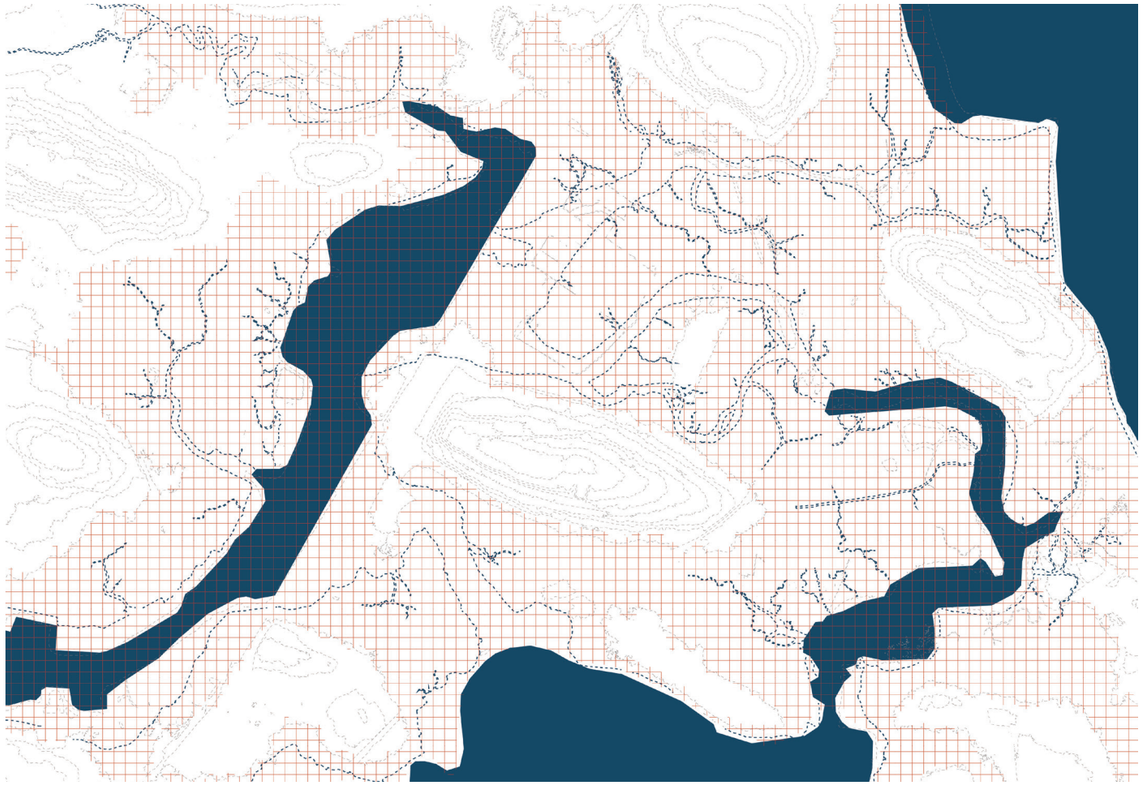


Figure 10.6 - Historic high water overlaid with flood risk - Made by author



Figure 10.7 - Soil map - Made by author - Data: (USDA, 2022)

The local site hosts different types of wetlands that used to be connected in the pre-land making historical condition. The spatialization of the flood probability model suggests that these wetland could be reconnected to form a drainage basin that would alleviate flood pressure in the area.

To understand how water moves through the site, a hydrological terrain analysis (r.watershed) has been done in QGIS. A LiDar Digital Elevation Model is used as input to generate a drainage direction model, based on elevation. This intermediate output is used to model water flows from higher to lower grounds. This analysis has resulted in a flow accumulation model, which indicates the amount of cells that contribute to water flow. The edited flow accumulation model in figure 10.8 shows how water flows down through the site, picturing flow paths (channels & depressions).

Another output that can be seen in the appendix is the topographic index (TPI). Here, the slope of upstream cells is also taken into account to model where water stays, resulting in pools and detention zones.

This data is essential in understanding flood patterns and to identify flood accumulation patterns and to reveal (hidden) depressions in the landscape. These informative clues can be used as guidance in the spatialization of flood design interventions in the next stage of the design process.



Figure 10.8 - Wetlands - Made by author



Figure 10.9 - Flow accumulation - Made by author

Urban analysis
The figure ground analysis reveals the potential of the underused (old) industrial site. This is confirmed by the land use map, showing a significant area of vacant land. However, given the historic industrial land use, water and soil pollution in this area is plausible.

The flood risk layer in the map shows how almost the entire site is prone to flooding. The Orient Heights neighborhood distinguishes itself because of its elevation, similar to the paddock building of the Suffolk Downs Racetrack.

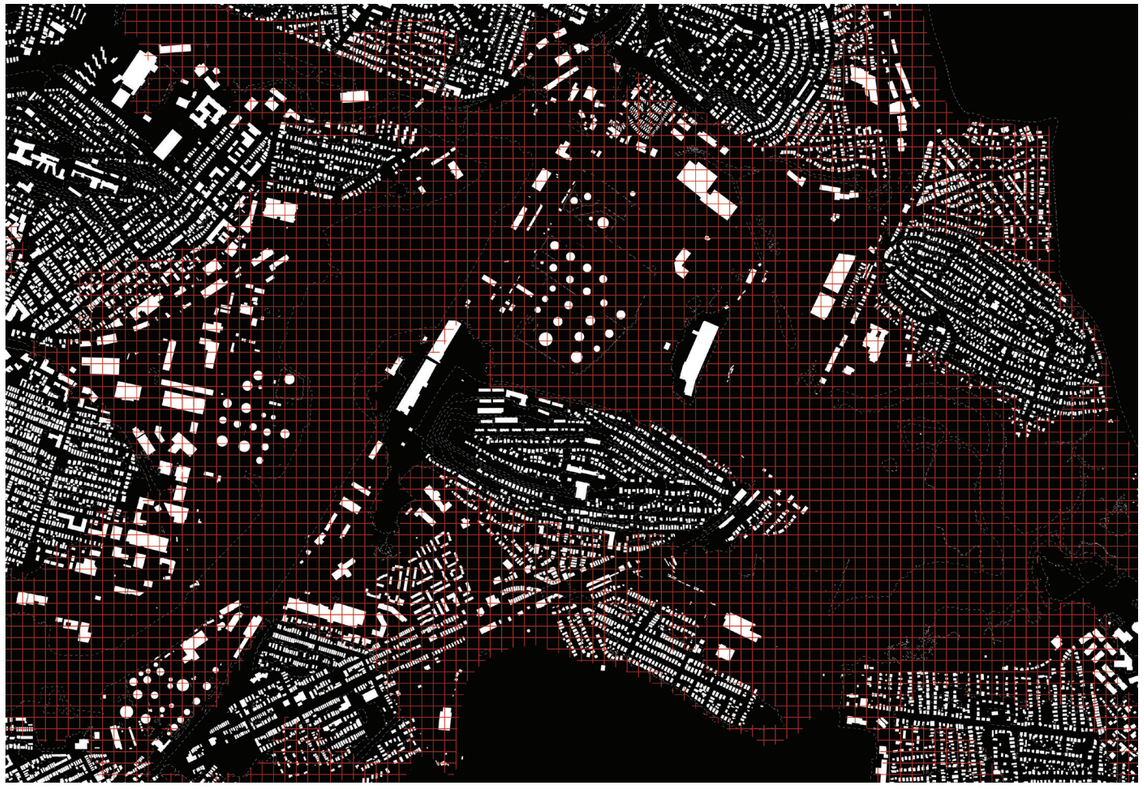


Figure 10.10 - Figure ground analysis overlaid with flood risk - Made by author



Figure 10.11 - Land use - Made by author (MassGIS, n.d.)



Figure 10.12 - Figure-ground, overlaid with flood risk and historic high water - Made by author

The spatial analysis shows the correlation between the historic hydrological patterns and contemporary flood probability and vulnerabilities. At the same time, the mobility network disperses through the historical hydrological patterns, potentially obstructing a hydrological reconnection. These hard barriers obstruct water and mobility flows in the East-West direction.

The organization of the mobility infrastructure indicates the car dominance in Boston, with the only exception being the MBTA Blue subway line in the east of the site. The hierarchy in the street network confirms the presence of vacant (industrial) lots in the middle of the site.

The absence of a fine-grained street structure coincides with large vacant and underutilized plots, confirming the dominance of infrastructural and industrial logics over urban continuity. Together, these spatial conditions illustrate how historic water systems, flood zones, and mobility infrastructure are intertwined, producing a landscape in which water is constrained rather than accommodated. This understanding informs the identification of spatial relationships that guide the subsequent analytical and design explorations.

The section lines in figure 10.14 are drawn to investigate the relationship between topography and land use, to form the last analytical layer before the analysis synthesis. These can be found on the next page.

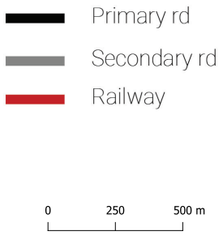




Figure 10.13 - Mobility network - Made by author

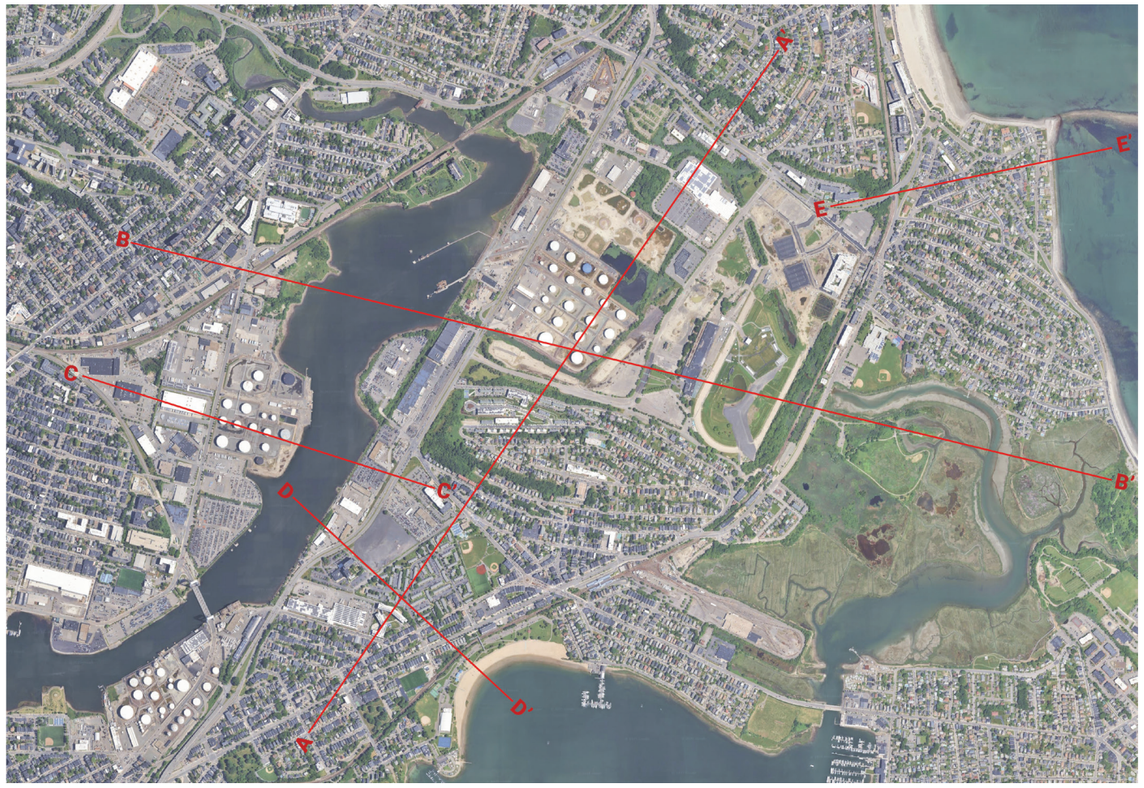


Figure 10.14 - Sections

Land use sections

AA’
- Orient Heights: residential area out of flood risk
- Both residential elevations drain stormwater into industrial and vacant lot area

BB’
- The topography suggests that the artificial filled landscape is disconnected from the Belle Isle Salt Marsh
- If the area would be restored to a salt marsh, extensive excavation processes would have to be planned to reconnect the landscape with the tides.

CC’
- Industrial waterfront of Chelsea Creek and the transportation barrier that separates the industrial land from the commercial land

DD’
- Artificial fill disconnects land from waterscape

EE’
- Shows coastal suburban and the transportation artery that connects and also separates the suburban area from the surrounding urban fabric

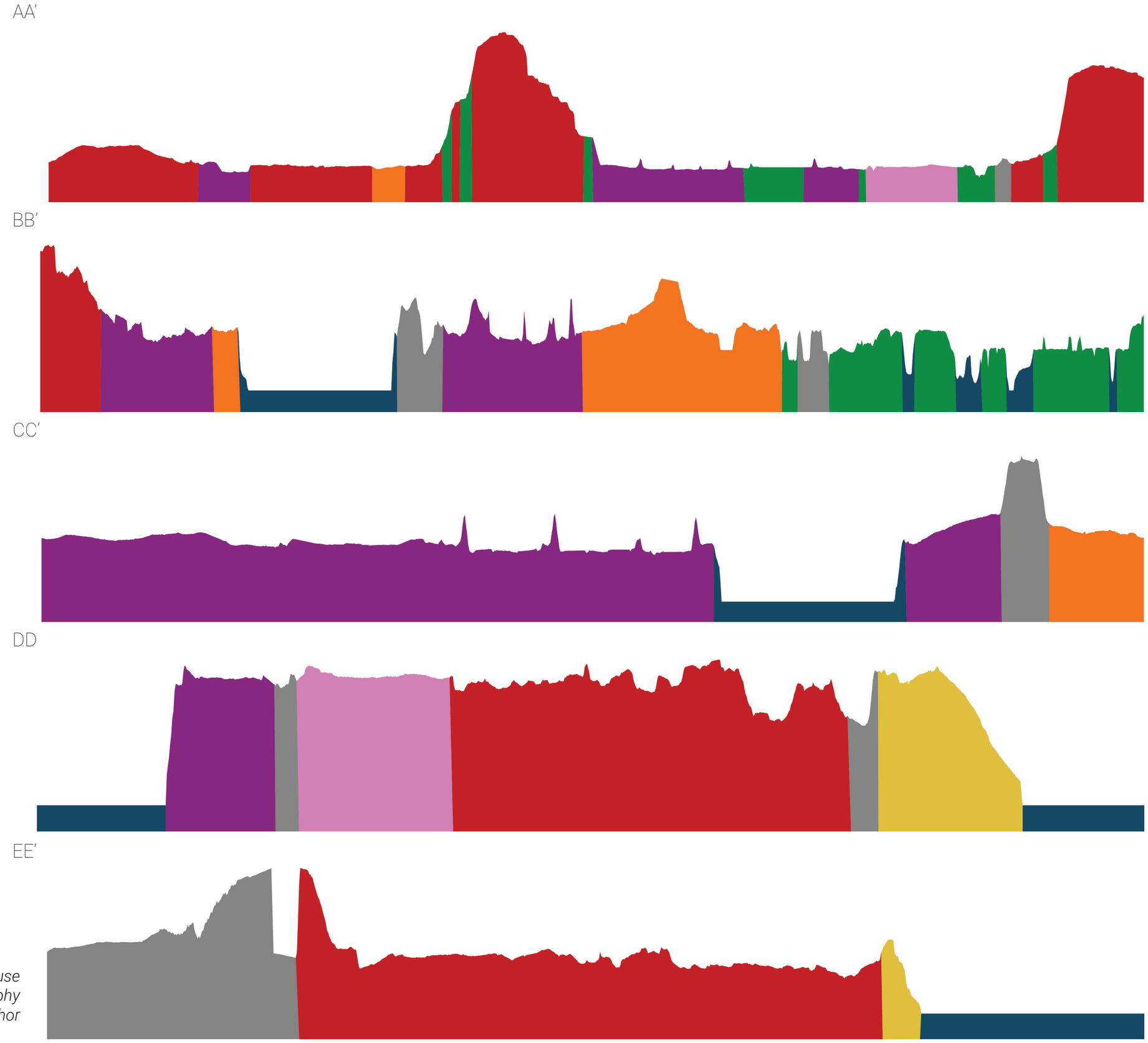


Figure 10.15 - Land use sections showing topography
Made by author

10.2 Analytical synthesis

The analytical synthesis consist of six steps that provide the foundation for the design framework in the next sub chapter.

Step 1
The overall objective of the thesis is to connect the urban and environmental systems. In the site, Chelsea Creek, the wetlands in between, and the Belle Isle Marsh are the main landscape elements that represent the environmental system, surrounded by urban areas. The goal, however is not to create a large salt marsh by excavating the artificial fill, but to create flood accommodation within the current condition of both systems.

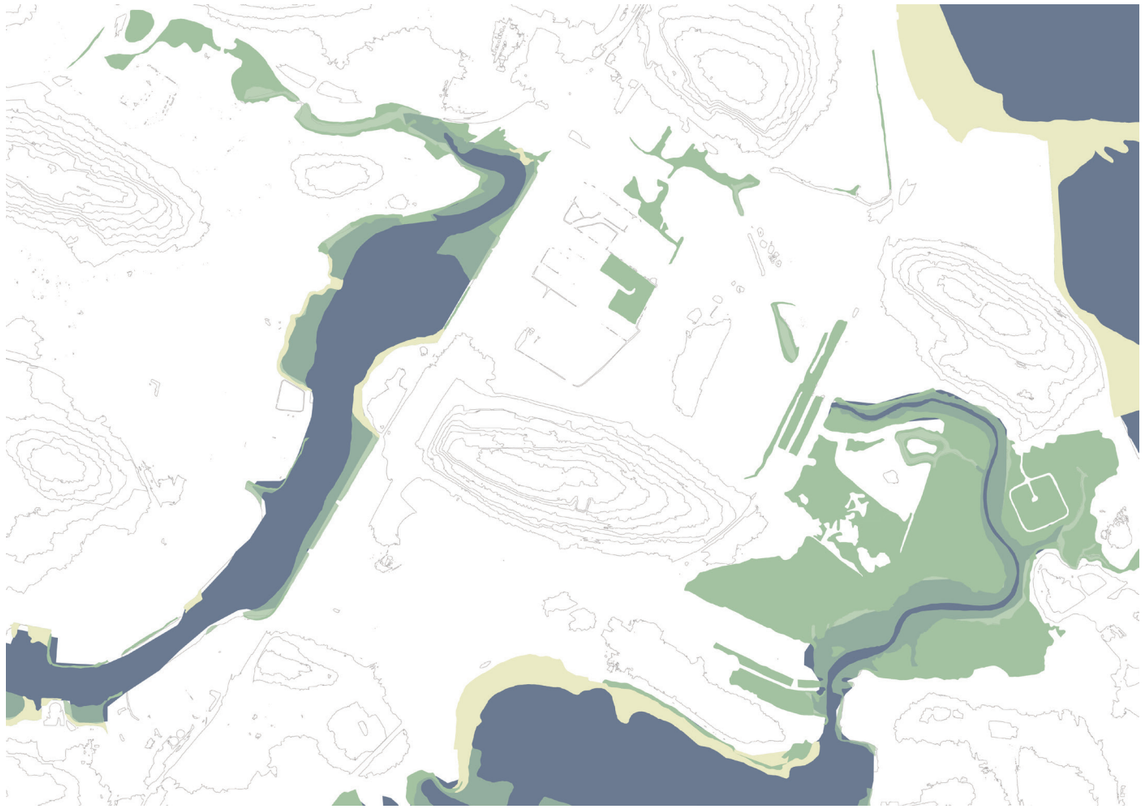


Figure 10.16 - Step 1

Step 2
The design process investigates how the reactivation of historic hydrological systems can form the basis for a new relationship between water and the urban fabric through the lens of floods, by reconnecting existing wetland systems in the site. This reconnection refers to the historical hydrological system and reveals how it still affects flood risk through the correlation of the landscape's natural drainage logic.



Figure 10.17 - Step 2

Step 3
Simultaneously, the urban analysis revealed a North-South disconnection in the urban fabric, just like an East-West disconnection of the landscape. The site should accommodate both systems by integration a reconnection in both directions in the form of a flood accommodating buffer landscape.

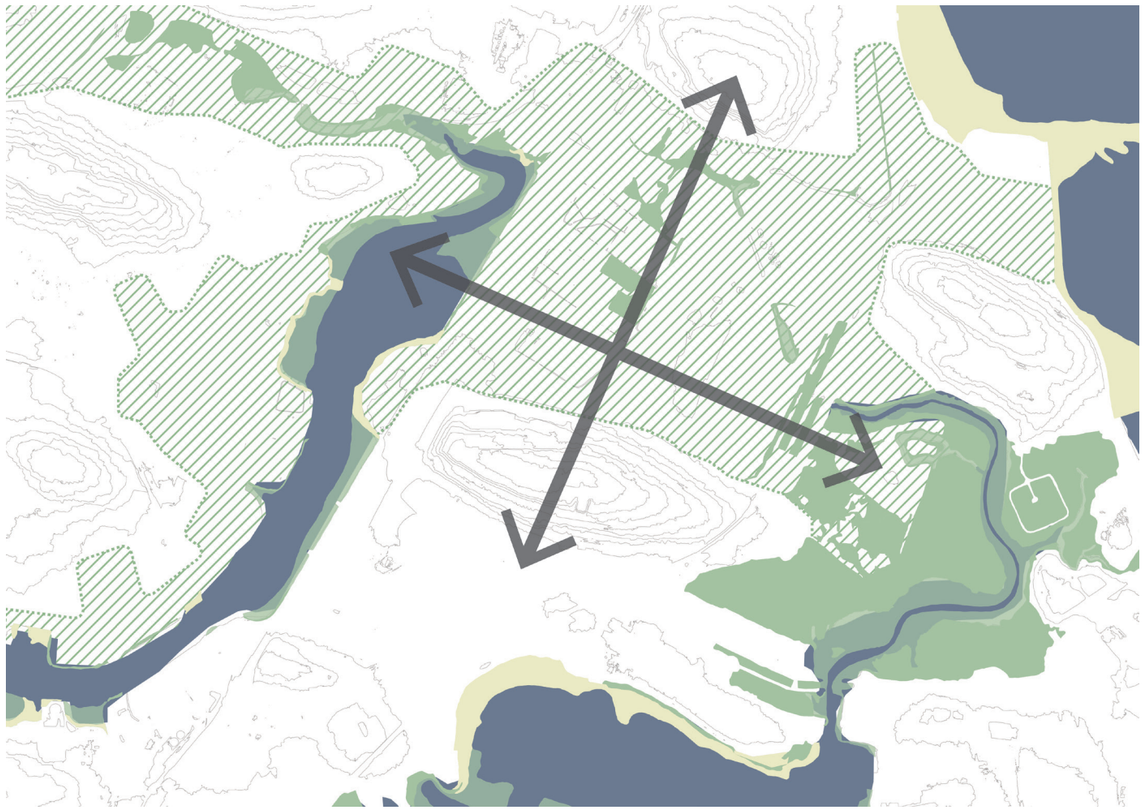


Figure 10.18 - Step 3

Step 4
The hydrological flow patterns out of the landscape analysis can be used to establish the reconnection between wetlands to form drainage pathways that store, convey, and buffer stormwater. The edges of these flow patterns form transitional landscapes where hydrological flows intertwine within the urban fabric.



Figure 10.19 - Step 4

Step 5
By overlaying the urban fabric, the flood vulnerable buildings become visible. To alleviate flood pressures, the concept of the research by design experiment is a flood accommodating stormwater park that is integrated with the urban system.



Figure 10.20 - Step 5

Step 6
The last step shows the zoom-in of the design process, where the relationship between flood accommodating landscapes, the urban fabric, people, ecology, vegetation, and animals is investigated and bundled into an ecological stormwater park.



Figure 10.21 - Step 6

10.3 Design framework

The design of the ecological stormwater park is based on a layered approach. The layers are not hierarchically organized but interrelated systems that continuously influence and transform one another. This type of relationship between all the layers forms a dynamic network, instead of a vertical sequence.

In order to bring the environmental and urban system together, two layers per system work together in the framework. The Soil & Substratum layer informs the design regarding the historic land-making processes: the water infiltration capacity and pollution levels in the soil. The Water & Landscape Dynamics layer is related to the low infiltration potential of the soil. Based on this, the main hydrological objectives of the ecological stormwater park are to buffer, exchange and (temporarily) store stormwater to contribute to flood resilience. These objectives are directly related to the flow accumulation pathways, and the topographic index of the landscape.

The Performance & Use layer ties directly to the land use. In this case, the industrial activities that contributed towards water and soil pollution. The performative aspect of the layers shows the importance of ecological, social, and economic value of the stormwater park. This represents habitat creation, not only for people, but also for animals, plants, and water.

The operational networks layer represents the systemic integration of metabolic (water, energy, food), human, and ecological flows, which has to do with the integration of urban development in the ecological stormwater park. This concept is based on actual development plans for the site, as well as the contribution towards the thesis objective: integrating the urban and environmental system.

These consequential relationships can originate from every layer in the framework. In the end, they all lead to the three cells in bold, representing the design objectives: remediation & restoration, park amenities doubling as flood infrastructure, and urban development.

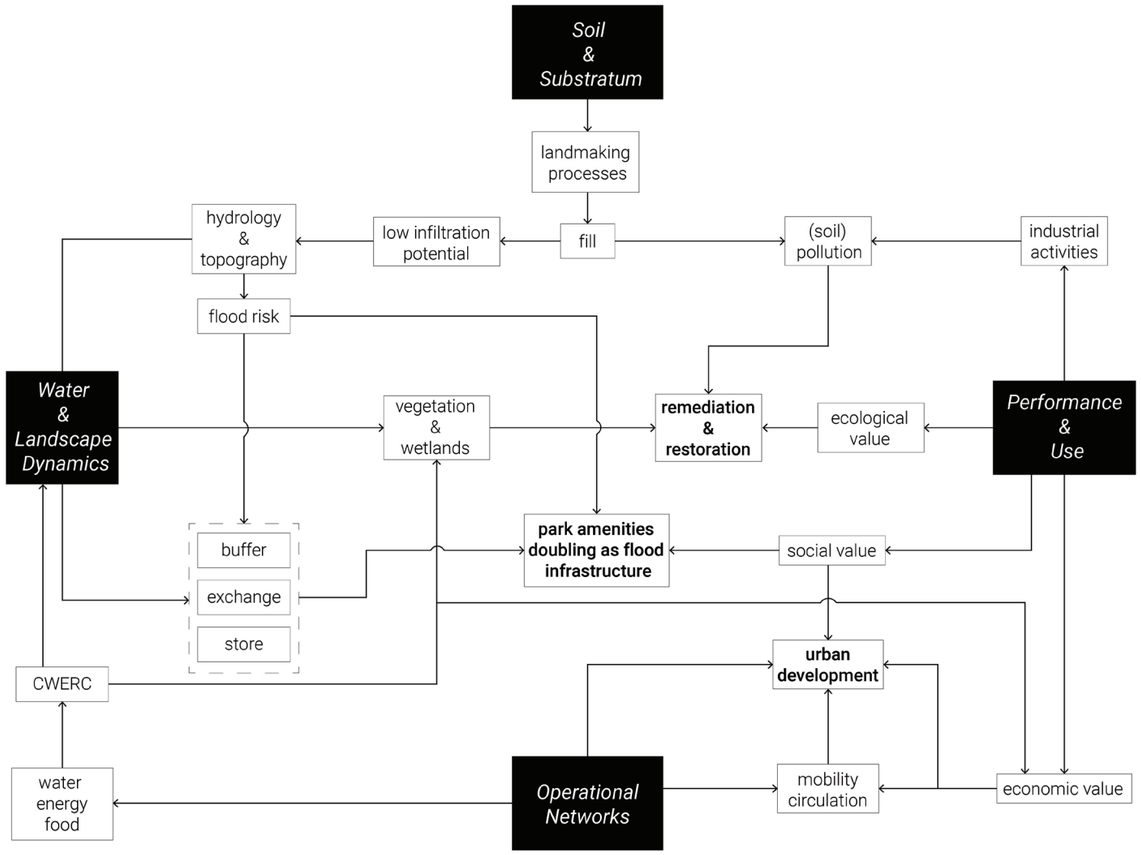


Figure 10.22 - Design Framework
Made by author

The design framework is conceptualized through the spatialization of the core elements of the design.

The existing landscape structures are used as a spine and reconnected through the (storm)water flows and local depressions based on the topography of the site.

The shape of the ecological stormwater corridor follows the shape of the water analysis and forms a spine throughout the site, reaching from Chelsea Creek to Belle Isle.

The urban analysis reveals that the Suffolk Downs paddock building is not within flood boundaries according to the coastal storm surge model.

Given the fact that urban development is planned on the site, and the urban blocks that have already been built in the North-East, urban development is planned in the cul-de-sac of the corridor and facing in the North-East.

Lastly, the urban fabric is connected through existing road infrastructure and new, ecologically-sensitive boardwalk infrastructure. This promotes slow mobility, whilst connecting the new and existing urban fabric through the corridor.

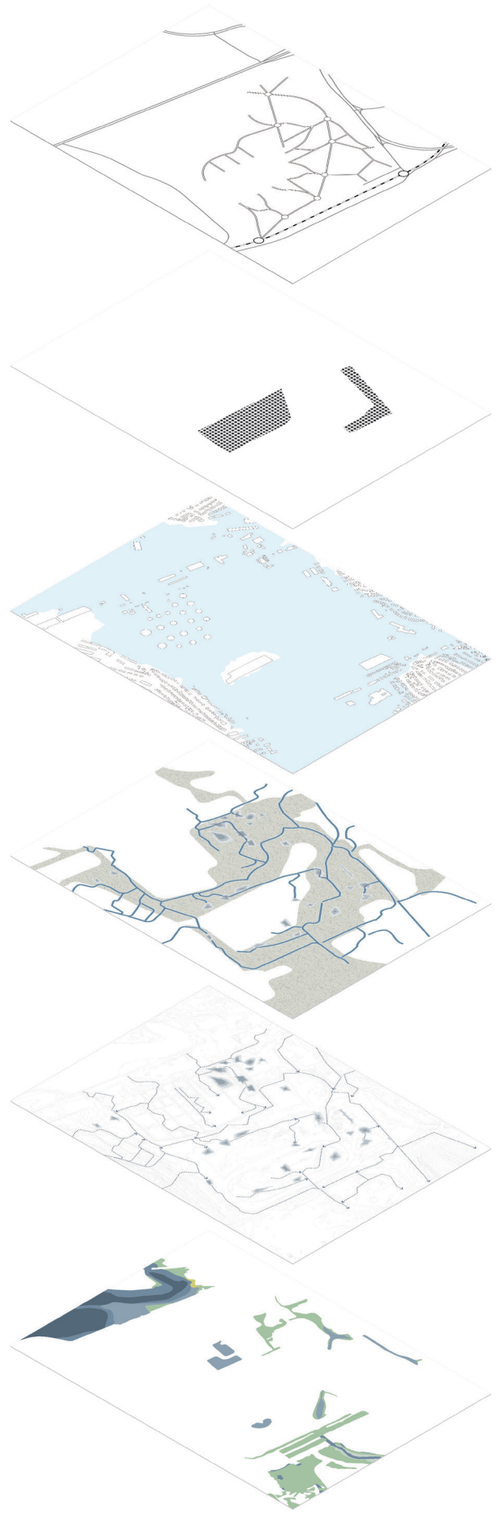


Figure 10.23 - Axonometric layering
Made by author

10.4 Systemic sectional exploration

In this sub chapter, the complexities and interconnectedness of the different design subsystems are being explored to illustrate the symbiosis, where landscape and urbanism co-exist in the field of flood management, remediation, and ecology. This section-based design exploration is methodologically constructed by creating a comparison between the current situation on site, addressing the problems, and showing how design interventions interact with soil, water, landscape, human processes, and ecology.

The Hydrological Heart - Ecological Stormwater Corridor

The hydrological foundation of the design is based on existing wetlands in between Chelsea Creek and Belle Isle Marsh. These wetlands are currently disconnected. However, historically, they belonged to a large marsh landscape. This condition has been disrupted by the large land-making operations that destroyed the landscape machine of water management and the water infiltration potential of the soil; by turning it into a contaminated, industrialized landscape. Presently, old industrial areas and obsolete road infrastructure disconnect existing wetlands.

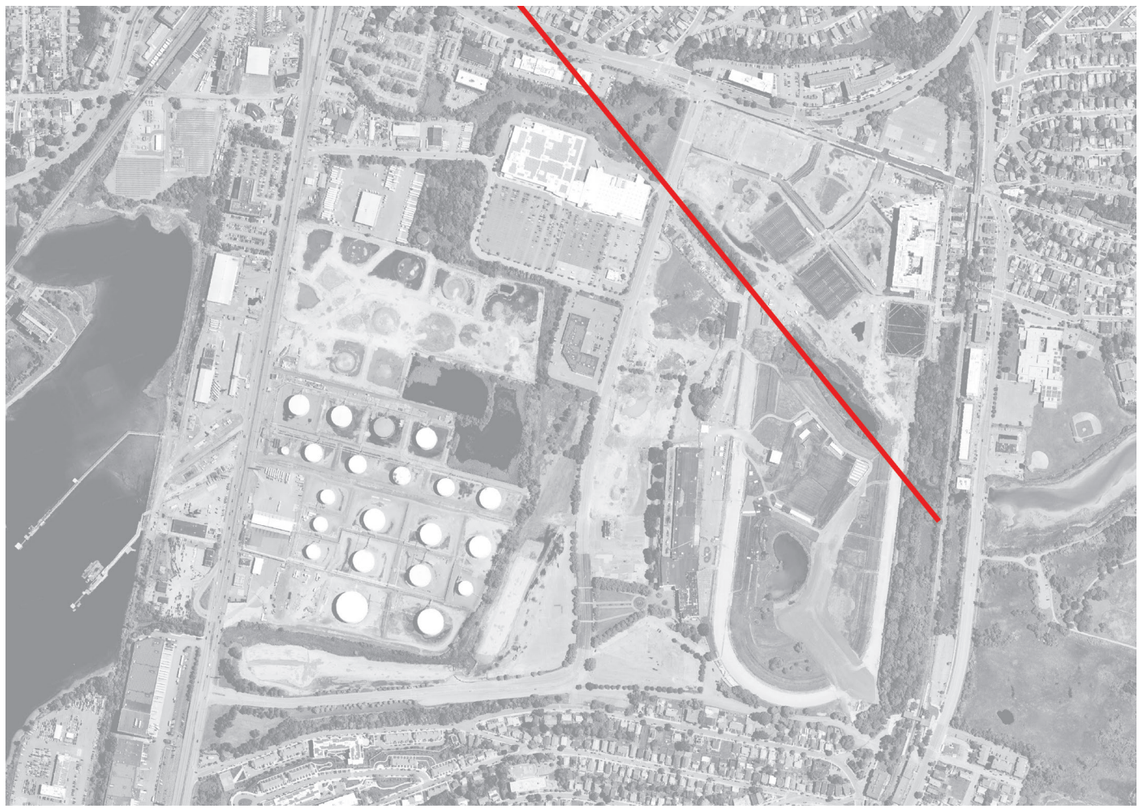
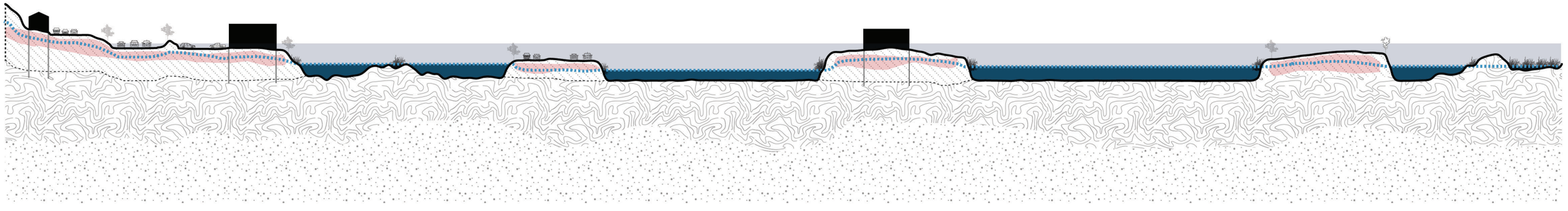


Figure 10.24 - Profile location
Made by author

Figure 10.25 - Current situation (elevation exaggerated 5x)
Made by author

Current situation



Program



Due to this condition, the ecological stormwater corridor prioritizes (storm)water filtration, conveyance, and buffering to alleviate flood pressures on the landscape, remediate (storm)water and soil, and environmental restoration. A network of bioswales and detention ponds is constructed based on the flow accumulation of water, and the topographic index of the landscape.

The Hydrological Heart forms a remediating, ecological spine through the site to form the reconnection between Belle Isle Marsh and Chelsea Creek, cleaning polluted runoff, creating habitat, and providing flood resilience to surrounding urban environments. Human accessibility is allowed, but restricted to designated boardwalk pathways that connect the urban fabric around the corridor for people to admire the scenery and protect the ecological processes that ensure flood resilience.

The removed land is part of a cut and fill process that is part of the remediation strategy in order to clean soil and manage water. Polluted soil layers are removed and treated on-site, preferably in places that could benefit from extra elevation regarding their flood vulnerability. The cut open land is remediated through phytoremediation and is used to create micro elevation differences that support the ability of the site to convey, store, and buffer stormwater, whilst remediating.

The boardwalk is designed as mobility infrastructure that enables limited human accessibility inside the corridor, to protect the ecological performance of the corridor, while simultaneously connecting the urban environments surrounding the corridor, resulting in a social, high-quality public space in nature. The pile construction ensures safe connectivity in case of (extreme) floods and independence of the unstable artificial fill, which is prone to land subsidence.

The sequence of drawings on the next few pages shows the temporal aspect of flood dynamics and how the bioswale vegetation deals with stormwater, ranging from dealing with local precipitation to extreme compound floods. The vegetation in and around the bioswale is flood-tolerant and has phytoremediation properties to combat pollution. The boardwalk inside the ecological corridor shows how social and ecological systems intertwine through landscape-driven infrastructure.

New situation

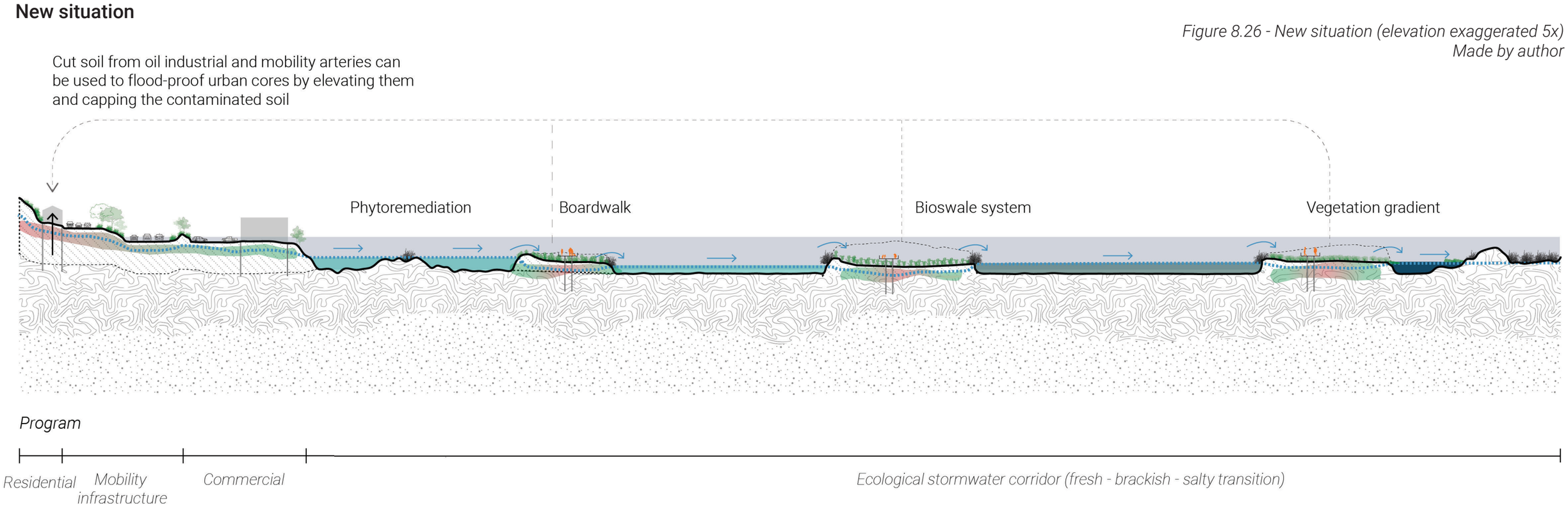


Figure 8.26 - New situation (elevation exaggerated 5x)
Made by author

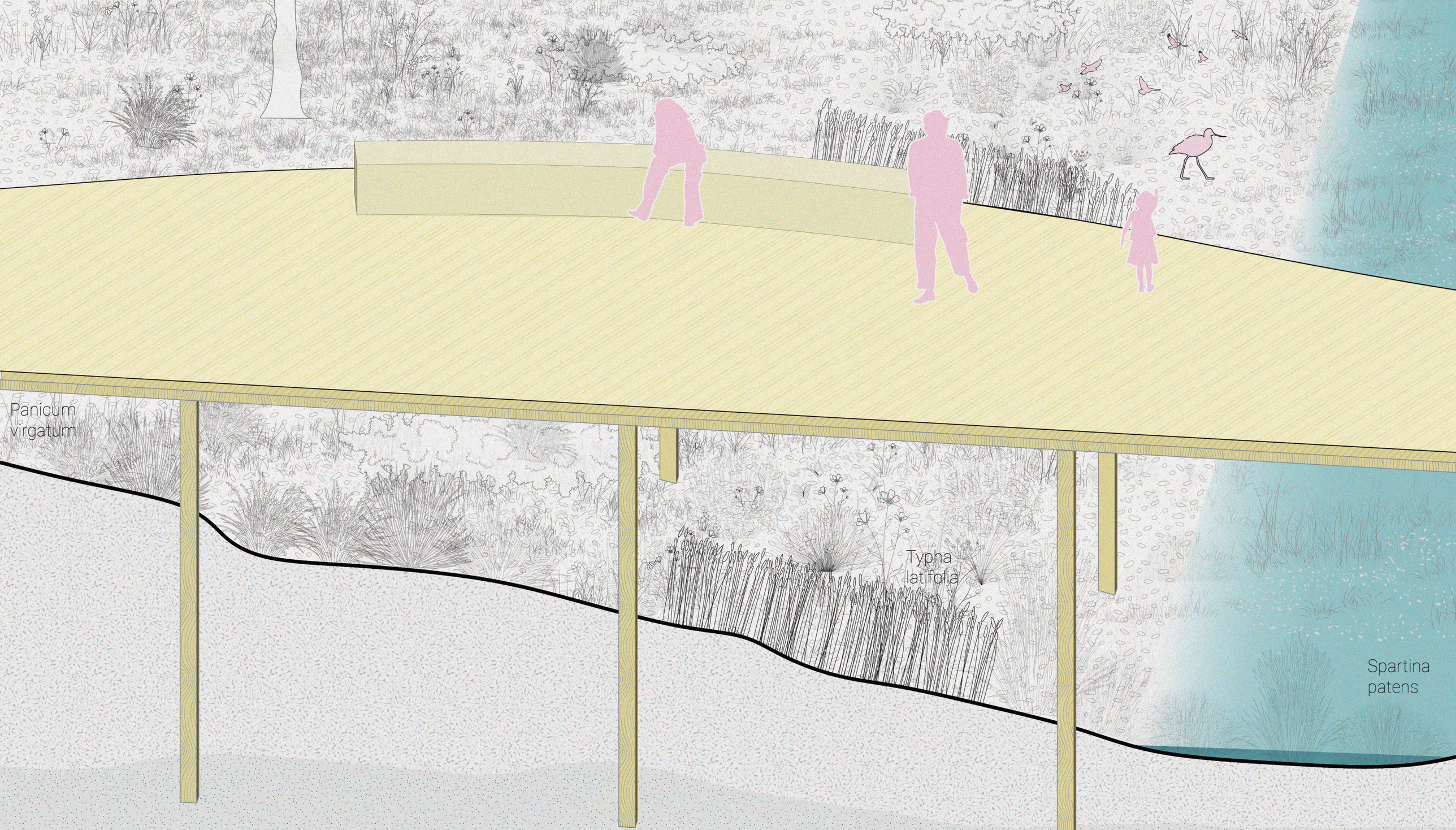


Figure 8.27 - Corridor with little hydrological pressure
Made by author

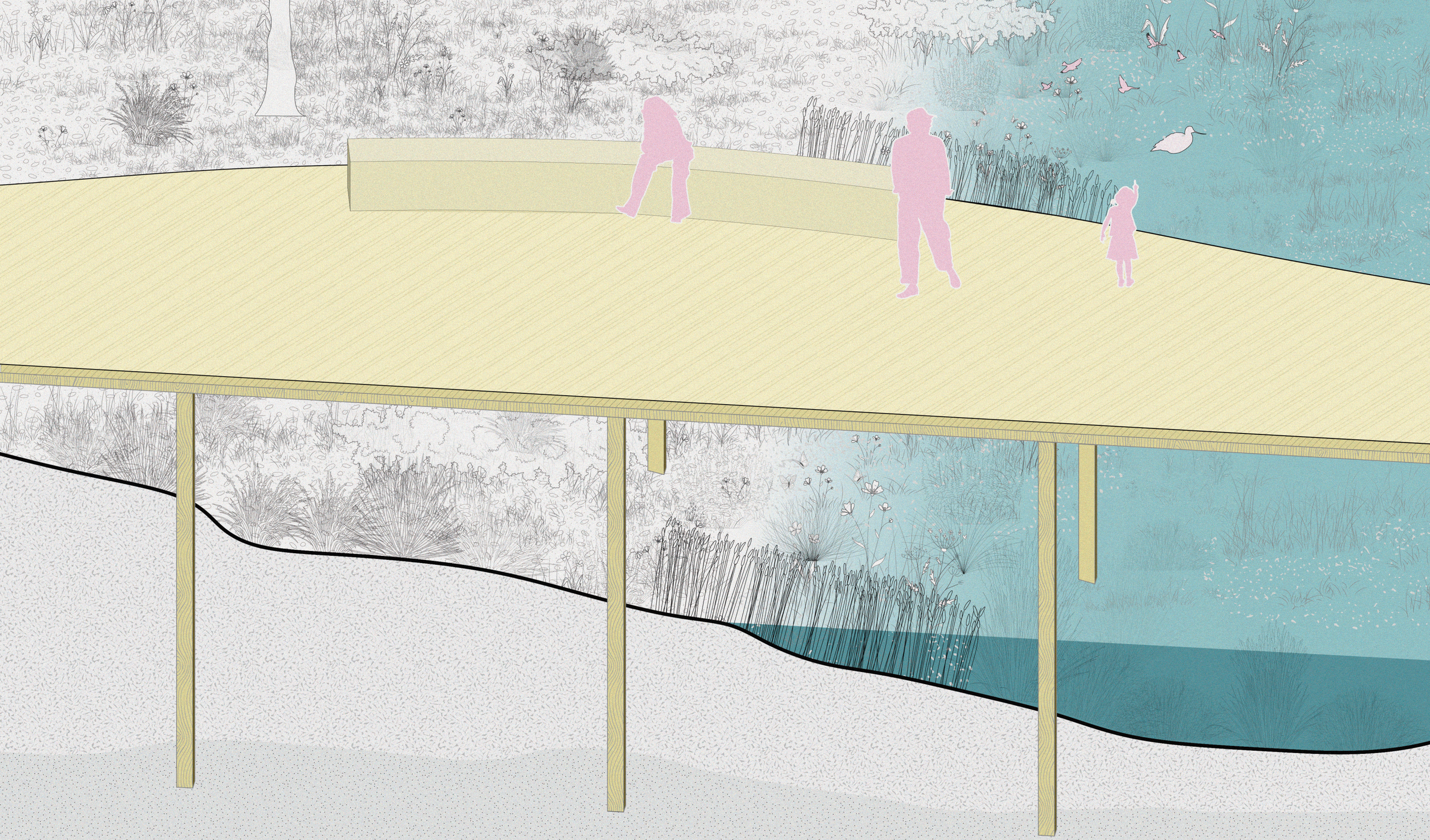


Figure 8.28 - Corridor with moderate hydrological pressure (small storm)
Made by author

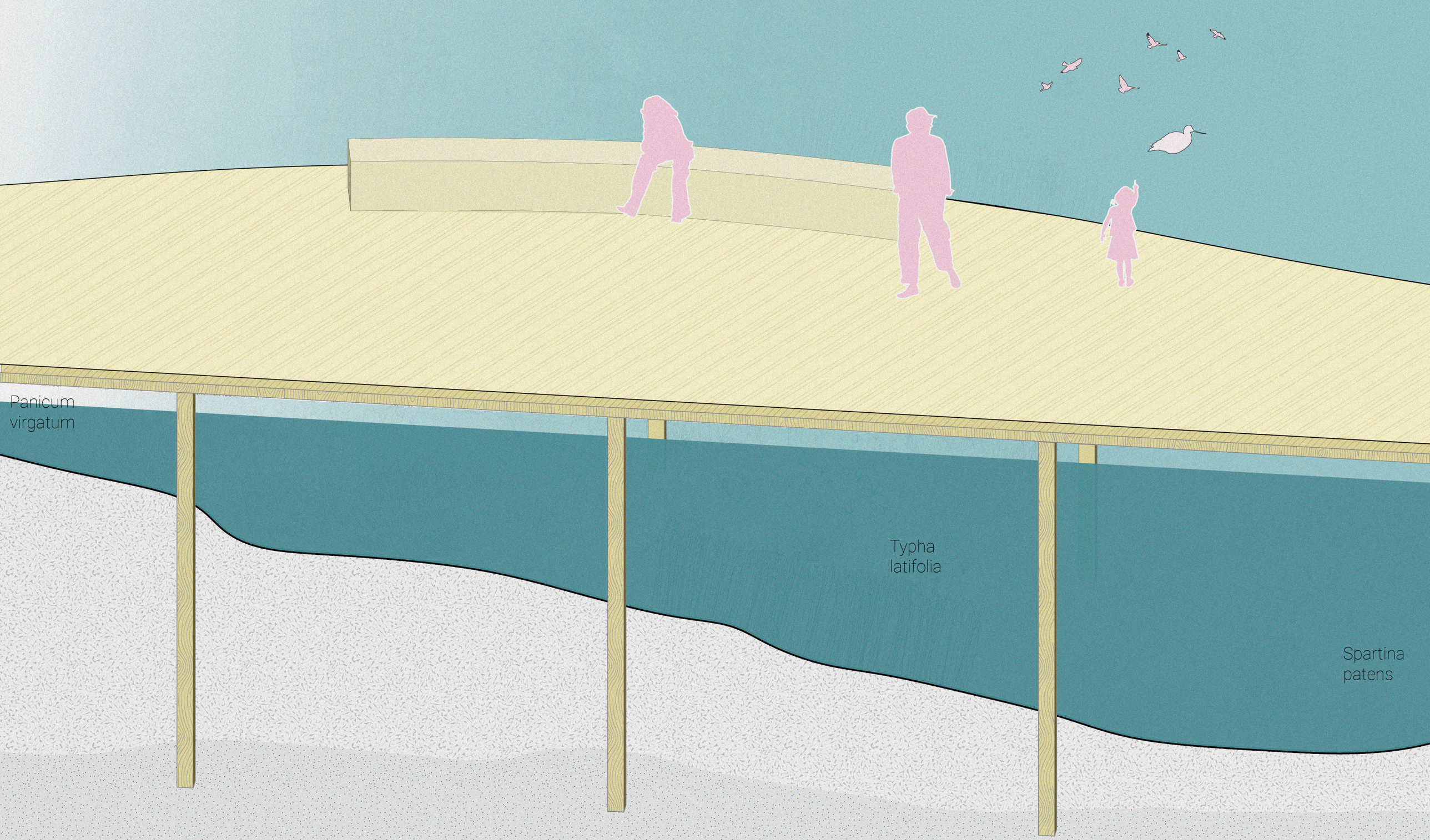


Figure 8.29 - Corridor with large hydrological pressure (big storm)
Made by author

Connecting the Heart (I) - Corridor & Belle Isle Marsh Connection

Currently, mobility infrastructure obstructs the potential connection between the wetland on site and the Belle Isle Marsh. The limited brackish-salt water exchange due to small, blocked culverts denies water exchange and habitat connection. In case of flooding, the current situation traps stormwater inside the design site, with limited drainage possibilities to the Belle Isle Marsh.

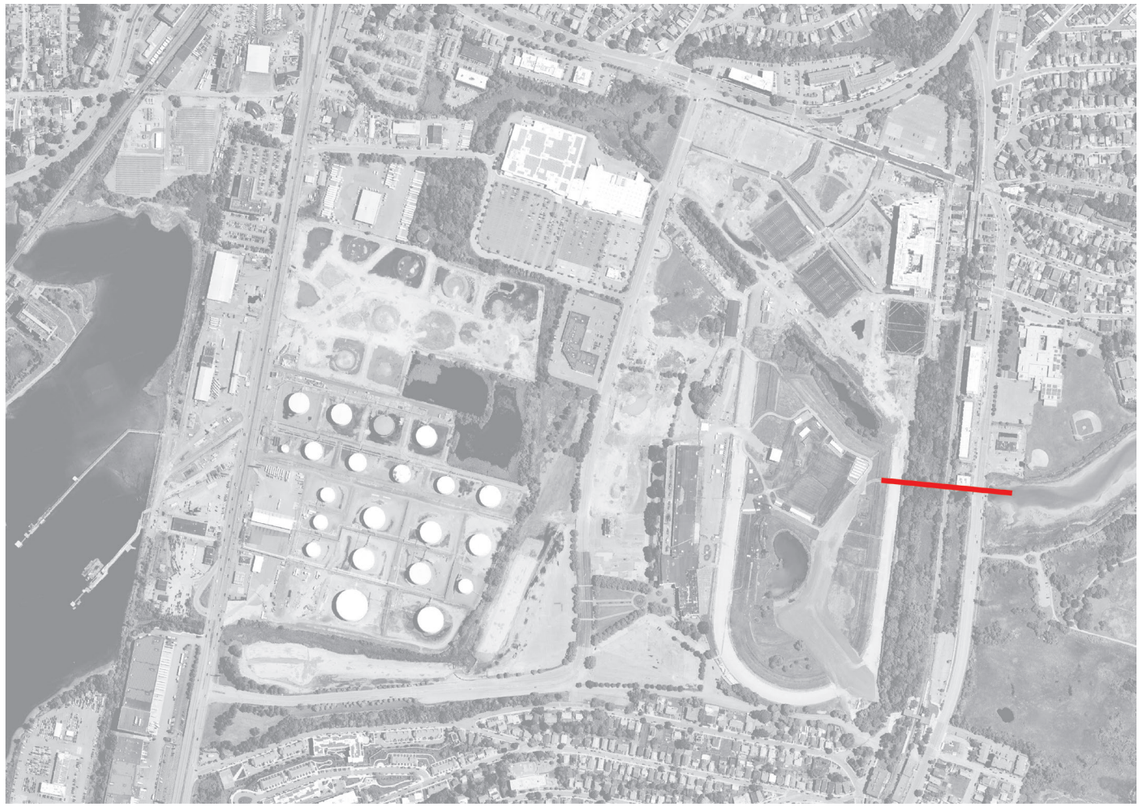


Figure 8.30 - Profile location
Made by author

Current situation

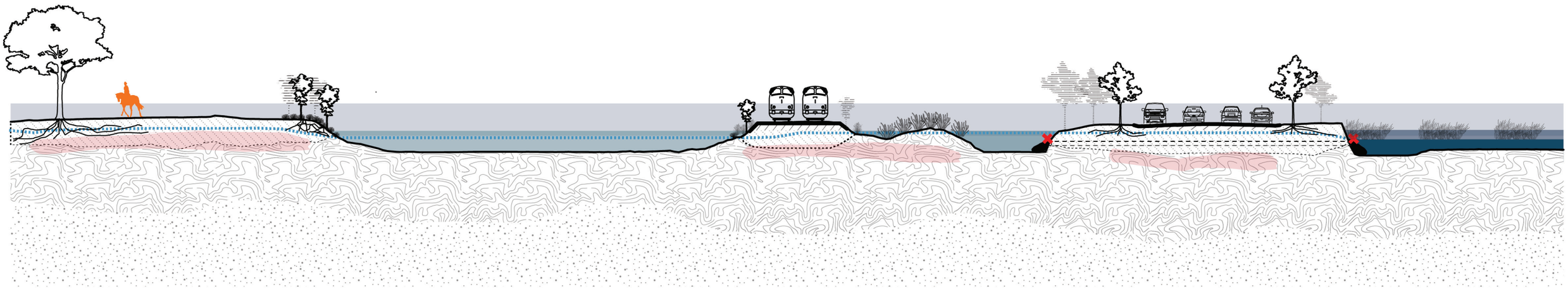


Figure 8.31 - Current situation
Made by author

Program

Former Race Track

Estuarine emergent wetland

MBTA Railway

Estuarine emergent wetland

Bennington St

Belle Isle Salt Marsh

The proposed interventions reconnect the on-site wetlands with the Belle Isle Marsh by reconfiguring road infrastructure to break the barrier, giving space for tidal flows. In the new situation, a fresh-brackish-salt gradient establishes better water quality and an improved water exchange mechanism based on historic hydrology concepts.

The infrastructural embankment bundles mobility flows. Based on the existing embankment, slopes are softened, creating a gradual transition that allows for wetland vegetation to expand upslope on both sides. The capped soil traps pollutants and disconnects them from active ecologies. Through a tidal window, the existing wetlands are reconnected with the Belle Isle Marsh.

In case of a coastal storm or compound flood event, the second culvert allows controlled spillage of stormwater to exchange between the marsh and the wetlands. The stormwater overflows in one of the spillways that enable managed conveyance to the wetlands.

The hydrological and ecological connectivity between the Belle Isle Marsh and the stormwater corridor is further strengthened by the ecological overpass that allows species to cross the mobility artery safely. Animals are able to enter and exit both systems. For humans, the overpass connects to the boardwalk infrastructure, creating connectivity from transport nodes and urban areas through the ecological stormwater corridor to viewpoint platforms inside the Belle Isle Marsh.

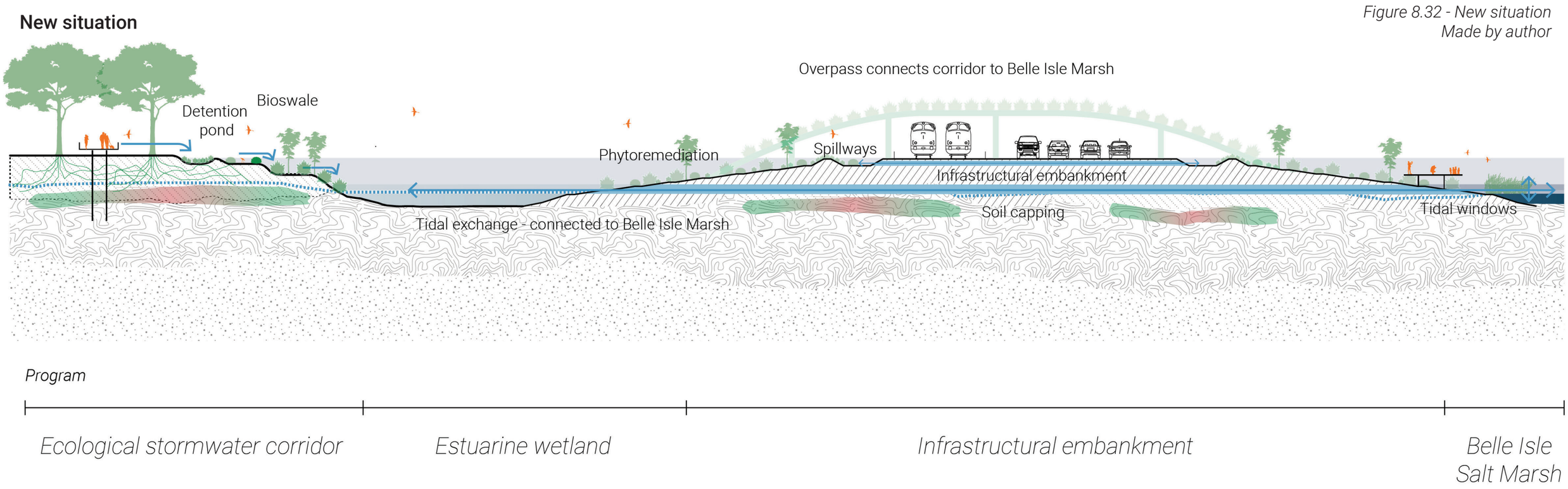


Figure 8.32 - New situation
Made by author

Connecting the Heart (II) - Corridor & Chelsea Creek Connection

The second part of the Hydrological Heart connection refers to the reconnection of surrounding water systems on the West side of the site. Again, the mobility infrastructure serves as a barrier. However, this side has a different character compared to the Belle Isle connection, due to the industrial land use activities along the Chelsea Creek riverbank.

Currently, the Irving Oil Terminal site is still active. All stormwater that flows into this site is identified as contaminated. The oil terminal has its own oil-water separator treatment and discharged the treated water into Chelsea Creek. Figure 8.33 shows the topography of Irving Oil, portraying a bathtub-like terrain profile. The ecological stormwater corridor and the Irving Oil Terminal are separated systems, which is why the corridor goes around the industrial site.



Figure 8.33 - Irving Oil Terminal elevation profile
Made by author

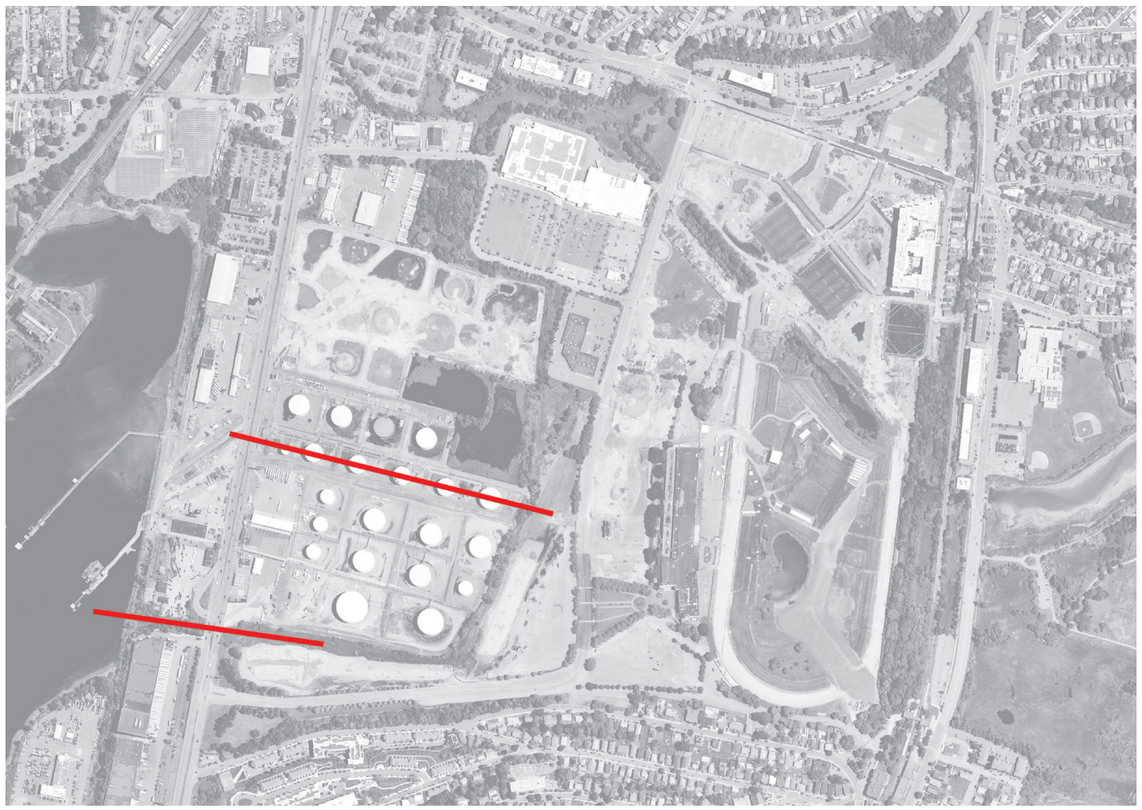
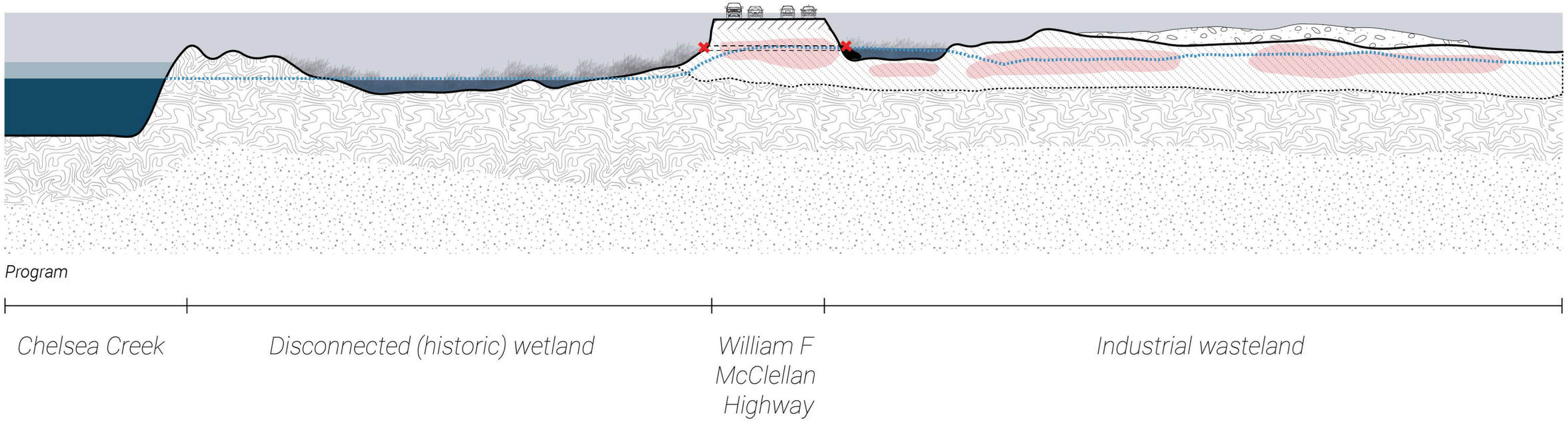


Figure 8.34 - Profile location
Made by author

Current situation

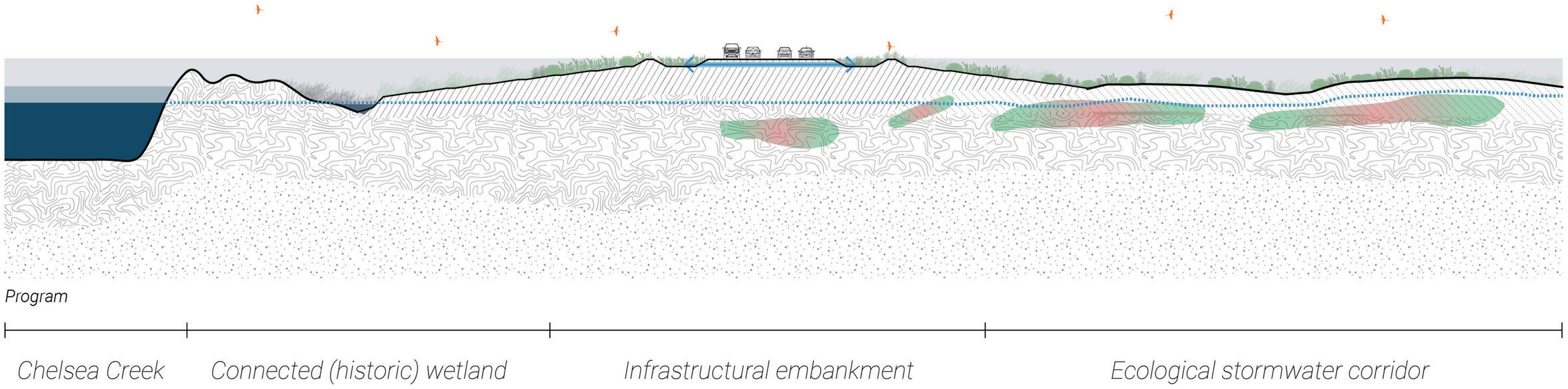
Figure 8.35 - Current situation (elevation exaggerated 5x)
Made by author



The Chelsea Creek riverbanks are characterized as a hard-industrial edge. However, in between industrial plots, the connection between the creek and the wetlands can be restored through a salt-brackish fringe in the corridor. A transition in salt-brackish tolerant vegetation in combination with phytoremediating properties are able to adapt to the water salinity and extract heavy metals and other pollutants out of water and soil. The reconnection is made through the transformation of the highway into the infrastructural embankment that interacts with existing wetlands and provides controlled spillage in case of a flood, just like in the Belle Isle Marsh site.

New situation

Figure 8.36 - New situation (elevation exaggerated 5x)
Made by author



Reconnecting the past -
Pond Park in Formal Industrial Site

The current situation reveals the industrial drosscape that has been caused by former oil industry on the site. The industrial land use is still present, but has shrunk. However, the topography of the oil terminal still exists. The contaminated and impervious soil obstructs infiltration and contributes to intensified surface runoff. Presently, the old industrial land has no connection to the wider urban fabric and lacks ecological value.

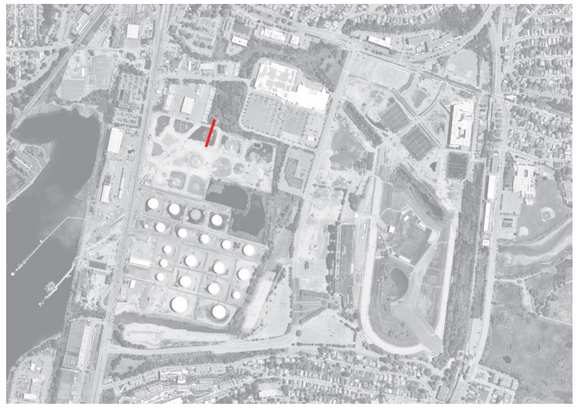
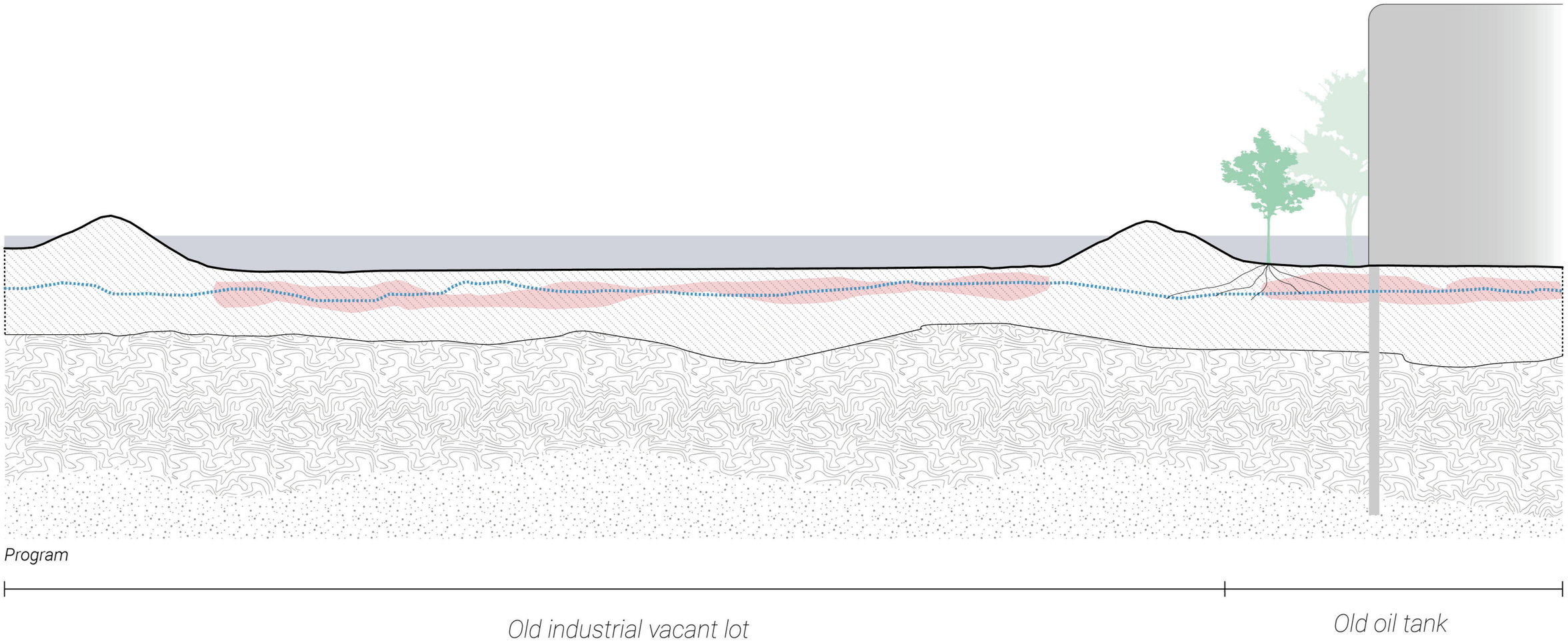


Figure 8.37 - Profile location
Made by author

Current situation

Figure 8.38 - Current situation
Made by author



In the new situation, the former industrial depressions are transformed into an interconnected pond park. The stormwater squares are able to (temporarily) capture and store stormwater, before conveying it towards the ecological stormwater corridor.

A soil cap traps the polluted soil. In this way, the stormwater will not mix with the trapped pollutants. The terraced form of the ponds allow for a slow release and extra storage capacity.

The Pond Park doubles as flood infrastructure and as public space. When floods are absent, the different layers of the park are flexible public spaces: sports fields, skate areas, local markets, and small events all take place in the ponds.

The old oil tank on site forms the transition between the Pond Park and the ecological stormwater corridor by transforming the tank into a climbing wall. The re-purposing of old industrial infrastructure respects the cultural and industrial values of the site. In this way, the Pond Park sustains historical value and transforms industrial wasteland into an adaptive landscape where hydrology, remediation, and public life are improved in symbiosis.

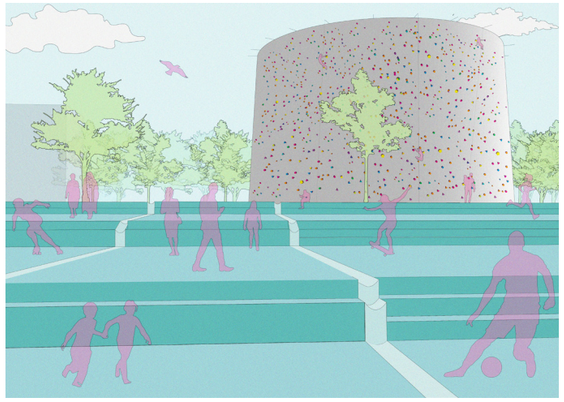


Figure 8.40 - Pond Park (dry)
Made by author

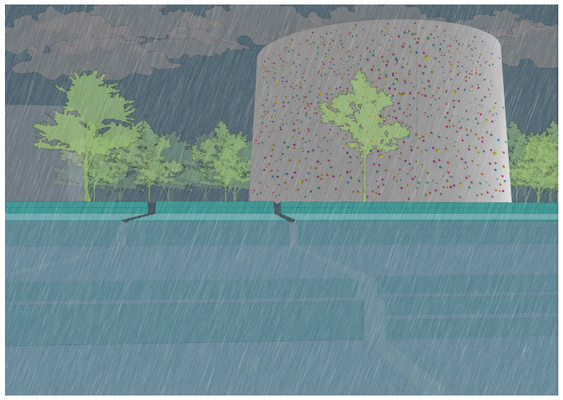


Figure 8.41 - Pond Park (flooded)
Made by author

New situation

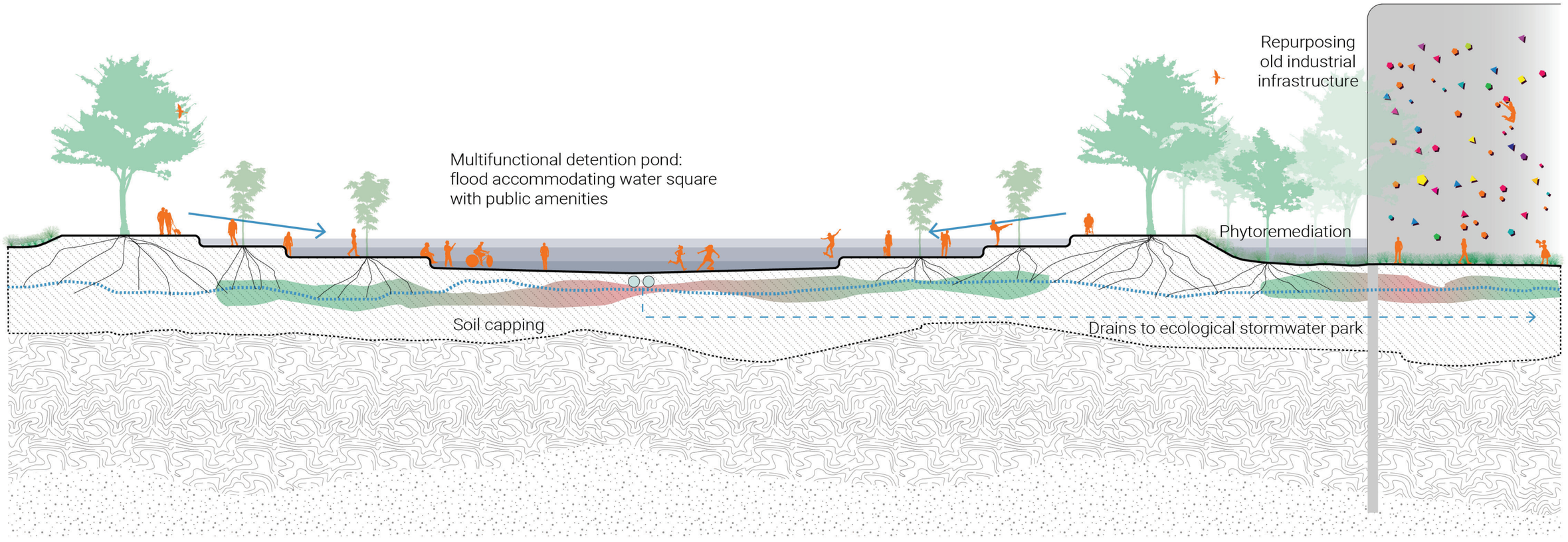


Figure 8.39 - New situation
Made by author

Program

Pond Park connected to ecological stormwater corridor

Suffolk Downs Transformation - From Old Racing Track to New Urban Buffer Landscape (I)

This section investigates how urban development can be integrated and flood resilience can go hand in hand together, based on the thesis objective and real urban transformation for the site. Currently, the paddock building sits out of the flood zone and the auxiliary parking lot portrays the impermeable paving, where stormwater spreads over the lot and is discharged without treatment through old drainage pipes. These single use spaces experience not only water, but also heat stress.

On the other side of the building, the old racetrack transitions into green space. Recently, the City of Boston started to demolish the racetrack to make space for new urban blocks that are planned to be built in the next few years.

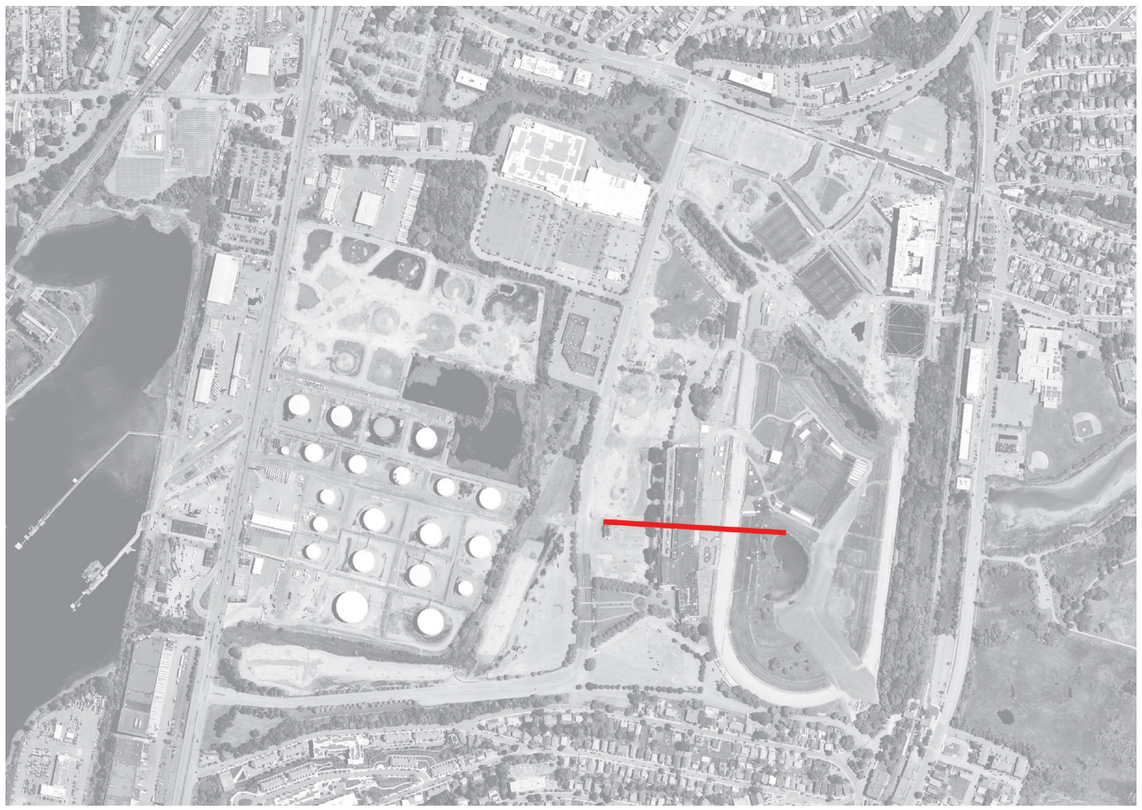


Figure 8.42 - Profile location
Made by author

Current situation

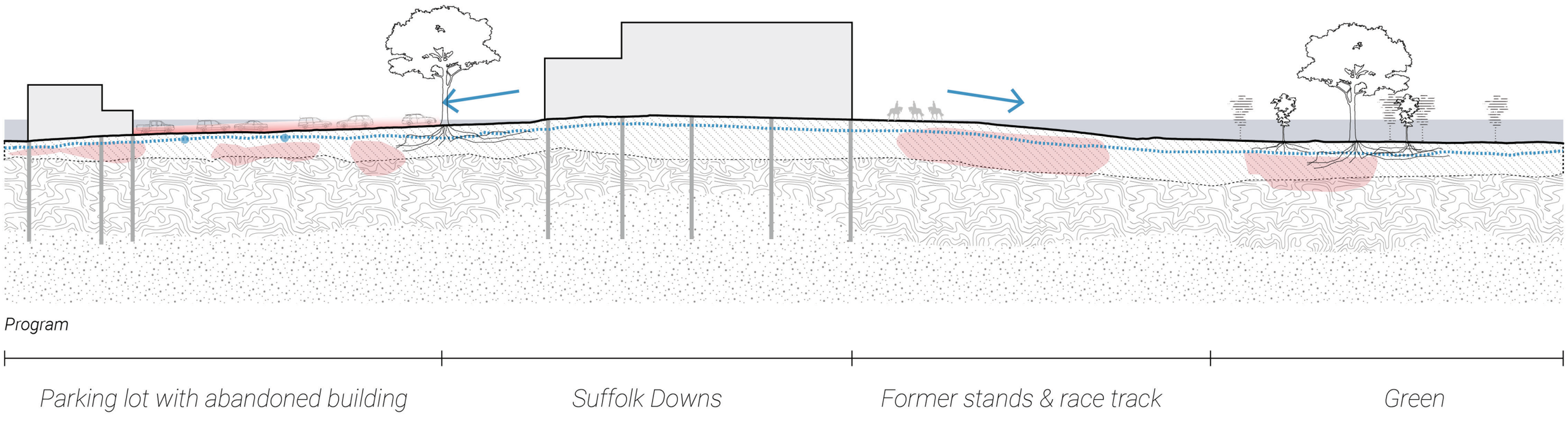


Figure 8.43 - Current situation
Made by author

Suffolk Downs Transformation - From Old Racing Track to New Urban Buffer Landscape (I)

The new situation proposes the Suffolk Downs area as a new urban core within the ecological stormwater corridor. The urban fabric is based on the existing paddock building. While the new buildings are positioned inside the flood zone, the urban environment is forced to work with stormwater instead of against it. In this section, multiple ways of buffering, accommodating, delaying, and conveying water are investigated. In this way, the urban buffer landscape contributes to soil and water remediation, and alleviates pressure on the surrounding water system.

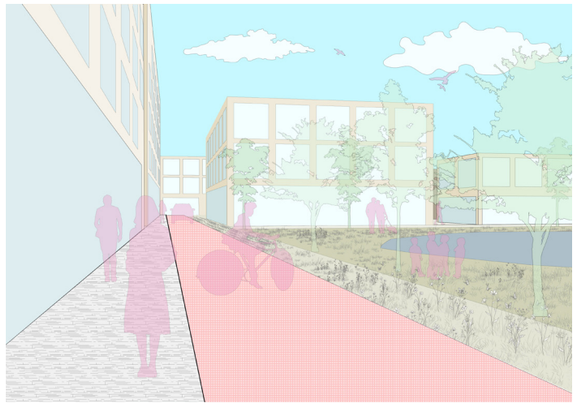


Figure 8.45 - Urban Core (dry)
Made by author

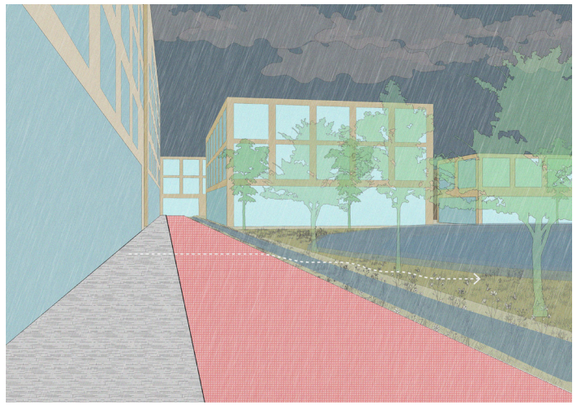


Figure 8.46 - Urban Core (flooded)
Made by author

New situation

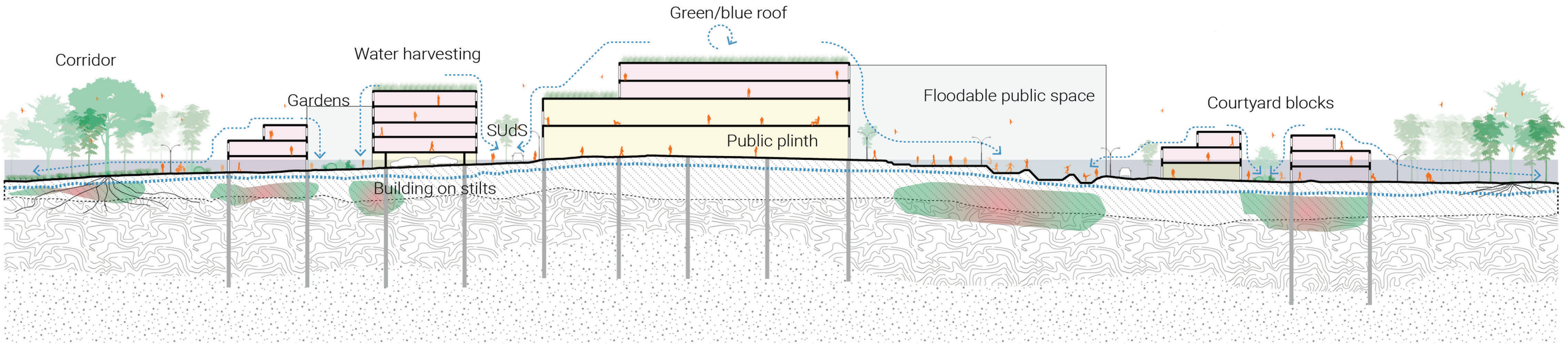


Figure 8.44 - New situation
Made by author

Suffolk Downs Transformation - From Old Racing Track to New Urban Buffer Landscape (II)

The second investigation of the urban core is predominantly focused on the transition from the current urban fabric towards the new urban core. In this section, the suburban area Orient Heights is shown and how the stormwater out of the suburban area drains on to the parking lot of the Suffolk Down Racetrack. This worsens the state of the polluted, heat and water stressed, mono-functional public space which is described in part one. Furthermore, the disconnection in topography is strengthened by the difference in land use. Currently, the suburban area is disconnected from its surroundings.

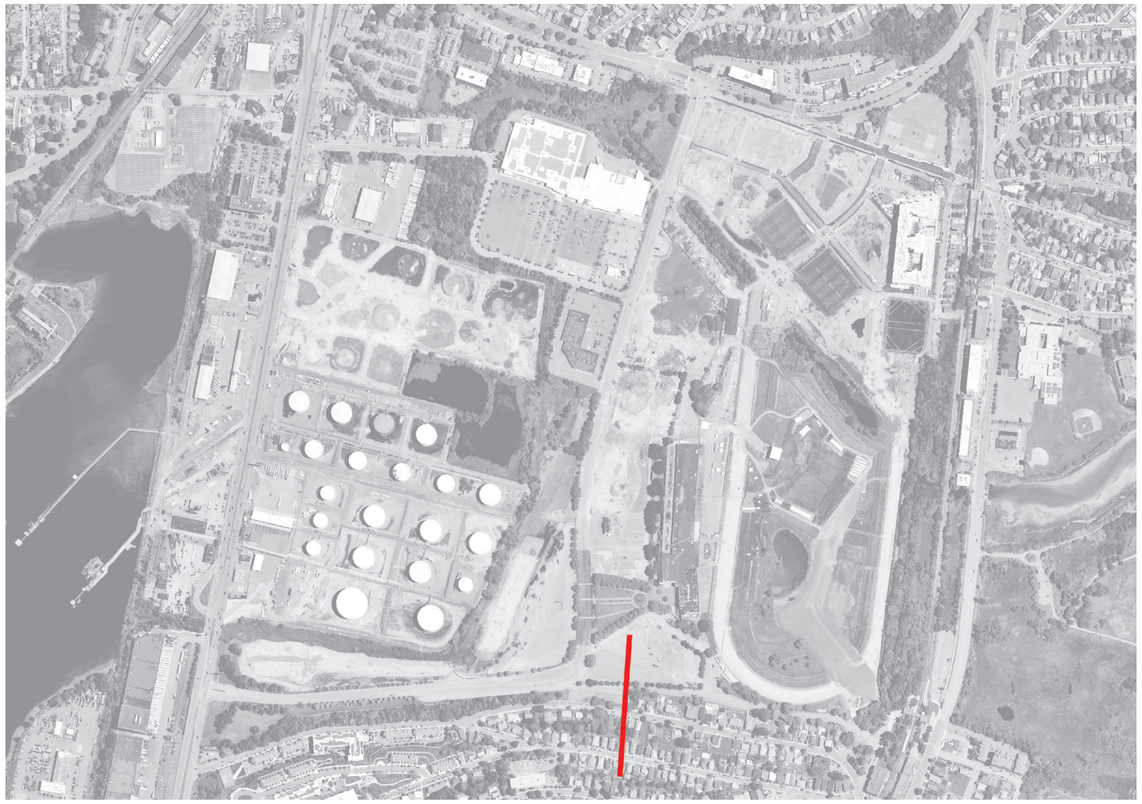


Figure 8.47 - Profile location
Made by author

Current situation

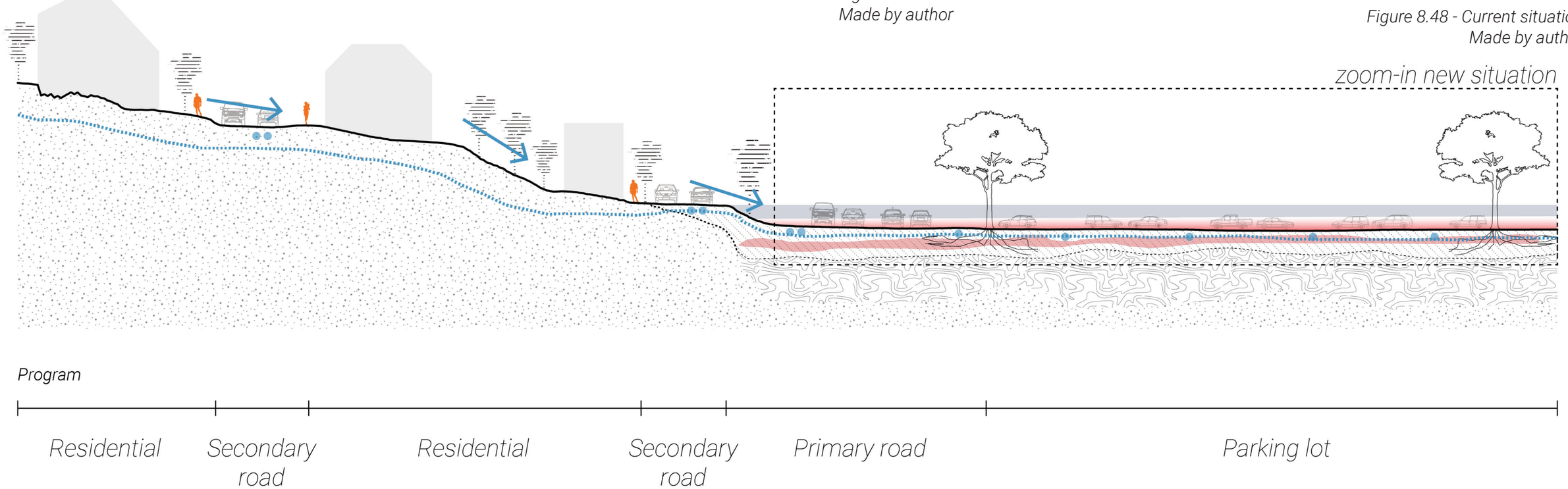


Figure 8.48 - Current situation
Made by author

In the new situation, the stormwater flows from Orient Heights are intercepted by the ecological stormwater corridor and are discharged into the wet pond, which slows down the water, filters the pollutants, and is conveyed to the bioswale system in the corridor.

The new situation shows how the corridor and urban environment blend. Street profiles allow for the integration of the corridor into the urban fabric. The open courtyard building blocks connect gardens and semi-public land with the corridor through the integration of bioswales and ponds. In this way, the integration of the urban and environmental system supports and combines urban flood resilience interventions with engaging public spaces.

The buildings have active plinths that allow for mixed use activities, and simultaneously protect the residential layers above in case of an extreme compound flood event.

New situation

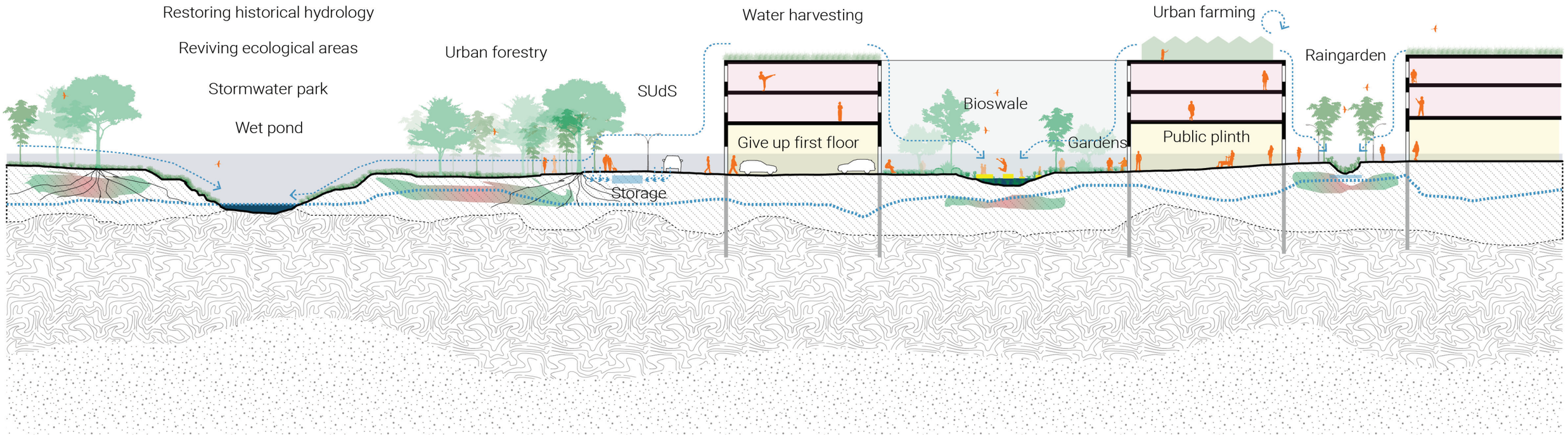


Figure 8.49 - New situation
Made by author

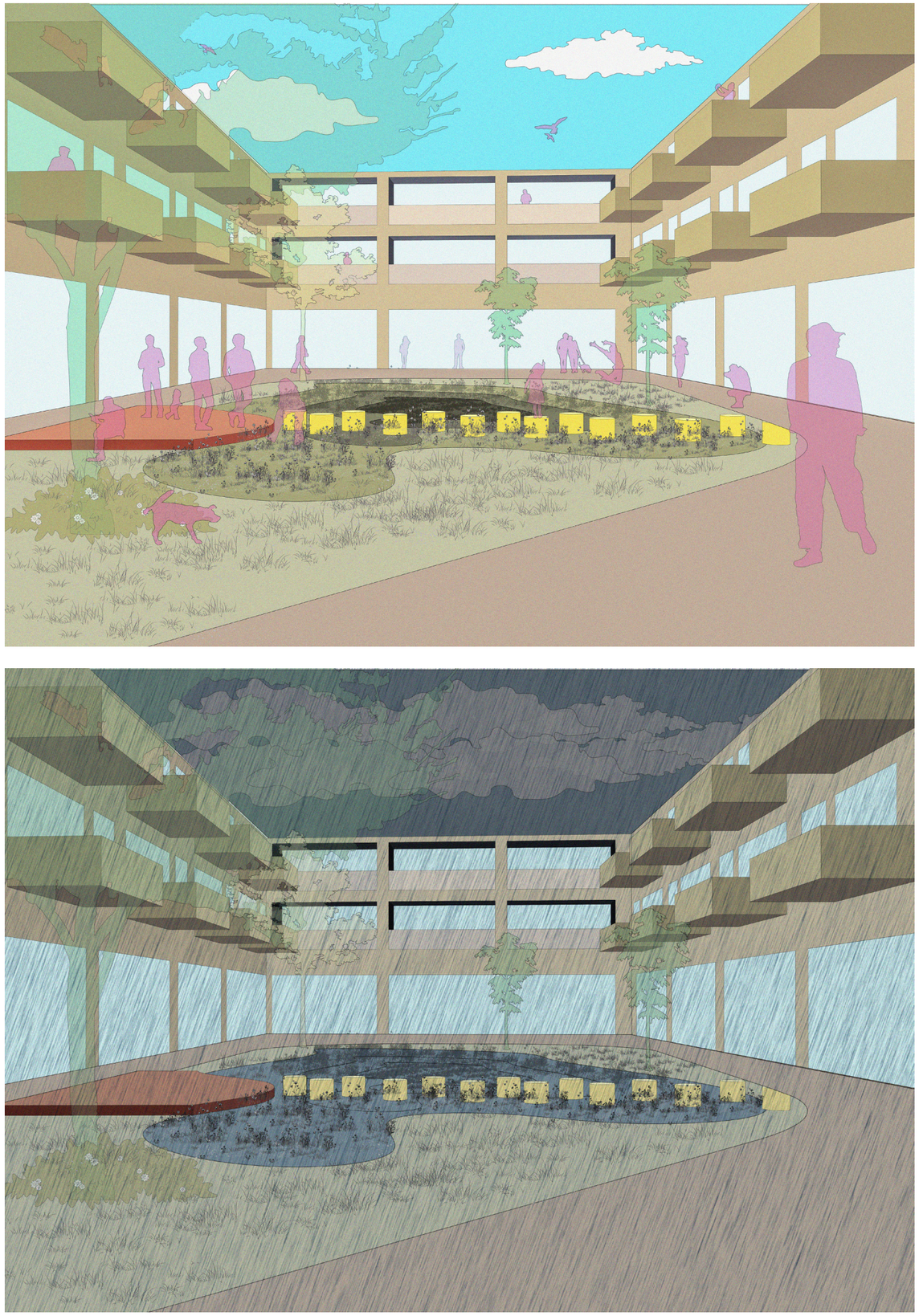


Figure 8.50 & 8.51 - Courtyard building block impressions (dry & wet)
Made by author

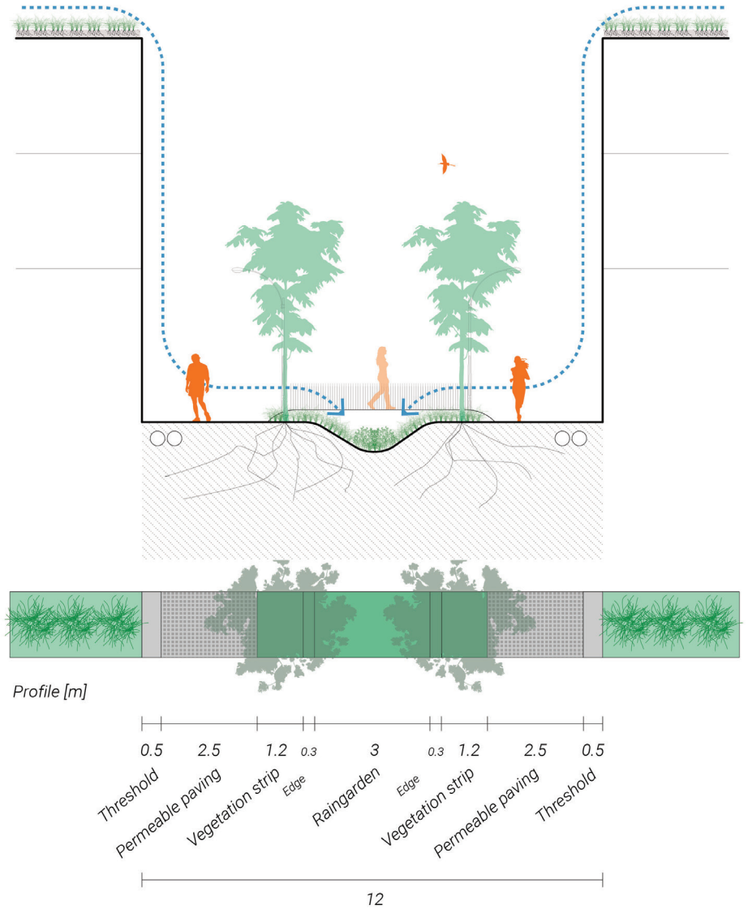


Figure 8.52 - Corridor fringe street profile
Made by author

The Circular Core -
Turning sewage, stormwater, and waste into ecological productivity

Currently, the northeastern area of the site is characterized by old industrial vacant lots, scattered (obsolete) road infrastructure, and a significant parking lot area, without functional use. These areas remain contaminated and stormwater rapidly spreads out.

Along this stretch, relatively new urban development is adjacent to a landscape that contributes little to urban life or environmental performance. However, the old, industrial character of the site has potential to be transformed into a field lab that decentralizes important infrastructural flows and systems.

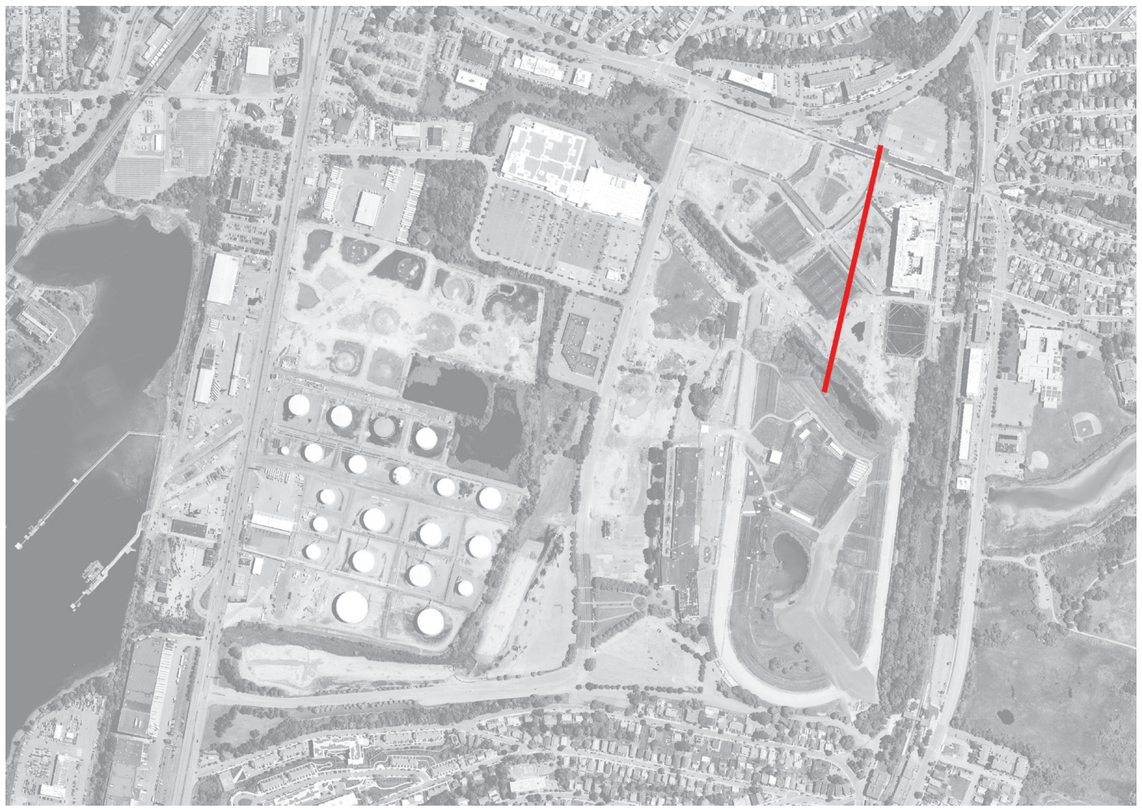
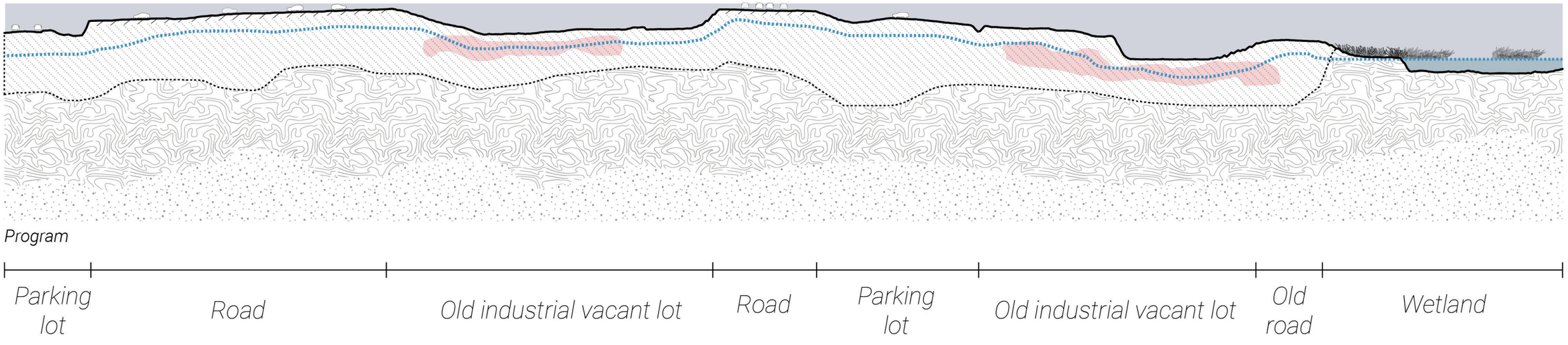


Figure 8.53 - Profile location
Made by author

Current situation

Figure 8.54 - Current situation
Made by author



The proposed interventions transform the vacant lots into a circular core, where urban development, the decentralization of the sewer system, and the localization of water and energy cycles intersect.

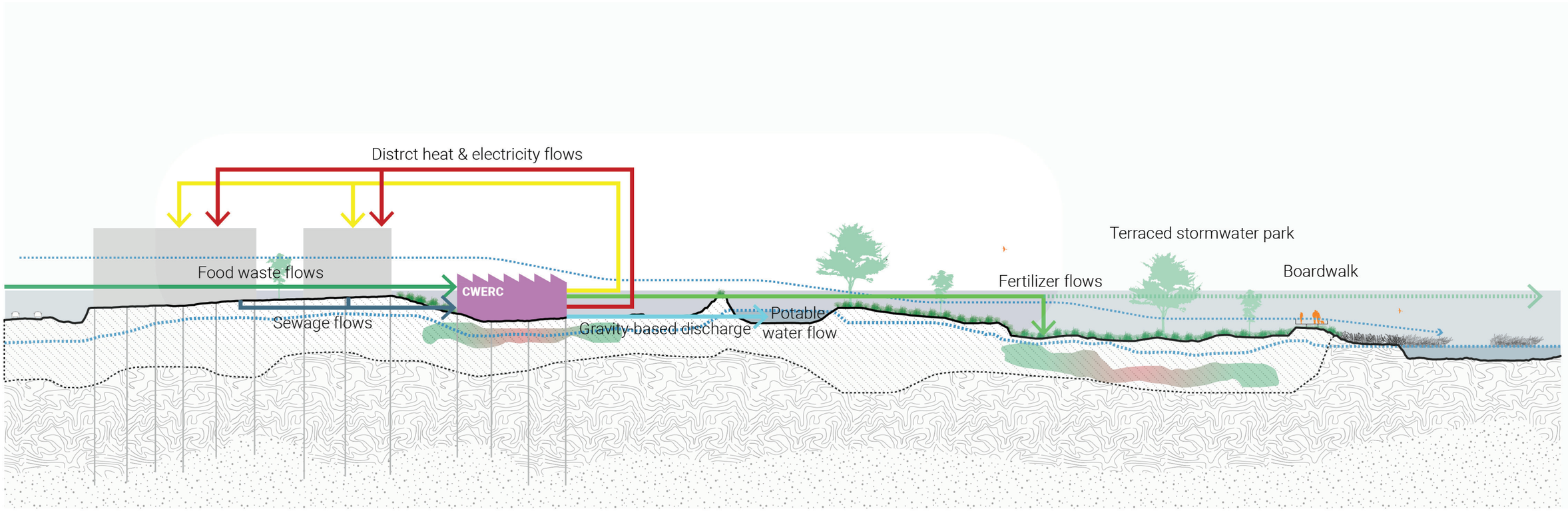
A CWERC (Community Water and Energy Resource Center) captures is connected to the new urban development on site and captures primarily sewage and stormwater. In addition, local food waste can be deposited into the CWERC. The treatment process treats sewage and stormwater, and transforms the organic waste through anaerobic digestion into local electricity, heat, potable water, and fertilizer.

The decentralization of metabolic flows contributes to stormwater management through the enhancement of base flow and by a constant supply, also in times of drought.

In this setup, the circular core helps kick-start a more regenerative way of organizing the area. It brings the different flows of water, energy, food waste, and soil remediation together, and turns them into a system where resources circulate instead of being lost. By doing so, it creates a more productive link between the new urban fabric and the ecological stormwater corridor.

Figure 8.55 - New situation
Made by author

New situation



10.5 Cross-scalar synthesis

Synthesizing sections

The research-by-design experiments developed through systematic sections are synthesized into a conceptual layered axonometric diagram that spatializes the on-site logic of the sections. The diagram uses the sections to demonstrate how landscape, through soil, topography, hydrology, and ecological performance, can actively inform urban flood adaptation. Beyond synthesis, the drawing functions as a conceptual translation tool, illustrating that landscape-based infrastructural principles are transferable to other flood-vulnerable coastal and deltaic environments where ecological capacity and water behavior must be integrated with the urban fabric rather than treated as a different system.

The different layers in the axonometric view relate to the design framework, revealing how (sub)soil and topography inform hydrological flows and relate to existing (and historical) landscape typologies. These elements fulfill a foundational role in the research-by-design process, where hydrological flow pathways are acknowledged and utilized to reconnect marsh ecosystems and integrate these structures with an urban core. The urban core interweaves with the corridor through ecological fringes that disperse through streets and are able to enter building blocks through their open courtyard typologies. This results in a high quality public space, which is necessary in socio-economically vulnerable environmental justice communities. Lastly, the metabolic flows of water, nutrients, energy, waste, and mobility enable landscape-based infrastructural adaptation through the decentralization of infrastructures (CWERC) and infrastructural embankments that allow for a tidal exchange and connect habitats.

Finally, the diagram integrates urban metabolism by spatializing infrastructural flows, including water, nutrients, energy, waste, and mobility, to show how these networks enable landscape-driven flood adaptation through the decentralization of infrastructural systems (CWERC), and mobility embankments that allow for tidal exchange and habitat connectivity. In this configuration, landscape operates as active infrastructure, structuring where water moves and collects, buffering flood vulnerability through ecological capacity, and integrating hydrological performance into urban public space. Revealing how flood adaptation is constructed through the co-production between ground, water, ecology, and urban systems that evolve over time.

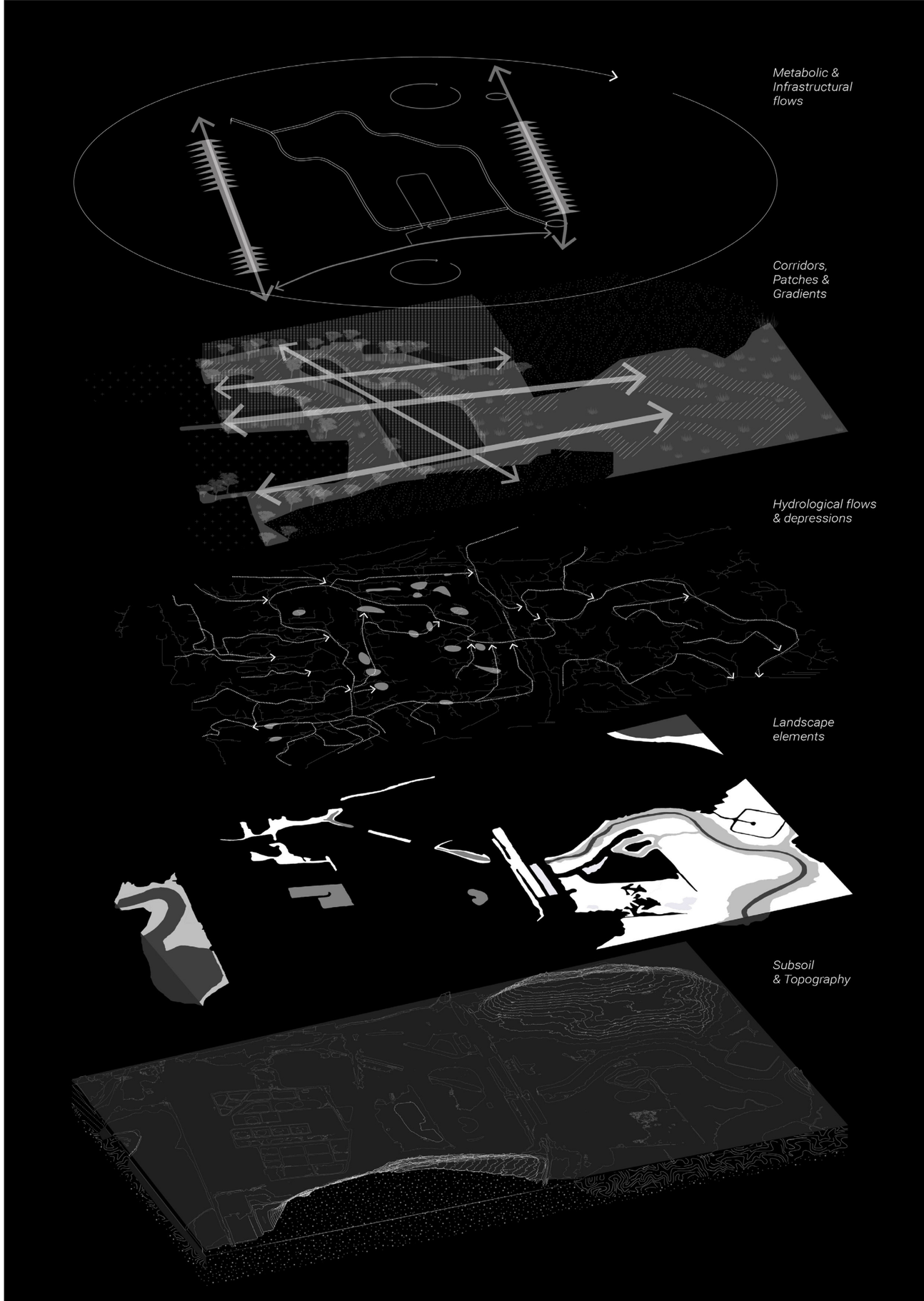


Figure 10.56 - Conceptual layering
Made by author

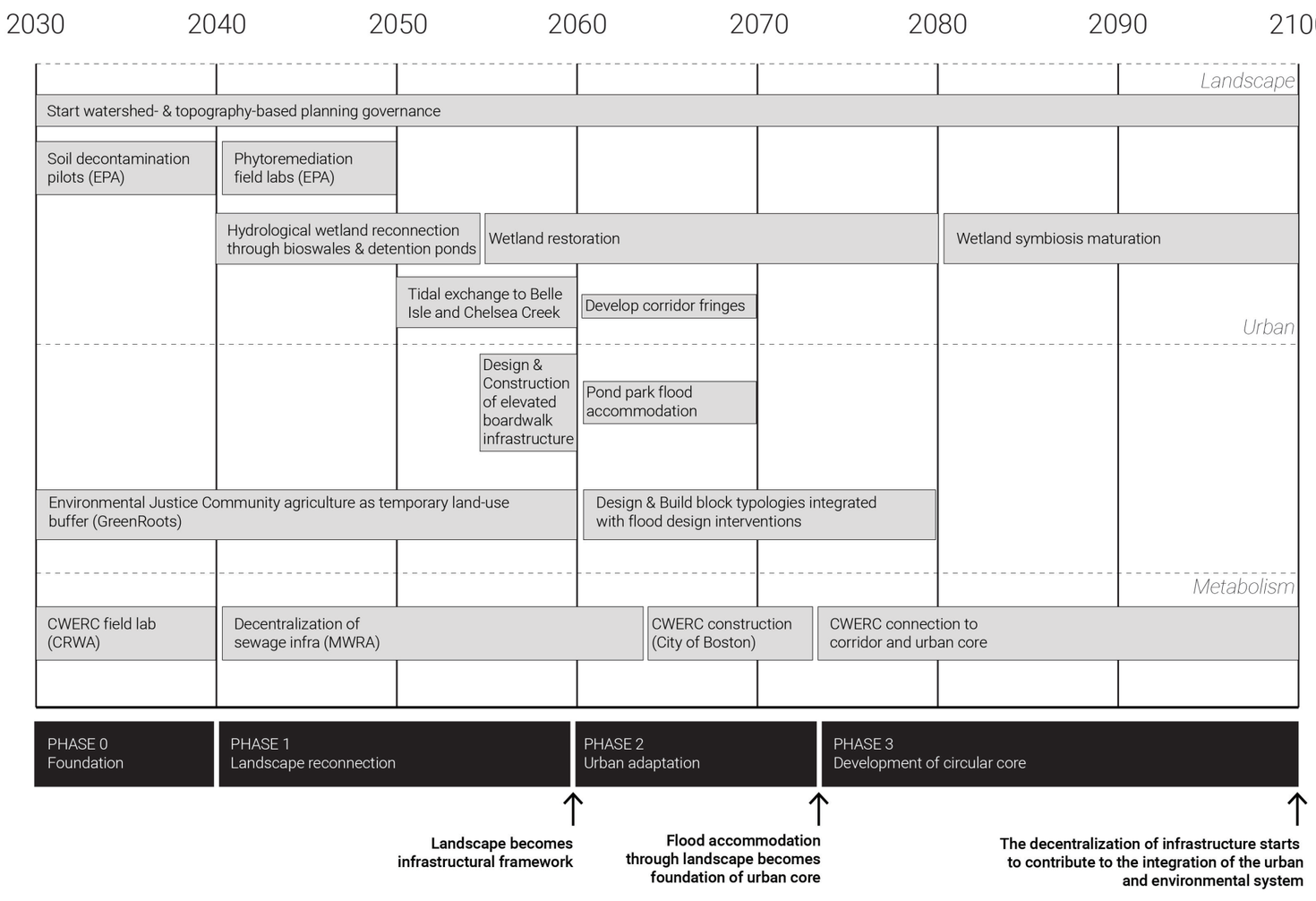


Figure 10.57 - Phasing
Made by author

Phasing

The phasing diagram reveals the prioritization according to the temporal dimension of the systemic sectional research-by-design process. The phasing sequence is based on the conceptual layering as well as the individual sections.

Phase 0 builds a stable foundation to accommodate further development. The shift towards watershed- and topography-based planning governance is a crucial and fundamental step in achieving a symbiotic relationship between the urban and environmental systems through the lens of flood resilience. Pilots and field labs in decentralized metabolic systems and soil decontamination frame the start of the transition. While land remains underdeveloped, vulnerable, and underutilized, environmental justice community groups can utilize the opportunity by temporarily allocating community gardens to enhance food security and foster social interaction.

In the first phase, landscape reconnection and restoration stand central to preparing the area for the intensified flood threats of the future. The second phase represents the start of the integration of the urban core with the environmental system to foster flood adaptation. This can only be achieved after preparing the landscape. The last phase finalizes the urban core by decentralizing sewage flows. This creates localized water, energy, and food flows.

Metropolitan implications - Integral scenario

The combination of the systemic sections, conceptual layering, and the phasing results in spatial principles that can be transferred to other sites within a similar context. The last step of the design process is to combine these elements with regional, impactful structures into an integrative scenario on the bigger scale that demonstrates the transferability of localized flood adaptation principles to the metropolitan and city scales and serves as a synthetic combination of the scenarios produced in Chapter 9.

The first set of relevant metropolitan elements of the upscaled design logic acknowledges the landscape as a foundation to steer metropolitan development in the right direction (Nijhuis et al., 2023). The explorations in the design process were deeply intertwined and based on flow accumulation patterns that are derived from topography and watershed analysis. Therefore, the experiment argues for topography and watershed-based planning to boost strategic interventions. On top of that, the flood probability maps reveal the correlation between (historic) landscape structures and flood probability. This correlation encourages wetland restoration, where possible, to increase regional flood resilience. Lastly, environmental restoration can be boosted through the lens of flood resilience by strengthening the connection between regional landscape corridors and by attempting to integrate them into the urban system where possible.

The second set of relevant elements on the metropolitan scale refers to the layered systematic approach from the design framework of the research-by-design process. First, existing engineered protection infrastructures must be acknowledged. These infrastructures should co-exist and work together with the landscape-based principles in order to create system coherence on the bigger scale. In terms of order, priority should be given to socio-economically vulnerable areas that are also identified as environmental justice tracts, since these communities experience the most complex patterns of vulnerability. Local areas that are underused or vacant can kickstart this transition through their potential as a field lab to test how urban and environmental systems can integrate, by assigning housing, promoting environmental restoration, and testing how flood design interventions can improve public space design. Existing urban cores should be retrofitted to contribute to flood resilience through local water harvesting and detention, in which the landscape can be utilized. Lastly, the dependency on centralized infrastructural systems should be decreased by promoting decentralized systems, such as CWERCs. This ensures that responsibility spreads more evenly across the region, aiming for a more equal spread of protection and risk.

In conclusion, the outcomes of research by design experiments can be scaled up to the larger scale by transforming them into a metropolitan structuring logic. Flood resilience for Metropolitan Boston lies in the ability to translate landscape performance into the organization of metropolitan systems. The research by design experiment scales outward as a transferable spatial framework, framing flood adaptation as a process of reorganization and transformation, not resistance. The integral scenario also highlights areas of priority, where the relevant elements from the integral scenario overlap, highlighting that these areas should be transformed as soon as possible.

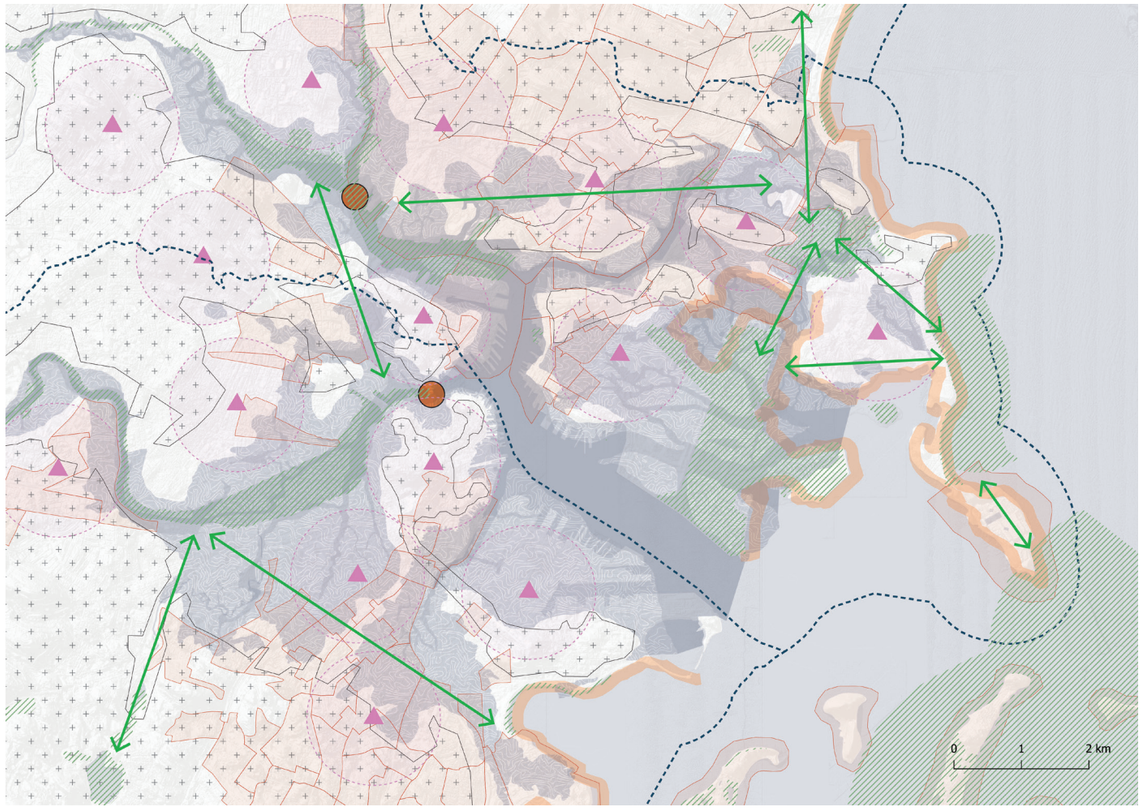


Figure 10.58 - Integral scenario
Made by author

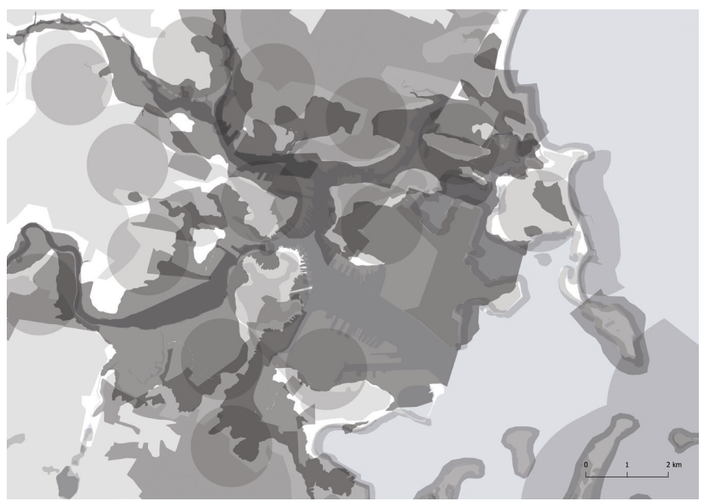


Figure 10.59 - Priority map
Made by author

11. THESIS OUTCOMES

11.1 Conclusion
11.2 Discussion
11.3 Reflection



11.1 Conclusion

In this sub chapter, The main- and subquestions are answered

Main Question:

How can landscape, understood as infrastructure, guide future scenarios of flood adaptation that strengthen the spatial and ecological relationship between water and urban life in Metropolitan Boston?

The metropolitan area of Boston is characterized by its dependence on hard, engineered infrastructures. Historical land-making activities, in combination with centralized infrastructural systems, provide a false sense of security and worsen flood vulnerability, the socio-economic unfairness in protection, and environmental degradation in the area. The one-sided reliance on a centralized, engineered flood management approach does not take the potential of the landscape into account and has little to no effect on the integration of the urban and environmental systems.

This thesis shows that water and landscape dynamics should be seen as guiding elements in the design and planning of flood-vulnerable urban environments. Future flood management should not be one-sided and overly focused on a Technocratic Fix approach. Instead, by adopting an open and multi-directional flood management approach, different interventions can reinforce the relationship between ecological systems and local flood adaptation. The scenario framework developed in this thesis helps reveal these possible pathways, showing how different configurations of flood management approaches and responsibility can guide flood-resilient futures. Such an approach makes visible the spatial correlations between soil conditions, infiltration capacity, historical land use, contamination, urban development, remediation strategies, flood management practices, and social, ecological, and economic values.

By acknowledging the correlation between the urban and environmental (sub)systems, in combination with a flood accommodating approach, landscape-based infrastructures can transform (storm)water from a hazard into a driver that enables the co-evolution of landscape, ecology, and urban life.

Subquestions:

1. What is the current condition of Boston's water and landscape infrastructures?

The current condition of Boston's water and landscape infrastructures results from historical land-making processes that define the urban landscape and allowed the metropolitan area to expand as the population grew. The use of mostly contaminated, artificial fill makes the metropolitan area prone to land subsidence, which places pressure on the state of buildings and infrastructural systems. Relative sea level rise also increases, exposing the metropolitan area to flooding.

At the same time, Boston depends on centralized infrastructural systems, including long-distance freshwater supply networks, a fully centralized sewer system that is already breaking down, and an external energy supply. While these systems accounted for urban expansion, they are now aging and reaching the end of their lifespan. The centralization of infrastructural systems creates vulnerabilities, and failures can have region-wide impacts.

Historically, these systems also encouraged urban development in flood-prone areas. Large dams, pipes, and engineered shorelines created a false sense of security, while the underlying risks continued to grow. As a result, vulnerability today is layered: environmental, infrastructural, and socio-spatial. Flood exposure increases not only because of climate change but also because the infrastructures designed to manage water are becoming less reliable.

Finally, a disconnection between the environmental and urban systems is found. Wetlands, rivers, and habitat cores have been fragmented by highways, dams, and other infrastructural networks, weakening natural water regulation and contributing towards environmental degradation. This results in the reduction of the hydrological function of the landscape, making ecosystems and communities more exposed to flooding, water pollution, and habitat loss.

2. What are the (spatial) implications of extreme water scenarios, caused by climate change, in Metropolitan Boston?

The spatial implications of extreme water scenarios reveal how climate change contributes to a bigger flood vulnerability in Metropolitan Boston. Increasing temperatures and a warming ocean lead to more frequent and more intense storms, nor'easters, hurricanes, and heavy rainfall events. The Northeastern United States is experiencing a rising trend in extreme weather, which directly increases the probability of both coastal and inland flooding.

Coastal storm surge models for 2030, 2050, and 2070 clearly illustrate how flood probability expands over time. Over time, filled-in land and low-lying areas return to conditions similar to their pre-land-making state. This shows the correlation between flood probability and the historic morphology of the landscape. Existing shoreline barriers and engineered protections cannot keep up forever, especially as many of these structures reach the end of their lifespan.

The analysis of the river systems in Boston shows that the Charles River Natural Valley Storage areas still buffer upstream catchments, while the Charles River Dam and Amelia Earhart Dam protect the urban fabric from storm tides and riverine floods. However, their effectiveness becomes more uncertain as extreme events intensify, and water levels rise.

Pluvial floods are intensified, caused by Boston's urban development, which has replaced natural infiltration with impermeable surfaces, increasing runoff and delocalizing water cycles by capturing almost all water into pipes. During extreme rainfall, stormwater cannot infiltrate, which increases runoff, overwhelms sewer capacity, and causes street-level flooding.

3. How do social, ecological, and infrastructural vulnerabilities intersect within Boston's flood-prone areas?

The relationship between socio-economic vulnerability and flood-prone areas in Metropolitan Boston is investigated in the spatial analysis. Low-income households, communities living under the federal poverty line, and neighborhoods with high unemployment rates cluster in specific parts of the urban fabric, especially in East Boston, Dorchester, Roxbury, Chelsea, and parts of Revere. The analysis reveals how poverty, lack of education, and linguistic isolation intensify in these same census tracts, reinforcing their sensitivity to floods. Historically, these neighborhoods are categorized as under invested. This contributes to patterns of vulnerability and even segregation, based on the racial distribution in the metropolitan area.

When this socio-economic geography is compared to the vulnerability scorecards, the intersection becomes clearer. High social vulnerability closely aligns with high coastal and inland flood vulnerability. In summary, socio-economic vulnerabilities and flood risks reinforce one another in Metropolitan Boston. Historically underinvested and racially segregated communities are disproportionately located in flood zones. Based on these findings, flood risk in Boston is not only a spatial or environmental problem, but also contributes to complex patterns of vulnerability.

4. What future scenarios can be developed to explore how landscape-based infrastructures could mediate between flood dynamics and urban development?

Together with the clustering of design interventions, the popular elements of reality elaborate on the interpretive observations that describe current flood management practices. Instead of projecting statistical trends, they capture the dominant patterns that shape decision-making today. The scenarios explore the different flood management focuses (engineered – environmental) in combination with the type of responsibility (centralized – decentralized): Technocratic Fix, Eco-centrism, Patchwork Engineering, and Poly-centric Adaptation. Each scenario proposes a different relationship between governance, infrastructure, and landscape. All scenarios also come with their own advantages and limitations, whether in terms of spatial coherence, equity, flexibility, or environmental integration.

The clustering of the design interventions and construction of scenarios that determine the 'playing field' of future flood management in Boston reveals that there is not one single, universal way of flood management that can fully address the complexities of floods in the Metropolitan area of Boston. The different clusters and sub-groups confirm this statement. These clusters highlight the diversity of ways in which landscapes and infrastructures mediate between water and the urban fabric.

Overall, the scenarios demonstrate that future flood management must be understood as an open and multi-directional. The scenarios offer a framework for combining the strengths of different strategies. In this way, the scenarios support the search for integrated approaches where engineered interventions, ecological systems, and local adaptations reinforce each other rather than operate in isolation.

5. How can these scenarios be spatially translated into design strategies that reconnect urban form with its underlying land- and waterscapes?

The spatial translation of the scenarios starts with a local scale analysis that highlights the importance of water and landscape dynamics in the site. Historical hydrology maps show the lost connection between wetlands and drainage patterns that, if overlaid with

current water accumulation flow and topographic index analyses, still align with the current situation. Because of this, water and landscape dynamics are identified as guiding elements in the research by design process.

The synthesis of the local scale analysis leads to the investigation of an ecological stormwater park, where the urban and environmental systems are integrated. Historical land use patterns, industrial contamination, mobility barriers, and topography are not isolated: they are used to generate a design logic where environmental processes shape the spatial structure of the intervention. The design framework makes this relationship explicit by organizing the design into interrelated subsystems.

The Soil and Substratum layer informs the design process of the soil characteristics, as a result of historical land-making activities and contamination. This informs decisions on remediation and infiltration potential. The Water and Landscape Dynamics layer is based on the buffering, conveyance, and storage capacity of the site, based on flow accumulation and topographic index analyses. The Performance and Use layer positions the stormwater park as a social, ecological, and productive landscape. The Operational Networks layer connects metabolic, human, and ecological flows with new urban development and its water, energy, and soil systems. Together, these layers form a dynamic system where urban and environmental logics continuously influence each other.

The sectional systems exploration shows how the interrelated subsystems are spatialized and how the environmental and urban systems meet each other through the implementation of design interventions and street profiles. The reconnection of wetlands through bioswales, ponds, and boardwalks combines flood resilience, remediation strategies, and historic industrial use with public space. The Suffolk Downs transformation demonstrates how new urban blocks can accommodate water through the localization of water cycles, water harvesting, the integration of floodable public space, and the retrofitting of buildings. The Circular Core shows how decentralized water and energy systems can operate within the landscape, enhancing resilience while creating productive relationships between urban development and ecological processes.

Lastly, the combination of the conceptual layering diagram, phasing, and the integral scenario shows how to distill design strategies from the research-by-design experiment and apply them onto the metropolitan scale.

In summary, the scenarios are translated into design strategies by combining historical hydrology, soil conditions, water flow patterns, and urban form into a coherent spatial logic. The result is a set of landscape-based strategies that reconnect the city to its underlying land and waterscapes, not by replicating historical conditions, but by using them to guide new forms of flood-resilient urbanism.

11.2 Discussion

In the discussion, the outcomes are critically reviewed, taking into account their interpretations, implications, and limitations.

The outcomes suggest that flood adaptation in Metropolitan Boston is not limited to hydraulic engineering and flood protection infrastructure. The thesis stresses the relevance and influence of spatial systems on flood adaptation, such as urban development causing environmental degradation, socio-economic inequalities, and disturbed landscapes; climate change contributing to intensified extreme water scenarios in the future; and the state and centralization of infrastructural systems. These spatial systems reveal that protection measures and resistance against floods are insufficiently addressing the effects of floods on urban environments.

The research-by-design process addresses these spatial systems and showcases how, through landscape integration, urban design enables the integration of the spatial systems and flood adaptation. The integrative scenario suggests that future flood resilience is based on the hybrid, co-existence of flood infrastructure and landscape capacity.

The relevance of the results lies within the integration of the concept of resilience into the spatialization of the spatial system mentioned above, instead of framing it as a final step after urban developments. The Metropolitan area of Boston grew through artificial landfill construction that ignored original wetlands, marshes, and other landscape structures. The thesis argues that landscape performance must be embedded within flood adaptation practices.

The project also matters within a broader urbanism debate. Housing shortages, limited space, infrastructure renewal, and productive (energy) landscapes are putting pressure on the current urban fabric globally. The research-by-design process explores the multifunctionality of flood adaptation within urban design and landscape architecture to become a multi-purpose spatial system. This also reveals that climate resilience futures will spatialize where urban growth can occur in the metropolitan area, simultaneously determining where the landscape must take over.

The project results also have their limitations. While the thesis provides spatial direction, its feasibility is bounded by systemic constraints. The proposed hybrid resilience logic assumes a metropolitan coordination capacity that does not yet exist in Boston's institutional organization. Without governance reform, long-term land use plans, and funding programs, decentralized landscape infrastructures risk becoming spatial concepts that are operationally vulnerable.

The long-term performance of interventions is uncertain, caused by the absence of engineering and environmental modeling. These models are highly complex and concern tidal dynamics, flood simulations, and the ecological capacity of the landscape to deal with different flood intensities.

Besides this, the financial, institutional, and jurisdictional feasibility is not deeply studied within the project. The reconnection and restoration of (historic) wetlands requires modifications in current national zoning laws, environmental policy, and legislation. Within the context of the local site, the Designated Port Areas (DPA) present the first policy & zoning law changes. To implement these changes, a reorganization of governance is required, which is not explored in this project. On top of that, the political dimension and resistance that could occur are recommended directions for further research.

Finally, a potential consequence of the transformation concerns displacement issues. The integration of the urban and environmental system requires the landscape to enter the existing urban system. Land allocation for these structures and the other interventions that are explored puts pressure on the existing urban fabric. This conflict is crucial, since it usually concerns the risk of displacement of the most vulnerable groups within the metropole. Within the thesis, the integration of landscape and urban systems means densification elsewhere in the metropole. However, this assumption is not explored deeply within the project. Moreover, the creation of a new urban core that co-exists with the landscape risks high property value, which displaces locals and contributes to gentrification, which is an existing problem in many communities within the metropolitan region of Boston. Further research should prioritize deeper investigation into displacement issues and how to counter gentrification within the context of landscape integration for flood accommodation.

11.3 Reflection

1. How do you see the relation between your graduation project topic, the studio topic, your master's track (Urbanism), and your master's program?

This thesis explores landscape-based infrastructural futures for flood adaptation in Boston. It starts from a personal fascination with water and landscape, and the objective of integrating the environmental system within the urban system (and the other way around). By treating floods as a lens to read and redesign the relationship between soil, topography, hydrology, ecology, and urban form, the project positions itself within the context of climate adaptation by accommodating water instead of fighting it through a technocratic fix.

Consequently, this aligns closely with the Metropolitan Ecologies of Places studio, which focuses on socio-economic and ecological transitions in urban areas under climate stress. In the context of Boston, the vulnerable urban fabric, historic land-making processes, and uneven exposure to flood risk are explored. The project contributes to the studio's ambition to understand climate adaptation not only as technical protection, but as a spatial, social, and ecological reconfiguration of urban landscapes.

Within the Urbanism track, the project reflects the tradition of integrating urban design, landscape architecture, planning, and engineering into multi-scalar, systemic research & design. The project embodies the Architecture, Urbanism and Building Sciences programme's emphasis on research by design and its aim to develop innovative, cross-disciplinary approaches for sustainable and resilient urban development in the future.

2. How do you see the relation between research and design in your graduation project?

The relationship between research and design has shaped the entire development of my graduation project. In the beginning, the analytical phase felt very research-oriented, as I worked through the first three sub-questions using mapping, literature, and field observations. This helped me understand the complexity of flood adaptation in Metropolitan Boston and made me realize that I was dealing with a complex problem, caused by the multifaceted and entangled nature. The more I uncovered about the relationships between hydrology, land-making, socio-economic vulnerability, and infrastructure, the harder it became to define the problem clearly. This made me aware that a linear or purely analytical approach would not be a suitable approach to advance. This is where the research by design methodology came into play. The use of the design process as a tool led to new knowledge. Using the scenarios to realize that there is not one way of dealing with floods, in combination with the systemic section exploration, led to new insights. This interesting but also challenging correlation between research and design made the process feel uncertain and even a bit procedural. This led to moments when I realized I did not always fully know what the next step was. Looking back, those moments were important because they showed me that uncertainty is part of the process and that new understanding can emerge whilst combining research and design.

Throughout the project, design informed the research as much as research informed the design. This iterative exchange allowed the project to evolve beyond fixed solutions and toward a more exploratory understanding of how landscape-based infrastructures and urban development could deal with floods in the future. For me, this has been the most valuable aspect of the project: learning how research and design can reinforce each other, and how designing can become a way of thinking, questioning, and discovering.

3. What do you see as the value (and limitations) of your way of working: your approach, your used methods?

The values and limitations of the project were closely related to each other throughout the process. Starting with a regional analysis helped me build an evidence-based understanding of Boston's water and landscape infrastructures. This gave me a strong foundation before moving toward the city and neighborhood scales. The analytical work allowed me to frame the problem and discover the multi-faceted nature of floods in urban environments, and helped me understand flood adaptation. The fieldwork became an important step in the transition from analysis toward the design phase. Observing the sites, speaking with people, and documenting through photography allowed me to evaluate my desk-based findings and connect small observations to larger systemic patterns. The fieldwork journal helped me to connect the analytical findings to each other and to develop the narrative of the project, and it was during the fieldwork that I discovered the concept and importance of historic hydrology for my thesis. Another value of my method the experimentation by developing scenarios, clustering design interventions, working in sections, and bringing it all together. This contributed to the progression of the project and made connections visible that I did not notice at the start of the year.

At the same time, I became aware of several limitations in my way of working. Spending a relatively long time in the analytical phase meant that I had less time to fully develop the design. In the beginning, I adopted more of a linear approach to the project, which was not suitable. Sometimes I felt that the transition between the two phases could have been more balanced. There were moments where my process became 'procedural', and I did not always know what the next step was. This led me to spend time on elements that I eventually did not use. I also struggled at times with positioning myself within the project. In the beginning, I approached the work from a helicopter perspective, without clearly expressing my standpoint. Another challenge was finding a balance between evidence-based argumentation and interpretation, especially when working with uncertainty and future scenarios. I also think that the project could have benefited from a three-dimensional design approach, whereas I noticed that I work mainly in 2D.

Working iteratively, dealing with uncertainty, and navigating complexity means accepting that the process is not linear. The project taught me how to work within that reality and how to let methods evolve as you dive deeper into the topic of research.

4. What are the academic and societal value, scope and implications of your graduation project, including ethical aspects?

The societal relevance of my project lies in addressing the complex patterns of vulnerability caused by land-making history, socio-economic vulnerability, the spatial dimension of flood probability, and the aging infrastructural systems in certain areas in Metropolitan Boston. By working with landscape as a spatial system that can accommodate water, the project reframes adaptation as both an ecological and social task. This thesis argues that resilience strategies should not only reduce risk but also contribute to more inclusive and livable urban environments.

Academically, the project contributes to the academic discourse within urbanism and landscape architecture by showing how research by design can be used to integrate the urban and environmental system. The thesis extends the landscape-as-infrastructure discourse and applies it within the urban fabric of Metropolitan Boston.

From a professional perspective, the project deals with contemporary challenges like climate adaptation, aging water infrastructures, and the need to rethink hard-engineered protection. The scenarios and design strategies developed can support planning agencies, resilience offices, and designers working on flood adaptation, especially in the U.S. East Coast region.

The project also carries ethical considerations. Flood vulnerability in Boston overlaps with environmental justice zones, meaning that decisions about water, land, and protection have direct implications for communities that already face social and economic pressures. Designing with water raises questions about who is vulnerable in the current as well as the future, relating to displacement and relocation issues. The project made me aware that adaptation must not become an excuse for sacrifice zones.

5. How do you assess the transferability of your project results?

The transferability of my project results depends on the level at which they are interpreted. The design proposals themselves are strongly connected to the specific context of Metropolitan Boston, particularly the proximity of Belle Isle Marsh, the characteristics of the artificial fill, the topography, and the existing land use patterns. These site-specific conditions shaped the design direction and, therefore, make the final spatial outcome less directly applicable to other locations. The North American planning framework, the history of land-making, and the socio-economic realities of Boston also differ from the Dutch context, which means that the project cannot be translated one-to-one.

However, the design process and methodology are more transferable. Many flood-vulnerable urban areas in the Global North, especially where urban development has become disconnected from ecological systems and where planning and management rely heavily on engineered flood interventions. The combination of regional analysis, spatial vulnerability assessment, and landscape-based design experimentation can be used in other metropolitan settings facing climate risks, infrastructural aging, and uneven exposure to flooding. For me, the value of the work lies more in the approach than in the final form.

The project highlights how research by design can reveal relationships between water, landscape, and urban form, and how iterative experimentation can help explore adaptation as both an ecological and social transformation. These insights are transferable to contexts where adaptation must navigate uncertainty, competing interests, and layered vulnerabilities. At the same time, applying the methodology elsewhere would require sensitivity to local governance structures, communities, and cultural relationships to water.

Overall, I see the project as a reference for how to work, think, and design within complex climate adaptation contexts, rather than a template for what

the outcome should look like. The methods can travel, but the interventions must be rooted in place.

6. How has working in a North American context influenced the development of my thesis?

I saw this thesis as a valuable opportunity to work in a different context than what I am used to. This has had a significant impact on the development of the thesis. The first aspect that stimulated the development of the analytical subquestions, was the significant availability of geospatial and historical data. This supported the evidence-based aspect of the project and helped me understand patterns that might have remained invisible in a context with more restricted data access. However, it took some time to acquire and interpret the data, since the data storage and organization are completely different from the Dutch context. This slowed me down in the beginning, but also taught me how to be able to acquire almost all the data that you need in an unfamiliar context with the help of some creativity.

The North American context also exposed me to a different relationship between flood management, governance, and socio-economic inequality. In Boston, historic land-making, insurance systems, and the state of infrastructural systems have contributed to disparities in protection. This made the issue of climate injustice more explicit than I was used to, even though I am sure that this also happens in Europe. It influenced the way I approached adaptation as both a spatial and ethical concern. It helped me recognize that resilience is not only about water, but also about who is most affected, who is protected, and who participates in decision-making.

Another element that shaped the project was the literature on aging infrastructural systems in North America in combination with my own findings. The narrative of aging and centralized infrastructural systems and how they correlated to flood risk strengthened my focus on landscape-based infrastructures as an alternative. It pushed the project toward exploring how environmental systems can complement or replace failing engineered approaches, and how adaptation can become an opportunity to rethink urban-environmental relationships. Working in a context that I am not part of also made me more conscious of my own position as a designer. It required me to avoid making assumptions based on my own experiences. This awareness added depth to the project. In that sense, working in the North American context not only shaped the content of the thesis but also the way I approach research and design.

7. How did I learn to navigate moments of uncertainty and lack of clarity in the design process, and how has this influenced my development as an urbanist?

Looking back at last February, I started this graduation year without a proper plan for what I wanted to do. Over the course of a year, this project started as a small idea and has been transformed into a real thesis, paired with a lot of confusion. Navigating this uncertainty or lack of clarity became a recurring obstacle in the process. At times, I did not clearly know how to advance, and I struggled with making decisions, leading to a more procedural way of working. This occasionally led me to put my time into things that did not help me move forward. Even if it would help me forward, I was not aware of the steps that I have been taking in the right direction. Initially, this made me question whether I was progressing in the right direction. Looking back, these moments exposed the nature of research-by-design, where understanding does not always precede action, but often emerges through it.

Learning to work within this uncertainty caused me to change the way I approached the project. Instead of waiting for clarity, I had to simply start and dive into the topic as a way to create understanding. This helped me move from a distant helicopter view toward a more grounded and situated position. It also made me more comfortable with the idea that complexity cannot always be resolved, but can be worked with.

This experience has influenced my development as an urbanist by teaching me to trust the iterative process and to accept that clarity often arrives little by little. It strengthened my ability to make decisions without having all the answers and helped me understand that design can function as a method of inquiry rather than only as an output. It also made me more aware of the value of reflection, self-positioning, and interpretation during the process. In the future, I will feel more confident navigating complex projects like these, knowing that uncertainty can be productive when approached with curiosity, patience, and critical awareness.

12. BIBLIOGRAPHY



Aero Scenic Airviews Co. (Boston, Mass.). (1939). Suffolk Downs race track [Photograph]. Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/vd66zq37z

Albers, P. P., & Evers, M. (2024). Assessing Flood Risk: Identifying Indicators and Indices for Period-Specific Flood Measures. EGUsphere. https://doi.org/10.5194/egusphere-2024-2534

Alehashemi, A., Mansouri, S., Barati, N. (2017). Landscape infrastructure; A new concept for urban infrastructures in 21st century. Bagh-e-Nazar. 13. 5-18.

American Community Survey. (2019). Demographics & Ethnicity. [Dataset]. Via Climate and Economic Justice Screening Tool. Retrieved from https://edgi-govdata-archiving.github.io/j40-cejst-2/en/downloads/

American Community Survey. (2019). Linguistic isolation. [Dataset]. Via Climate and Economic Justice Screening Tool. Retrieved from https://edgi-govdata-archiving.github.io/j40-cejst-2/en/downloads/

American Community Survey. (2019). Low median income as a percentage of the area's median income. [Dataset]. Via Climate and Economic Justice Screening Tool. Retrieved from https://edgi-govdata-archiving.github.io/j40-cejst-2/en/downloads/

American Community Survey. (2019). The percentage of individuals of 25 years and older with less than a high school degree. [Dataset]. Via Climate and Economic Justice Screening Tool. Retrieved from https://edgi-govdata-archiving.github.io/j40-cejst-2/en/downloads/

Applied Geographics & MWRA Sewerage Division. (1998). MWRA Sewerage System. Boston Public Library: Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:f1886n550

Bélanger, P. (2016). Landscape as Infrastructure. In Routledge eBooks. https://doi.org/10.4324/9781315629155

Bélanger, P. (2010). Redefining infrastructure. Published in Ecological Urbanism edited by Mohsen Mostafavi and Gareth Doherty (Baden, Switzerland: Lars Müller Publishers, 2010): 332-349. https://www.academia.edu/128220743/REDEFINING_INFRASTRUCTURE

Berger, A. M., Wilson, M., Susskind, J., & Zeckhauser, R. J. (2020). Theorizing the resilience district: Design-based decision making for coastal climate change adaptation. Journal of Landscape Architecture, 15(1), 6–17. https://doi.org/10.1080/18626033.2020.1792648

Boston. (1858). Photograph of loading gravel train in Needham, negative #15757-B. Retrieved from Gaining ground: A History of Land-making in Boston.

Boston (Mass.). (1909). 132 Marginal Street, East Boston. [Photograph]. Retrieved from https://cityofboston.access.preservica.com/uncategorized/IO_d5679a0a-8d19-40d0-b2de-5e4921fd138d/

Boston (Mass.). Park Commissioners. (1876). Proposed parks and parkways [Map]. Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/js956k85m

Boston (Mass.). Transit Commission. (1915, June 18). Dorchester tunnel section H Dorchester Avenue trench north of Woodward Street [Photograph]. Retrieved from https://cityofboston.access.preservica.com/uncategorized/IO_c3c1dc0e-8615-4594-b863-77376084bcfa/

Boston (Mass.). Water Board, & D. W. (David W.) Butterfield. (1893). Sudbury Department, Lake Cochituate, Outlet Dam, Framingham, Mass., 1893 [Photograph]. Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/4j03d417q

Boston (Mass.). Water Board, & L. Black & Co. (1878). Sudbury Department, Sudbury Aqueduct, Waban Bridge, Wellesley, Mass., ca. 1878 [Photograph]. Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/nc580q27s

Boston Olde South Publishing Company (1992). Birds-Eye Boston: An Axonometric Rendering of the City in 1992. With 1630 shoreline and some labels added. (Courtesy of Kane Maps). Retrieved from Gaining ground: A History of Land-making in Boston.

Boston Society of Civil Engineers Section. (2024, December 19). Historic New England infrastructure: the Great Spring [Photograph]. https://www.bsces.org/news/historic-new-england-infrastructure-the-great-spring/

Boston Water & Sewer Commission (BWSC). (2017). Extreme Precipitation Events. [Graph]. In Climate Resiliency Guidance – Boston Planning & Development Agency. Retrieved from https://www.bostonplans.org/getattachment/5d668310-ffd1-4104-98fa-eef30424a9b3

Boston Water & Sewer Commission (BWSC). (2024). 2024 Stormwater Management Report. https://www.bwsc.org/sites/default/files/2025-02/Stormwater%20Management%20Report%202024.pdf

Boston Water and Sewer Commission (BWSC). (n.d.). Water system. https://www.bwsc.org/environment-education/water-sewer-and-stormwater/water-system

Central Transportation Planning Staff. (2023). Transport infrastructure. [Dataset]. Retrieved from https://www.mass.gov/info-details/massgis-data-massgis-massdot

Charles River Watershed Association. (2022). A river interrupted. ArcGIS StoryMaps. https://storymaps.arcgis.com/stories/62917edcb76c4e10868cbb7a79638282

Charles River Watershed Association. (2023). Impacts of Dams on the Charles River Ecosystem. [Image]. ArcGIS StoryMaps. https://storymaps.arcgis.com/stories/62917edcb76c4e10868cbb7a79638282

City of Boston. (2023). Resilient Boston Harbor Vision. Boston.gov. https://www.boston.gov/environment-and-energy/resilient-boston-harbor

Civil Protection Knowledge Network. (2024). Catalogue of best practices for building flood resilience. https://civil-protection-knowledge-network.europa.eu/media/catalogue-best-practices-building-flood-resilience

Clark, E. (2024). During a coastal flooding warning in January, cars traveled through flood waters along Atlantic Avenue. [Photograph]. Boston Globe. Retrieved from https://www.bostonglobe.com/2024/04/05/science/boston-sea-level-rise-real-estate-development-slowdown/

Commonwealth of Massachusetts – MassGIS. (n.d.). Statewide Vector Data. [Dataset]. Retrieved from https://www.mass.gov/forms/massgis-request-statewide-vector-data

Commonwealth of Massachusetts – MassGIS. (2011). Tidelands Jurisdiction (M.G.L. c.91). [Dataset]. Retrieved from https://www.mass.gov/info-details/massgis-data-tidelands-jurisdiction-mgl-c91-datalayers

Corner, J. (2006). Terra Fluxus. in C. Waldheim, The Landscape Urbanism Reader (pp. 21-33). New York: Princeton Architectural Press.

CRWA Archives. (1964). Fish death. [Photograph]. Retrieved from https://storymaps.arcgis.com/stories/62917edcb76c4e10868cbb7a79638282

Curtis, G. C. (with New York Public Library). (1900). A description of the topographical model of metropolitan Boston. Boston: Wright & Potter. http://archive.org/details/descriptionoftop00curt

Davenport, F. V., Burke, M., & Diffenbaugh, N. S. (2021). Contribution of historical precipitation change to US flood damages. Proceedings of the National Academy of Sciences, 118(4). https://doi.org/10.1073/pnas.2017524118

Davoudi, S., Brooks, E., & Mehmood, A. (2013). Evolutionary Resilience and Strategies for Climate Adaptation. Planning Practice & Research, 28(3), 307–322. https://doi.org/10.1080/02697459.2013.787695

Decennial Census. (2020). Disadvantaged communities. [Dataset]. Via Climate and Economic Justice Screening Tool. Retrieved from https://edgi-govdata-archiving.github.io/j40-cejst-2/en/downloads/

Decennial Census. (2020). The percentage of individuals who fall under the federal poverty line. [Dataset]. Via Climate and Economic Justice Screening Tool. Retrieved from https://edgi-govdata-archiving.github.io/j40-cejst-2/en/downloads/

Decennial Census. (2020). Unemployment rate. [Dataset]. Via Climate and Economic Justice Screening Tool. Retrieved from https://edgi-govdata-archiving.github.io/j40-cejst-2/en/downloads/

Department of Transportation (DOT). (2022). Transportation barriers. [Dataset]. Via Climate and Economic Justice Screening Tool. Retrieved from https://edgi-govdata-archiving.github.io/j40-cejst-2/en/downloads/

Division of Marine Fisheries. (2023). MassGIS Data: Diadromous Fish. [Dataset]. Retrieved from https://www.mass.gov/info-details/massgis-data-diadromous-fish

Dryzek, J. S. (2005). The politics of the Earth: Environmental discourses (2nd ed.). Oxford University Press.
European Space Agency (2024). Copernicus Global Digital Elevation Model. Distributed by OpenTopography. https://doi.org/10.5069/G9028PQB. Accessed: 2025-05-09

Environmental Protection Agency. (2014). Greening CSO plans: Planning and modeling green infrastructure for combined sewer overflow (CSO) control. https://www.epa.gov/sites/default/files/2015-10/documents/greening_cso_plans_0.pdf

Fairchild Aerial Surveys, inc. (1925). East Boston [Photograph]. Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/8k71nx91m

Fiore, C., Breiteneicher, D., & Murphy, C. A. (2023). Energy Matters: MWRA Perspective. 31(1). Civil Engineering Practice. Retrieved from https://www.bscesjournal.org/wp-content/uploads/BSCES-Civil-Engineering-Practice-Summer-2023-11.pdf

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). ADAPTIVE GOVERNANCE OF SOCIAL-ECOLOGICAL SYSTEMS. Annual Review of Environment and Resources, 30(1), 441–473. https://doi.org/10.1146/annurev.energy.30.050504.144511

Gahagan, B.I. & Bailey, M.M. (2020). Surgical Implantation of Acoustic Tags in American Shad to Resolve Riverine and Marine Restoration Challenges. Mar Coast Fish, 12: 272-289. https://doi.org/10.1002/mcf2.10108

Godin, D., & Zahedi, M. (2014). Aspects of Research through Design: A Literature Review.

Hajer, M., & Dassen, T. (2014). Smart about cities: Visualising the challenge for 21st century urbanism. Rotterdam: NAI Publishers.

Hajer, M. A. (1995). The politics of environmental discourse: Ecological modernization and the policy process. Oxford University Press.

Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. Nature Climate Change, 3(9), 802–806. https://doi.org/10.1038/nclimate1979

HARVARD GRADUATE SCHOOL OF DESIGN. (2024). Laredo resilience project.https://rgisc.org/wp-content/uploads/2024/06/laredo-resilience-project-1a.pdf

Hills, J. (ca. 1770–1779). Boston Harbour, with the surroundings, [Map]. Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:t722hs68s

Holling, C. S. (1996) Engineering resilience versus ecological resilience, in: P. C. Schulze (ed.).Within Ecological Constraints, pp. 31–45 (Washington, DC: National Academy Press).

Holling, C.S. & Meffe, G.K. (1996). Command and Control and the Pathology of Natural Resource Management. Conservation Biology, 10: 328-337. https://doi.org/10.1046/j.1523-1739.1996.10020328.x

Home Owners' Loan Corporation (HOLC). (2021). Tracts that have experienced historic underinvestment. [Dataset]. Via Climate and Economic Justice Screening Tool. Retrieved from https://edgi-govdata-archiving.github.io/j40-cejst-2/en/downloads/

Hooimeijer, F. L., Yoshida, Y., Bortolotti, A., & Iuorio, L. (2022). Integrated urban flood design in the United States and the Netherlands. In S. Brody, Y. Lee, & B. Kothuis (Eds.), Coastal Flood Risk Reduction: The Netherlands and the U.S. Upper Texas Coast (pp. 241-254). Elsevier. https://doi.org/10.1016/B978-0-323-85251-7.00018-4

Hopkins, J. (n.d.). Fish Ladder. [Photograph]. Retrieved from https://storymaps.arcgis.com/stories/62917edcb76c4e10868cbb7a79638282

Hopkins, J. (2021). NVSA wetlands naturally storing flood water after a week of intense rain in Medfield/ [Photograph]. Retrieved from https://storymaps.arcgis.com/stories/6a2c80a73cd143d0a6eaa795bc53eace

Iuorio , L., & Kanj, T. (2025). Editorial . Journal of Delta Urbanism, (5). https://doi.org/10.59490/jdu.5.2024.8151

Jensen, O. P., Vastano, A. R., Allen, M. C., Hernandez, M. F., Lockwood, J. L., Vasslides, J. M., & Weldon, O. (2024). Migratory passage and run size of American Shad and river herring in the Raritan River, New Jersey, USA. Transactions of the American Fisheries Society, 153(3), 289–300. https://doi.org/10.1002/tafs.10467

Jet Commercial Photographers (Boston, Mass.). (1979, November 5). Aerial view of Northeastern's campus and the Back Bay Fens [Photograph]. Retrieved from http://hdl.handle.net/2047/d20160692

Jha, A. K., Bloch, R., & Lamond, J. (2012). Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century. World Bank Publications.

Jones, L. (1995, July 1). Boston, Deer Island, wastewater treatment plant [Photograph]. Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/8c97pg33t

Jones, L. (1940). Island in Jamaica Pond [Photograph]. Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/8c97n3722

Kempe, M. (2006). 385 years of drinking water, 125 years of New England Water Works Association. 120(3), 158. https://www.mwra.com/media/file/kempe-historypaper-all

Laidlaw, S., Percival, S. (2024). Flood resilience: a review of evolving definitions. Nat Hazards 120, 10773–10784. https://doi.org/10.1007/s11069-024-06627-9

Lambert, A. (2024). Ecocentrism. https://www.ebsco.com/research-starters/science/ecocentrism

Laskey, F. A. (2014). A History of Boston's Water System. UMass Amherst. https://www.mwra.com/sites/default/files/2023-11/040314-water-history-umass.pdf

Leopold, A. (1949). A sand county almanac and sketches here and there. Oxford, UK: Oxford University Press.

Liao, K. (2012). A theory on urban resilience to floods—a basis for alternative planning practices. Ecology and Society 17(4): 48. http://dx.doi.org/10.5751/ES-05231-170448

MA Executive Office of Energy and Environmental Affairs. (2023). New England Electrical Transmission Substations. [Dataset]. Retrieved from https://czm-moris-mass-eoeea.hub.arcgis.com/datasets/new-england-electrical-transmission-substations/explore?location=42.392689%2C-70.986192%2C10.72

Map Works, Inc. (1999). Boston shoreline 1630. [Map]. Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:q524n430n

Map Works, Inc. (1999). Boston shoreline 1795. [Map]. Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:q524n4326

Map Works, Inc. (1999). Boston shoreline 1852. [Map]. Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:q524n434r

Map Works, Inc. (1999). Boston shoreline 1880. [Map]. Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:q524n4369

Map Works, Inc. (1999). Boston shoreline 1916. [Map]. Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:q524n438v

Map Works, Inc. (1999). Boston shoreline 1934. [Map]. Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:q524n440w

Map Works, Inc. (1999). Boston shoreline 1950. [Map]. Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:q524n442f

Map Works, Inc. (1999). Boston shoreline 1995. [Map]. Norman B. Leventhal Map & Education Center. https://collections.leventhalmap.org/search/commonwealth:q524n4440

Massachusetts Department of Environmental Protection (MassDEP). (2025). FINAL 2025 INTENDED USE PLAN FOR THE CLEAN WATER STATE REVOLVING FUND. Commonwealth of Massachusetts – Executive Office of Energy & Environmental Affairs. Retrieved from https://www.mass.gov/doc/2025-final-clean-water-intended-use-plan/download

Massachusetts Infrastructure Investment Coalition (MIIC). (2007). Infrastructure Status Report: Massachusetts Wastewater Facilities. Volume 4. Number 1. Retrieved from https://files.engineers.org/file/Infrastructure-Status-Report-on-Waste-Water.pdf

Massachusetts Metropolitan District Water Supply Commission & Louis G. Albertine. (1945, August 27). Quabbin Reservoir, looking northerly from the Administration Building, water elevation 520.02, Quabbin Reservoir, Mass., Aug. 27, 1945 [Photograph]. Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/0z709151w

Massachusetts Office of Dam Safety. (2012). Dams in Massachusetts [dataset]. Retrieved from https://www.mass.gov/info-details/massgis-data-dams

MassGIS. (1995). Aerial imagery of Massachusetts from the 1990s. https://www.atlascope.org/. https://atlascope.org/#/view:share$mode:glass$center:-70.997820,42.391719$zoom:14.38$base:maptiler-streets$overlay:massgis-1990s-orthos

Meng, M., Dabrowski, M. M., & Stead, D. (2022). Four clusters of thought on flood resilience and climate adaptation: The state of the art and new directions for spatial planning. In R. Rocco, G. Bracken, C. Newton, & M. Dabrowski (Eds.), Teaching, learning & researching spatial planning (pp. 112–132). TU Delft OPEN Publishing.

Mortreux, C., & Barnett, J. (2017). Adaptive capacity: exploring the research frontier. Wiley Interdisciplinary Reviews Climate Change, 8(4). https://doi.org/10.1002/wcc.467

MWRA. (2012). 23_IMG_0160 [Photograph]. Flickr. https://www.flickr.com/photos/masswater/7637979136/in/album-72157630730946346/

MWRA. (n.d.). Photograph of water pollution sign at the beach in Boston Harbor. Retrievied from https://boshw.us/sign/harbor-of-shame-no-more/?lang=english#

MWRA. (2012). Renewable Energy Case Study: Deer Island Wastewater Treatment Plant, Mass. Water Resources Authority. Retrieved from https://www.mass.gov/doc/renewable-energy-installations-at-deer-island/download?_

MWRA. (n.d.). Reservoirs & watersheds. MWRA. https://www.mwra.com/your-water-system/reservoirs-watersheds#:~:text=MWRA%20and%20the%20Department%20of,and%20Wachusett%20(65%20billion).

MWRA. (n.d.). Sewer system history. https://www.mwra.com/your-sewer-system/sewer-system-history

MWRA. (n.d.). The MetroWest water supply tunnel. [Photograph]. https://www.mwra.com/projects-and-programs/projects/metrowest-water-supply-tunnel

MWRA. (n.d.). Your water system. https://www.mwra.com/your-water-system

MWRA. (n.d.). Your sewer system. https://www.mwra.com/your-sewer-system

National Centers for Environmental Information (NCEI), Business Insider, Statista, & Insurance Information Institute. (2023). The rising (insurance) costs of climate change [Dataset]. https://www.gzeromedia.com/the-graphic-truth-the-rising-insurance-costs-of-climate-change-2661556399

National Geographic. (n.d.) How to live with it: Wild Weather. [Image]. https://www.nationalgeographic.com/climate-change/how-to-live-with-it/weather.html

National Oceanic and Atmospheric Administration's (NOAA) & Office of Coastal Management (OCM). (2019). Land Use. [Dataset]. Retrieved from https://www.mass.gov/info-details/massgis-data-2019-land-coverland-use

National Research Council Canada. (2024.). Nature-based infrastructure for coastal flood and erosion risk management. https://nrc-publications.canada.ca/eng/view/object/?id=58396f73-fa9e-42ec-8f77-9524df841921

Nijhuis, S., & Jauslin, D. (2015). Urban landscape infrastructures. Designing operative landscape structures for the built environment. Research In Urbanism Series, 3(1), 13-34. doi: 10.7480/rius.3.874

Nijhuis, S., Sun, Y., Cannatella, D., & Xie, G. (2023). A Landscape-Based Regional Design Approach for Sustainable Urban Development in the Pearl River Delta, China. In S. Nijhuis, Y. Sun, & E. Lange (Eds.), Adaptive Urban Transformation. Urban Landscape Dynamics, Regional Design and Territorial Governance in the Pearl River Delta, China (1 ed., pp. 81-114). (The Urban Book Series). Springer Nature. https://doi.org/10.1007/978-3-030-89828-1_5

Nors, D. (2022) A Line in the World. A Year on the North Sea Coast. London: Pushkin Press.

OECD. (2019). Applying the OECD Principles on Water Governance to Floods: A Checklist for Action. OECD Studies on Water. OECD Publishing. Paris. https://doi.org/10.1787/d5098392-en.

Ohenhen, L. O., Shirzaei, M., Ojha, C., & Kirwan, M. L. (2023). Hidden vulnerability of US Atlantic coast to sea-level rise due to vertical land motion. Nature Communications, 14(1), 2038. https://doi.org/10.1038/s41467-023-37853-7

Ohenhen, L. O., Shirzaei, M., & Barnard, P. L. (2024). Slowly but surely: Exposure of communities and infrastructure to subsidence on the US east coast. PNAS Nexus, 3(1), pgad426. https://doi.org/10.1093/pnasnexus/pgad426

Ohenhen, L., Shirzaei, M., Zhai, G., Lucy, J., Werth, S., Carlson, G., Khorrami, M., Onyike, F., Sadhasivam, N., Tiwari, A., Ghobadi Far, K., Sherpa, S. F., Lee, J.-C., & Zehsaz, S. (2024). Dataset associated with: Land subsidence risk to infrastructure in US metropolises (Version 3). University Libraries, Virginia Tech. https://doi.org/10.7294/27606942.v3

Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari. (2019). Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner,

D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 321-445. https://doi.org/10.1017/9781009157964.006. https://www.ipcc.ch/srocc/chapter/chapter-4-sea-level-rise-and-implications-for-low-lying-islands-coasts-and-communities/

Opperman, J. (2014). A flood of benefits. https://www.conservationgateway.org/ConservationPractices/Freshwater/HabitatProtectionandRestoration/Documents/A%20Flood%20of%20Benefits%20-%20J.Opperman%20-%20May%202014.pdf

Ostrom, E. (2010). Poly-centric systems for coping with collective action and global environmental change. Global Environmental Change, 20(4), 550–557. https://doi.org/10.1016/j.gloenvcha.2010.07.004

Parker, H. (2021). Hurricane Ida floods. [Photograph]. Retrieved from https://lailluminator.com/2025/01/27/insurance-flood/

Roggema, R. (2016). Research by Design: Proposition for a Methodological Approach. Urban Science, 1(1), 2. https://doi.org/10.3390/urbansci1010002

Rinaldi, J. (2018). Boston floods after heavy rainfall. [Photograph]. Retrieved from https://www.bostonglobe.com/2018/08/12/roads-are-flooded-heavy-rain-boston-cambridge-somerville/IWlDVXXtQ1U91t38MA5WWO/story.html
Scape. (2018). Resilient Boston Harbor Vision. Retrieved from https://www.boston.gov/environment-and-energy/resilient-boston-harbor

Scape. (2018). Resilience toolkit. Retrieved from https://www.boston.gov/environment-and-energy/resilient-boston-harbor

Shattuck, L. (1908, October 20). Dam. Shut-off. Before closing. Oct. 20, 1908. [Photograph]. Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/37720p427

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. Global Environmental Change, 16(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008 Society for the Preservation of New England Antiquities.

Swope, E. (2025). Wildfires in Altadena, California. [Photograph]. Retrieved from https://edition.cnn.com/weather/live-news/los-angeles-wildfires-palisades-eaton-california-01-12-25

The Bostonian Society/Old State House. (1870). Fort Hill, negative #4649. [Photograph]. Retrieved from Gaining ground: A History of Land-making in Boston.

The Emerald Necklace Conservancy. (n.d.). Back Bay Fens. https://www.emeraldnecklace.org/park-overview/back-bay-fens/

The Nature Conservancy. (2021). Nature-based solutions evidence-based guidebook. https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_NBS_Guidebook-04-30-2021_LR.pdf

The Nature Conservancy. (2022). BioMap: The Future of Conservation. [Dataset]. Retrieved from https://www.mass.gov/info-details/massgis-data-biomap-the-future-of-conservation

Trustees of the Boston Public Library. (1882). In Eighth A.R.
BPC for 1882, City Doc. No. 20 (1883), opp. 12. Retrieved from Gaining ground: A History of Land-making in Boston.

Trust for Public Land. (2023). Metro Boston Community Resilience Scorecard. [Dataset]. Retrieved from https://web.tplgis.org/boston-scorecard/

Wachusett Reservoir with helicopter pilot [Photograph]. (1966, November 14). Retrieved from https://ark.digitalcommonwealth.org/ark:/50959/0v838r724

Wallace Floyd Associates. (1984). A HISTORY OF THE DEVELOPMENT OF THE METROPOLITAN DISTRICT COMMISSION WATER SUPPLY SYSTEM. Metropolitan District Commission Water Supply Study and Environmental Impact Report-2020. https://www.mwra.com/sites/default/files/2023-11/ws1984book.pdf

Wing, O.E.J., Lehman, W., Bates, P.D. et al. Inequitable patterns of US flood risk in the Anthropocene. Nat. Clim. Chang. 12, 156–162 (2022). https://doi.org/10.1038/s41558-021-01265-6

Woods Hole Group. (2023). Massachusetts Coast Flood Risk Model. [Dataset]. Retrieved from https://woodsholegroup.com/mc-frm-data/

World Bank. (2021). A catalogue of nature-based solutions for urban resilience (License: CC BY 3.0 IGO). http://hdl.handle.net/10986/36507

Seasholes, N. S. (2003). Gaining ground: A History of Land-making in Boston. MIT Press.

United States Coast Survey. (1857). Boston Harbor, Massachusetts [Chart Map]. David Rumsey Historical Map Collection.https://davidrumsey.oldmapsonline.org/maps/2571d324-ba7c-584f-bd74-8ad211d8820a/

United States Department of Agriculture Natural Resources Conservation Service (USDA). (1999). Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Survey. Second Edition. Number 436. Retrieved from https://www.nrcs.usda.gov/sites/default/files/2022-06/Soil%20Taxonomy.pdf

U.S. Army Corps of Engineers. (n.d.). National Inventory of Dams. https://nid.sec.usace.army.mil/#/

U.S. Department of Agriculture & Natural Resources Conservation Service (USDA). (2021). Geospatial soil types. [Dataset]. Retrieved from https://www.mass.gov/info-details/massgis-data-soils-ssurgo-certified-nrcs & https://sdmdataaccess.sc.egov.usda.gov/Query.aspx

U.S. Energy Information Administration. (2024). Massachusetts State Energy Profile. Retrieved from https://www.eia.gov/state/print.php?sid=MA&utm_

U.S. Energy Information Administration. (2025). Natural Gas Interstate and Intrastate Pipelines. [Dataset]. Retrieved from https://atlas.eia.gov/datasets/eia::natural-gas-interstate-and-intrastate-pipelines/about

U.S. Energy Information Administration. (2024). Power Plants. [Dataset]. Retrieved from https://atlas.eia.gov/datasets/bf5c5110b1b944d299bb683cdbd02d2a_0/explore

U.S. Energy Information Administration. (2024). Transmission lines. [Dataset]. Retrieved from https://atlas.eia.gov/datasets/bd24d1a282c54428b024988d32578e59_0/explore

Zevenbergen, C., Veerbeek, W., Gersonius, B., & Van Herk, S. (2008). Challenges in urban flood management: travelling across spatial and temporal scales. Journal of Flood Risk Management, 1(2), 81–88. https://doi.org/10.1111/j.1753-318x.2008.00010.x

Zimmerman, R. (2025). Working Landscapes: Natural Resiliency And Redesign [Slide show]. Harvard University

13. APPENDIX

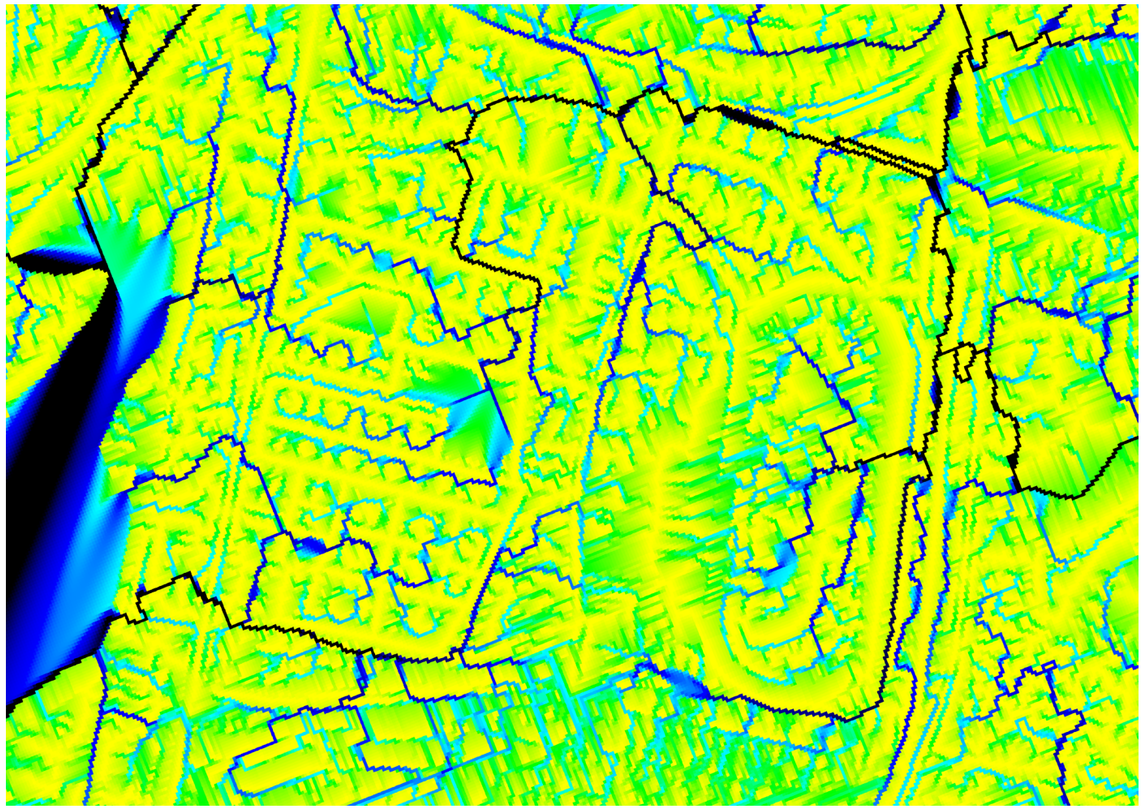


Clustering of flood interventions

Intervention	Infiltration	Absorption	Storage	Delay	Conveyance		Protection	Accommodation	Restoration	Flood type	Intervention scale	Source
Urban forestry	X	**X**								Pluvial + Riverine	City	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Terraces & Slopes				**X**						Pluvial	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
River & Stream renaturation									**X**	Pluvial + Riverine	City	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Building interventions	X	X	X	X		X				Pluvial	Building	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Open green spaces	**X**	**X**								Pluvial + Riverine	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Green corridors	**X**	**X**			X					Pluvial + Riverine	Region	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Urban farming		**X**								Pluvial	Building	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Bioretention areas	**X**	**X**								Pluvial	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Retention ponds		X	**X**							Pluvial	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Natural wetlands	X	**X**	X	X				**X**	**X**	All	City	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Constructed wetlands	X	**X**	X	X				**X**	**X**	All	City	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Restore river floodplains								**X**	**X**	All	City	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Mangrove forests	X	**X**	X	X		X		**X**	**X**	Coastal	Region	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Salt marshes	X	X	X					**X**	**X**	Coastal + Riverine	Region	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Sandy shores	**X**					X		**X**	**X**	Coastal	Region	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Green roofs	**X**	X		**X**						Pluvial	Building	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Blue roofs			**X**	**X**						Pluvial	Building	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Permeable paving	**X**									Pluvial	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Restoring historical hydrology	X	X						**X**	**X**	Pluvial + Riverine	City	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Porous asphalt	**X**									Pluvial	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Dredging / mud motor						**X**				Coastal + Riverine	Region	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Dune restoration	**X**					**X**			**X**	Coastal	Region	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Oyster reefs						**X**			**X**	Coastal	Region	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Dike relocation						X		**X**	X	Coastal + Riverine	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Riparian buffers	**X**	**X**		**X**					**X**	Pluvial + Riverine	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Bank stabilization						**X**				Coastal + Riverine	Region	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Aquifer recharge	**X**									Pluvial	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Living shorelines						**X**				Coastal + Riverine	Neighborhood	A CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN RESILIENCE - WORLD BANK
Dam removal								**X**	**X**	Riverine	Region	NATURE-BASED SOLUTIONA FEMA
Tidal circulation / Tidal parks	X	X	X					**X**	**X**	Coastal + Riverine	City	NATURE-BASED SOLUTIONA FEMA
Floodable waterfront parks	X	X	**X**	**X**		**X**		**X**		Coastal + Riverine	City	NATURE-BASED SOLUTIONA FEMA
Stormwater parks	X	X	**X**	**X**		**X**		**X**		Pluvial	City	NATURE-BASED SOLUTIONA FEMA
Buyout programmes								**X**		All	Region	NATURE-BASED SOLUTIONA FEMA
Flood control dams						**X**				Coastal + Riverine	Region	A FLOOD OF BENEFITS
Flood control reservoirs						**X**				Pluvial + Riverine	Region	A FLOOD OF BENEFITS
Levees						**X**				Coastal + Riverine	City	A FLOOD OF BENEFITS
Dikes						**X**				Coastal + Riverine	City	A FLOOD OF BENEFITS
Seawalls						**X**				Coastal	City	A FLOOD OF BENEFITS
Channel modifications						**X**				Coastal + Riverine	City	A FLOOD OF BENEFITS
Spillways / Bypasses					**X**	**X**				All	City	A FLOOD OF BENEFITS
Floodwalls						**X**				All	City	A FLOOD OF BENEFITS
Bulkheads						**X**				Coastal + Riverine	City	A FLOOD OF BENEFITS
Submerged aquatic plants						**X**			X	Coastal	City	A FLOOD OF BENEFITS
Storm surge barrier structures (MOSE)						**X**				Coastal	Region	A FLOOD OF BENEFITS
Sediment transport and flow modifications						**X**				Coastal	Region	NATURE-BASED INFRASTRUCTURE FOR COASTAL FLOOD AND EROSION RISK MANAGEMENT
Rain harvesting	X		**X**	**X**						Pluvial	Neighborhood	GREENING COMBINED SEWER OVERFLOWS
Rain gardens	**X**	X	**X**	X						Pluvial	Neighborhood	GREENING COMBINED SEWER OVERFLOWS
Decentralization of sewer system	X								X	Pluvial + Riverine	Region	GREENING COMBINED SEWER OVERFLOWS
CWERCs	X								**X**	Pluvial + Riverine	Region	LAREDO RESILIENCE REPORT
Urban retreat								**X**		All	Region	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Rewilding rivers								**X**		Riverine	Region	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Natural meandering of rivers								**X**		Riverine	Region	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Room for the river								**X**		Riverine	Region	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Canals					**X**	X		**X**		All	City	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Modular / movable flood infrastructure				X	**X**	**X**				All	Neighborhood	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Reviving ecological areas	**X**	X							**X**	All	City	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Restoring natural drainage terrain	**X**	X						**X**	X	All	City	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Bioremediation of water bodies								**X**		All	Region	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Recharge wells	**X**		X							Pluvial + Riverine	Neighborhood	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Green walls	**X**	X		**X**						Pluvial	Building	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Warning systems						**X**				All	Region	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Flood control centres						**X**				All	Region	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Reservoirs			**X**	X						All	Region	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Swales	**X**	**X**	X	**X**						Pluvial + Riverine	Neighborhood	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Underground storage structures			**X**	X						All	City	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Floodable public space			X	X				**X**		All	Neighborhood	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Water squares			**X**	X				X		All	Neighborhood	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Terps						**X**				All	Neighborhood	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Pumping systems						**X**				All	City	CATALOGUE OF BEST PRACTICES FOR BUILDING FLOOD RESILIENCE
Land use management								**X**		All	Region	FOUR CLUSTERS OF THOUGHT ON FLOOD RESILIENCE AND CLIMATE ADAPTATION
Sustainable drainage systems	**X**									All	Neighborhood	FOUR CLUSTERS OF THOUGHT ON FLOOD RESILIENCE AND CLIMATE ADAPTATION
Building codes						**X**				All	Building	FOUR CLUSTERS OF THOUGHT ON FLOOD RESILIENCE AND CLIMATE ADAPTATION
Double dike						**X**		**X**		Coastal + Riverine	Neighborhood	DESIGN PRECEDENTS
Flexible dike						**X**		**X**		Coastal + Riverine	Neighborhood	DESIGN PRECEDENTS
Aquaculture						**X**			**X**	Coastal	Neighborhood	DESIGN PRECEDENTS
Give up first floor								**X**		All	Building	DESIGN PRECEDENTS
Housing on stilts								**X**		All	Building	DESIGN PRECEDENTS
Floating dwellings								**X**		All	Building	DESIGN PRECEDENTS
Check dams				**X**		X				All	City	DESIGN PRECEDENTS
Detached breakwaters						**X**				All	Neighborhood	DESIGN PRECEDENTS
Island barriers						**X**				All	Region	DESIGN PRECEDENTS
French drains	**X**									All	Neighborhood	DESIGN PRECEDENTS
Reconnecting oxbow lakes			**X**					X	**X**	Pluvial + Riverine	Neighborhood	DESIGN PRECEDENTS

Technocratix fix (19) Ecocentrism (27)
Patchwork (15) Polycentric adaptation (22)
engineering

Flow Accumulation analysis



TPI-analysis

