ABSTRACT

Title of Thesis:	THE CITY SYMBIOTIC: INTEGRATING ARCHITECTURE AND HYDROLOGY IN THE PUBLIC REALM
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This thesis approaches climate resilience through a comprehensive urban-scale system that incorporates integrated stormwater management to address sea-level rise and urban flooding, while leveraging the power of community as a tool for environmental stewardship.

The City Symbiotic has dual notions. At its core, the concept alludes to a mutually beneficial relationship between the built and natural environment. This thesis will be an exploration of designing with water through the lens of climate resilience. Built structures will incorporate an integrated stormwater management network for capturing, filtering, storing, and reusing water, bettering our understanding of the symbiotic relationship between the built and natural environment by blurring the line between the two.

The City Symbiotic is also a reference to the relationship between people and their environment. In this respect, this thesis approaches climate resilience through community and connection. Climate change exacerbates existing vulnerabilities that are the result of historical planning failures like Euclidean and exclusionary zoning, urban disinvestment, car-centric planning, environmental racism, and displacement. Reimagining the civic commons as a more inclusive and resilient center of public life can help redress marginalization and inspire environmental stewardship.

The outcome of this thesis will demonstrate the value of symbiotic urban design, connecting the built, natural, and human environments to build resilience to water-related impacts of climate change.

THE CITY SYMBIOTIC:
INTEGRATING ARCHITECTURE AND HYDROLOGY IN THE PUBLIC REALM

by

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Thesis submitted to the Faculty of the Graduate School of the
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Dedication

To my mom – I owe everything to your endless love and support on this journey.

And in loving memory of my dad, whose fight for a better planet for future generations inspires everything I do.

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Chapter 1: People, place, and water

Introduction

The central question of this thesis asks: how do we redesign cities and public spaces to be more resilient to the impacts of climate change? There is no single place to look for the answer to this question. Instead, the research done for this thesis approaches the problem through many lenses. The topics explored range from the social sciences to the natural sciences to the arts and humanities. Ultimately, this research will provide support for the creation of a design proposal that seeks to solve the driving question at hand. But for now, given the wide range of topics explored in the pages of this thesis, the most fitting place to start is at the very beginning.

Water in the context of urban history and theory

Since the dawn of civilization, water has driven physical and social patterns of urban development. Availability and access to water determined the locations of cities and their development density and growth patterns. The relationship between water and technology and economy also drove the formation of organized governance structures to manage large-scale engineering projects and the distribution of surplus resources. Because of the integral nature of water and cities, it is not surprising that water has contributed not just to their rise, but to their fall. Civilizations can flourish by their ability to manage natural resources and can be brought down by their inability to adapt to changes in the hydrological processes on which they are so dependent. As we grapple with the most wicked problem to face cities of our time, a changing climate, it is important to begin by looking back at the ways societies have developed around water in the past and to understand their achievements and their shortcomings.

The earliest ancient civilizations settled near river floodplains where the land was most fertile for agriculture. The Egyptians relied on the annual flooding of the Nile to naturally irrigate crops without the need for engineered hydraulic systems to control the flow of water. However, these civilizations were highly susceptible to natural climatic variability, and extended periods of drought could force abandonment of entire villages.

In ancient Greece, cities began to depend more on trade than agriculture and moved their cities inland to higher and drier climates and farther from water-borne diseases.[1] This coincided with the political shift toward the *polis,* or Greek city-state, and the foundation of Greek city planning, which placed heavy importance on criteria for the siting of cities. A definite criterion was the existence of natural springs, which would provide clean drinking water to the town.[2] According to Aristotle, the siting of the acropolis with its own access to water was especially important to provide security during times of war.[3] If there was no direct source of water, giant rain cisterns would be constructed to provide a backup supply. Aristotle also described the importance of potable and non-potable water in regard to the health of inhabitants, emphasizing the separation of drinking water from other water. While rainwater collected from roofs and stored in cisterns would be used for washing clothes,

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[1] N. Zarkadoulas et al., "A Brief History of Urban Water Management in Ancient Greece."
[2] Mays, Koutsoyiannis, and Angelakis, "A Brief History of Urban Water Supply in Antiquity."
[3] Aristotle*, Politics*, 7, XI.

drinking water had to come from fresh water sources like wells. As the core of the city shifted from the Acropolis to the Agora, the center of social, political, and commercial life, larger scale hygienic infrastructure was needed to support city life at the scale of the Agora.

Figure 1: Plan of Priene (Source: Charles Gates, "Ancient Cities." Figure 17.5).

During the Classical period, Hippodamos' invention of the gridded city plan allowed major advancements in urban water management. The regularity of the grid enabled engineers to better design and construct hydraulic infrastructure. During the Hellenistic period, the Greeks began constructing pipes under pressure to transfer larger supplies of water to the city. Aqueducts with larger pipes brought more publicly accessible water to the Agora, reducing the need for private wells and cisterns. A common aqueduct technique was the inverted siphon, which moved water across a valley by shooting the water down one side of the valley and back up the other under its own pressure. Inverted siphons were constructed with lead pipes, which were stronger than clay or terra cotta and could withstand the immense water pressure.

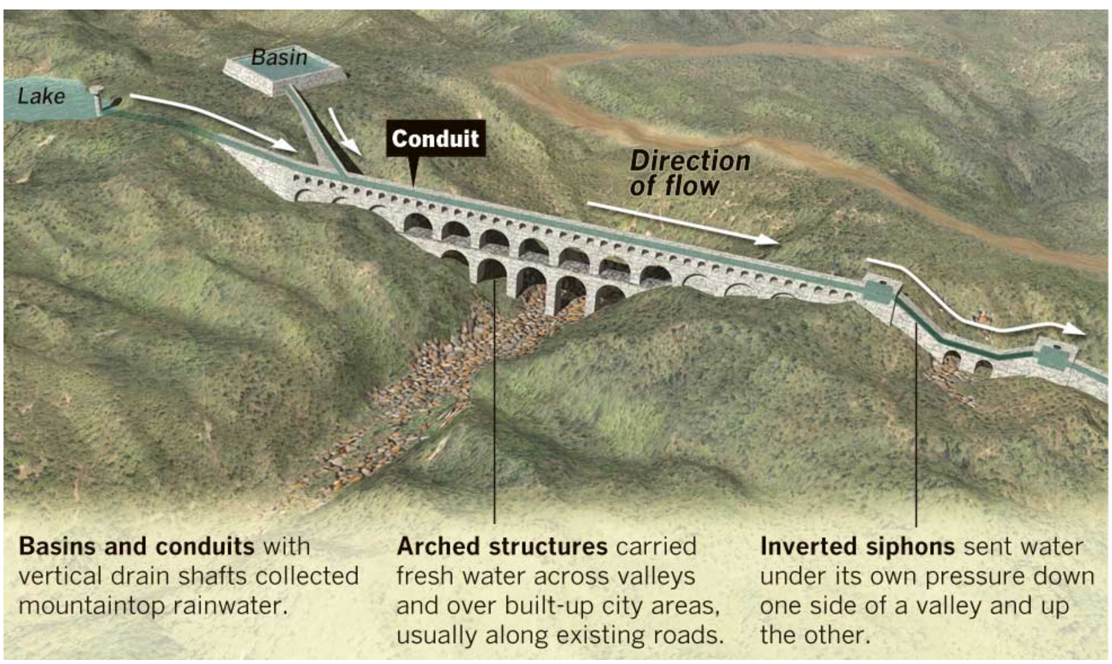

Figure 2: Aqueduct diagram (Source: Velhagen & Klafing, Plan of Imperial Rome; Credit: Graphic by Doug Stevens).

Following the Greeks, the Romans adopted the aqueduct technology and developed it to new scales. The Romans' control over their empire made them less fearful of wartime water insecurity and less reluctant towards large scale infrastructure projects. Massive aqueducts could deliver fresh spring water to a city from over fifty miles away. Contrasting the Greeks, Roman aqueducts tended to rely on gravitational surface flow rather than pressurized flow, more often using water bridges than siphons to pass valleys. A reason for this shift was explained by Vitruvius in *de Architectura,* Book VIII, in which he discusses that water from lead pipes can by injurious to human health, and therefore less preferable to earthen ones.[4]

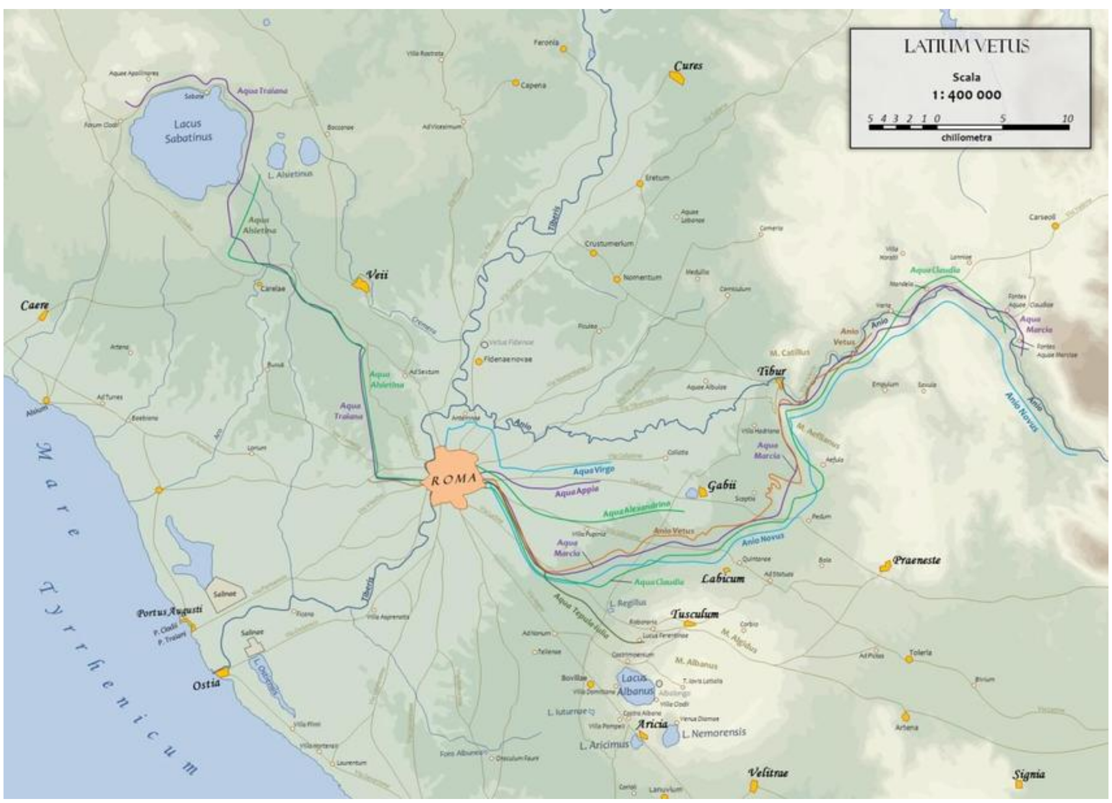

Figure 3: The aqueducts of Ancient Rome (Source: Walter Dragoni; Credit: Map by Cassius Ahenobarbus).

[4] Vitruvius, *de Architectura*

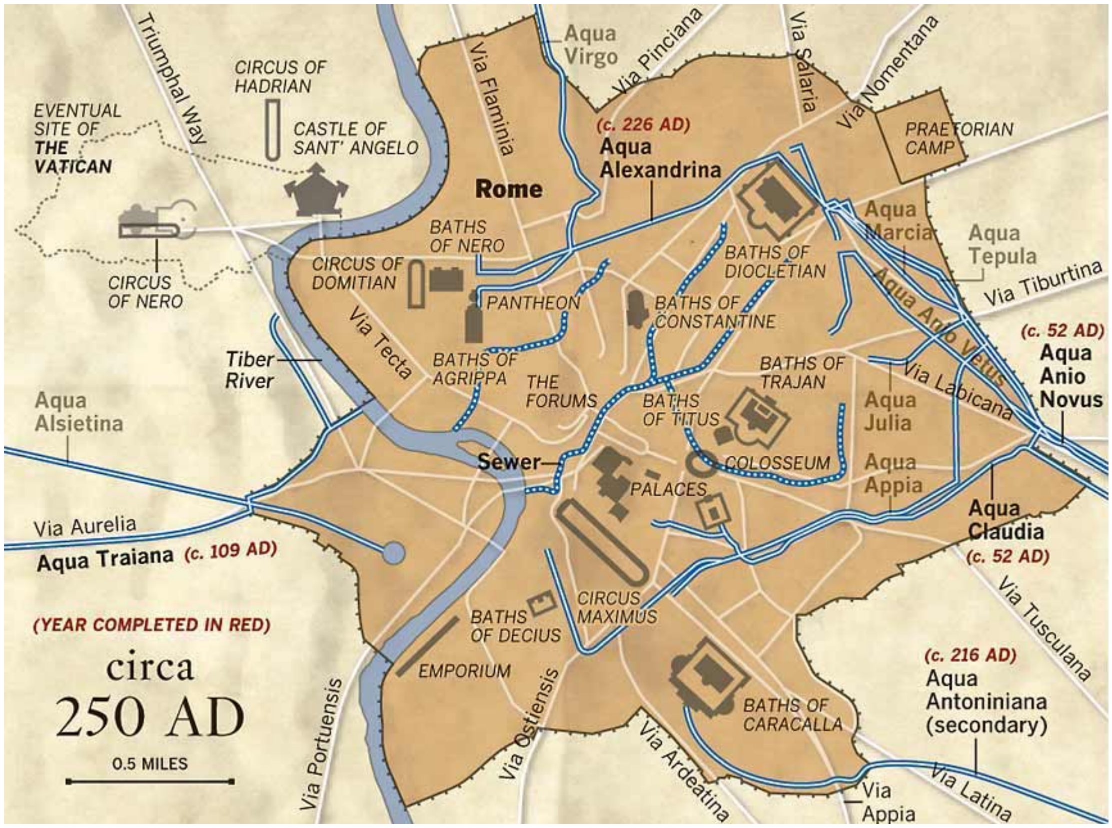

Figure 4: Aqueducts and baths in Ancient Rome (Source: Velhagen & Klafing, Plan of Imperial Rome; Credit: Graphic by Doug Stevens).

The importance of water to Roman life is undoubted. Vitruvius dedicated an entire book to the handling of water in architecture and city planning. Further, the architecture of Roman baths provides evidence of the central role water played in Roman public life. Not only did the baths play an essential health and hygiene role, they were an important setting for gathering, social interaction, and leisure. The Romans' pervasive relationship with water make it unsurprising that when the sources on which they were dependent became unreliable, it weakened the empire. While there is no single definitive cause for the fall of the Roman Empire, strong evidence suggests that climate change could have played a significant role. One theory suggests that natural climatic changes caused fluctuations in hydrologic cycles, which impacted agricultural production and contributed to the empire's instability.[5]

Figure 5: "Destruction," 1836, part of the "Course of Empire" series, by Thomas Cole (Source: Wikipedia, Public Domain)

In Venice, water became quite literally the center of public life through the necessity of communal *pozzi* (wells), which resided in the center of the *campi* (open spaces). The *campi* were the urban and social nuclei of the archipelago. For centuries, dating back to the Middle Ages, *pozzi* were the main source of potable water and a necessity of daily life.[6] Each *campo* had one or multiple public watering holes where the collection of water became a social activity and an impetus for community organization. Each with its own water supply, *campi* became semi-autonomous

[5] Harper, *The Fate of Rome.*
[6] Ciriacono, "Management of the Lagoon and Urban Environment in 18th-Century Venice."

community centers where one would find the local market stalls, artisan shops, place of worship, and the private houses of leading families.[7]

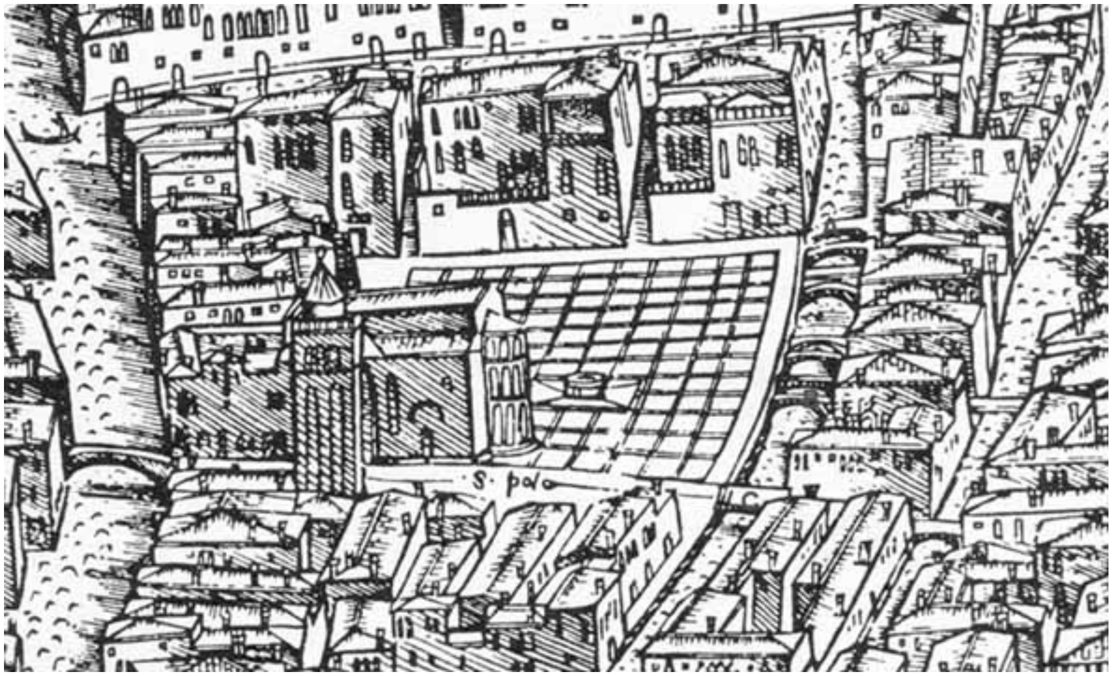

Figure 6: The 'pozzo' and permeable paving of the 'campo' are visible in Campo San Polo in Jacobo de Barberi's birds eye view of Venice, c. 1500. (Source: Laura Sabbadin, "Campo San Polo in Venince.")

Pozzi actually are not wells in the traditional sense. Situated within a saltwater lagoon, fresh, potable water is not easily available in Venice. The saltwater that surrounds and permeates the city also saturates the groundwater, so freshwater cannot be attained by digging a conventional well to access the groundwater supply. Instead, *pozzi* utilize a rainwater harvesting system underneath the *campi* to collect, filter, and store water for potable use.[8] Large cisterns were built by excavating the area beneath the *campi* by a depth of five to six meters – just deep enough not to breach the water table – and lining the base and walls with clay or stone. A cylindrical pipe at the

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[7] Psarra, *Venice Variations*.
[8] Burkett, "Venetian Pozzi."

center formed the pit of the well. The excavation was then filled with sand and covered with stone pavers, which provided the ground of the *campo*. On the ground above the cylinder, a (often ornate) stone wellhead provided access to potable water and the social centerpiece of the public realm. When it rained, water was conveyed through gutters into the sands of the cistern, which purified the water and conveyed it toward the central well shaft where it was stored.[9]

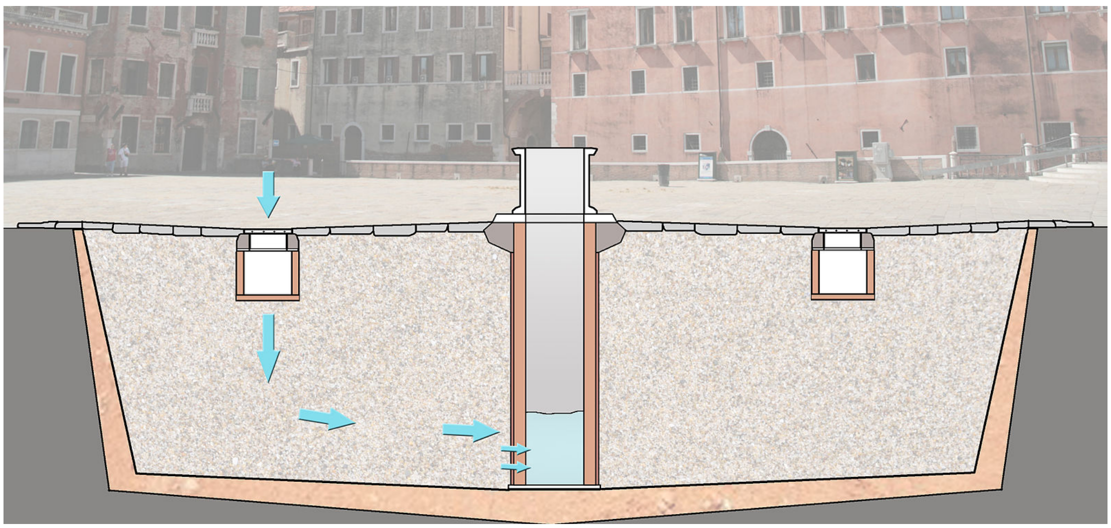

Figure 7: Section of a Venetian water well system (Source: Wikimedia Commons by Marrabbio2)

The *pozzo* provides an interesting case study of the role of the city in distributing public resources and the right to clean, potable water for all of its inhabitants. With the limited supply of water, every inhabitant, even those of lower social classes, had to be guaranteed an average of 5.5-6.8 liters of water per day.[10][11] The need to regulate access to the resource also required a local community leader who would be responsible for locking and unlocking the well twice a day. In addition to strictly

[9] Sabbadin, "Campo San Polo in Venice."
[10] Venezia Autentica, "The Innovation Which Allowed Venetians to Survive and Thrive."
[11] Ciriacono, "Management of the Lagoon and Urban Environment in 18th-Century Venice."

controlling access to water, the governance structures surrounding the *pozzi* may also be seen as an early example of the use of public-private partnerships for the funding and maintenance of large-scale public infrastructure projects. The city government appointed a private guild of water bargemen, *aquaroli*, to oversee the construction and maintenance of wells.[12] In exchange for granting the corporation a monopoly over the public utility, the *aquaroli* had to supply one hundred barges of water a year in "poor aid."[13]

Figure 8: The Vera da Pozzo of Campo San Francesco della Vigna, painted by Canaletto ca. 18th cent. (Source: Metropolitano, "Venezia: ritrovata la Vera da Pozzo dipinta da Canaletto e Guardi.")

Through careful maintenance and rigorous control of water resources, Venice grew and thrived for centuries with the *pozzi* as the primary source of potable water

[12] Colucci, "Vere da pozzo."
[13] Ciriacono, "Management of the Lagoon and Urban Environment in 18th-Century Venice."

for the city. With the end of the sovereign Republic of Venice at the end of the eighteenth century, the quality of the water and the functionality of the wells diminished alongside the administration of the city.[14] By the time their function was replaced by an aqueduct in the nineteenth century, more than six thousand cisterns had been built under the city.

Figure 9: Spatial distribution of ancient cisterns in Venice (Source: Ursino and Pozzato, "Heritage-Based Water Harvesting Solutions.")

Because of their size and quantity, it is likely that *pozzi* also served an important flood prevention function by acting like a sort of drain for the city. Capturing and detaining huge volumes of rainwater that fell on the streets and *campi* would have helped to prevent the rain from further raising the levels of the canals, which frequently overflowed during storms. Today, all of the underground cisterns have

[14] Venezia Autentica, "The Innovation Which Allowed Venetians to Survive and Thrive."

been closed off with cement or metal covers and no longer function.[15] Several hundred wellheads remain, but their function today is purely aesthetic and social, still serving as a great public meeting spot or gathering place.


Figure 10: The pozzo is still the social heart of Campo San Polo today (Source: Wikimedia Commons by Zairon)

Finally, we can look to the Netherlands for an example of a society that has been living with floodwater for centuries. Inhabitants of the Netherlands have long faced water management challenges in their attempts to hold back the sea. Much of the country is covered by compressible peat or clay soils and has experienced land subsidence over time from historic land use practices. Combined with tidal fluctuations, storms, and sea level rise, one-third of the country now lies below mean sea level. Without an elaborate system of dunes, dikes, canals, sluices, and pumps, 65% of the land would be under water at high tide.[16] Yet today, through their deep-

[15] Sautariello, "Vere da pozzo."
[16] Hoeksema, "Three Stages in the History of Land Reclamation in the Netherlands."

rooted relationship to water and philosophy for living with water, the country that is largely at or below sea level almost never floods.

The unique Dutch polder landscape formed as a way to live in harmony with the encroaching waters of the sea. Since as early as the twelfth century, the Dutch have been protecting and reclaiming land from the sea using the polder technique.[17] To build a polder, a ring canal would first be built around the designated area and then an internal network of smaller canals, pumps, sluices, and dikes would pump and keep water out. The drained water that was pumped out to the ring canal could then be expelled to a receiving body of water. Through this technique the water table could be lowered below the level of the sea.

Extensive draining of the peat soil created issues with land subsidence as the dry soil oxidized and decayed. The sinking land and continued lowering of the water table made drainage increasingly difficult and initially worsened problems with flooding. To further counterbalance the natural forces, the mouths of rivers started being dammed around the thirteenth century.[18] At the same time, the first towns started to form around the new dams which were good points for transshipment. Amsterdam and Rotterdam were two original dam-towns.

Economic growth in Dutch cities increased water pollution from industrial activities. Combined with a growing population, the self-cleaning capacity of surface

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[17] FAO, "The remarkable history of polder systems in The Netherlands."
[18] Borger and Ligtendag, "The role of water in the development of The Netherlands."

Figure 11: 1550 map of the city of Rotterdam by Jacob van Deventer (Source: Nationaal Archief, Creative Commons)

waters deteriorated and made securing the freshwater supply a challenge. In Rotterdam, surface waters suffered greatly from industrial pollution and stagnation, as dikes inhibited sufficient water flow to flush the interior canals around the polder.[19] As the city grew over time, many strategies were implemented to improve the public water supply. The seventeenth-century extension of the city in the *Waterstad* opened

[19] Loen, "Thirsty Cities."

Figure 12: 1858 expansion plan of the city of Rotterdam, with the new parksingels for improving water quality (Source: Hoogheemraadschap van Schieland en de Krimpenerwaard, Creative Commons)

up the harbor and canals and brought in fresh river tides, which improved water quality. As the size of the city expanded in the nineteenth century, city architect W.N. Rose introduced public green waterways, or *parksingels,* to help improve the quality of the public water supply.[20] Originally intended for utilitarian purposes, today the green waterways have become better appreciated for their spatial and aesthetic

[20] Loen, "Thirsty Cities."

qualities. A wise lesson could be learned from the Dutch in recognizing how designing with water may be understood not only for its function in the provision of water and flood regulation, but for its ability to enhance public space.

Living with water today

In the United States, the modern urban drainage system was developed just after WWII and consists of a system of pipes and basins to prevent flooding by delivering runoff directly to the nearest waterbody.[21] Though the system was quickly discovered to create problems with downstream flooding, bank erosion, and destruction of aquatic habitats, efforts to implement design methodologies for runoff volume control through low impact development (LID) and conservation design only just started in the 2000s.[22] However, principles of LID originated decades earlier with Ian McHarg's seminal work *Design with Nature*.[23] Designers are now trying to figure out how to develop sites while maintaining natural hydrology, such as infiltration, frequency and volume of discharges, and groundwater recharge. Some of the techniques becoming common include infiltration practices, functional grading, open channels, disconnection of impervious areas and the use of fewer impervious surfaces, narrower streets, disconnected roof drains, rain gardens, and grass swales. These techniques radically depart from past practices and are still rapidly evolving as new technologies allow us to better assess their effectiveness and understand future needs of stormwater infrastructure.

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[21] National Research Council, *Urban Stormwater Management in the United States.*
[22] Prince George's County, "Low-Impact Development Design Strategies."
[23] McHarg, *Design with Nature*

Chapter 2: Urbanism in the age of climate change

Natural hydrologic cycles

Water moves cyclically through the environment, taking on many forms and processes as it travels in an infinite loop between earth, ocean, and atmosphere. As water flows, it sculpts the land into a network of terrestrial and aquatic biomes where important ecosystem functions take place and that provide habitat to a diversity of plants, animals, and organisms. Unhindered, the water cycle is self-sustaining and resilient to natural fluctuations.

The movement of water fluctuates due to seasonal effects and natural climatic variability, with changes in temperature, humidity, and wind affecting the speed of

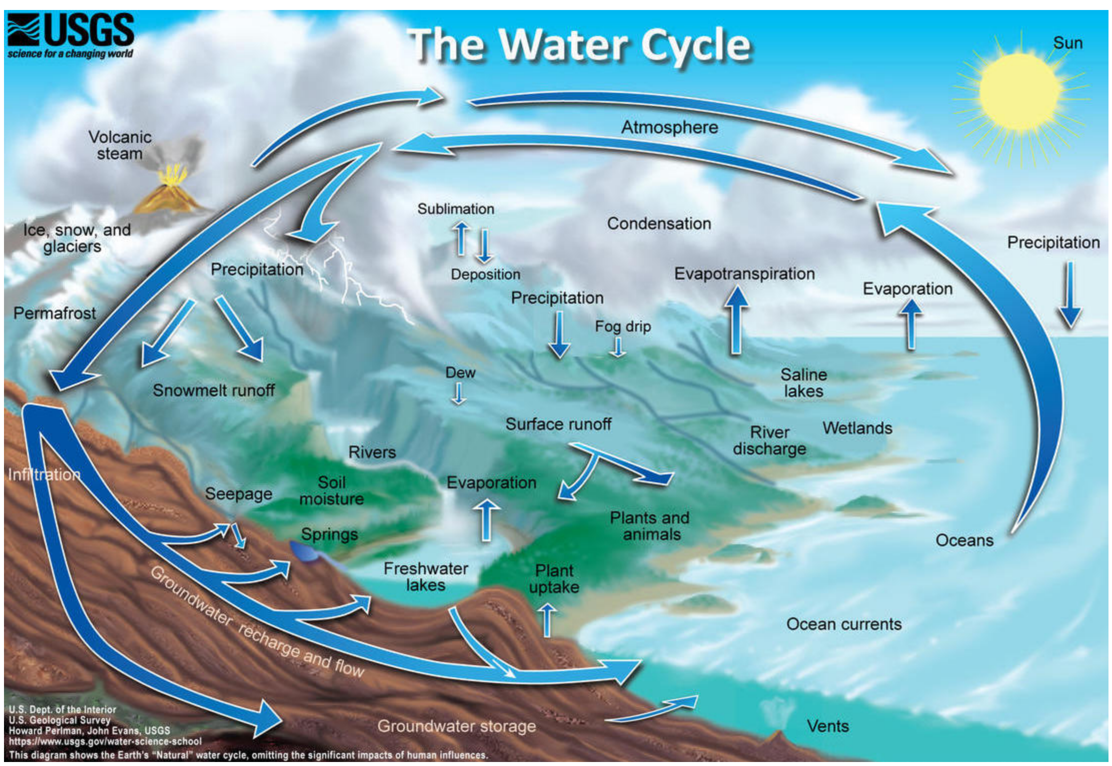

Figure 13: This diagram shows Earth's "Natural" water cycle, omitting the significant impacts of human influences. (Credit: Howard Perlman, USGS. Public domain.)

water cycle processes. Precipitation, which provides much of the planet's fresh water supply, is an important process largely driven by energy from the sun.[24] The radiative heat balance in the atmosphere drives the evaporation of surface water to the atmosphere where cloud formation and precipitation occurs.

When precipitation occurs over land, many complex processes occur as the return flow of fresh water makes its way back to the ocean.[25] The flow of fresh water creates important functional connections between the atmosphere, terrestrial systems, groundwaters, estuaries, and marine environments.[26] Ecosystems rely on hydrological processes like surface runoff, stream flow, groundwater recharge, floodplain

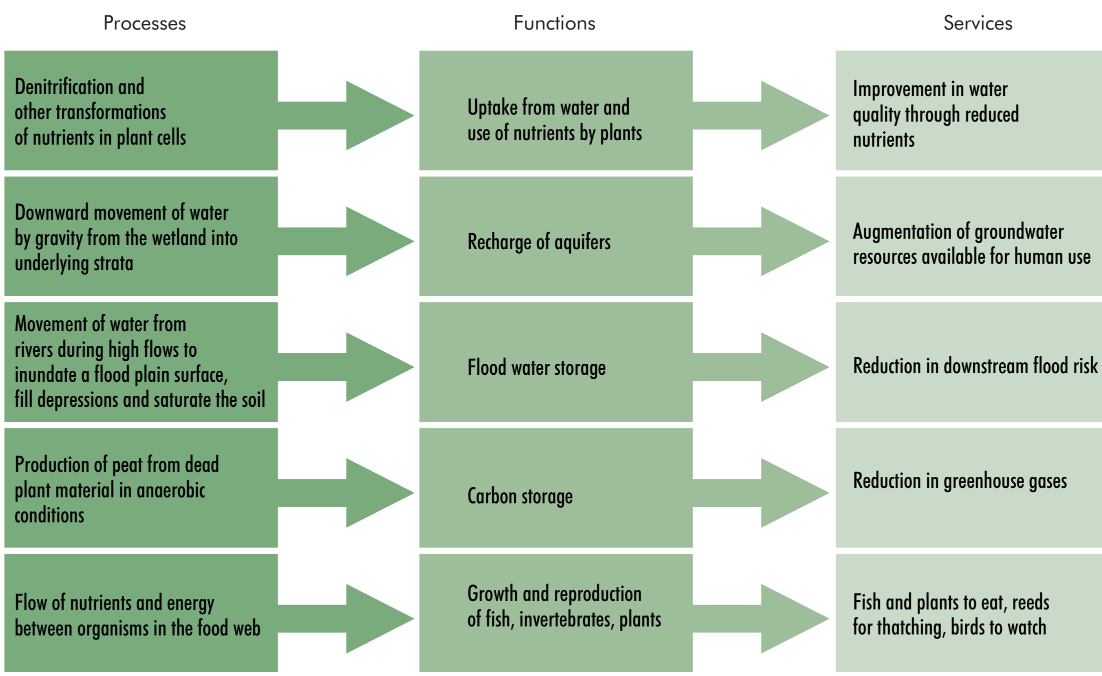

Figure 14: Relationship between the processes, functions and ecosystem services of Freshwater habitats. Source: Maltby et al. (2011), Figure 9.3.

[24] NASA, "Water Cycle and Precipitation."
[25] NASA, "Water Cycle."
[26] Maltby et al., "Freshwaters–Openwaters, Wetlands and Floodplains."

inundation, and river discharge to perform important ecological functions including moving sediments, organisms, and energy across the landscape, filtering pollutants, storing floodwaters, and capturing carbon.

At the junction of land and water, wetlands provide vital functions in the hydrologic cycle by linking terrestrial and aquatic ecosystems, forming some of the most ecologically rich habitats on the planet. Because of the complexity of wetland ecosystems there is no single wetland classification system.[27] Traditional terminology classifies wetlands as marshes, swamps, bogs, and fens. This terminology is limited and leaves out important wetland types. The U.S. government classifies wetlands as marine, estuarine, riverine, lacustrine, and palustrine,[28] while the Convention on Wetlands classifies wetlands as marine/coastal, inland, and human made.[29] The common characteristic that defines a wetland is that the water table is very close to

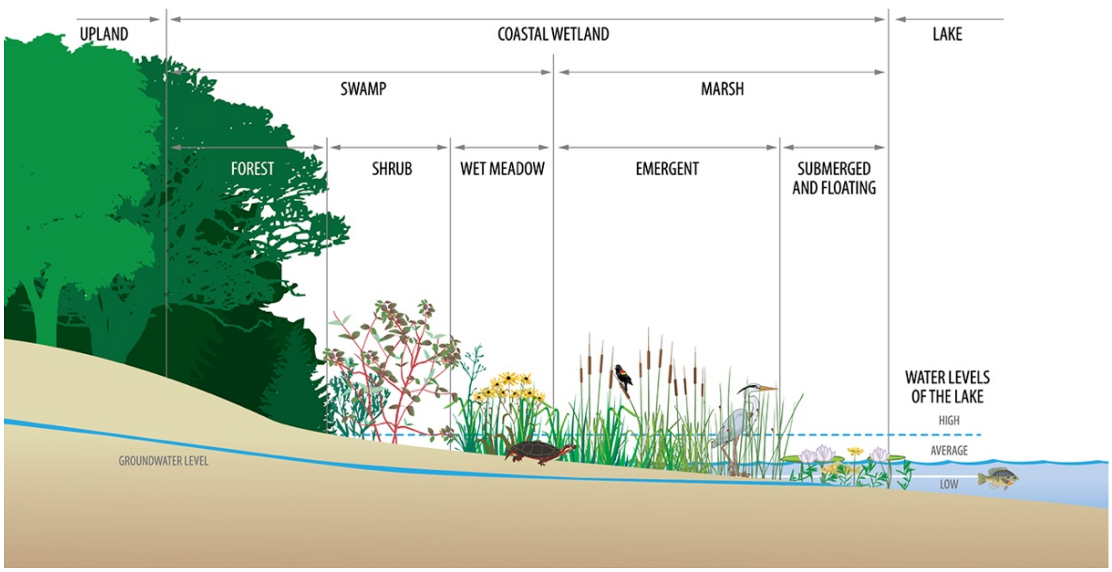

Figure 15: Example of a coastal wetland (Source: University of Michigan, Michigan Sea Grant).

[27] Bullock and Acreman, "The Role of Wetlands in the Hydrological Cycle."
[28] Ramsar, "Convention on wetlands of international importance, especially as waterfowl habitat."
[29] Cowardin, *Classification of wetlands and deepwater habitats of the United States*.

the surface or shallow water covers the surface for part of the year. This morphology of wetlands creates unique ecological structures capable of sustaining nurseries for fish and shellfish, providing wintering grounds for migratory birds, regulating floodwaters, buffering the land from storms, and forming natural reservoirs for water filtration and storage.[30]

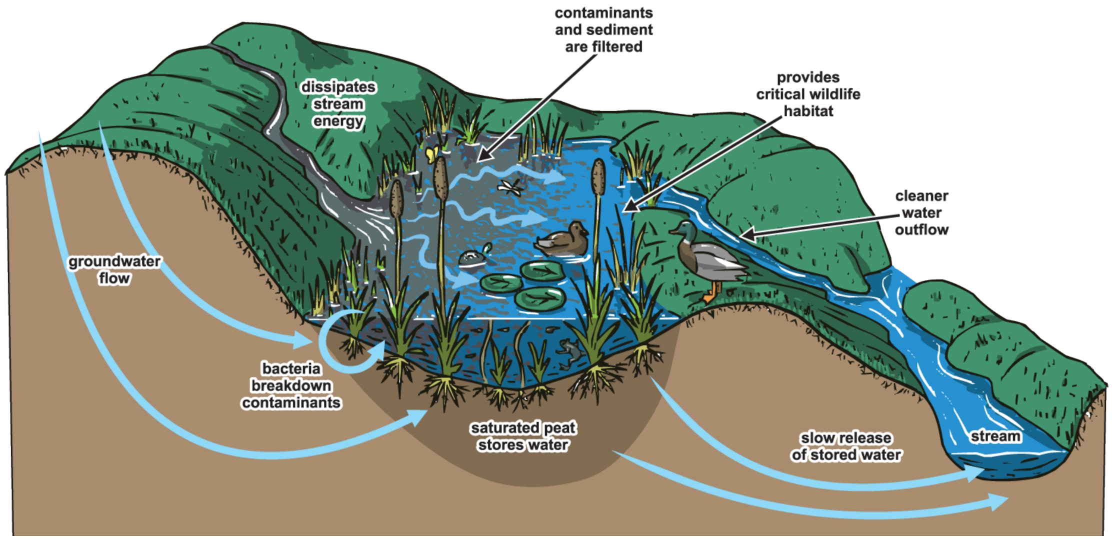

Figure 16: Wetlands' Role in Water Quality and Ecosystem Health (Source: Kanabec Soil & Water Conservation District).

The water cycle exists at a scale of space and time so massive that it is difficult for people to comprehend the vast interconnectedness of the system as a whole. In fact, by design, we live in a world where we rarely notice water at all. By constructing barriers and hiding it in pipes under the streets, we intentionally design water away. We make the most omnipresent resource in our daily lives practically invisible. Most people probably do not spend time thinking about the life cycle of the water coming out of their faucet or imagining that the water running down their drain

[30] USGS, "Why are wetlands important?"

will someday wash up on a beach thousands of miles away. We distance ourselves from water so much that, from a psychological perspective, it is not surprising that our emotional connection to water is highly selective. Someone can simultaneously feel a deep personal connection to the lake where they go boating or the beach they played at as a child, meanwhile allow their car grease to wash down a storm drain. The reality is that human impacts are so powerful we have begun to impact the natural hydrologic cycle of the entire planet. Natural or not, humans have become so wildly influential a force within the water cycle that we should no longer distinguish ourselves from it.

Urban hydrology and stormwater systems

In urban areas, humans heavily influence natural hydrologic cycles. High densities of people necessitate significant control over the direction and flow of water. We regrade topography to keep water away from structure and prevent it from damaging foundations. We engineer pumps and pipes to ensure constant water availability in places it would not naturally be. We dig drains and reservoirs because impervious surfaces restrict water's ability to infiltrate the soil. Together, these constructed systems prevent water from naturally cycling through the environment and performing important ecosystem functions. As a result, we exist in constant tension with our environment, exhaustedly building levee after levee as nature tirelessly fights back.

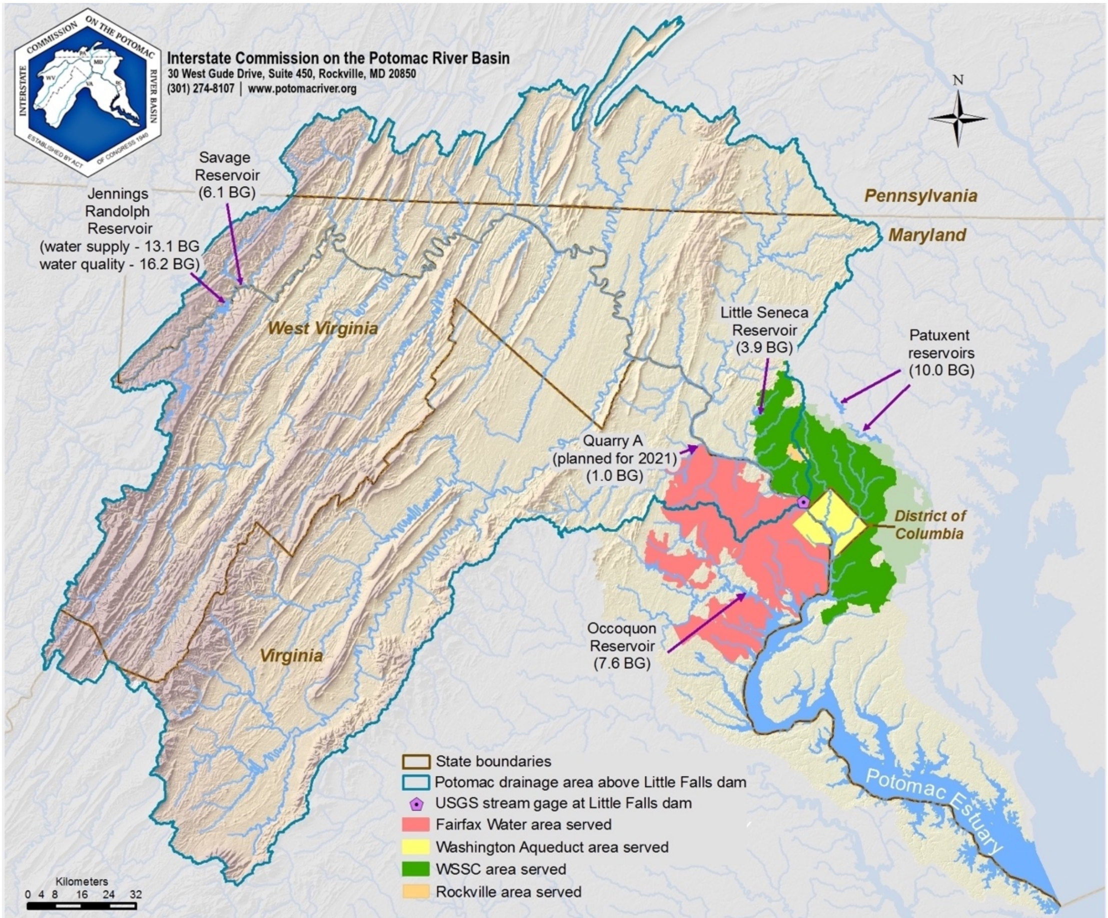

Figure 17: Washington metropolitan area water supply service areas and resources (Source: Interstate Commission on the Potomac River Basin).

One of the most drastic ways we manipulate hydrology is through engineered systems for the conveyance of drinking water, wastewater, and stormwater. Below the city, a complex network of pipes distributes clean drinking water and carries away wastewater and stormwater. Most cities source their municipal water supply from fresh water sources like lakes, wells, rivers, and reservoirs. Fresh water can be carried long distances via aqueducts but must follow the direction of gravity or else requires expensive pumping systems.

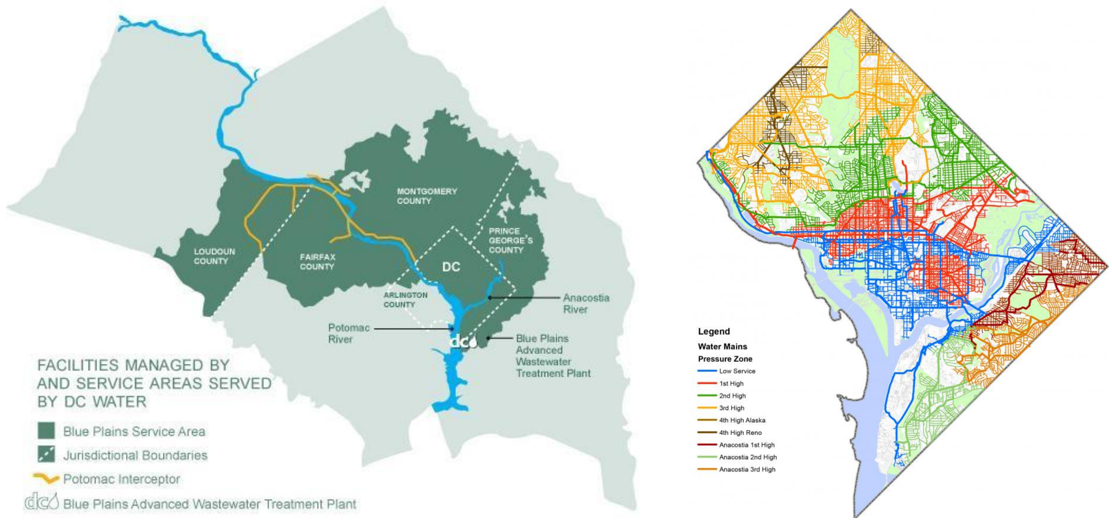

Figure 18: Blue Plains Wastewater Treatment Plant service area (left) and map of potable water main pressure zones (right) in Washington, D.C. (Source: DC Water).

For transporting wastewater and stormwater, there are two types of sewer systems. Municipal separate storm sewer systems (MS4s) use two separate pipe systems. Wastewater is sent to a treatment plant while stormwater is discharged directly back into the local body of water. Combined sewer systems (CSSs) use a shared pipe to carry both wastewater and stormwater to a plant for treatment. Most CSSs are in older cities in the northeast, and there has been a nationwide effort to separate them when possible.

With CSSs, because sanitary sewage shares a pipe with stormwater, large storms can overwhelm the capacity of the system. When this occurs, excess volume that cannot be stored discharges into the natural waterbody. Sanitary sewage pollutes water, harming aquatic ecosystems and making treasured recreational sites dangerous to human health. In certain scenarios, flood events can overflow storm drains and sewage can spill into the street, creating foul smells and posing incredible health concerns. As climate change exacerbates stresses on water utilities, the problems associated with sewer system capacities will continue to increase into the future.

MS4s have their own share of issues. A major concern in cities that use MS4s is controlling polluted surface runoff into storm sewers, since everything that washes off the street into the drain goes directly into a natural waterbody. Another concern is the speed of water flowing into the waterbody at outfall locations. Large, concentrated streams of fast-moving water pouring into a waterbody can damage delicate aquatic ecosystems and destroy wildlife habitats.

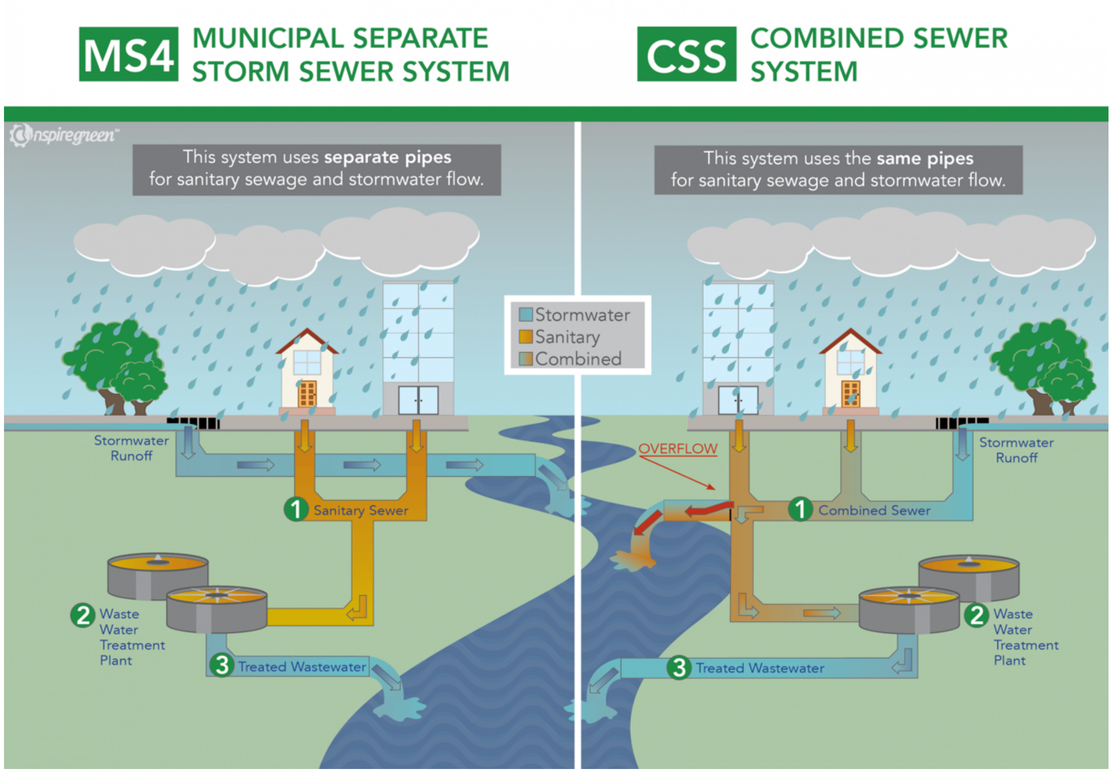

Figure 19: Municipal separate storm sewer system (MS4) & combined sewer system (CSS) diagram (Credit: Image created by Nspiregreen, LLC for DOEE).

When urban hydrological systems fail: Climate impacts and projections

Some scientists argue we have entered the Anthropocene, an entirely new geologic epoch characterized by human influence on atmospheric, geologic, hydrologic, biospheric and other earth systems.[31][32][33] Human impacts on natural hydrologic systems include: modifying the terrestrial water cycle by intercepting natural river flows from uplands to the sea and altering water vapor flows from land to atmosphere through changes to vegetative land cover;[34] eutrophication and the destruction of freshwater and marine habitats largely due to nitrogen and phosphorus in agricultural and industrial runoff;[35] and, as a direct result of human-induced climate change,[36] ocean acidification and the dissolution of calcifying organisms (e.g. coral reefs), sea level rise via ice melt and thermal expansion of the oceans, and drastic changes in the frequency and severity of weather events including flooding and drought. As stated in the *Climate Science Special Report*: Fourth National Climate Assessment, Volume I:

"Changes in precipitation are one of the most important potential outcomes of a warming world because precipitation is integral to the very nature of society and ecosystems. These systems have developed and adapted to the past envelope of precipitation variations. Any large changes beyond the historical envelope may have profound societal and ecological impacts."[37]

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[31] Crutzen, "Geology of Mankind."
[32] Zalasiewicz et al., "Are We Now Living in the Anthropocene."
[33] Ellis, "Anthropocene."
[34] Steffen et al., "The Anthropocene."
[35] Smith et al., "Eutrophication of freshwater and marine ecosystems."
[36] Solomon and Intergovernmental Panel on Climate Change, *Climate Change 2007*.
[37] Easterling et al., "Ch. 7: Precipitation Change in the United States."

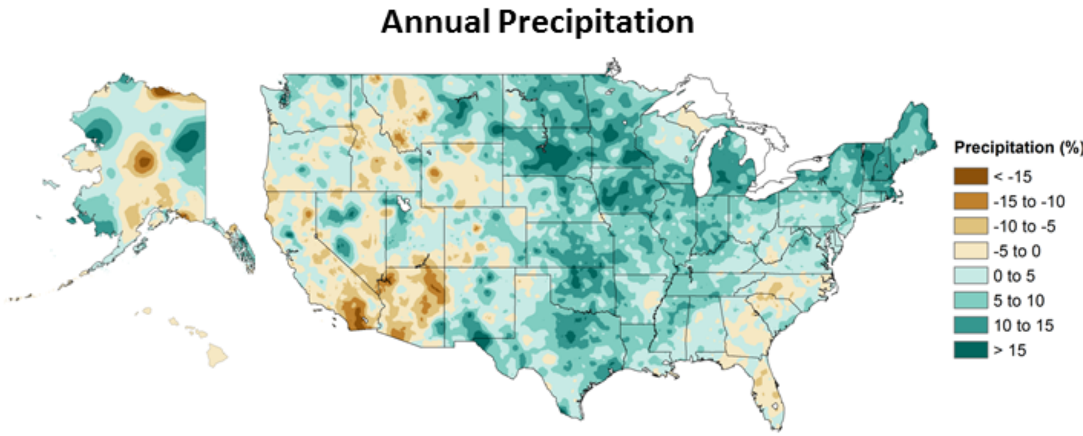

Figure 20: Annual and seasonal changes in precipitation over the United States. Changes are the average for present-day (1986–2015) minus the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i) divided by the average for the first half of the century. (Source: Fourth National Climate Assessment)

The National Climate Assessment findings include that the West, Southwest, and Southeast are experiencing less annual precipitation, while most of the Northern and Southern Plains, Midwest, and Northeast are experiencing increasing annual precipitation. Meanwhile, the intensity and frequency of heavy precipitation events have generally increased across the country since 1901 and are expected to continue to do so. These changes will have drastic effects on urban hydrological systems and pose incredible challenges for existing stormwater infrastructure which was designed to accommodate pre-anthropogenic precipitation loads.

Chapter 3: Toward a symbiotic urbanism

Symbiosis of the built, the natural, and the human

Human perception of the environment challenges our ability to create a resilient society. Our constructed narratives distance the human world from the physical world, the man-made and industrial from the natural. In reality, these are mutually dependent parts of a complex and interconnected web of systems. Adapting to a changing climate requires us to be nimble to fluctuations, reimagining our cities as a set of dynamic components constantly adjusting to maintain a balance conducive to our quality of life. Through design, we can make the line between the human world and the physical world disappear, forcing people to embrace the indistinguishable reality that we are our environment, and our actions and interactions have the power to shape every aspect of the world that surrounds us. This chapter explores how integrating design with hydrological systems and fostering human connection to the environment can be tools for building climate resilience.

Architectural benefits of designing with water

Looking to the future, one of the most imperative ways water will play into design is through strategies for minimizing the stormwater footprint of a site. Due to increasing impervious surfaces and severity of storm events, developed areas are experiencing larger quantities and higher velocities of water running off hard surfaces beyond that which existing stormwater infrastructure was designed to accommodate. Water that cannot enter storm drains pools in the streets and around buildings and can damage structures and flood basements. This is why designing with water on an individual site must be conceptualized as part of a larger context of interconnected systems. Minimizing water usage and discharge on a site can benefit a building individually, but more importantly it benefits the system as a whole. If all the structures that share a landscape operate in the same way, the whole will be greater than the sum of its parts. The benefits of designing with water can extend beyond preventing costly damages and pollution to becoming a shared investment in better public spaces.

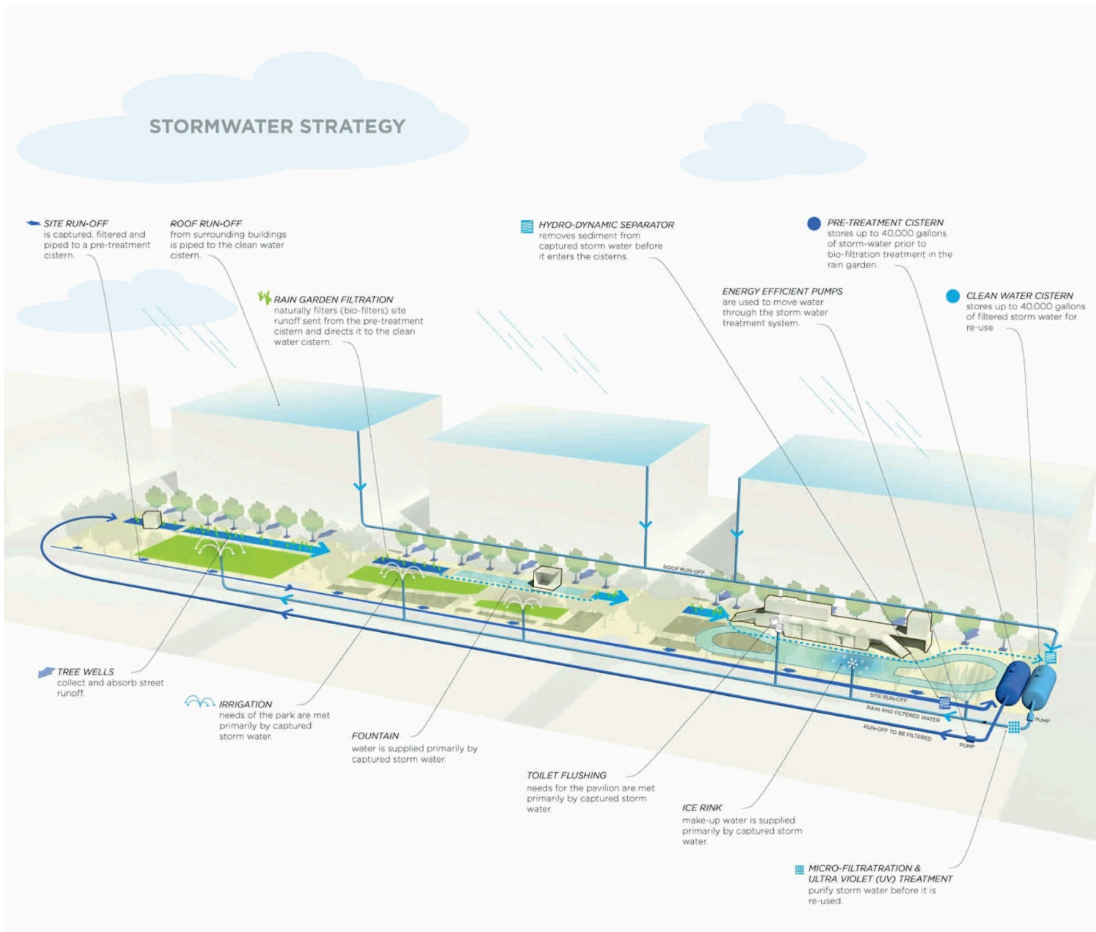

Figure 21: Stormwater strategy for Canal Park in Washington, D.C. includes capturing, storing, filtering, and recycling rainwater for use in the building and in the landscape (Credit: OLIN).

Designing structures that are resilient to water is important for longevity. Incorporating spaces that are designed to flood and withstand increasing storm events can prevent structural damage and increase the lifespan of buildings and infrastructure.

Figure 22: The Copenhagen Strategic Flood Masterplan includes streets that are designed to flood, protecting infrastructure and public safety (Credit: Ramboll Studio Dreiseitl).

Figure 23: Infrastructure serves as both public space and stormwater barrier and collector in OMA's design for the Hoboken Waterfront. The proposal, Resist. Delay. Store. Discharge., aims to prevent destruction like that occurred during Hurricane Sandy (Credit: OMA).

Integrating natural hydrological systems with building systems can improve building efficiency and reduce energy costs. Several passive cooling techniques use water to cool down atmosphere and regulate microclimate. Evaporative cooling techniques use water evaporation and wind for cooling. As water evaporates it draws large amounts of heat from surrounding air.

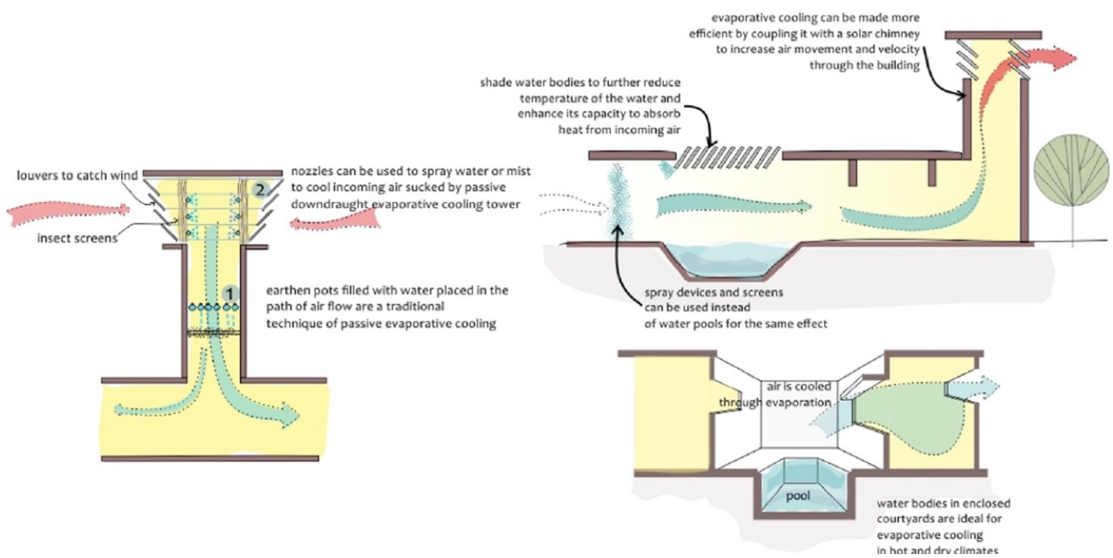

Figure 24: Pools, ponds, or water features accompanied by cross-ventilated openings or cooling towers passively cool indoor climates (Source: NZEB).

Blue-green roofs help cool buildings and provide additional benefits like low-intensity food production. By providing a thermal insulation layer and lowering roof surface temperature, green and blue-green roofs can reduce indoor temperatures by several degrees.[38] Studies also demonstrate potential for decreasing urban heat island effects.

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[38] Solcerova et al., "Do Green Roofs Cool the Air?"

Recycling water for non-potable uses reduces a building's overall water consumption. Recycled water can come from harvested stormwater, which helps minimize a site's stormwater footprint by collecting and retaining rainwater on site. It can also come from gray water sources like showers and washing machines. Gray water can be treated on site and fulfill non-potable uses like irrigation and toilet flushing.

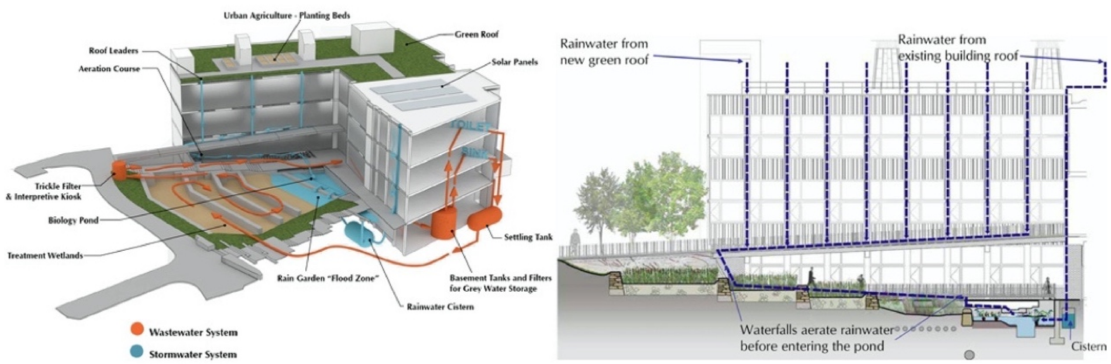

Figure 25: Hydrological systems at Sidwell Friends Middle School in Washington, D.C. include stormwater capture, a filtration landscape, and graywater reuse for irrigation and building plumbing (Credit: Andropogon Associates).

Though in the long term such systems for on-site water treatment, storage, and recycling return more than financial benefits, the initial investment can be prohibitive in many practical cases, notably small-scale residential projects.[39] Consequently, we typically only see these systems implemented in large-scale developments. This poses a significant challenge for sustainable building in the United States, where 80% of developed land use is residential.[40] Comprehensive masterplanning projects could

[39] Revis, "Cost Analysis of Public Wastewater Versus Onsite Wastewater."
[40] Nickerson et al., *Major Uses of Land in the United States, 2007*

provide the opportunity to integrate such systems at a neighborhood or urban scale, making it more financially feasible for smaller-scale infrastructures to participate.

Architects also design with water for its powerful spatial qualities. Like a river, water can form a strong edge or boundary. It can also form a plane, extending as a vast vertical or horizontal surface. Its malleability lends to its potential for architectural expression. The dichotomous sensory qualities of water–still, rough, calm, choppy, shallow, deep, silent, loud, translucent, opaque–can create both tranquility and tension. The ephemeral quality of water evokes nature and can create a spiritual or sublime experience. For this reason, it is often used in spaces of contemplation, meditation, and reflection.

Figure 26: Water creates a space for contemplation at the National Museum of African American History and Culture. (Credit: Freelon Adjaye Bond, rendering by Imaging Atelier)

Ecological benefits of designing with water

The last century of development in the United States has drastically altered the ecology of the landscape, often unknowingly interrupting, impeding, or even accelerating ecosystem functions and throwing natural equilibriums out of balance. As architects, we now have the imperative to reverse that legacy, not just by minimizing our impact on the landscape, but by striving for design that repairs the damage of the past. Designing in harmony with natural hydrological cycles could have profound ecological benefits.

One of the worst impacts humans have had on hydrological functioning is the introduction of harmful pollutants and simultaneous destruction of the natural vegetative systems that filter them. Bacteria and nutrients occur naturally in the environment. However, when they are added in extreme quantities, for example due to human activities, natural systems for processing them are thrown out of balance. When natural systems cannot keep up, bacteria and nutrients such as nitrates and phosphorous decimate aquatic environments.

Design can help restore natural processes by incorporating vegetation to uptake pollution and improve water quality. Integrating such techniques at a large enough scale can improve the local ecosystem and create new habitats for fish and wildlife. Within the field of architecture and landscape architecture, constructed wetlands are beginning to emerge as a successful design strategy. Constructed wetlands have potential for reviving wetland ecosystems that have been damaged or lost to human development. They can also be introduced as an alternative wastewater treatment strategy, which can be a mutually beneficial system for reducing water consumption and restoring ecosystem health.

Figure 27: A constructed wetland at Sidwell Friends School treats building wastewater and recycles it for grey water use within the building (Image credit: Albert Vecerka/Esto)

Another way development has exacerbated water quality issues as well as flooding can be traced to the widespread culverting, piping, and paving over of streams that has taken place since the 19th century. Originally intended to control flooding and disease and make room for more development, we now know burying streams increases pollution transfer and flooding.

Normally, plants and organic matter in streams feed on nitrates, keeping stream ecosystems healthy and oxygenated. The natural velocity of stream flows enables the landscape to filter potential pollutants before they pass the watershed, limiting pollution transfer. In buried urban streams, nitrates travel on average 18 times farther before they are taken out of the water column.[41]

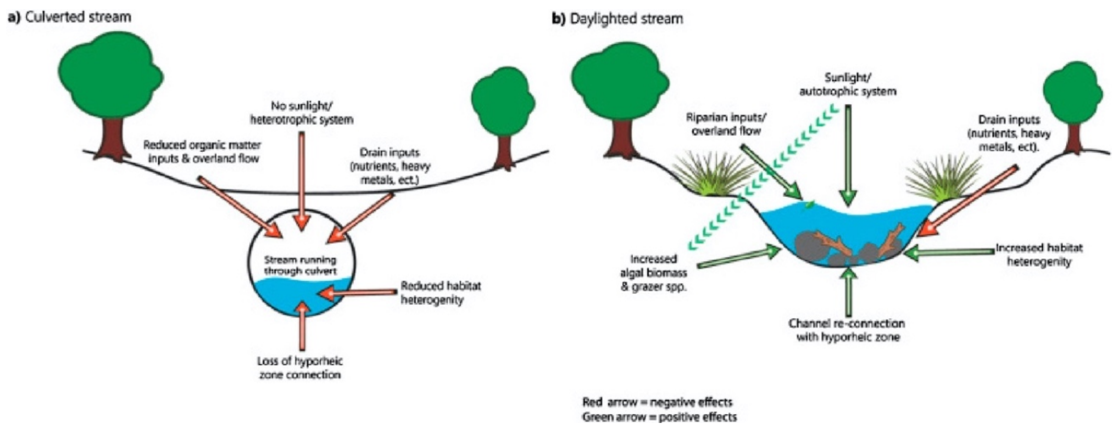

Figure 28: Benefits of stream daylighting on stream ecology (Source: Neale and Moffett, "Re-engineering buried urban streams")

When streams are buried, groundwater still follows the natural topographic gradient underground, and the coarser-grained material of old stream channels can create preferred flow paths alongside the channels.[42] Therefore, buried streams may continue to flow to some extent beyond the confines of the channel. During heavy storms, these areas may still be prone to pool at the surface, especially in low-lying areas where the water table is close to the surface and the ground becomes saturated. Buried streams can also flood basements and cellars and trigger combined sewer

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[41] Beaulieu et al., "Urban Stream Burial Increases Watershed-Scale Nitrate Export."
[42] Schneider et al., *Groundwater Resource Assessment Study for the District of Columbia.*

overflows when millions of gallons of water pour into an already overwhelmed sewer system.[43]

Daylighting is the process of restoring buried streams as a means to address water quality and flooding by exposing water to sunlight, air, soil, and vegetation. Daylighting benefits include improving the local ecosystem and providing natural habitat, reducing erosion and slowing urban runoff from directly entering waterways, mitigating flooding by providing room for water, regulating groundwater recharge and reducing loads on sewer infrastructure. In addition, daylighting can also provide beautiful aesthetic features in urban landscapes and create more access to public green space.

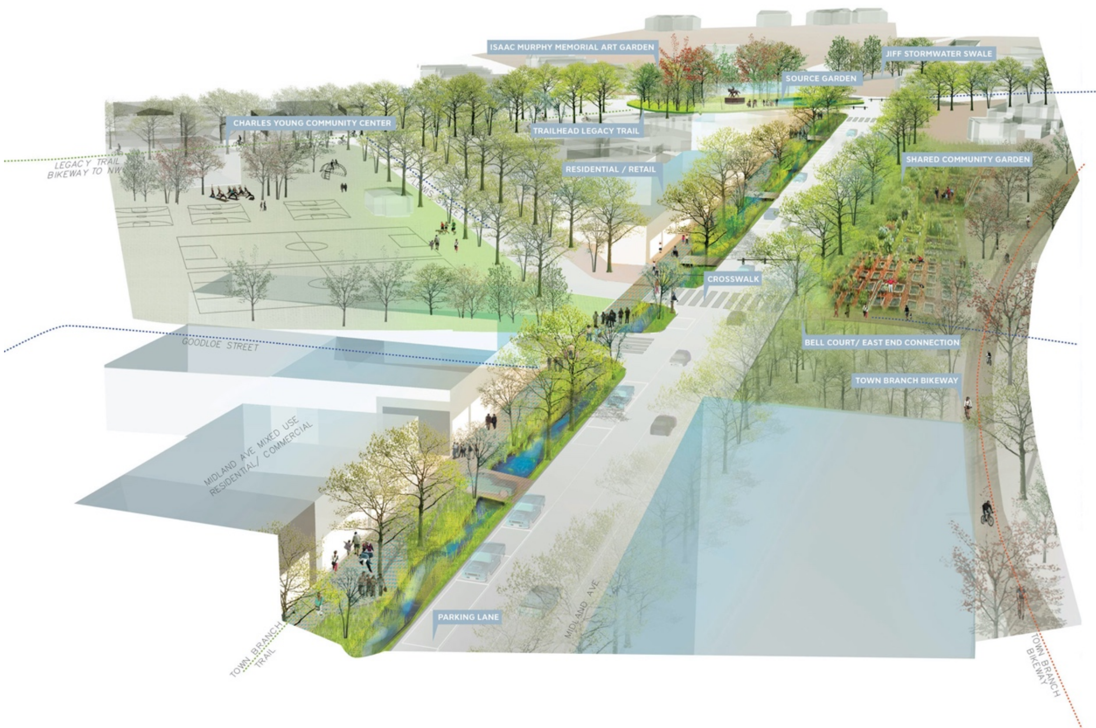

Figure 29: Stream daylighting proposal for Town Branch Commons (Credit: SCAPE Studio)

[43] Tomkiewicz, "Buried Streams."

Social benefits of designing with water

Of all the social benefits of water, its gift of recreation can be one of the most beloved and most taken for granted. We enjoy spending time on and near water because its many recreational options joyfully fulfill our desire for connection to nature. Because water comes in many shapes and forms, no two bodies alike, its opportunities are infinite. Of the multitude of aquatic recreational activities, some favorites include boating, kayaking, rowing, paddle boarding, fishing, swimming, bird watching, hiking, and ice skating. But when we do not care for our water, it can become a hazard instead of an amenity.

Figure 30: Bassin de la Villette swimming pool on the Canal de l'Ourcq in Paris (Credit: Shutterstock via Curbed).

Designing with water is incredibly important for public health. Health benefits of designing with water include reducing water contamination, managing pests by creating a balanced ecosystem, and improving quality of fish and shellfish for consumption. Architects play an important role in public health because of the highly interconnected nature of the built environment and the natural environment. Architects have a responsibility to design in such a way that not only minimizes the impact on the environment but makes a net positive change to the existing conditions. The architect's job has always necessitated thinking long into the future and understanding the lasting impacts of design. However, now more than ever before, sustainability, health, and wellness have become some of the utmost imperatives of design, as we witness how significantly it impacts not only the quality of life of the current generation but future generations as well. Designing in symbiosis with natural ecosystem processes and hydrological functioning will be crucial for maintaining the health of the environment and of people.

Figure 31: Floating wetlands at the District Wharf improve water quality and provide an educational amenity to the public (Source: District Wharf via Potomac Conservancy).

Water can also be used for public education purposes. Designing with water is an opportunity to generate ecological awareness and inspire environmental stewardship. Making hydrology more visible in the public realm can help people better understand their interconnectedness with nature and reveal how drastically human activities have altered the natural landscape.

Figure 32: A network of floating wetlands at the Baltimore National Harbor would improve water quality while educating visitors on wetland ecology. (Credit: Ayers Saint Gross)

Figure 33: Water Squares in Rotterdam, the Netherlands double as functional public spaces and drainage infrastructure. Drawing attention to stormwater management in the public realm serves to educate the public. (Credit: De Urbanisten)

Chapter 4: Site introduction

Site selection process

This thesis aims to explore design strategies for developing a symbiotic urbanism, using a selected site as a case study for integrating natural hydrological systems with the built environment. The ultimate goal is for this case study to provide a replicable framework for future development.

The premise of this thesis inherently requires it to address major challenges of climate change like urban flooding and community resilience. As such, an initial study of area flood maps played a significant role in determining potential site options. Flooding analyses were considered in tandem with insights gained through discussions with colleagues and mentors and research into future growth and sustainable development goals for the region. Ultimately, three site options in

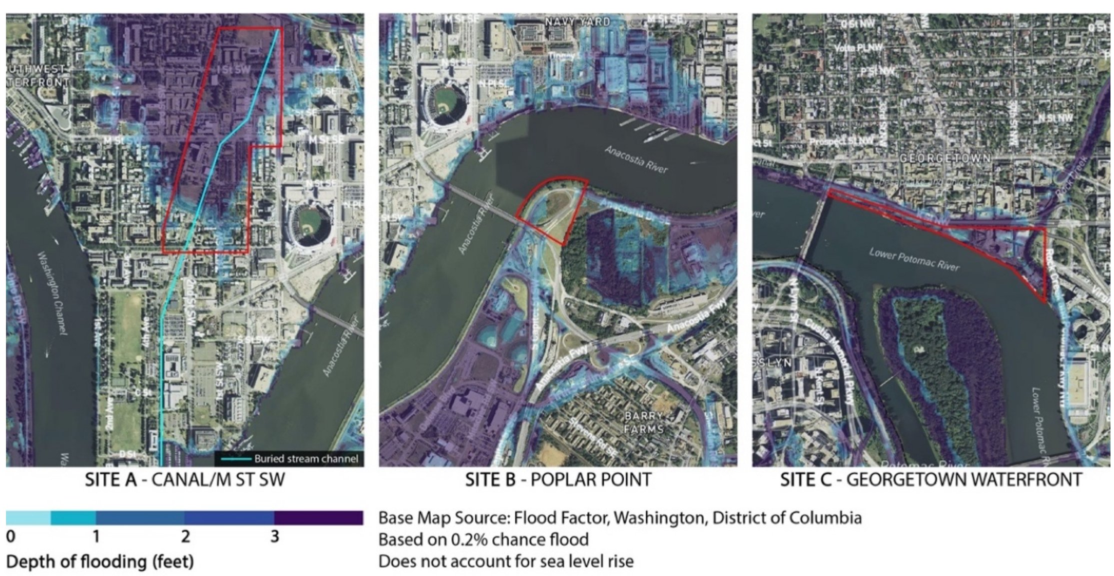

Figure 34: The three site options considered for this thesis (Source: author)

Washington, D.C. emerged as strong contenders for the project. The three site options were thoroughly considered based on a set of key criteria deemed important for the direction of this thesis. While additional sites outside the district were originally considered, the decision was made to focus site selection locally, considering personal knowledge and access to the site would ultimately be valuable assets to the project.

The site selection matrices evaluate and rank the three site options based on six criteria, listed in descending order of importance on the left of the matrix. Through a preliminary site analysis process, each site revealed unique opportunities and

	SITE A - CANAL/M ST SW	**SITE B** - POPLAR POINT	**SITE C** - GEORGETOWN WATERFRONT
HIGH RISK FOR WATER-RELATED CLIMATE IMPACTS	- Higher risk for interior flooding due to elevation, topography, and historic buried stream - MS4 sewer type means area is also a priority for reducing runoff	- High risk for riverine and coastal flooding - Less immediate risk for people because it's undeveloped - A levee has been constructed	- High risk for riverine and coastal flooding - Current floodwall system ineffective - Combination MS4 + CSS sewers
MIX OF USES + BUILDING TYPOLOGIES	- Interesting mix of uses and building typologies includes primarily government-owned public housing and public services/facilities (USPS, police station, DMV)	- No existing development	- Mix of commercial, residential, embassy
EXISTING COMMUNITY	- Long-term residents of public housing + senior housing - Community assets include parks, rec center, schools, fire/EMS station	- No existing community on site - Existing community within mile radius	- luxury condominium residents on immediate waterfront
POPULATION VULNERABILITY	- Low-income and public housing residents have more economic vulnerability, typically have less control of their environment, and lower neighborhood investment	- No immediate community, but peripheral communities in Anacostia have higher vulnerability	- Low vulnerability
WATERFRONT PROXIMITY	- 1/2 mile from District Wharf; <3/4 mile from Diamond Teague Park; <1 mile from Yards Park; 1 mile from James Creek Marina/ Buzzard Point	- Immediate proximity to Anacostia River	- Immediate proximity to Potomac River
TRANSIT / MULTI-MODAL ACCESSIBILITY	- 2 metro stations within 1/2 mile radius (Waterfront + Navy Yard) - Capital bikeshare, dockless scooters/bikes high availability - Southeast Freeway	- <1 mile from Anacostia metro - Capital bikeshare, dockless scooters/bikes low availability - Anacostia Freeway	- <1 mile from Foggy Bottom metro - Capital bikeshare, dockless scooters/bikes high availability - Whitehurst Freeway

Figure 35: Site selection criteria matrix (Source: author)

constraints. A successive chapter dedicated to site analysis provides a more thorough investigation of the chosen site.

For the final site ranking matrix, numerical values indicate a point system from zero to three, with three being the maximum number of points, i.e., most adequately satisfying the criteria. Ultimately, Site A in Southwest D.C. proved to provide the best opportunity to advance topics integral to this thesis. A discussion of the evaluation process follows.

	SITE A - CANAL/M ST SW	**SITE B** - POPLAR POINT	**SITE C** - GEORGETOWN WATERFRONT
HIGH RISK FOR WATER-RELATED CLIMATE IMPACTS	2	3	3
MIX OF USES + BUILDING TYPOLOGIES	3	0	3
EXISTING COMMUNITY	3	0	3
POPULATION VULNERABILITY	3	0	0
WATERFRONT PROXIMITY	2	3	3
TRANSIT / MULTI-MODAL ACCESSIBILITY	3	2	3
	16	**8**	**15**

Figure 36: Site selection ranking (Source: author)

<u>Site evaluation</u>

As the primary intent of this thesis aims to make communities more resilient to the water-related impacts of climate change, the top criterion qualifies each site's risk factor for such issues. Water-related impacts include many potential influences on hydrological processes as discussed in preceding chapters. Some of the most significant impacts in urban areas like Washington, D.C. include flooding and sea level rise. Figure 37 shows the three site options overlaid on a flood map for the district.

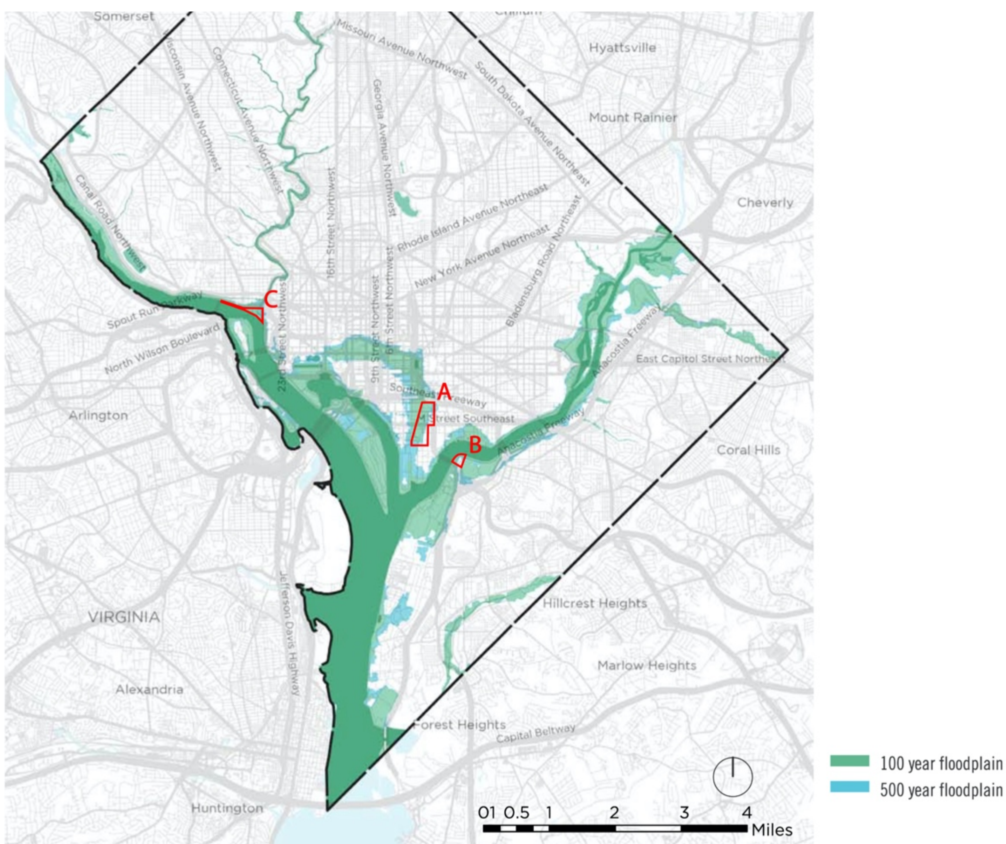

Figure 37: FEMA flood insurance rate maps, 100-yr and 500-yr Floods, with the three site options outlined in red. (Source: FEMA map overlaid on GIS map base, Kleinfelder, 2015)

It is important to note that the flood map is based on FEMA flood data, which underrepresents flood risk for several reasons. FEMA maps do not reflect future projected climate scenarios, which will greatly increase the probability and severity of flood events. Further, FEMA's maps use outdated data. Washington, D.C.'s FEMA maps are derived from 1999 LIDAR data. They were published in 2010 and use topographic data from 2004.[44] D.C.'s FEMA maps also only assess coastal and riverine flooding, even though interior flooding is one of our most significant problems, especially in low-lying and highly impervious areas. As a result, significantly more properties are at risk for flooding than accounted for in FEMA's flood model. A newer, climate-adjusted model by First Street Foundation (FSF), for example, estimates that the current number of properties at substantial flood risk in Washington, D.C. is 438% greater than FEMA's model estimates.[45]

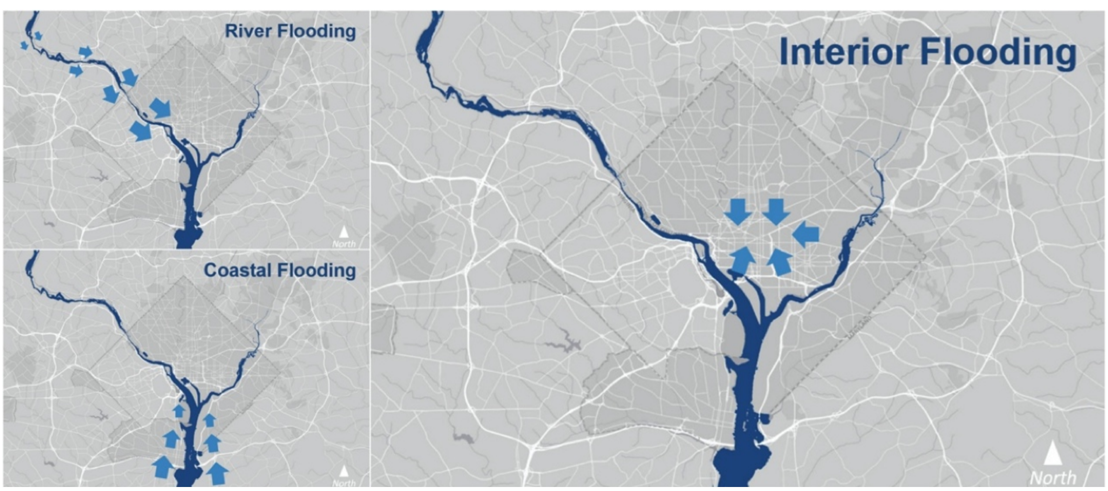

Figure 38: The three different types of flooding in Washington, D.C. (Source: NCPC)

[44] National Capital Planning Commission, *Flood Risk Management Planning Resources for Washington, DC.*
[45] "Highlights From 'The First National Flood Risk Assessment.'"

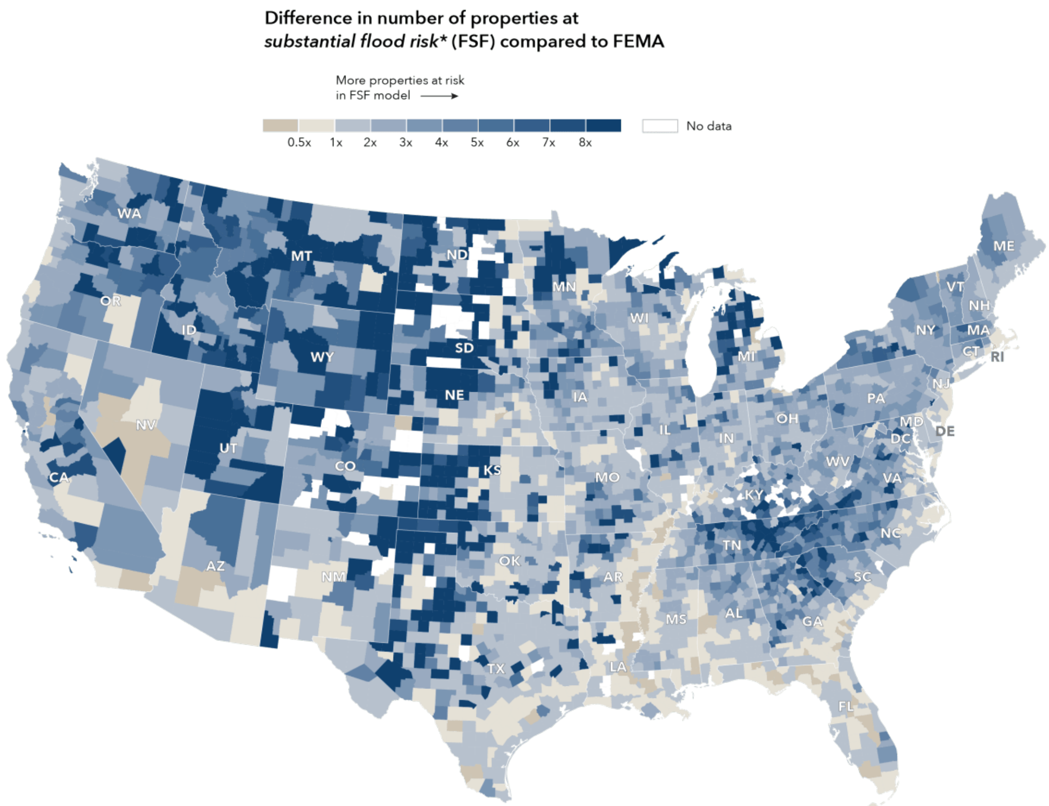

Figure 39: Up to 7x more properties may be at substantial flood risk in Washington, D.C. than FEMA estimates. (Credit: FSF)

In addition to assessing the potential for water-related issues on each site, several other criteria were identified as important site selection considerations due to their relevance in establishing risk factors and design opportunities. Based on the goals of this thesis, it was necessary to select a site with both an existing mixture of uses and building typologies as well as potential developable or re-developable land. Improving an existing community rather than starting from scratch is more sustainable, and it allows for addressing more practical design challenges like working within the constraints of existing fabric and incorporating retrofits to existing infrastructure. Addressing such challenges will prove increasingly important as cities plan for adapting to climate change.

Another important and related consideration involved assessing population vulnerability. The Southwest D.C. site is in Planning Priority Area 4, shown in Figure 40, which contains a large concentration of assets that the city deemed to be high-risk based on their contribution to the overall functionality of the District and the impact it would have on the city as a whole if they were to fail.[46] Planning priority areas also take into account social vulnerability factors like age and income, which can impede residents' ability to adapt to the impacts of climate change.

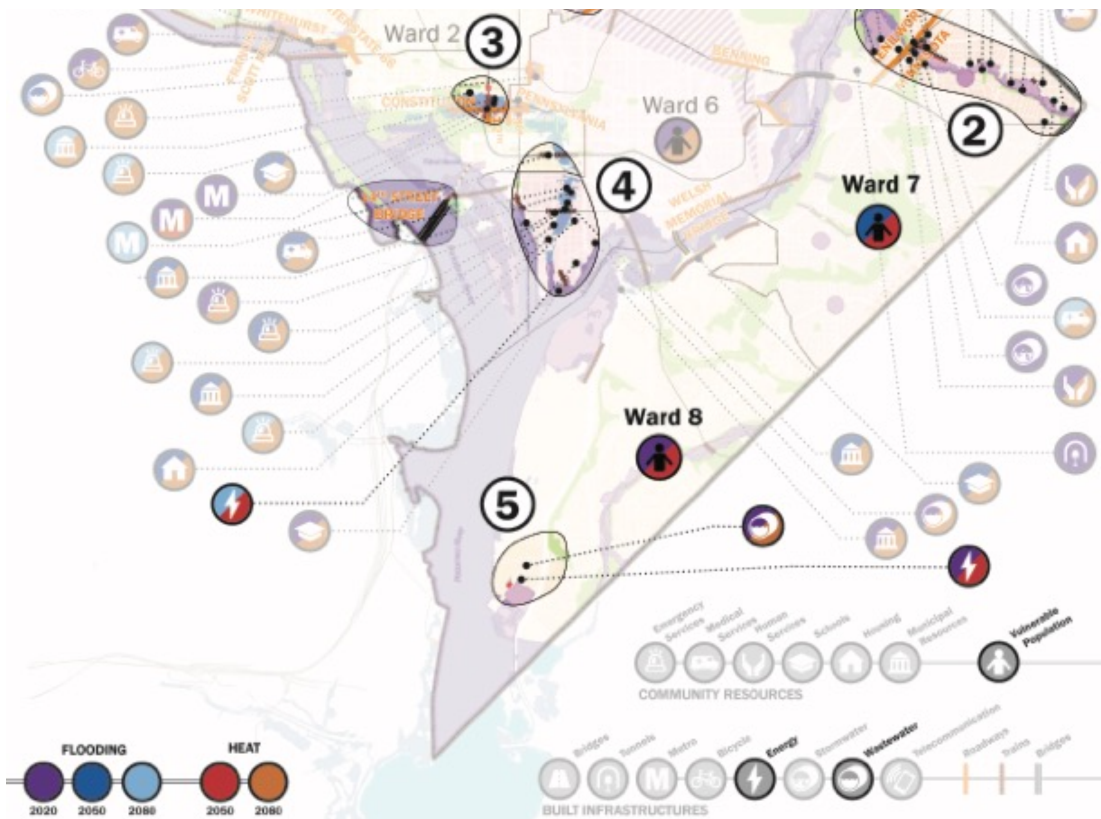

Figure 40: Planning priority areas have been identified as concentrated areas with the most at-risk assets and highly vulnerable populations. (Source: Kleinfelder, 2016)

[46] "Vulnerability & Risk Assessment: Climate Change Adaptation Plan for the District of Columbia."

Site introduction

The site in Southwest D.C. weaves over 20 city blocks in the area between Delaware Avenue and South Capitol Street from east to west and G Street to P Street from north to south. This area is unique for its concentration of public land uses, community resource facilities and infrastructure including public safety, public housing, human services, transit, energy and wastewater, all of which are at high risk for flooding. This area is home to the district Department of Motor Vehicles (DMV), United States Postal Service (USPS), DC Fire and Emergency Medical Services (EMS), Metropolitan Police Department (MPD) headquarters, SW Community Gardens, Randall School, Playground, and Recreation Center, and Greenleaf Park and Recreation Center. Also in the area are several aging public and senior housing projects including Greenleaf Gardens and Greenleaf Senior Center which are scheduled for redevelopment in the near future,[47] James Creek, and Syphax Gardens.

Another unique aspect of this site is its location sandwiched between two rapidly gentrifying neighborhoods, Navy Yard and the Southwest Waterfront, which includes the newly developed District Wharf. Likely due to its abundance of government owned properties, the area has resisted encroaching redevelopment, a fact that is clearly noticeable in its aging infrastructure and poorly functioning public realm. The site's location in proximity to public transit and new development along the waterfront make it a key point of connection in the city that is currently vastly underutilized and will inevitably make it a target for redevelopment in the near future.

[47] "Vulnerability & Risk Assessment," 11.

As such, this site should be seen as an opportunity to explore mechanisms for redevelopment that avoid displacement and exclusion and ensure that existing communities are the guaranteed beneficiaries of public investments.

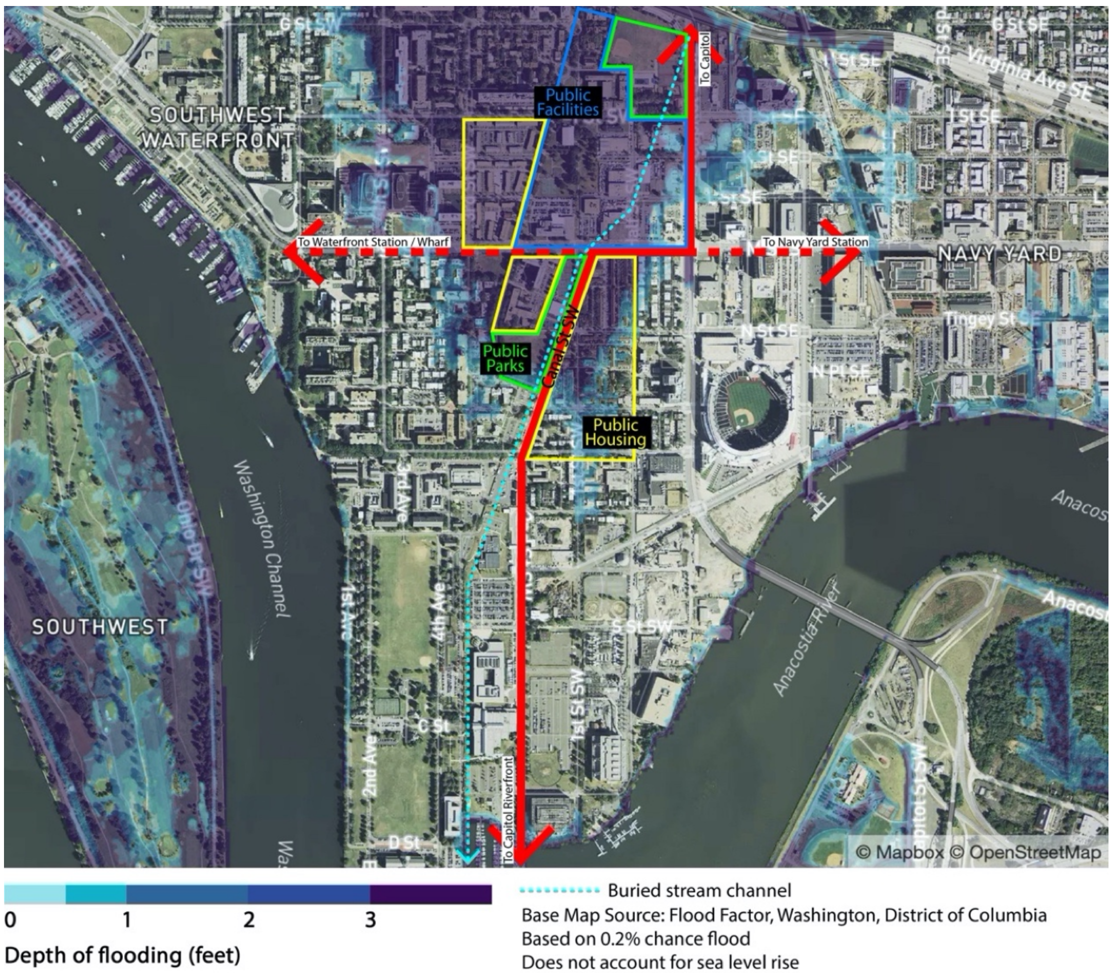

Figure 41: Diagram of Southwest D.C. site (Source: author)

The quantity of government owned land on this site provides a unique opportunity to coordinate a master plan that integrates a range of land uses, including public housing, civic buildings, and community spaces. It is important to note that because many government-owned properties are at high flood risk, this area should be a priority for the city and any new development would require a comprehensive strategy for managing stormwater across the site.

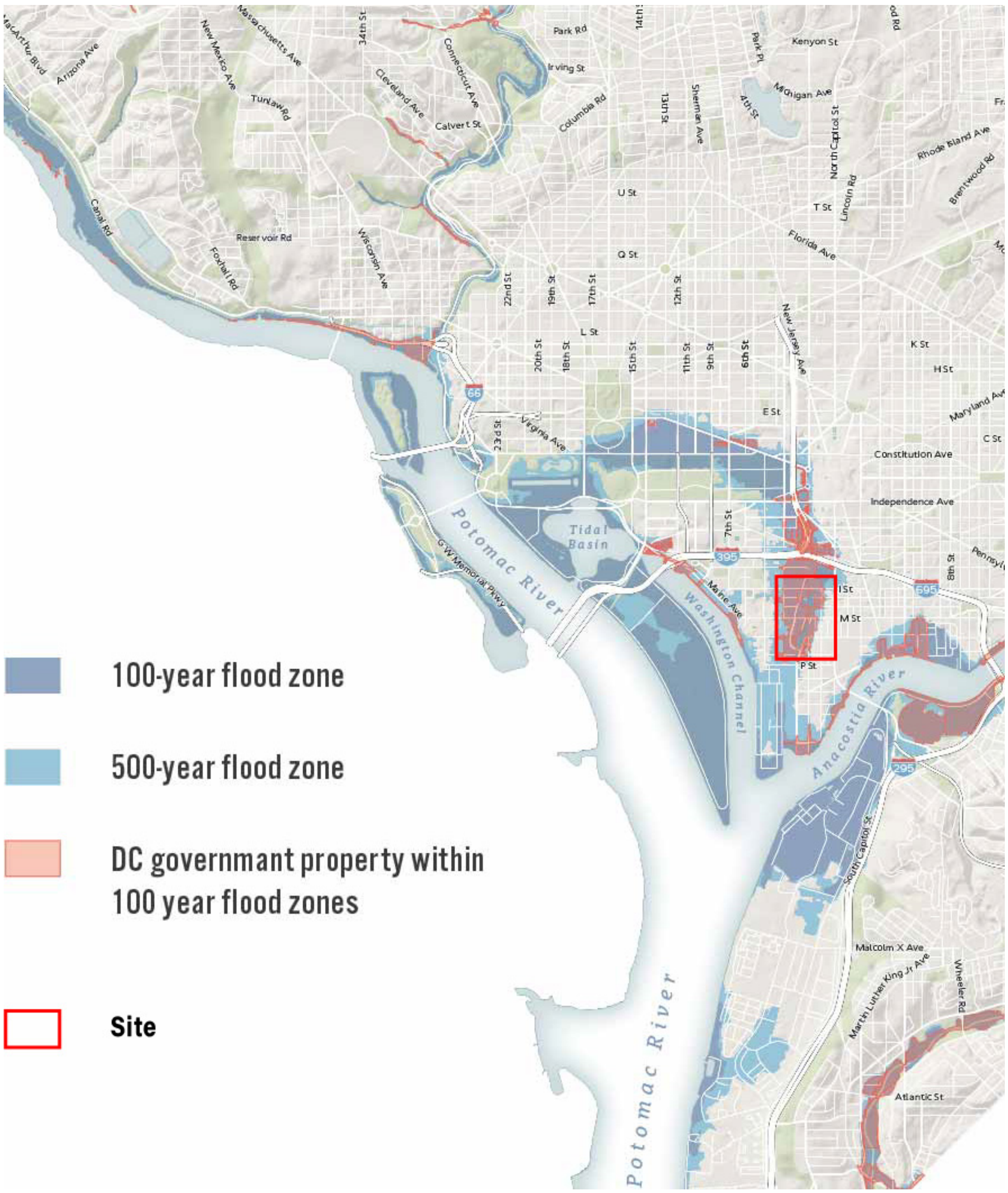

Figure 42: District of Columbia Special Flood Hazards map with project site outlined in red (Source: Office of the Chief Technology Officer, Prepared by Kelly Montague, January 2015)

Chapter 5: Site context and analysis

Historic hydrology of Southwest D.C.

When development of Washington D.C. began at the end of the eighteenth century, the natural landscape looked very different than it does today. One of the most profound transformations has been the disappearance of an entire hydrological landscape, which remains buried beneath the city today. Studying Washington's

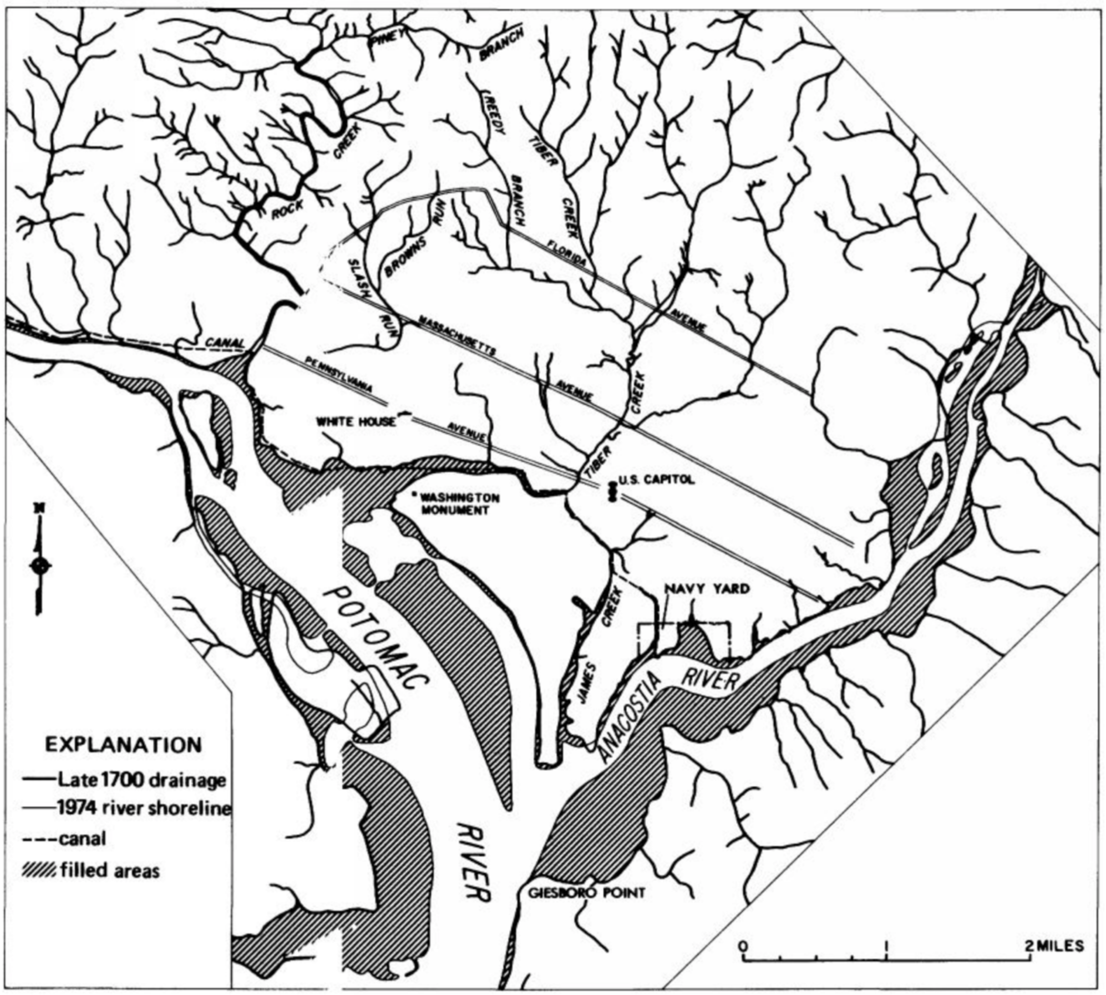

FIGURE 1. — Stream network and river shorelines of the central Washington, D.C., area in the late 1700's, compared to 1974 river boundaries. Selected reference streets and points and the 19th-century canals are also shown.

Figure 43: Original hydrology of Washington, D.C., prior to channelization and burial of historic creeks (Source: Williams, "Washington D.C.'s Vanishing Springs and Waterways," Geological Survey Circular 752)

original hydrology reveals important truths about how our attempts to constrain forces of nature can impact future generations.

Two significant streams used to flow through the center of Washington: Tiber Creek, which ran along current day Constitution Avenue and the Mall and emptied into the Potomac at 17th Street, and St. James Creek, which originated near the southern shore of the Tiber and flowed southward towards the Anacostia. The large, navigable creeks were integral to the original plan of the city. L'Enfant envisioned them as a connected system of canals that would help establish Washington as an important port and trade center.

Figure 44: Aerial perspective of Washington showing the original hydrology. James Creek is visible in the lower right. (Credit: painting by Peter Waddell, "The Village Monumental," 2018)

St. James Creek, which drained the area south of the Capitol to the Anacostia, was a major hydrological feature of Southwest D.C.[48] The path of the stream began near Maryland Ave and 3rd St SW and flowed southeast toward South Capitol St, south, and then southwest toward the Anacostia. It emptied near the southernmost tip of Southwest in a small bay between Greenleaf's Point and Buzzard Point (James Creek Marina today).

The original landscape of Southwest was a marshy wetland from about 'I' Street southward. James Creek had a deep enough flow through the marshy area to be navigable for small boats and was well-known as a favorite area for bird hunting.[49] The upstream portion of James Creek, from its headwaters near the Capitol down to about South Capitol and G St SW, was channelized as part of the Washington City

Figure 45: Visualizing James Creek in the early 19th century, prior to the development of Southwest D.C. (Source: Smithsonian American Art Museum / Public Domain. Painting by De Lancey Gill, "Mouth of James Creek", created between 1859 and 1940)

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[48] Williams, "Washington D.C.'s Vanishing Springs and Waterways."
[49] Williams, 9.

Streams, shorelines, marshes, and canals of Washington, D.C. in 1857, overlaid on the modern city. The 19th century marshes appear in green, and tidal flats in brown. Historical data come from Albert Boschke's 1861 map.

Figure 46: Washington's historic hydrology, showing James Creek where it would be today (Source: David Ramos, ImaginaryTerrain.com)

Canal by 1815, but the remaining downstream portion remained in its natural state until the 1860s.

Development contributed to the deteriorating quality of the stream and by the mid-1860's concerns about malaria instigated plans to convert the entire creek into a canal and to infill its marshy sections. Problems with mud and sewage entering the canal quickly became problematic. With the lack of streetlamps and parapets, there was also a problem with pedestrians falling in at night.[50] By 1931 the canal was covered over. The sad fate of the once picturesque James Creek was conversion into a sewer and concealment under a street called Canal Street. Today, a remnant of Canal Street runs between M and P St SW, revealing the location of the stream channel that still flows beneath the city.

The path of the buried waterways still follows the natural contours of the land, running directly under the city's crescent-shaped floodplain. Though much work has been done over last two centuries to control floodwaters through channelization and burial of the creeks, infill of the land, and construction of levees, Washington is still

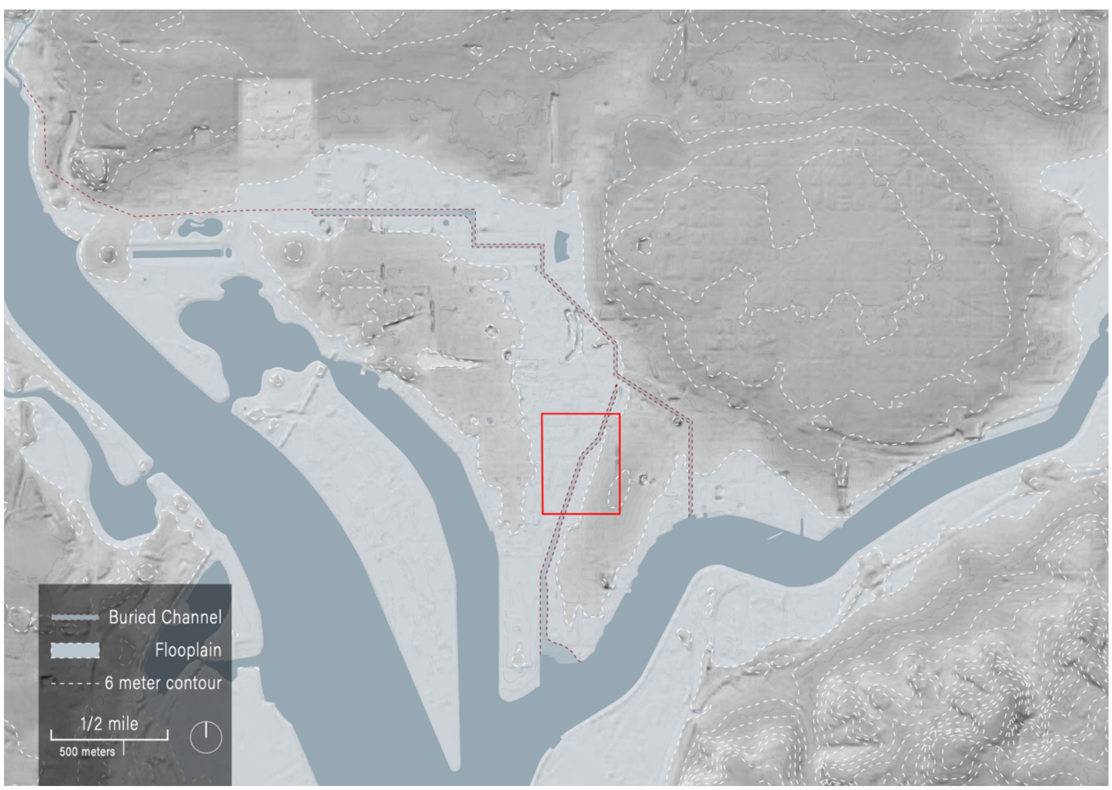

Figure 47: Location of buried stream channels with the project site highlighted in red (Source: author)

[50] Washington Times, "Tragedy and Disease Revel in James Creek Canal."

susceptible to flooding along the contour of low-lying topography where the rivers once ran. The floodplain's persistence today underscores the futility of attempts to banish natural waters from cities.

<u>Current hydrological challenges</u>

The fortification wall surrounding Fort McNair and a temporary sandbag levee that can be installed at 2nd and P St SW help mitigate riverine flood inundation when heavy rainfall causes the Potomac River to rise. However, these structures actually exacerbate interior flooding, which is the most significant flood risk factor in the Southwest neighborhood due to its low-lying elevation relative to the rest of Washington and the volume of urban runoff produced by the densely developed upland areas of the city that drains through Southwest. The formation of the landscape combined with the fortification at Fort McNair effectively turn the Southwest neighborhood into a basin, from which stormwater can only drain through ground infiltration or conveyance by storm pipes. The speed of ground infiltration would currently not suffice to prevent water from pooling due to the quantity of impervious surfaces in the area. Therefore, the majority of stormwater runoff must be accommodated by the sewer system.

Total reliance on the existing sewer system will be unrealistic under future climate scenarios, which project increasing and heavier downpours in the region. While models predict a range of precipitation scenarios, it is likely that DC will experience shorter but significantly more frequent intense rainfalls due to planetary

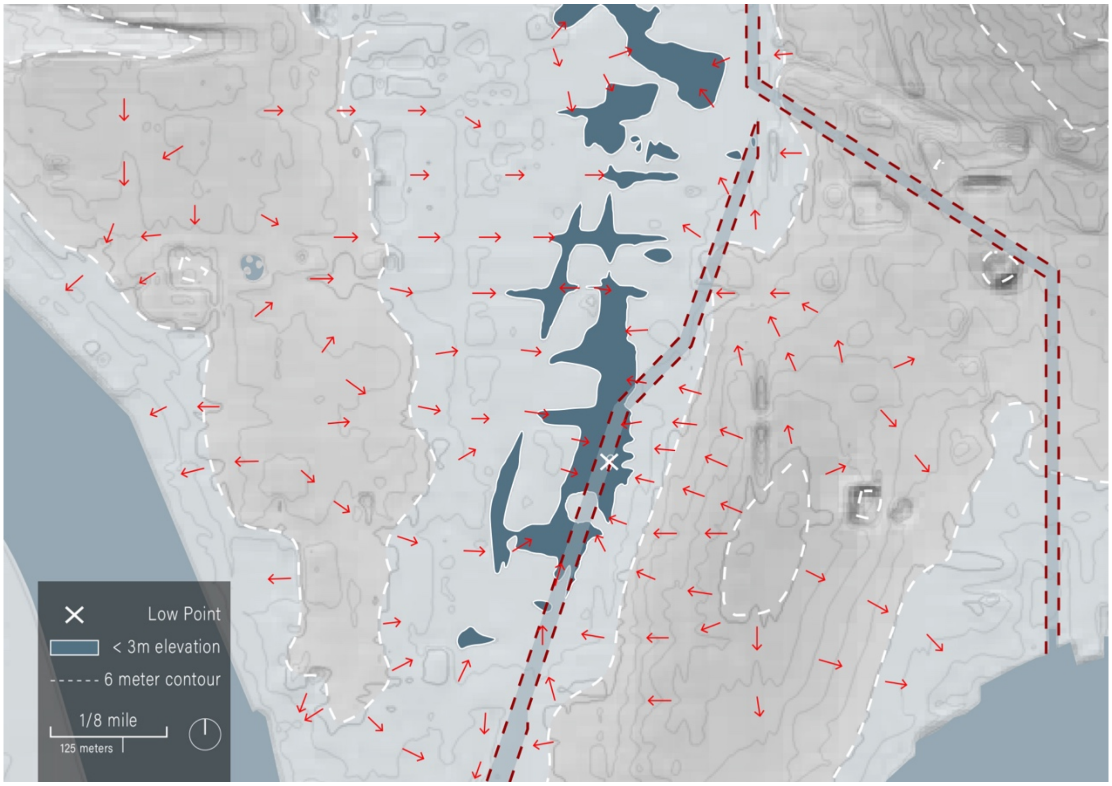

Figure 48: Water flow on the site (Source: author)

warming speeding up the hydrologic cycle and impacting cloud formation and cloudburst. The existing sewer system in DC was sized to accommodate pre-climate change hydrological conditions and is not equipped to handle the drainage needs of a city experiencing the trifold impacts of coastal storm surge, riverine flooding, and interior flooding, all of which will be drastically intensified by sea level rise and increasing precipitation.

To visualize approximate drainage needs under current-day peak rainfall conditions, runoff volume for the site was calculated using the "rational" method equation (Q=ciA). This calculation estimates the volume of runoff that exceeds the capacity of the site's natural infiltration capabilities, accounting for the soil, slope, ground cover, site area, and rainfall intensity. In order to quantify a relevant site area that would account for runoff volume captured from uphill sources, a study of water flow was done to define the boundaries of a subcatchment area. Runoff volume was then calculated for the specified subcatchment area of 210 acres, using a peak rainfall intensity of eight inches over six hours.[51] The calculation determined that over six hours of peak rainfall intensity, this water catchment area could collect 22.5 million gallons of stormwater runoff, equivalent to three million cubic feet or 69 acre-feet. Figure 49 diagrams the relative site area that would be required to harvest 100% of the runoff volume if the harvesting system were one, two, four, or eight feet deep.

Compounding the sewer system challenges in Southwest, the neighborhood houses two distinct sewer systems, with the sewershed boundary bisecting the project

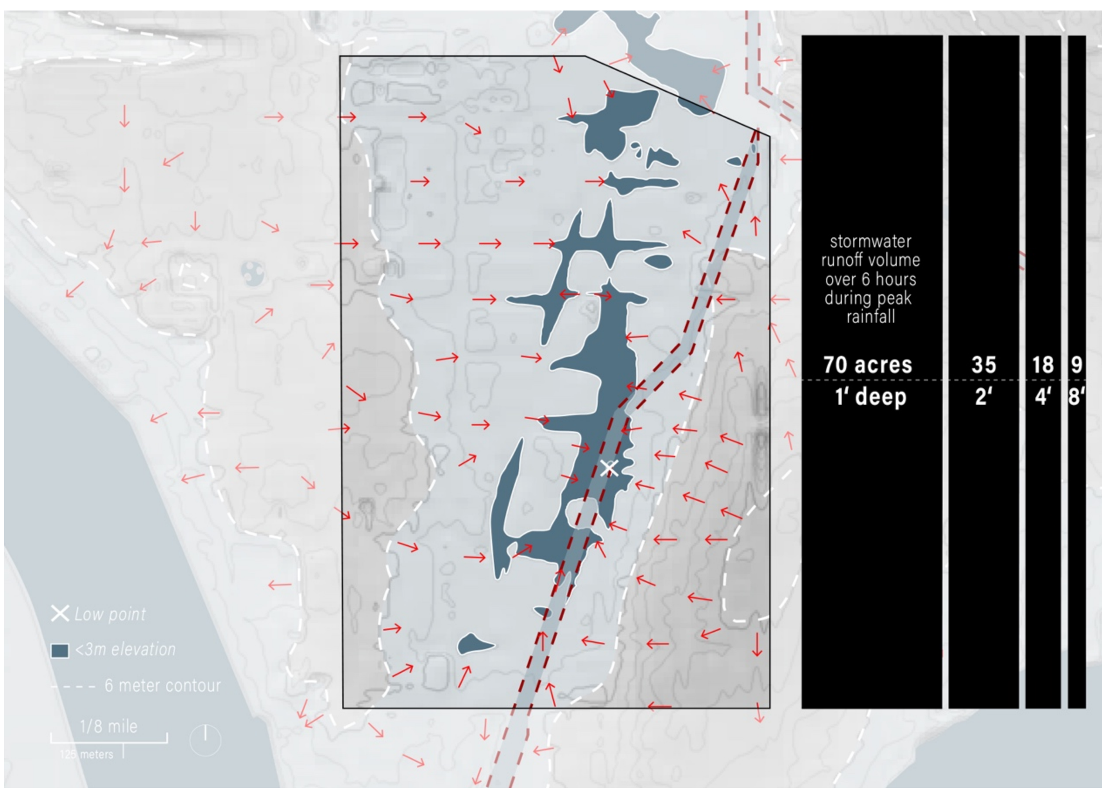

Figure 49: Visualizing runoff volume during peak rainfall (Source: author)

[51] NOAA, "NOAA Atlas 14 Point Precipitation Frequency Estimates: DC."

site along M St SW. To the north of M St, storm sewers are part of a combined sewer system (CSS) which conveys combined sanitary wastewater and stormwater to the Blue Plains Treatment plant operated by DC water southeast of the Anacostia River. The area south of M St is served by a municipal separate storm sewer (MS4), which means sanitary sewage is conveyed separately to Blue Plains while stormwater discharges directly into the river. There are two stormwater outfall locations that serve the project site. Water that enters storm drains between M St and P St SW discharges at the end of P St into the Washington Channel. Storm drains south of P St discharge at the outfall at the end of 2nd St SW at the James Creek Marina.

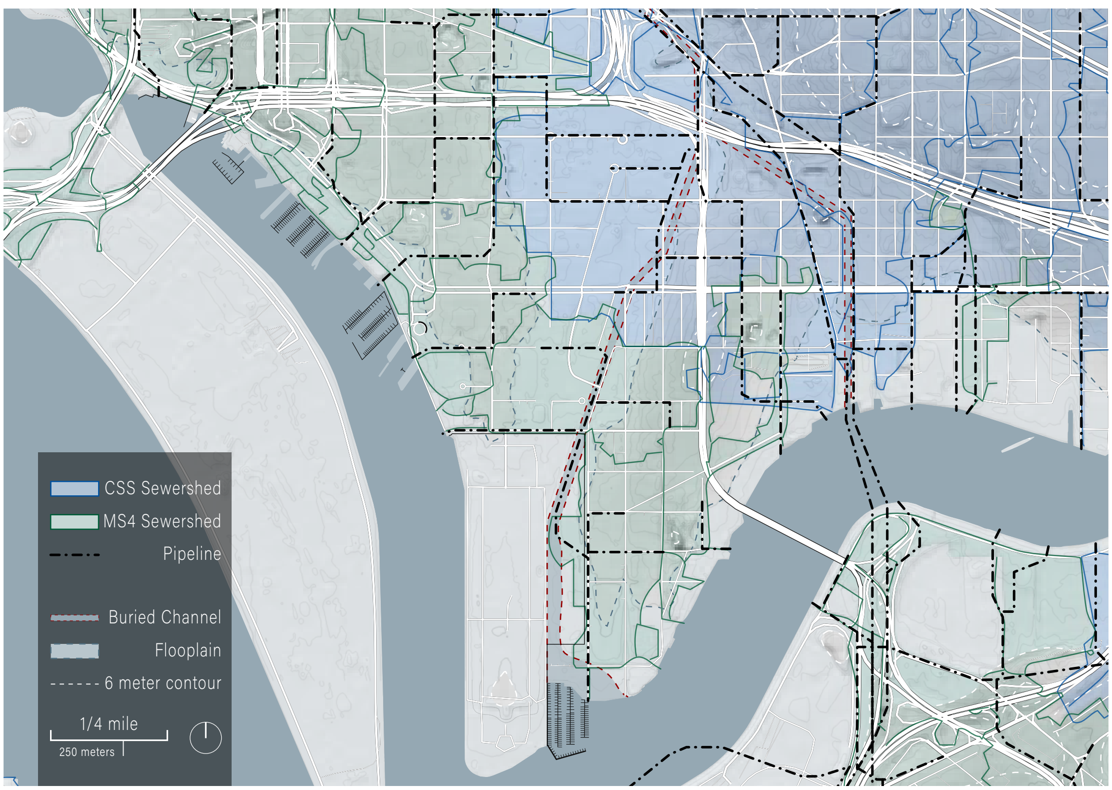

Figure 50: Sewershed map. (Source: author)

Another factor contributing to the challenging hydrology of Southwest is the high water-table. Figure 51 shows the water-table elevation of the site sits around zero feet. In some parts of the site, that is less than seven feet below the surface, and sea level rise will raise the water-table even closer to the surface.[52] A high water-table creates challenging building conditions, especially for underground structures. It is also a particular concern for older buildings whose foundations may be susceptible to water damage or where there may be cracks in basement walls. In addition, due to the fluctuating nature of the water table which can rise significantly during heavy rainfall, the ground may become too saturated to absorb stormwater, causing water to pool in the streets and flood buildings.

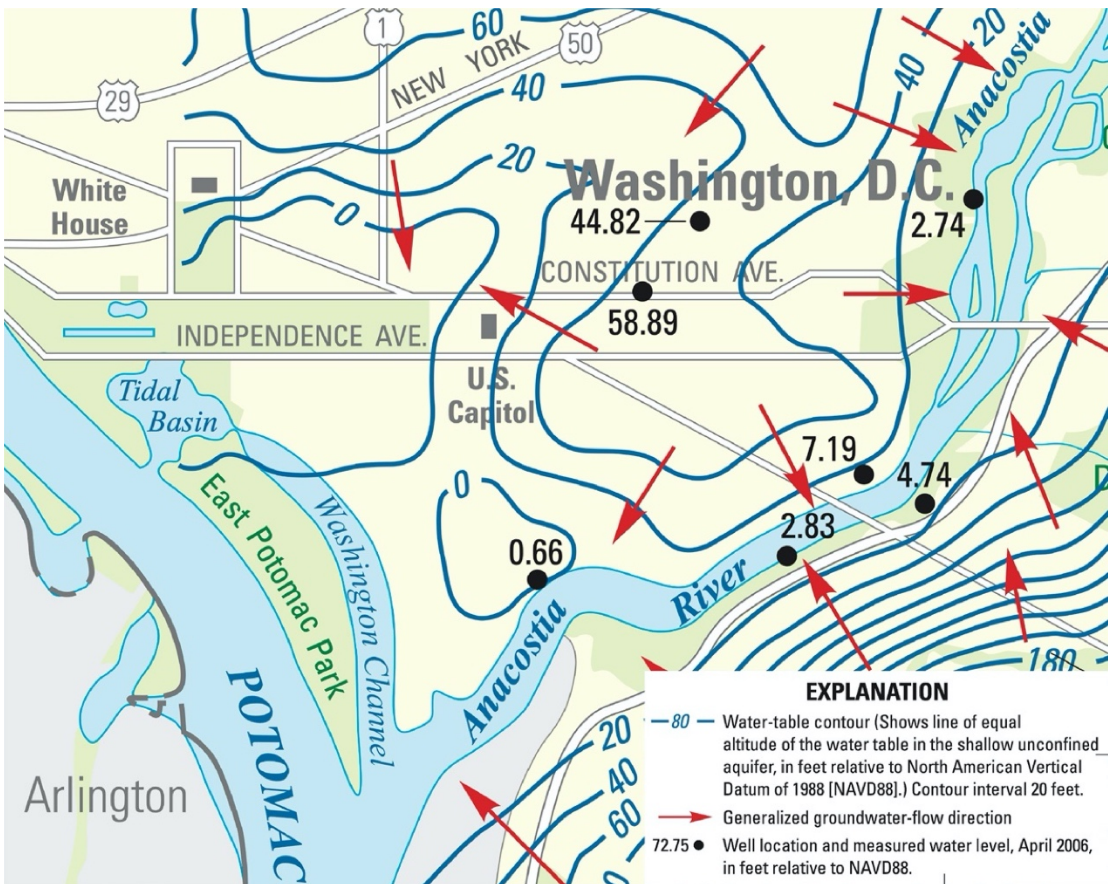

Figure 51: Water table elevation contours (Source: Ator and Dieter, 2020, modified from Matheson and others, 1994, on the basis of groundwater-level measurements, April 2006)

52 DC Silver Jackets Interior Flooding Task Group, "Interior Flooding in Washington, DC."

Legacy of urban renewal

In order to fully understand the context of Southwest D.C., it is necessary to acknowledge the enduring legacy of D.C.'s urban renewal policies that prevailed in the 1950s, 60s, and 70s. Today, the lasting impacts of the destructive forces that razed an entire community and displaced tens of thousands of Black residents remain visibly manifest in the neighborhood's urban fabric.

In the early twentieth century, a thriving community in Southwest was home to many of the city's African American owned businesses and residences. The neighborhood had the density of a small town with rowhomes and a few single-family houses along tree-lined streets, a housing stock very similar to Capitol Hill's.[53] A study commissioned midcentury indicated that many of the area's working-class

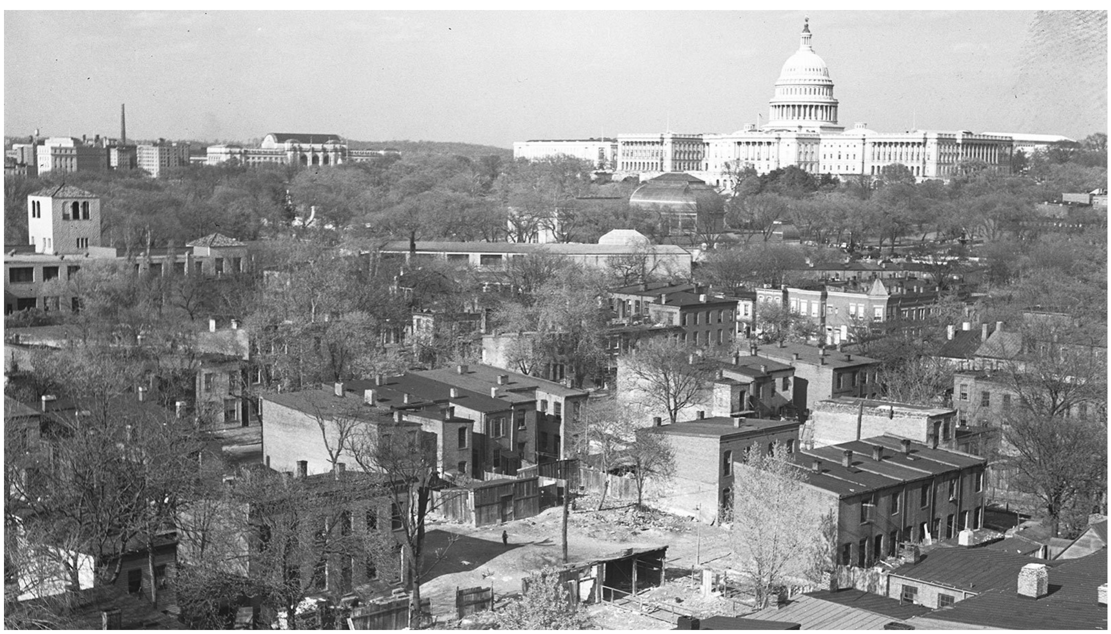

Figure 52: In 1939, many of the residents of Southwest resided in alley dwellings, which were razed during urban renewal. (Source: Library of Congress, Public Domain)

[53] Scott, "Capital Engineers," 244.

families lived in alley dwellings that lacked modern facilities like indoor plumbing and central heating.[54] By that time, years of redlining practices had prevented Black residents from acquiring loans for home improvements.[55]

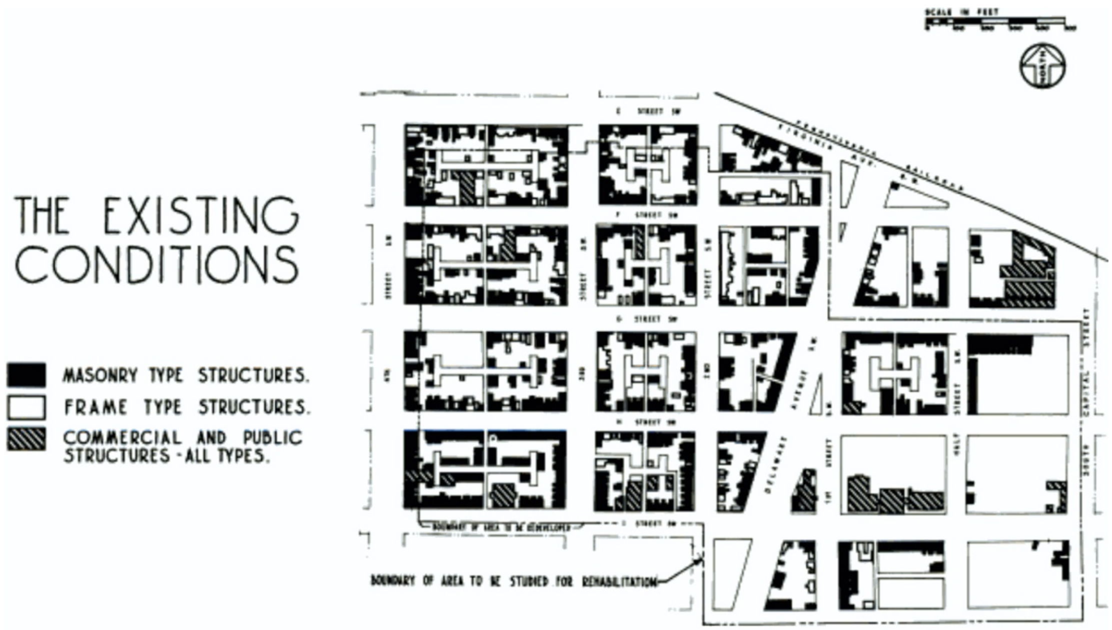

Figure 53: A rehabilitation study prepared by the Home Owners' Loan Corporation in 1942 shows then existing conditions in Southwest D.C. (Source: NCPPC)

Over the next decades, rather than invest in local rehabilitation, the federal government sponsored the large-scale demolition and redevelopment of Southwest into a middle to upper class neighborhood intended for federal employees and professionals. The District of Columbia Redevelopment Land Agency (RLA) was established in 1945 to facilitate slum clearance in the city, and in 1950 the first ever comprehensive plan of Washington, produced by the National Capital Park and Planning Commission (NCPPC), identified Southwest as a "problem area." The plan

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[54] Scott, "Capital Engineers," 244.
[55] Zickuhr, "Discriminatory housing practices in the District: A brief history."

focused on alley dwellings and “slums” as the cause of crime and disease and initiated the use of the RLA to acquire and redevelop large tracts of “blighted” and “obsolete” areas.[56] Southwest was the RLA’s first target for urban renewal.

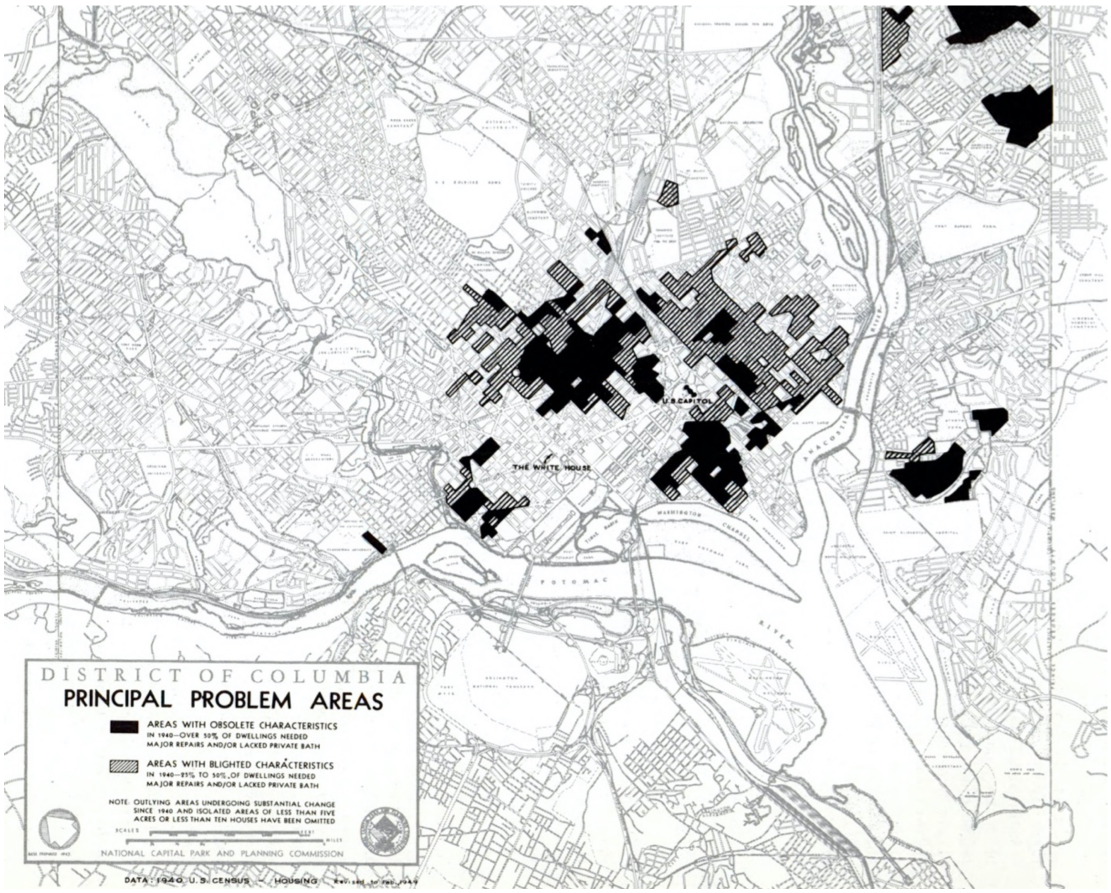

Figure 54: The 1950s Comprehensive Plan for Washington and its Environs identified Southwest as an “area with obsolete characteristics.” (Source: NCPPC)

Ninety-nine percent of the buildings on the 560-acre redevelopment area in Southwest were leveled, displacing 1,500 businesses and 23,000 residents.[57] The cost of newly constructed housing excluded many of the former, low-income inhabitants, who had to endure finding non-discriminatory, affordable housing elsewhere, or else

[56] NCPPC, “Housing and Redevelopment.”
[57] DC Preservation League, “Southwest Washington, DC Urban Renewal Area and Plan.”

move into public housing. Of 5,900 new buildings, only 310 units at Syphax Gardens were moderately priced.[58] Other public housing just outside the redevelopment area included Greenleaf Gardens (493 units), constructed in 1959, and the James Creek Dwellings (239 units), built in 1942 through a previous slum clearance program under the Alley Dwelling Authority.[59] St. James Mutual Homes (107 units), completed in 1939 during the sanitary housing movement, was the only multifamily community to survive the renewal.[60]

Figure 55: Southwest in 1959, with the newly constructed Greenleaf Gardens visible and the freeway still under construction. (Source: Copyright Washington Post; reprinted in "Capital Engineers" by permission of the D.C. Public Library)

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[58] Whose Downtown? "Urban Renewal."
[59] University of Maryland Historic Preservation Studio, "The Old Southwest Historic Resource Documentation and Preservation Plan."
[60] "Saint James Mutual Homes."

The architectural vision for Southwest was a modernist utopia designed by Chloethiel Woodard Smith and Louis Justement, whose plan called for total demolition of the neighborhood in order to build a mixture of high-rise and rowhome building typologies sited in extensive open landscape. By 1959, most of the area was razed to make room for the first of the residential towers and garden apartment complexes, as well as a new freeway. The residential superblocks replaced much of the street grid with dead end cul-de-sacs, impeding circulation within the neighborhood.[61] Most of the street connections north were also cut to make way for the freeway, reinforcing Southwest's seclusion from the city fabric.

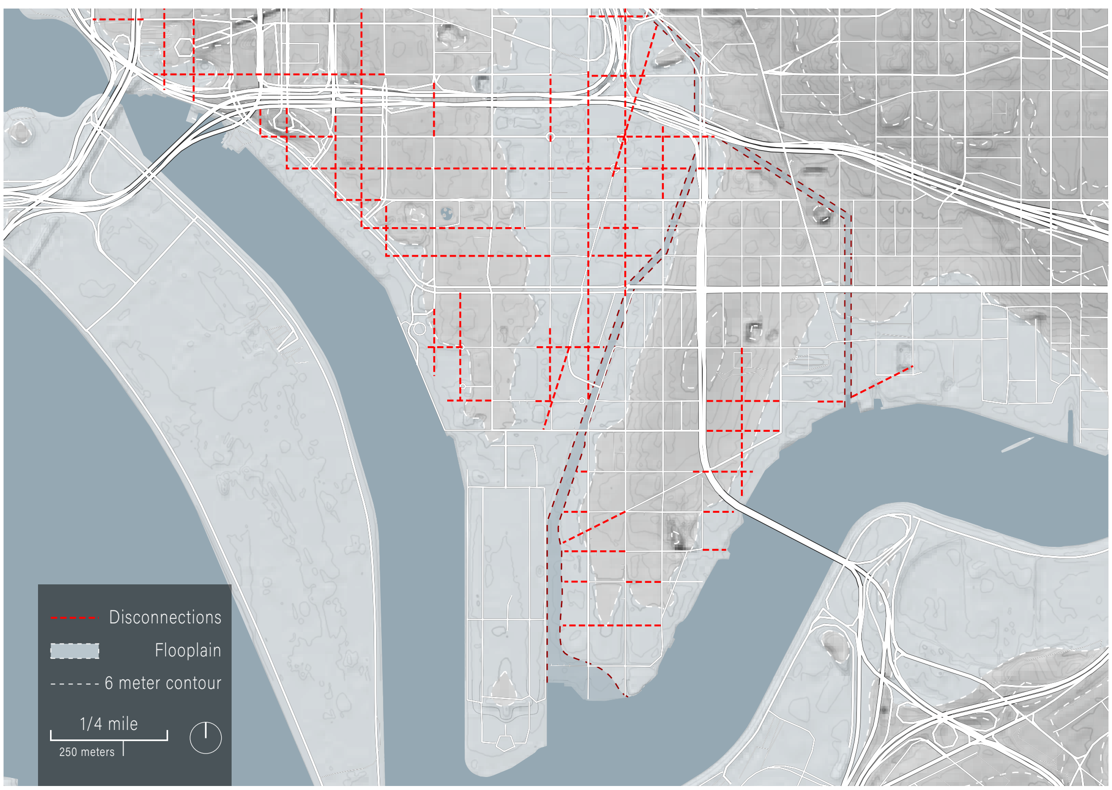

Figure 56: Red dashed lines depict streets lost to urban renewal. (Source: author)

[61] Government of the District of Columbia, "Southwest Neighborhood Plan."

Chapter 6: Program introduction

A multiscale, interdisciplinary approach

This thesis looks at the city as a system of scales, influenced by everything from as small as a street sign to global scale hydrological processes. The fight for a more sustainable and resilient city will require a paradigm shift towards a more integrated and holistic design process. In that nature, the program integrates multiple scales of the built and natural environment and explores design methodologies for harnessing the interconnected relationships between the building, the block, the neighborhood, and city.

This thesis also looks at the city through an interdisciplinary lens. The project aligns architecture and urban design with planning strategies for strengthening community resilience. The planning facet focuses on programming and phasing to help tailor the project to the needs of the existing community. Integrating equity planning during the earliest phases of design infuses the project with a more human-centered approach, a principle that should be imperative for designing in the public realm. Ultimately, this thesis strives to challenge current limitations of design practices and offer an aspirational example for future development.

Reimagining the civic commons

The programmatic aspect of this thesis focuses on transforming an area with several underutilized and disengaged public facilities by reimagining the civic commons. The concept of the civic commons explored in this thesis should first be defined, as the traditional concept of a “civic center” in the United States has devolved from its original use, particularly as it was understood historically in European cities. American usage of the word has come to imply more of a convention center or arena. This thesis considers the civic commons in a similar sense as the European civic centre and hopes to participate in reestablishing such places as the center of public life. The dictionary defines a ‘civic centre’ as “an area in a city where all the public buildings are.”[62] The nuance that might distinguish the reimagined civic commons from the historic civic centre is the added focus on communal assets and resources, rather than just civic ones. The ‘commons’ is defined as “the cultural and natural resources accessible to all members of a society, including natural materials such as air, water, and a habitable earth.”[63] The ‘civic commons’ conveys the idea that the public realm may include a combination of both civic and community-based programs and spaces.

The concept of ‘reimagining the civic commons’ follows a new national initiative of the same name that has arisen at the interface of architecture, landscape architecture, urban design, planning, and community development. The Reimagining the Civic Commons initiative describes their mission as:

“Demonstrating that transformative public spaces can connect people of all backgrounds, cultivate trust and create more resilient communities.”[64]

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[62] Longman Dictionary of Contemporary English.
[63] Wikipedia, the free encyclopedia.
[64] Reimagining the Civic Commons (website).

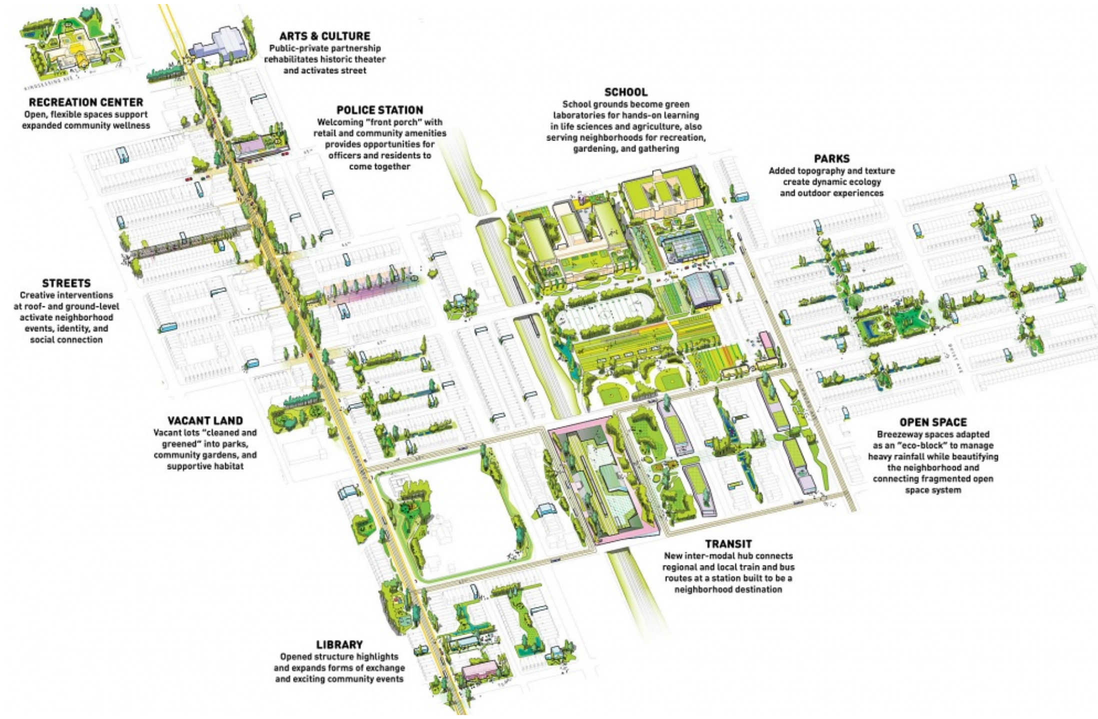

Figure 57: As part of the Reimagining the Civic Commons initiative, Studio Gang produced an urban design framework for the civic commons based on a case study of Philadelphia. The framework includes "physical and programmatic changes that can be customized and implemented for seven types of civic assets: libraries, parks, recreation centers, police stations, schools, streets, and transit." (Source: Studio Gang)

The initiative's theory of change is that ambitious social, economic, and environmental goals may be advanced through the design of the public realm.[65] This project hopes to build upon that framework by looking more deeply at the potential of hydrologic design and stormwater management as means to improve the civic commons and make communities more resilient. In this regard, the programmatic centerpiece is an integrated stormwater management system that weaves together a network of civic and community spaces and improves the social, architectural, and environmental quality of the public realm.

[65] Reimagining the Civic Commons, *Initiative Overview.*

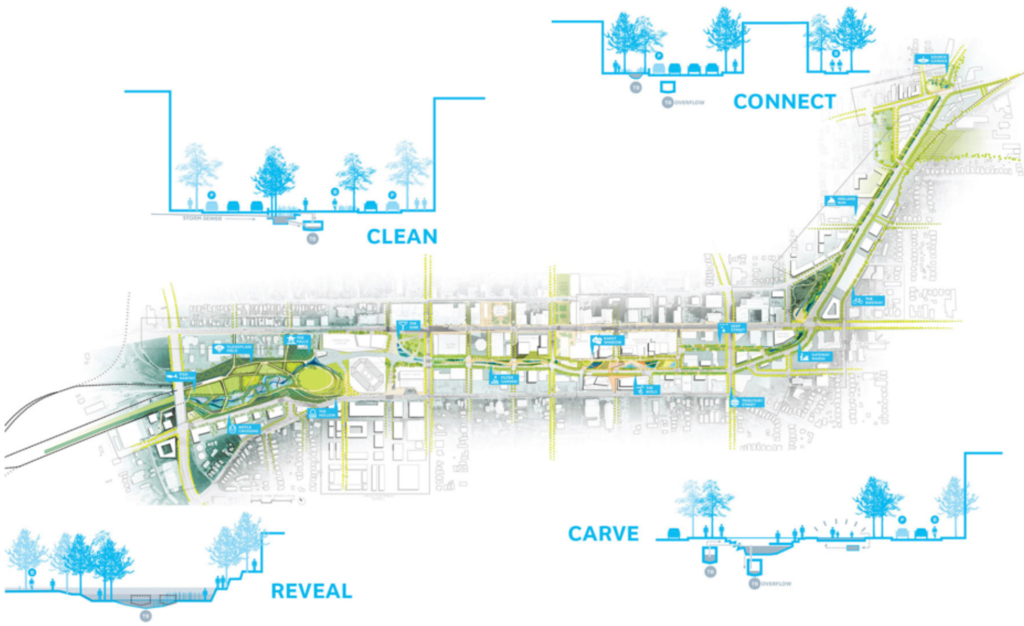

Figure 58: SCAPE Studio's program proposal for the Town Branch Commons includes "a series of pools, pockets, water windows, and stream channels that brings water into the public realm. A hybrid park network, multi-modal trail system, and water filtration landscape." (Source: SCAPE Studio)

Through programming this thesis aims to integrate the new and the old, introducing a combination of carefully considered redevelopment, redesign, and retrofit schemes to bring new life to a neglected site and reestablish the civic commons as the center of public life. Existing public buildings in the site area include the DMV, USPS, Fire & EMS, MPD, Greenleaf Recreation Center, and several public housing complexes including Greenleaf and James Creek.

As the goal of this thesis focuses on community resilience, proposals for new programming must reinforce that goal. Initial program development exercises produced three main concepts for new programming for the civic commons. Figure 59 shows a tabulation of some of the potential spatial needs for each of the three program concepts. Approximate square footages were achieved through analyses of an assemblage of programmatic precedents.

Program Description	Precedent NASF	Precedent GSF	Existing GSF
Stormwater Management			
Stormwater plaza & integrated urban stormwater management system			
Precedent: Washington Canal Park		**115,600**	
Rain garden bio-filtration	6,170		
Pre-treatment cistern	40,000 gallon		
Clean water cistern	40,000 gallon		
Stormwater-irrigated green space	16410		
Stormwater-supplied fountain	2,070		
Stormwater-supplied ice rink	14,000		
Tree wells	20,000		
Existing: Parks/green space			**330,000**
Rainwater/grey water recycling & educational wastewater treatment landscape and facilities			
Precedent: Sidwell Friends School			
Constructed treatment wetlands	9,000		
Rainwater cistern			
Grey water storage			
Green roof	8,800		
Resilience Hub			
Gathering space, digital library, resource center & emergency services during natural disasters (coordinated with existing Fire & EMS/DCPD stations)			
Precedent: Darling Exchange (Library and IQ Hub)		**23,584**	
IQ Hub (flex space & entrepreneurial support services)	3,200		
Internal open seating & circulation	13,240		
External	4,144		
Auxiliary	3,000		
Existing: Fire & EMS			**43,000**
Existing: DCPD			**45000 x 3**
Existing: Recreation center			**14,500**
Public & affordable housing			
Existing: Public Housing			
Existing: Senior Housing			**43,000 x 8**
Community Exchange			
Market hall/public trading forum for local goods and services (including public services like USPS, DMV)			
Precedent: Darling Exchange (Market Hall)		**15,543**	
Vendor Stations	5,487		
Internal open seating & circulation	6,756		
External	300		
Auxiliary	3,000		
Existing: USPS			**12,000**
Existing: DMV			**12,000 x 3**
Urban agriculture/food co-op			
Existing: Southwest Community Garden			**5,400**

Figure 59: Initial program tabulation exercise (Source: author)

Chapter 7: The City Symbiotic

Design introduction

Climate change is one of the biggest threats facing the future of our cities and the fate of our cherished public spaces. Our planet is undergoing changes that threaten to not only damage buildings and infrastructure, but to disrupt the very fabric of our public life. There is a way to make cities more resilient, but it is going to require some pretty drastic changes in the way we think about design and require us to think at a much larger scale than ever before. This thesis proposal provides an example of how an urban neighborhood that faces the threat of urban flooding could be transformed for a more resilient future.

Figure 60: Elevated perspective view looking east across the park (Source: author)

This thesis explores the concept of integrating urban design and architecture with stormwater management on a hydrologically sensitive site in Southwest D.C. As designers of our built environment, we have a responsibility to deal with the pressing social problems of our times in what we design. Resilient design not only addresses the impacts of climate change, but it also brings so many additional benefits to our communities. This project has the potential to significantly mitigate flooding for the city as a whole. It reimagines the types of civic functions that can exist in great urban spaces. It brings a significant amount of affordable housing to the city in a way that promotes environmental justice in a historically neglected part of the city. The design creates harmony between the built and natural environment that can promote environmental health and biodiversity, and also creates an amenity that drastically improves public life in the city.

Summary of thematic drivers

When we look at the floodplain map of Washington, D.C., a revealing pattern emerges about the hydrology of the city. The city floods along a crescent-shaped path that flows through the interior of the city. Comparing the floodplain map to a map of the original hydrology of the city helps us understand why we are seeing this pattern of flooding. There used to be two large creeks that cut through the landscape and emptied into the Potomac and Anacostia. The creeks were converted into a system of canals that ran through the city connecting Georgetown to Buzzard Point and Navy Yard. Looking at the flood map today, we can see those original canals run along the floodplain crescent. Though they have long been buried below the city, water still actively flows through those channels and on the surface. The James Creek Canal runs directly through the Southwest project site.

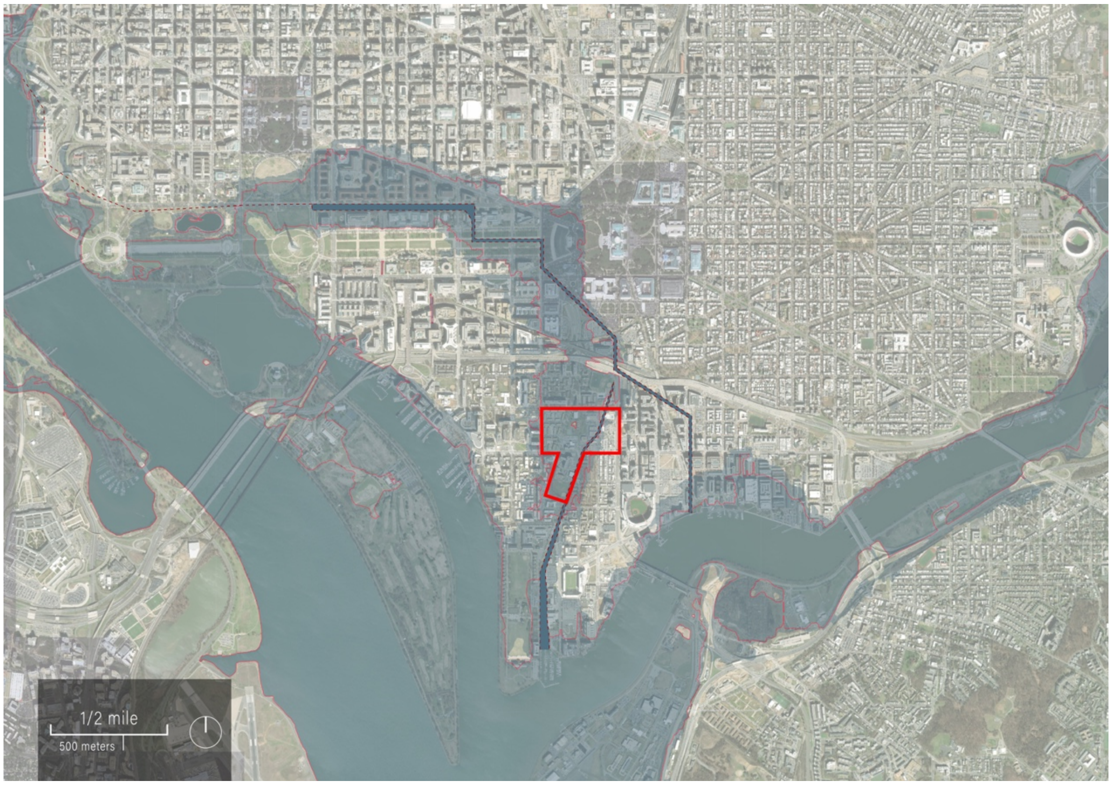

Figure 61: Floodplain map of Washington, D.C. with location of buried channels (Source: author)


Figure 62: Reconstruction of the topography of Washington, D.C. in 1791 (Author: Don Lockwood / Source: Library of Congress)

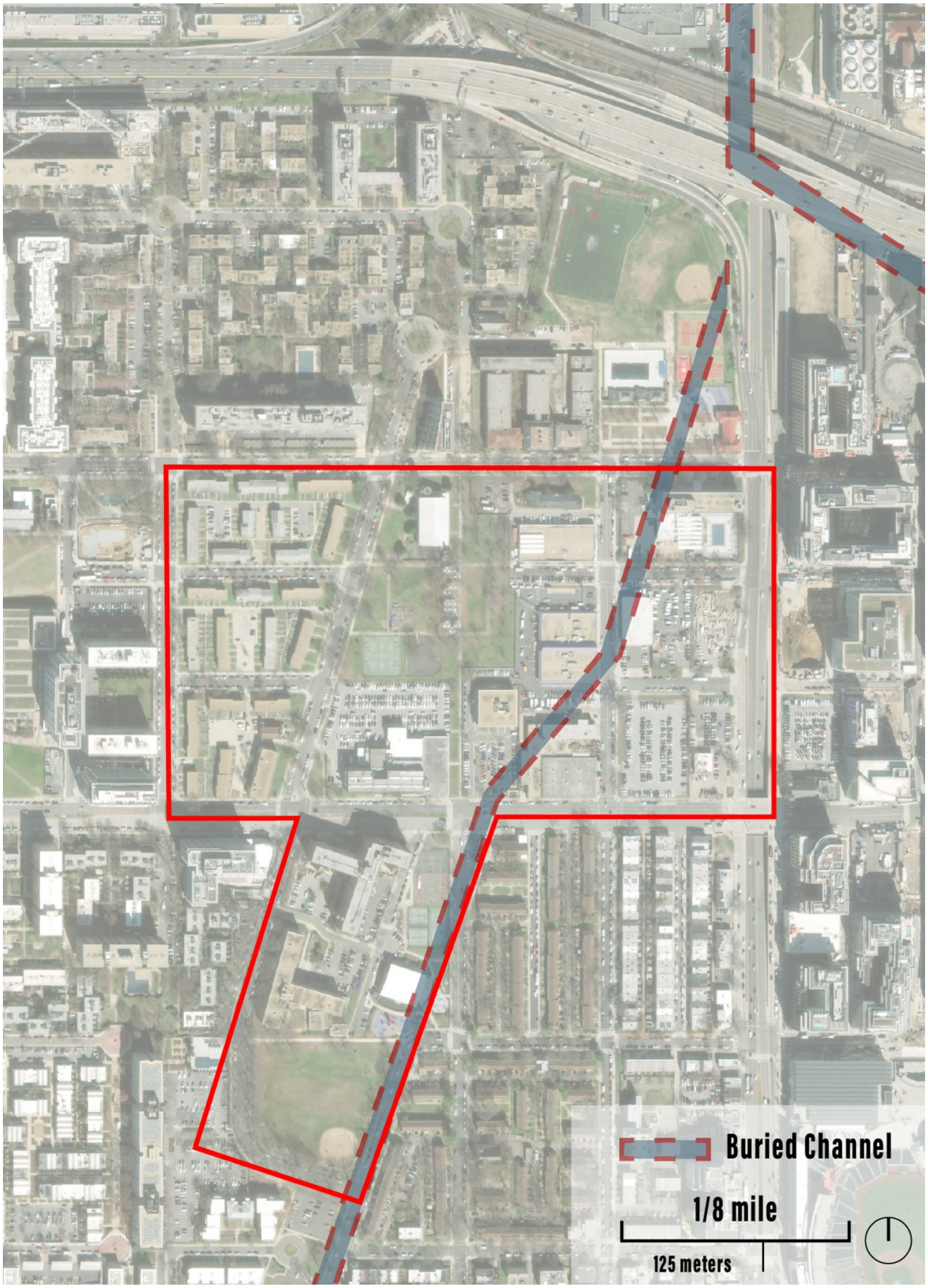

Figure 63: Southwest project site with location of buried stream channel (Source: author)

Figure 64 shows highlighted in red all the federal and local government-owned structures that lie within the floodplain crescent. The pattern that emerges maps a clear relationship between hydrology and land ownership, which tells us that the spatial form of the city has evolved very closely with the presence of water. It is evident that there is a topological continuity between these spaces that relates to both their civic function and their hydrological function.

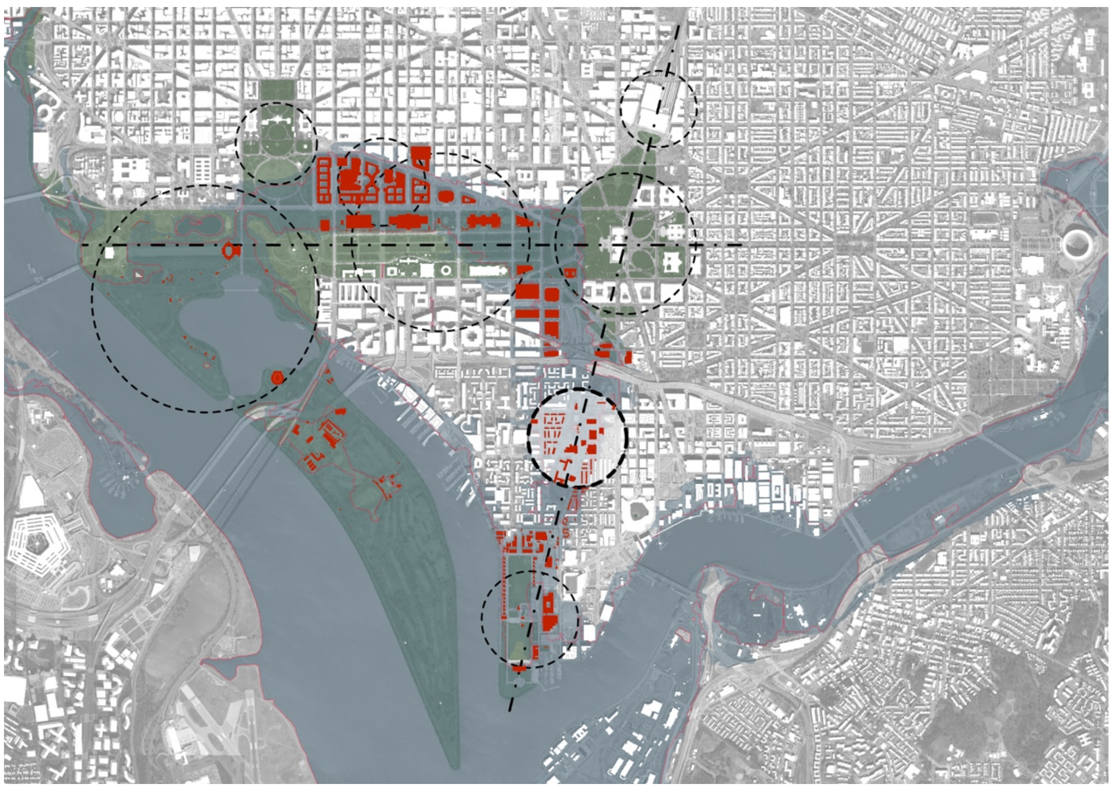

Figure 64: Mapping the relationship between civic space and flood risk (Source: author)

Along the monumental core there is a sequence of civic nodes, or centers of civic activity, with a very strong, legible connection. By contrast, the civic sites south of the freeway are fragmented. Another distinction is that the core is the heart of the federal government whereas the Southwest project site is more local in nature, with an existing agglomeration of public facilities owned or operated by the district. The language of the city reads with a clear hierarchy of power distribution between the federal city and the district. This area provides the opportunity to create a new civic centre that has a strong connection to the monumental core, by creating a green network connection that brings a node of local civic activity into this area and that elevates its presence in the District.

<u>Site and program responses</u>

Part of the reason this neighborhood is so disconnected from the rest of D.C. is due to the legacy of urban renewal that took a toll on the character and quality of the fabric of the neighborhood in the 1950's, 60's, and 70's, leaving behind a broken street grid, poorly designed public spaces, and a highway cutting the neighborhood off from the rest of the city. Today, the 50-acre site sits sandwiched between two rapidly developing neighborhoods, with the Wharf to the west and Navy yard to the east. The design proposal addresses the hydrologic challenges of the site situated in the floodplain crescent while also being very attentive to major contextual challenges inherited by this site.

Figure 65: Figure grounds – existing (left), demolished (center), and proposed (right). (Source: author)

Until now, this site has largely resisted encroaching gentrification due to the predominant presence of public housing and government-owned facilities. A significant lack of investment is very apparent in the quality of the public realm. Now that money is flowing into surrounding neighborhoods, redevelopment is highly imminent and even necessary due to the dilapidated state of the public housing facilities and the threat of increasing flood risk under climate change. This poses an opportunity to redesign the area in a holistic way that integrates the unique hydrological conditions of the site with the revitalization of the public realm.

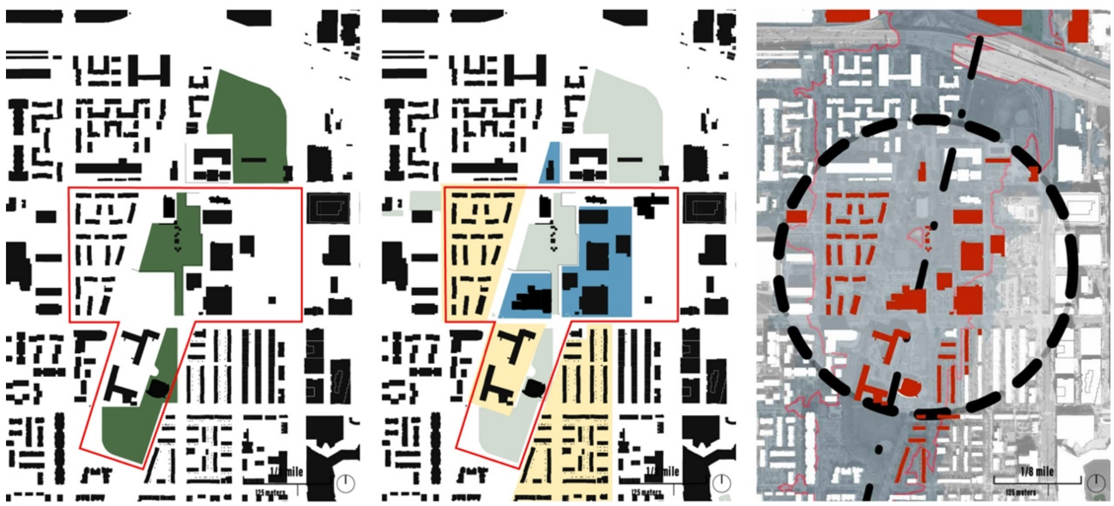

Figure 66: Existing parks (green), public housing (yellow), public facilities (blue), and government flood risk (red). (Source: author)

The major contextual issues that influence my design concept are 1) the fact that there are three parks here that could be better utilized to create great connected green spaces in an urban environment; 2) the majority of the land on this site is owned by the district government and is highly underutilized and has the potential to become a new civic center; and 3) the fact that it is sitting in the floodplain which is a huge design challenge but also an opportunity to design a neighborhood that is aggressive in its approach to manage flooding while providing public amenities.

In addition, we have an opportunity to significantly increase affordable housing and to also make it more mixed income. The area is the site of several public housing complexes, a couple of which have already been slated for demolition. There is a huge shortage of affordable housing in the city, and the city is looking for a way to redesign the area with more density and mixed use while still maintaining or actually increasing the amount of affordable housing available. My design proposal brings in 3,000 mixed income units and triples the quantity of affordable housing currently on the site.

Finally, in evaluating the site, I concluded that it offers rich opportunities for designing with water in a way that could improve access to urban parks and green spaces. The new scheme weaves the three existing parks, maximizing the opportunity for an urban green space that ties into the architecture that they are both serving to complement each other and mutually create connectivity, coherence, and a sense of place. The new design scheme would bring back the historic hydrology to control flooding through a series of water elements that evoke the natural wetlands, daylighting portions of the canal, using bioretention, and incorporating stormwater management into the architecture of the structures. By pealing back from the floodplain, the design gives room to the water and creates a sequence of beautiful public spaces defined within the walls of the city.

Figure 67: Proposed masterplan (Source: author)

Design concept

At the largest scale, my proposal is to sew my site into the network of civic and green spaces that span the city all the way from the tidal basin to the Anacostia and create a *green necklace* for the handling of water in the city interior. The green necklace connects to the broader tidal system, from the confluence of the Anacostia and the Washington Channel to the south and tying into the monumental core where a portion of the buried stream channel has already been daylit at the National Museum of the American Indian.


Figure 68: Birds eye view and diagram of green necklace. (Source: author)

The green network reinforces the spatial connection between the civic nodes in the city's monumental core and the project site, establishing it as another active civic center within this overarching sequence and drawing public life into the Southwest quadrant of the city through the new connectivity corridor.

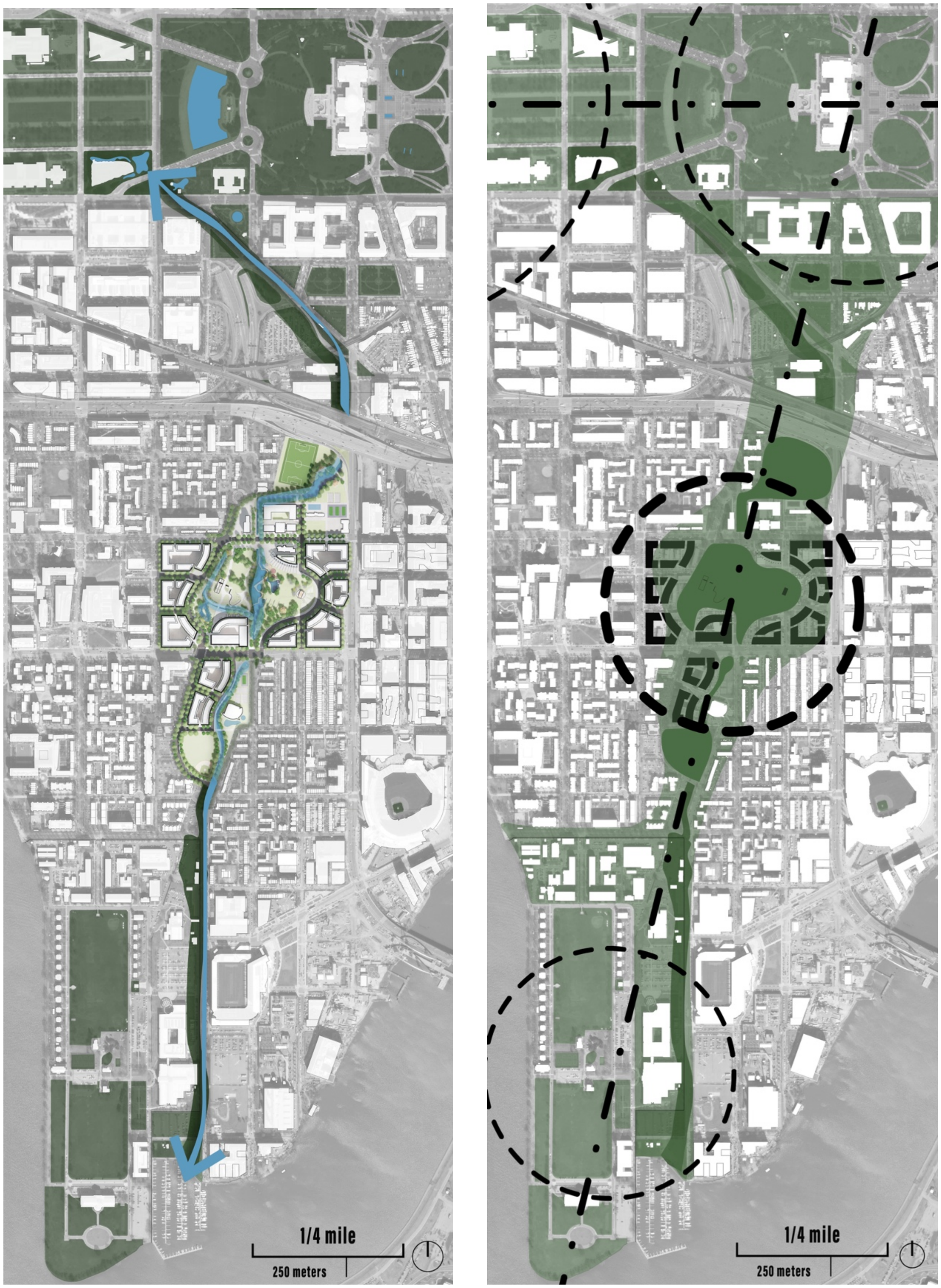

Figure 69: Connectivity to water and park systems. (Source: author)

Figure 70: Reintegrating existing structures (red) and park sequence (green). (Source: author)

Much of the land in this area is government owned yet it is largely cut off from the life of the community. The current design does not do any placemaking or add to the public realm. The presence of these public buildings presents both challenges and opportunities. These public facilities contribute to the function of the neighborhood and need to be reincorporated into the overall urban design in order to change the way they interact with public space to become part of public space making. The new design proposal incorporates existing programmatic uses by redesigning, renovating, and reintegrating existing structures to improve those space. Figure 70 shows which structures have been retained or renovated but remain on the site; and Figure 71 shows how demolished structures including the fire station, post office, and DMV and its service centers have been reintegrated as part of the new urban design scheme.

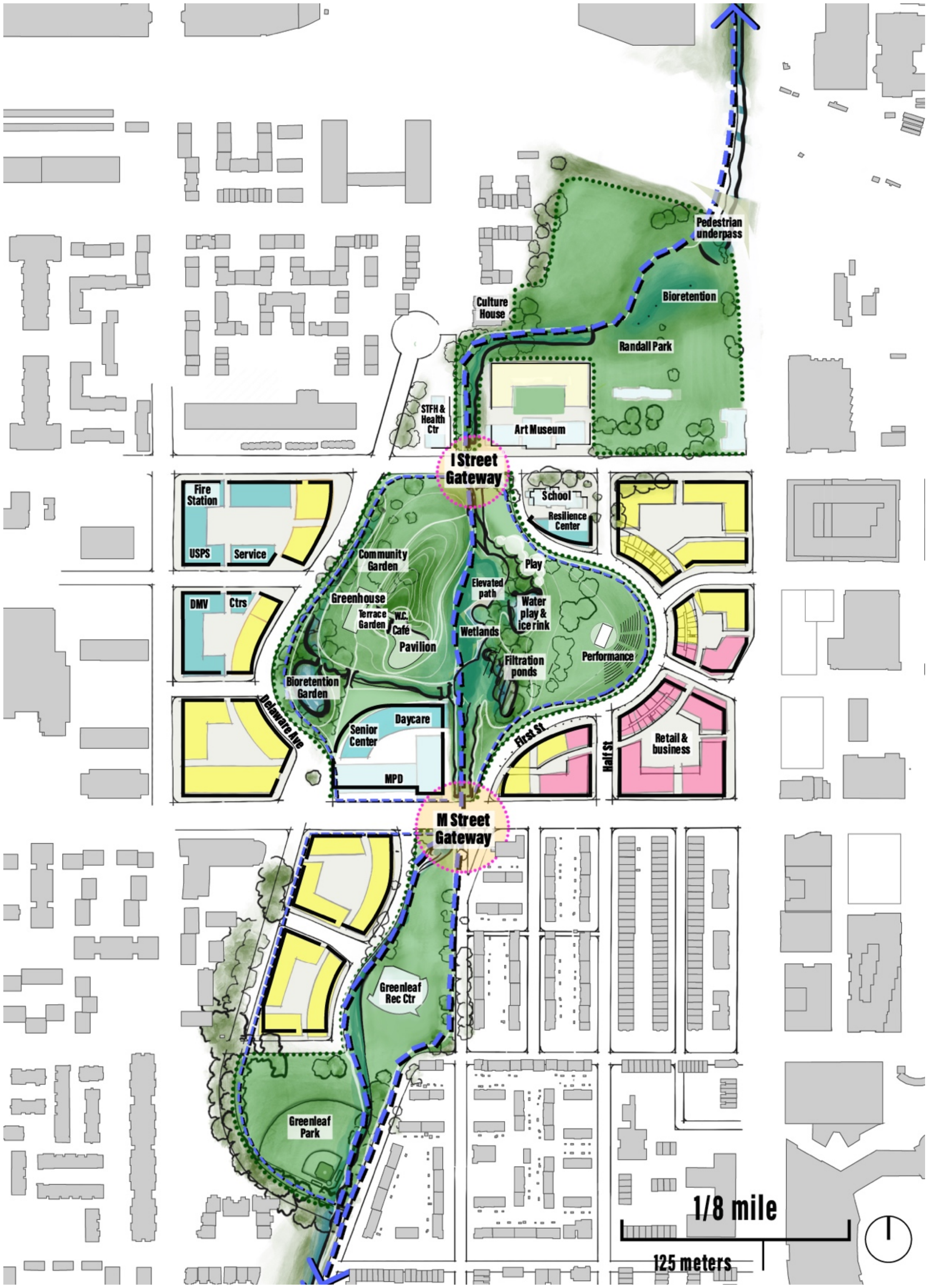

Figure 71: Places diagram (Source: author)

Figure 72: View of resilience center plaza, water play, and elevated wetland path. (Source: author)

Figure 73: View of park under different weather conditions. (Source: author)

The design proposal integrates architecture and hydrology in the public realm to show how the built systems function as part of the community system and part of the natural system. This is part of the overarching goal of rethinking how we design cities to help mitigate human impacts. The two images in Figure 73 show how the park adapts to various weather conditions and how each space is designed to accommodate their stormwater needs in various ways and contribute to the overall functioning of the public realm as a whole. In the rainy day shot we see several things occurring. The wetland has flooded and is naturally holding a significant load of water. This site will be required to handle much more than its own share of the stormwater footprint from the city. The design accommodates this need by naturally absorbing a huge amount of stormwater for the surrounding areas of the city. We also see the tops of the water columns in use. The water columns function as vessels that capture water, retain it, and then visibly send it into the landscape or filtration step pools.

Figure 74: View of water harvesting columns at the resilience center. (Source: author)

The water harvesting columns are part of the resilience center, a new civic space with multiple functions. It provides offices for staff who maintain the park, serves as a community resource on dealing with resilience issues, and provides space for educational and civic functions. The structure is designed to demonstrate how the park thinks about water - incorporated as part of the structure of the building, while also providing aesthetic value. As an educational element, it visualizes the flow and management of water, showing what happens with rainwater falling on the roof, flowing through the exposed structure into conduits that clean and transport water to the wetland.

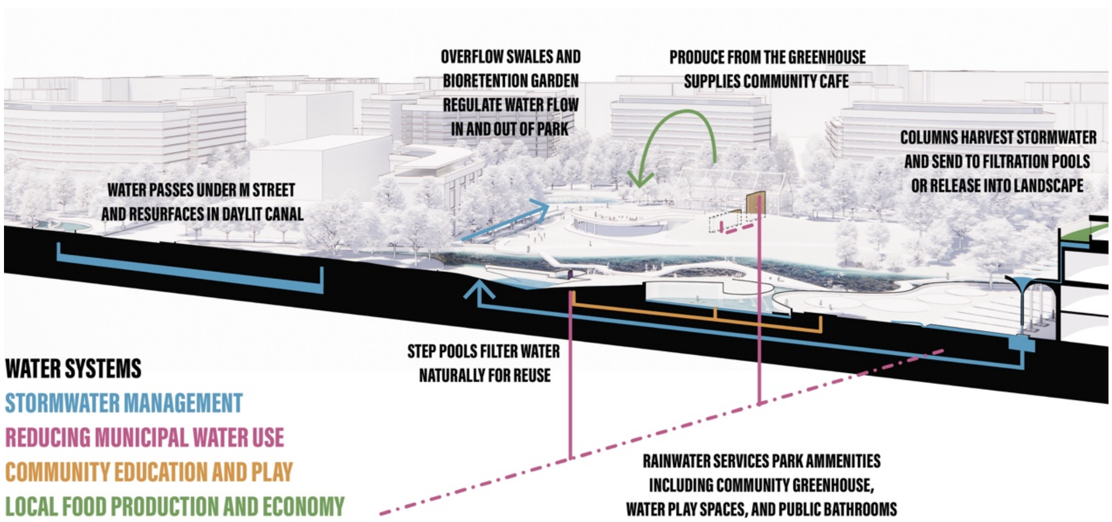

Figure 75: Section perspective diagram of integrated park systems. (Source: author)

Within the park, ecosystem functions are integrated with community services. The result is a highly efficient public space that demonstrates how to use water to design in sustainable ways. Systems are designed to complement each other and provide mutually beneficial services, for example reusing rainwater in the greenhouse to raise food for the cafe as part of the local economy while providing a green space amenity. The greenhouse is also designed together with the pavilion architecturally for utility - the thick wall that runs cross axially between the structures holds the recycled water to be used for irrigation and will also serve functionally for the public restrooms in the pavilion.


Figure 76: View of café pavilion, terrace garden, and greenhouse. (Source: author)

The design reintroduces the historic hydrology that was lost to this site, but in a way that creates a great public space and amenity, provides biodiverse habitat, restoring natural elements that can provide the green benefits we need to handle stormwater and prevent harm to people, buildings and communities. The design recreates nature within the walls of an urban space, daylighting a stream to restore it to its original wetland condition along the main axis of the site, with various elements introduced to help manage and control water. It is all done to be not just utilitarian, but also to aid in the sense of place, enjoyment of the public space, making the park part of the system that builds communities.

Figure 77: View of reconstructed wetlands and elevated path. (Source: author)

Figure 78: View of retail street and amphitheater pavilion. (Source: author)

One of the most archetypal urban experiences is the retail street. These have been strategically located near South Capitol and M Street, a highly trafficked area that can draw people in, further activating the public realm with an additional public space function. The new street typology carries the aesthetic of nature, in an experiential setting. As you approach the park along a street lined with shops and cafés, you are entering on axis with the amphitheater pavilion to have the joy of strolling, shopping, and dining while listening to a local performance and enjoying the view beyond into the park.

Figure 79: Framed vignettes viewed from the water play place. (Source: author)

Another aspect of the urban park experience is meant to give you a bit of a mystery through carefully framed views that offer just a glimpse of the next experience lying ahead. These vignettes evoke the sensation of whimsy and mystery that you would want to experience in a natural setting.


Figure 80: View of diverse park experiences. (Source: author)

The design concept embodies the wide array of co-benefits achieved through designing urban green spaces with diverse public experiences and demonstrates how creating places like this is good for the natural environment, biodiversity, and health of the city. We are not designing out of fear of nature, but because it is a symbiotic relationship that provides an incredibly rewarding natural and human experience.

The idea of bringing green spaces into cities is not a new concept. Opening up the city and bringing in light and air is a technique that has been used in the past to mitigate urban environmental problems in cities. But with climate change we are facing a new, immense issue unlike anything we have had to design for before. Looking to historic precedents to advise our path forward can help us, but we will have to adapt them in entirely new and radical ways to address the more extreme problems we face today.

Moving forward it is important as architects and planners to think about how we integrate green spaces into the built environment to address multiple issues. This design proposal does just that – it integrates stormwater management to mitigate flooding and provides a wide array of social benefits, all while creating aesthetic harmony by designing with nature.

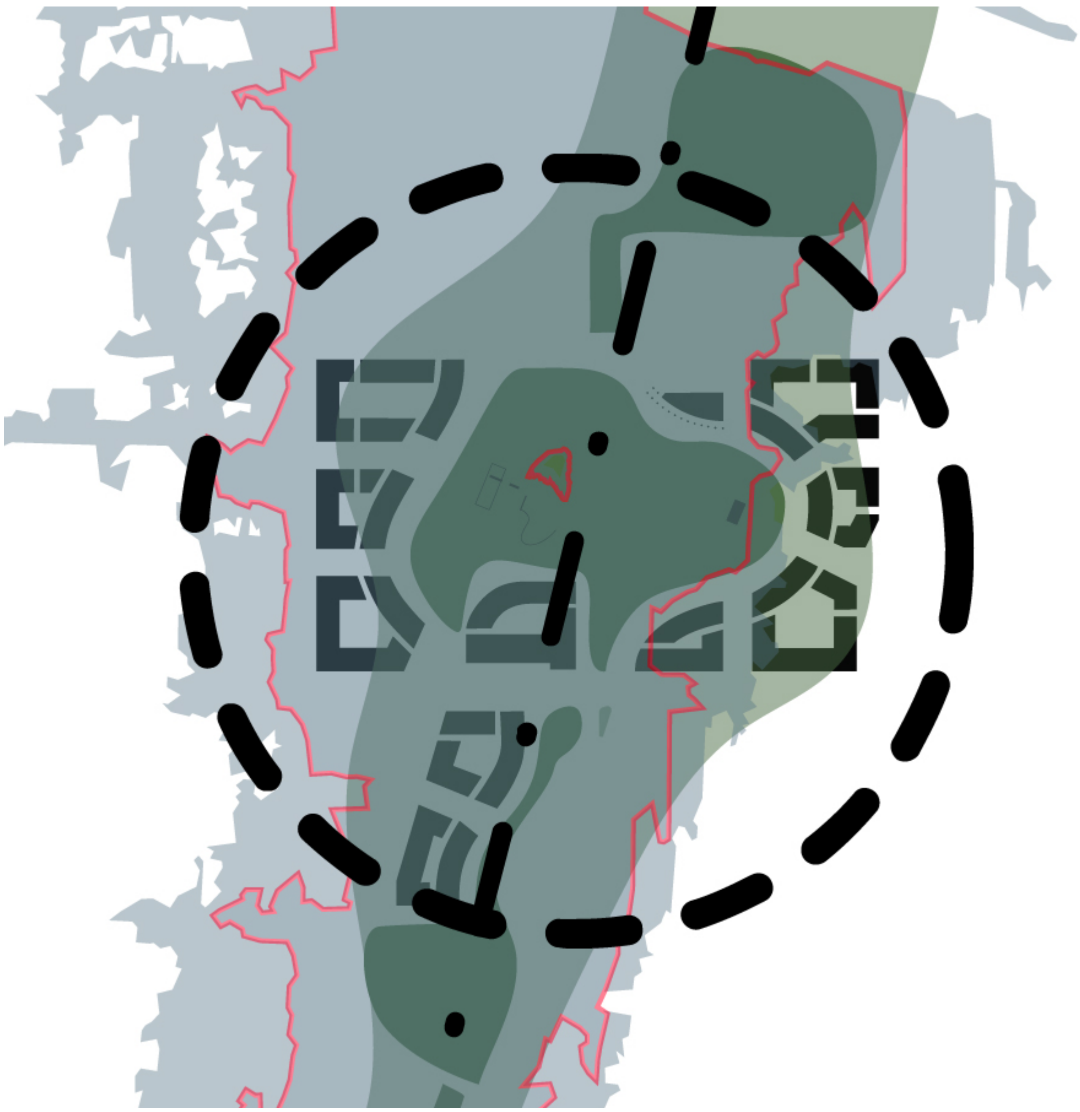

Figure 81: Design conceptualization. (Source: author)

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