SUSTAINABLE URBANISM, RISING SEA LEVEL, AND GREEN INFRASTRUCTURE: NEW STRATEGIES FOR CENTRAL LONDON

BY

LU PENG

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Landscape Architecture in Landscape Architecture
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2011

Urbana, Illinois

Advisors:

Professor David L. Hays, Chair
Professor Arthur R. Schmidt
Professor Carol Emmerling-DiNovo

ABSTRACT

With global climate change, adaptive urban infrastructures are needed in coastal cities to confront risks associated with rising sea level and storm water surge. This research studies flooding potentials in the greater London area, the hydrological situation of the Thames River Basin, and hybrid approaches to confronting those risks. It then explores the potentials of green infrastructure to supplement current civil engineering solutions and applies findings in a site-specific proposal for the City of Westminster in central London. Such interventions, including seven typical approaches with phasing strategies, could protect the City of Westminster by helping it to adapt to new environmental conditions, but they would also impact the character of London. Accordingly, this research also aims to envision a possible transformation of London in response to rising sea level and flooding.

ACKNOWLEDGEMENTS

This work would have been impossible without the valuable support and feedback of the faculty at the Landscape Architecture Department at the University of Illinois, Urbana-Champaign. I offer my thanks to everyone who has contributed toward the completion of this work, especially Professor David L. Hays, my chair and advisor, Professor Arthur R. Schmidt, and Professor Carol Emmerling-DiNovo.

TABLE OF CONTENTS

Chapter 1: Introduction

1.1 Research Purpose

The objective of this thesis is to explore the causes and impacts of flooding on coastal cities and to identify current solutions and potential measures for dealing specifically with urban flooding conditions in central London, England. The research methods for this project include literature review and local data collection from diverse local agencies and websites; use of projective urban design to generate an innovative refinement approaches; and transformation of "hard" engineering practices into "hard plus soft" infrastructure solutions, as a better way to help mitigate flooding in coastal urban areas while promoting regional ecological health and quality of urban life.

1.2 Background Information

Due to increasing emissions of greenhouse gases, the world is warming. Climate change is bringing more risky consequences. For example, sea level is rising inexorably as glaciers and polar ice sheets melt and ocean water expands. Extreme weather events, such as hurricanes and volcanic eruptions, are likely to become more violent and frequent, and those disruptions will push an already high sea surface farther inland and with increasing force.

Even worse, sea level rise in itself will lead to an increase in the occurrence of what is presently considered extreme flooding. Because of a higher baseline of water, the frequency and extent of flooding due to severe storm events will increase dramatically (Nicholls 1999). In the twenty-first century, what is currently considered the one-hundred-year flood could recur as often as every fifteen years, and the 500-year flood may recur as often as every 100 years (Ibid p. 9). Moreover, a rise in ocean surface temperatures could bring about an increase in the frequency and intensity of severe storms, escalating the threat of damaging storm surges far beyond that which we know today (Benjamin 1985).

From the historical record of urban flooding, we can see that many important cities within coastal regions are facing risks of flooding. New York City, New Orleans, Venice, Rotterdam, Washington DC, and London are among the cities of high cultural significance endangered by storm surge.

Until now, the primary method for dealing with rising sea level and storm surge flooding has been to reconfigure and harden the coast by building sea walls and filling wetlands. Despite those efforts, however, sea levels continue to rise, and storms appear to be intensifying, causing water to break down "hard" boundaries again and again, with immediate consequences for urbanism. For example, the coastline of New York Harbor (a.k.a., Upper Bay), between metropolitan New York and northern New Jersey, was reshaped again and again during the past century, at times through the introduction of hard material barriers and at times through retreat inland. In the meanwhile, beyond causing environmental damage and remaining unsustainable, the conventional approach to coastal infrastructure is failing. The circumstances surrounding Hurricane Katrina in 2005 present a dramatic example of inadequate infrastructure (Seavitt 2009). The expected ecological consequences of the Eastern Scheldt Storm Surge Barrier in the Netherlands are also indicative of the risky nature of such systems (Huib 2002).

Against that backdrop, the question is no longer whether we should build harder and higher seawalls and bulkheads more quickly to hold water back in conventional ways, an approach that separates people from water and decimates natural tidal and wetland ecosystems. Instead, the question is how to adapt existing urban fabric to accommodate water, transforming the hard boundary into a soft continuum, a smooth transition, allowing existing hard engineering systems to function collectively with newly introduced green infrastructure, in which urban systems and water comingle.

1.3 Conceptual Framework

This study begins with an estimation of river level rise in the Thames River and its floodplain, taking into account the causes of urban storm surge within the City of Westminster, in central London, as a study sample site. Given current civil engineering solutions and ecological factors, this study provides an alternative operational framework to evaluate the sustainability of solutions to urban flooding at levels estimated for the next 50 years. Keeping in mind the urban scenario of Westminster, existing civil engineering approaches, and soft approaches (i.e., living systems), this study proposes a sustainable urbanism design model including technical detail designs to confront urban flooding in Westminster while accommodating ecological and social activities in this historical city center. The structure of the research undertaken is shown in the diagram below (Figure 1).

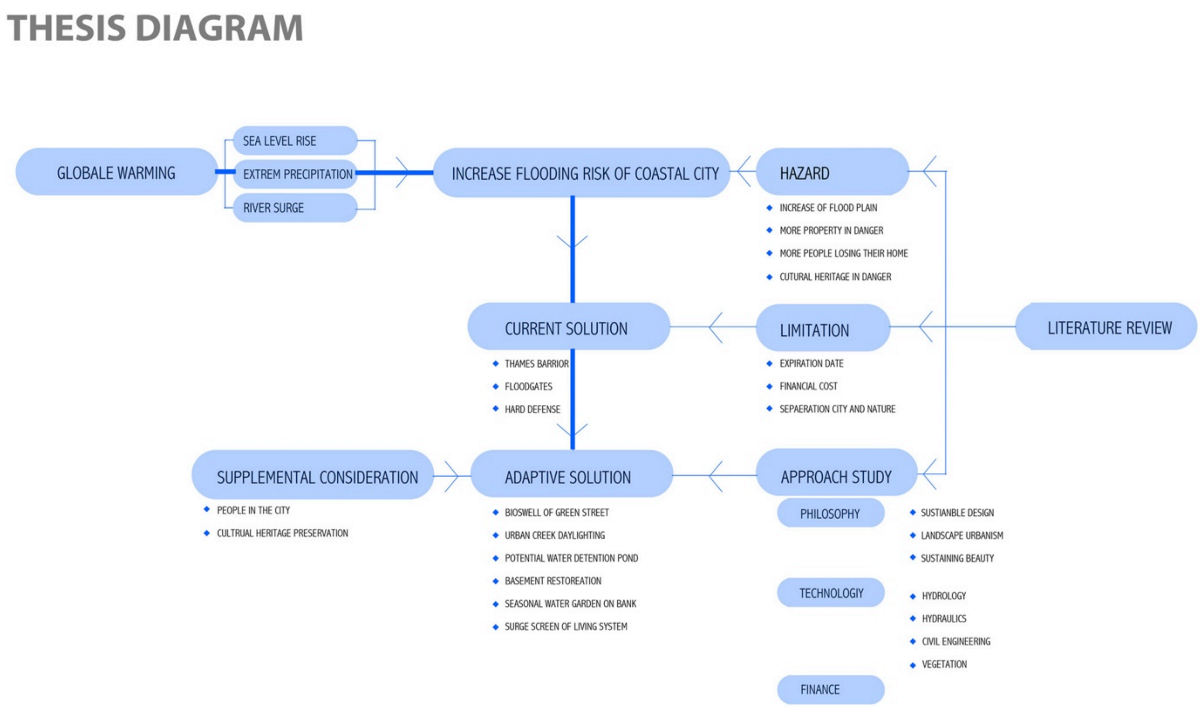


Figure 1 Thesis Framework Structure

1.4 Methods

1.4.1 Data Collection

This research draws primarily on digital data for information about the City of Westminster. Therefore, communication with government agencies and information databases in England became the main work of the data collection. Those sources included the Environmental Agency of the Government of the United Kingdom, the City of London, the British Geological Survey, the Natural Environment Research Council, the Natural England Organization, and the CGIAR Consortium for Spatial Information Organization, as well as Wikipedia and the Visit-Thames Corporation. The types of information accessed included historic data for the Thames River, with special emphasis on its floodplain in the London area; records concerning Thames Barrier; GIS shape files representing urban infrastructure in Westminster; maps and sectional drawings of the City of Westminster; and the Urban Development Plan of London in 2050.

1.4.2 Hydrology of Civil Engineering and Vegetation Courses Taken

In order to better understand the water environment and civil engineering conditions of the urban areas along the Thames River, and to predict the potential of soft infrastructure (i.e., living) systems to solve the urban storm surge and flooding, I took hydrology courses in Department of Civil Engineering at UIUC and had a vegetation advisor for knowledge about these two main aspects of my approach. The content of the hydrology courses included urban water detention and retention pond design and engineering operation calculation, urban pipes and sewage system management, urban storm water management, and hydraulic study. The vegetation information was introduced by faculty at my undergraduate college and concerned selection of constructed wetland species by pollutant cleansing and water absorption capacities parameters, which are the most important parameters for soft solutions to urban storm surge and flooding.

1.4.3 Selection of Operational Site

Equipped with those techniques and local information, I made the site selection according to the urban context best suited to illustrating the proposed approaches. Considering cultural and economic importance, as well as the representative character of the floodplain, I chose the City of Westminster the sample site. Westminster possesses highly important and eye-catching architectural heritage, manifold green spaces and marginal spaces, significant urban renewal potential, and, of course, a high risk of urban flooding.

1.4.4 Precedent Study

The exhibition "Rising Currents," held at the Museum of Modern Art (MoMA), in New York, NY, in summer 2010, represented five distinct proposals for urban development and renewal in the New York Harbor region according to five different urban scenarios in the context of sea level rise and urban flooding. The five projects were called New Urban Ground (ARO and dlandstudio), Working Waterline (Matthew Baird Architects), Water Proving Ground (LTL Architects), Oyster Texture (SCAPE Studio), and New Aqueous City (nARCHITECTS). The proposals combined excellent design principles, innovative planning strategies, and affordability.

1.4.5 Data Analysis

Based on a synthesis of the study of causes of urban flooding, maps of City of Westminster and all of the floodplain shape files I collected in GIS to understand the urban context, the hydraulic study, civil engineering solutions, vegetation study, soft solution about which I learned in the fore-mentioned courses and readings, and general economic statistics, my thesis proposes a holistic, projective urban design model for the City of Westminster.

1.4.6 Proposed Design Model

Through analysis and synthesis, the study proposes a systemic, adaptive urban design for the City of Westminster to deal with urban flooding and storm surge. It also provide a variety of detailed approaches to solve urban storm water whether implemented individually or in conjunction with other approaches, in a wide range of urban settings and typical civil engineering conditions.

1.5 Research Significance

In response to current climate change and corresponding sea level rise, urban storm surge, and historic urban renewal design, traditional approaches involving "hard" solutions to the control of urban flooding are unsustainable. Considering the significance of urban ecology, human living environments, and associated costs, adaptive solutions through soft (living) infrastructural interventions are an appealing compliment or alternative for addressing urban flooding in existing hard civil engineering contexts. Soft infrastructure supports the ecological vitality of the urban built environment by introducing and enriching green open spaces and transforming the current urban infrastructure and character of the city. Therefore, this thesis proposes soft, absorptive, resilient green infrastructure as a supplement to current hard solutions as a better way to deal with severe flooding scenarios in central London during the next fifty years.

Chapter 2: Literature Review

The following review of research concerning urban green infrastructure in relation to urban flooding and storm surge includes 1) topical background; 2) technical studies; 3) related projects and 4) related theories.

2.1 Topical Background

2.1.1 Sea Level Rise

With increasing carbon emissions, climate change is proceeding at a faster pace. Within the past decade, the mean temperature for 90% coverage of the globe has risen 1 degree centigrade (Figure 2). According to some estimates, the mean temperature will rise 5 degrees centigrade during the next fifty years (Figure 3). If that occurs, sea level will rise by nearly 1.2 meter in fifty years, with limitations depending on how quickly glaciers can melt (Pfeffer 2008).

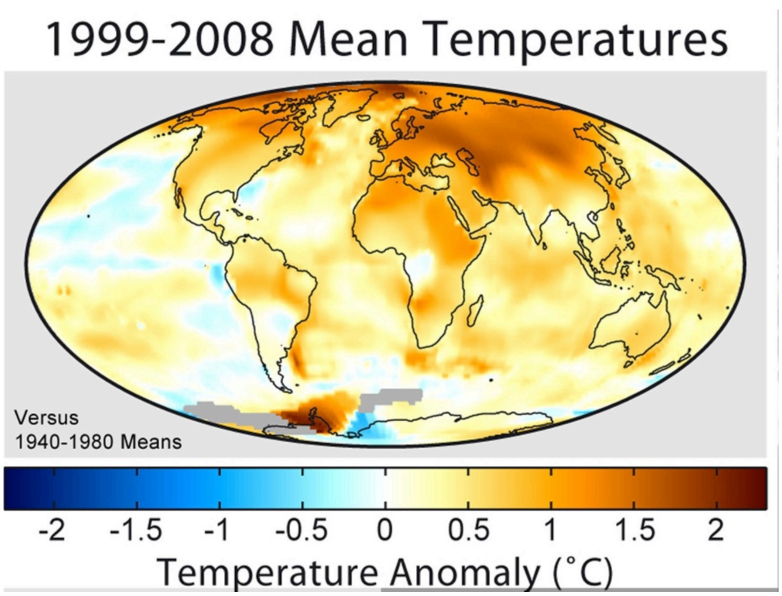


Figure 2 Mean Temperatures 1999-2008

Source: Wikipedia

Within our study area, the sea level rise is reinforced by sea tide surge, a so-called hump of water increased by water movement from deep ocean to the North Sea and into the narrow English Channel (Figure 4). Sea level rise and the tidal surges, as aspects of water surge, will aggravate directly the urban flooding risk of coastal cities, especially those near the English Channel, including London, situated on the estuary of the Thames River. Measurements indicate that the extreme high level within the tidal section of the Thames River has risen 1.5 meter between 1850 and 2000 (Pfeffer 2008).

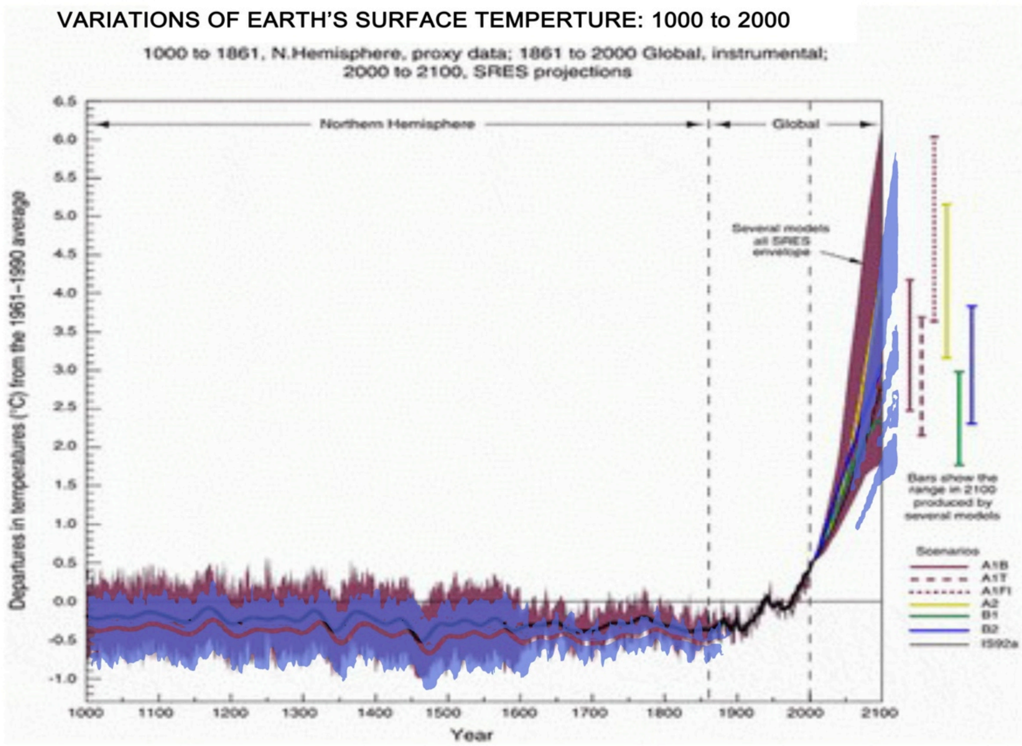


Figure 3 Variations of Earth Surface Temperature. Source: Wikipedia

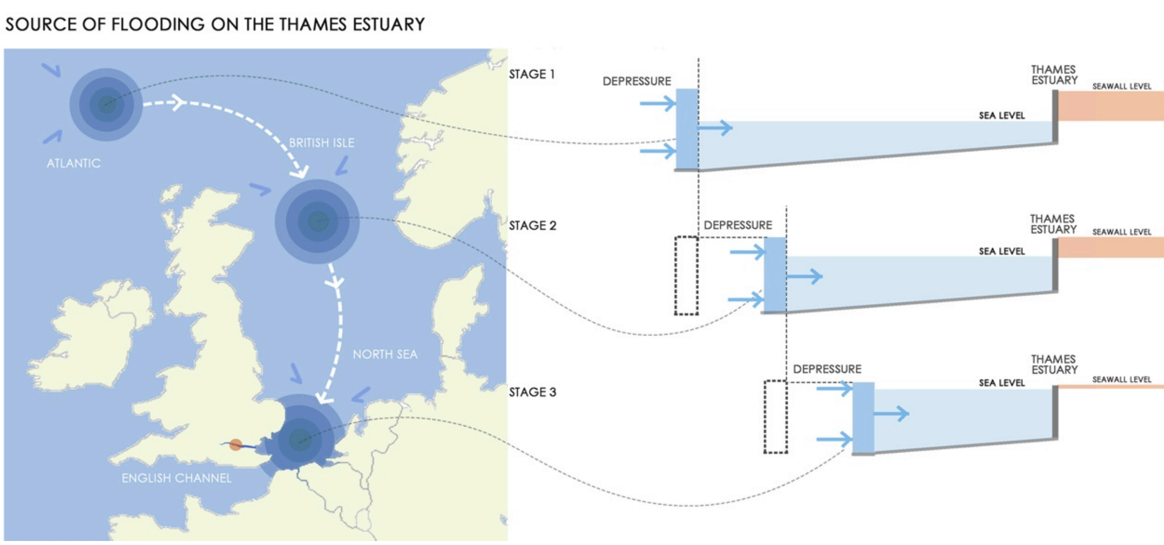
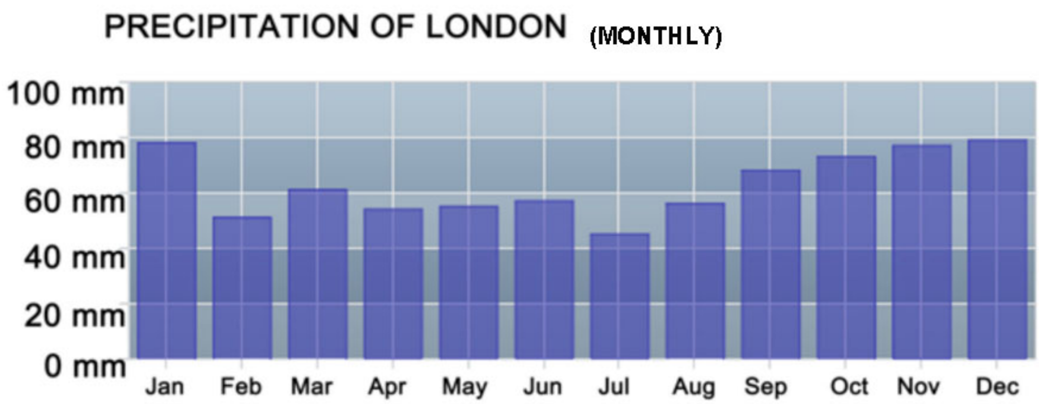


Figure 4 Source of Flooding on the Thames Estuary

2.1.2 Precipitation and Urban Storm Surge

For non-tidal sections of the river, storm water from uphill and the upper river, including feeder streams, is another factor contributing to urban flooding. Rather than putting flooding pressure on central London only from the mouth of the Thames River, extreme precipitation intensifies the water surge from up river. Due to the climate change, local, annual extreme precipitation is increasing. This is the current precipitation condition of London, which gives us a vision about runoff in London (Figure 5).



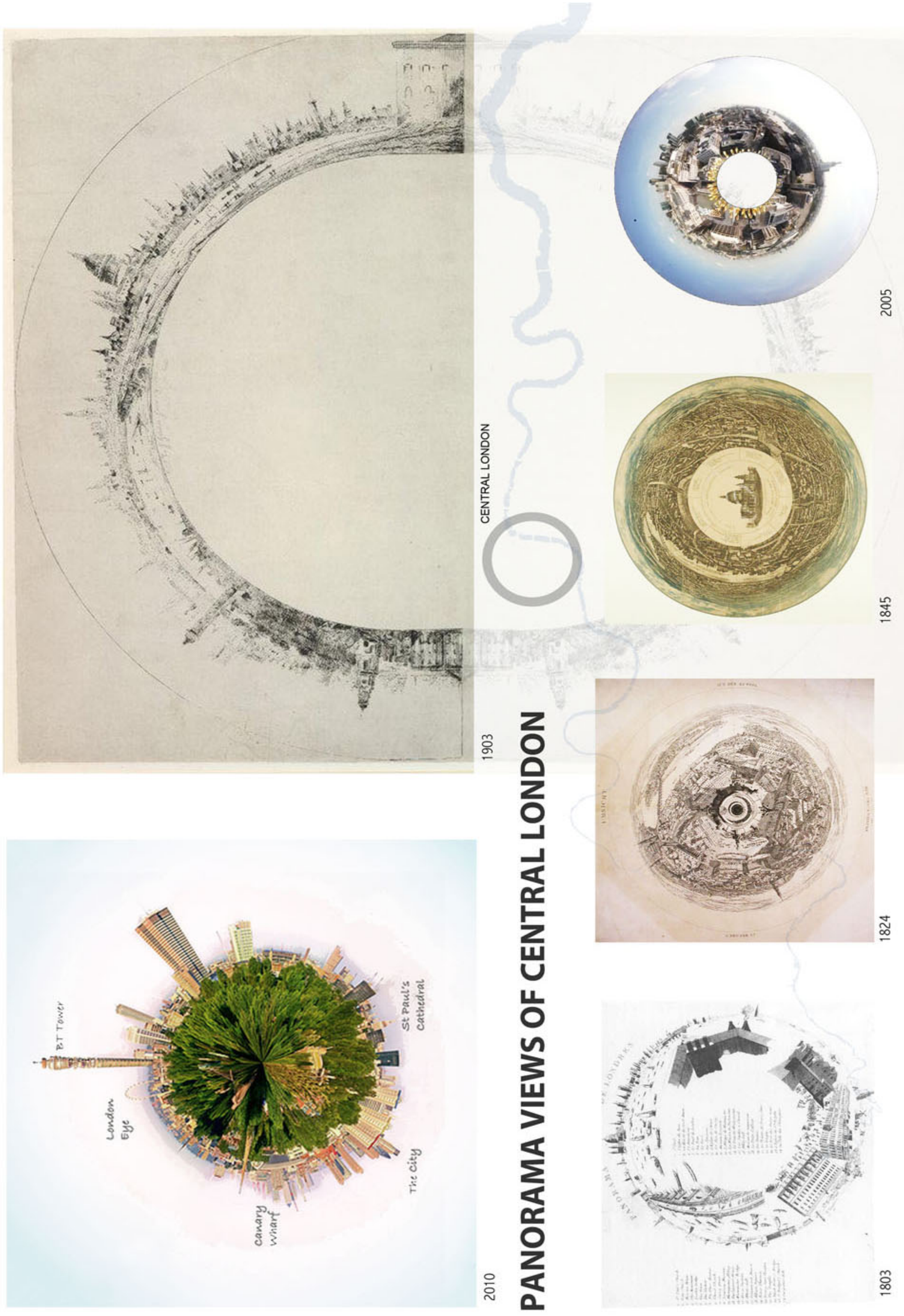
Source: City Council of London

Figure 5 Precipitation of London

2.1.3. The City of Westminster

Panorama views of central London suggest significant change during the past two centuries (Figure 6). The historic architectural legacy of the area is vast and includes the Houses of Parliament, Buckingham Palace, Big Ben, the Tower of London, and the Palace of Westminster. The impact of flooding on these icons of British civilization could be devastating. Furthermore, the density of the urban fabric and scope of hard surface has been growing over the course of the past century, leading to more and faster runoff (Figure 7,8).

The City of Westminster is 3.8 square miles with a population of about 242,000. The floodplain within Westminster will extend to about 1.4 square miles by 2060, according to the Environment Agency of Environmental Agency of the Government of Great Britain.



Source: Maps of London

Figure 6 Panorama Views of London Through History

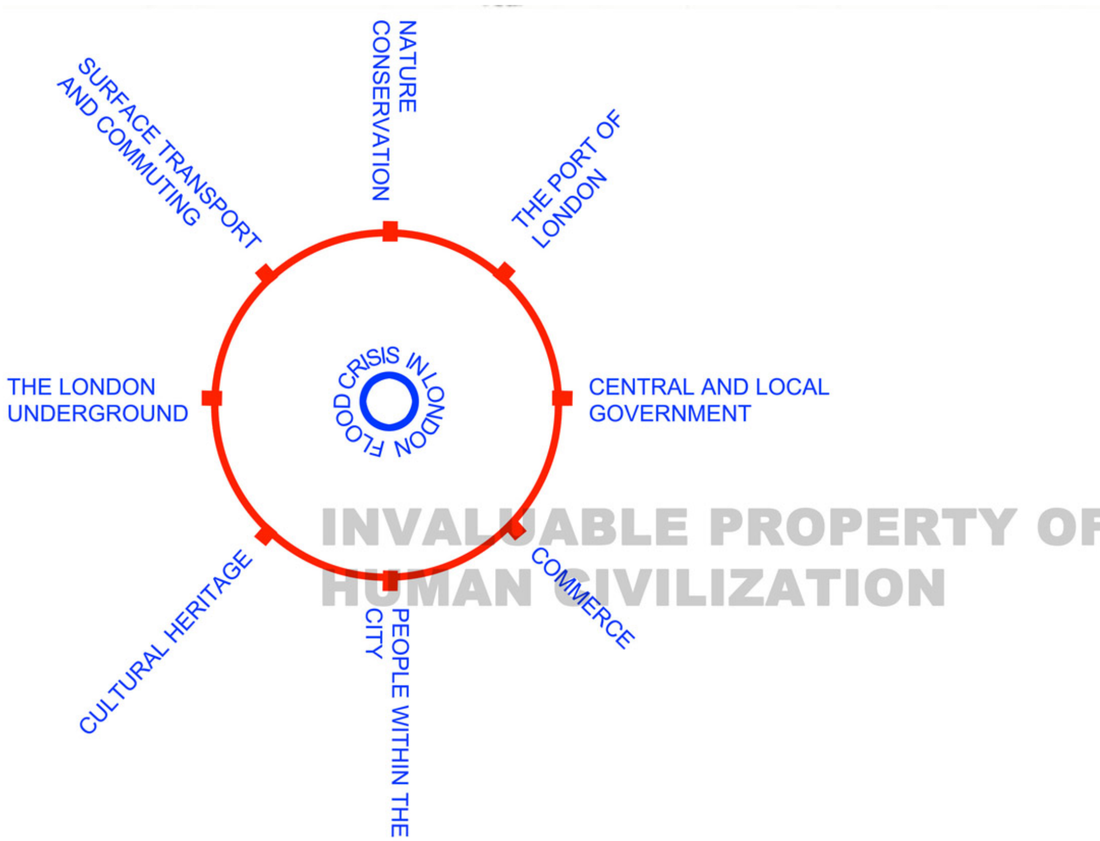


Figure 7 Importance of Central London

Figure 8 Views of Central London

Source: Wikipedia

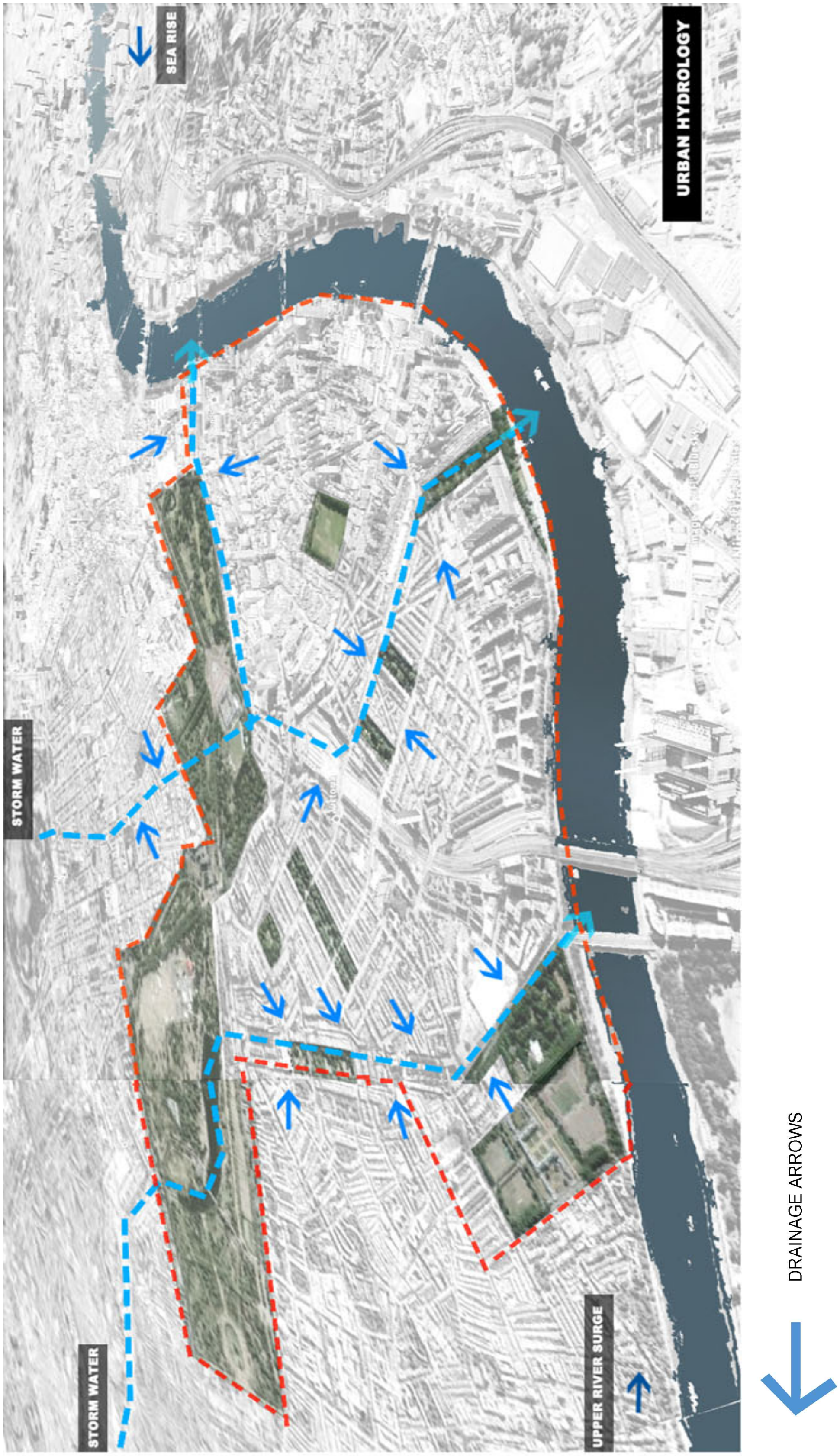
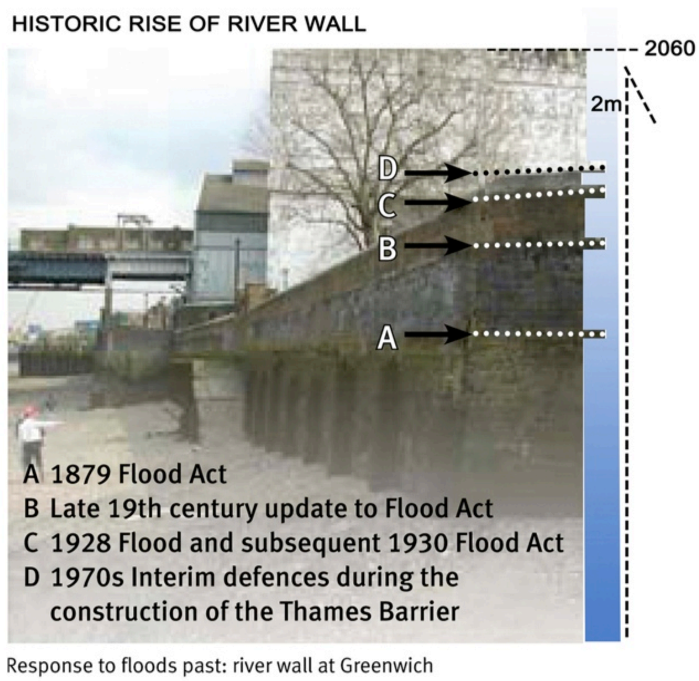


Figure 9 Urban Hydrology of City of Westminster

With climate change, water from extreme storm events will converge here from upper watersheds and streams. Water surge in this area has three sources: uphill, upper river, and river estuary, with the latter supplying the largest flooding threat (Figure 9).

2.1.4. Current Solutions and Limitations

According to historical data supplied by the Environmental Agency of the Government of Great Britain, the height of the containing wall along the Thames River has needed to be increased by about two meters between 1879 and 1970 in order to protect the city from river surges (Figure 10).



Source: Environment Agency of the Government of Great Britain

Figure 10 Historic Rise of River Wall

In addition to raising the level of the river wall, barrier and hard defense structures were introduced one by one to meet the increasing river surge level. Those hard solutions are aging quickly, and the annual operation frequency of the main flood control, the Thames Barrier, has increased dramatically (Figure 11). Moderate climate change scenarios predict that the Thames Barrier will be obsolete by 2050. A diagram comparing scenarios (Figure 12) represents the relative risks: the red line predicts the consequence of proceeding without any additional interventions; the green line represents the consequence of adding more hard defenses to keep up with climate change; the dashed red line represents a combination of all possible solutions. So, as planetary surface temperatures continue to rise, the mandate to protect our coastal cities in sustainable ways during the next fifty years is becoming increasingly urgent (Figure 13).

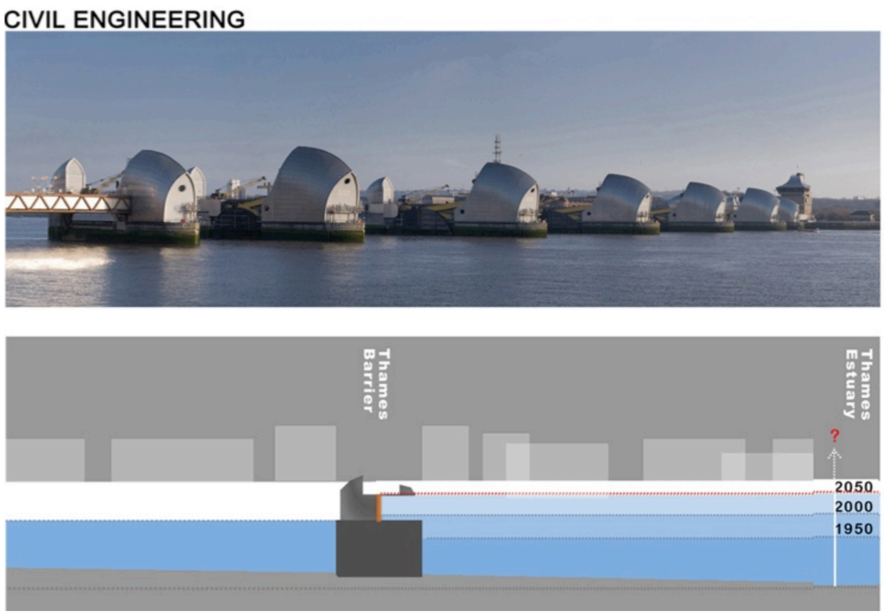
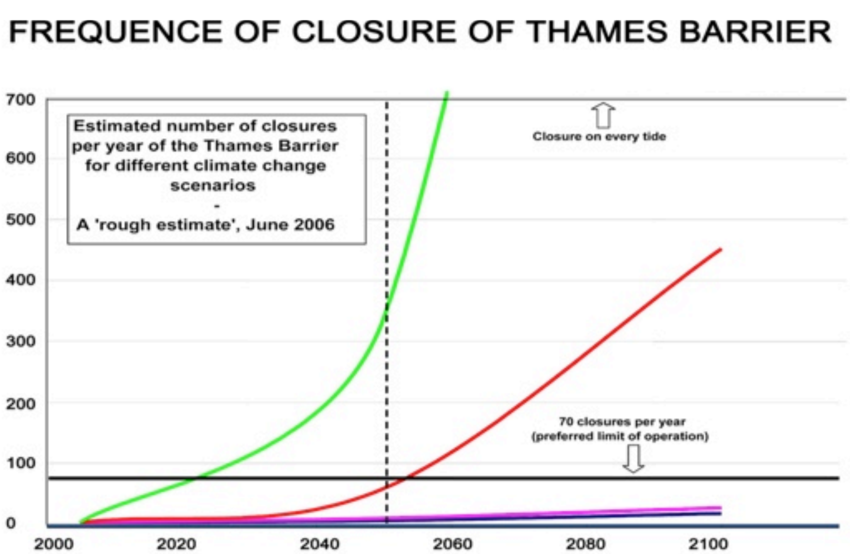
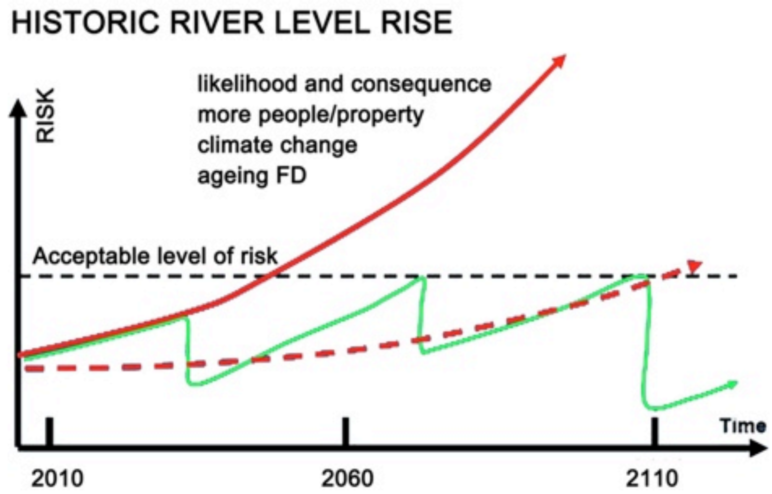


Figure 11 Situation of Thames Barrier



Source: Environment Agency of the Government of Great Britain

Figure 12 Situation of Thames Barrier

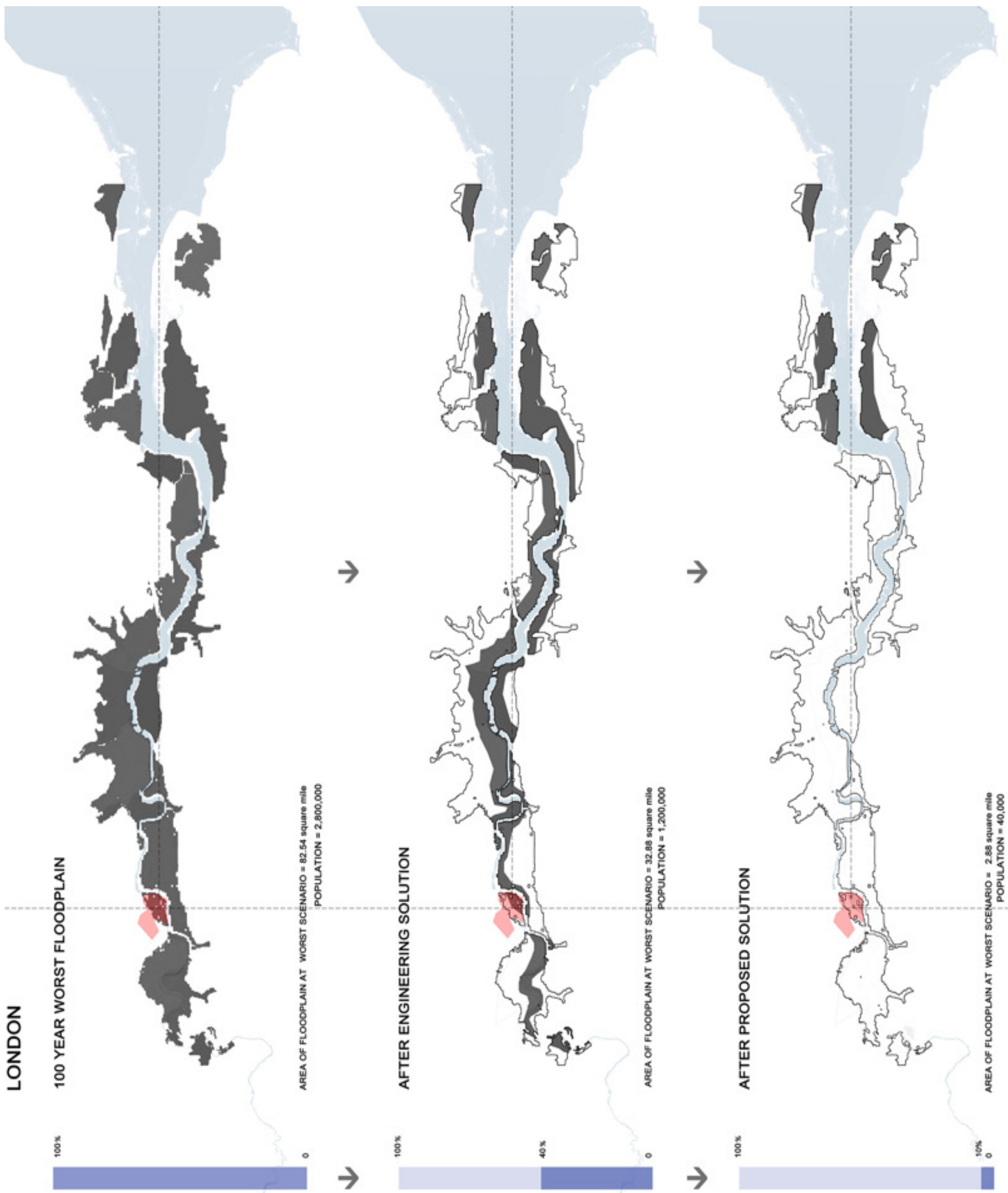


Source: Environment Agency of the Government of Great Britain

Figure 13 Historic River Level Rises

An overview of the Thames River floodplain in the greater London region, assuming a 100-year level flood (Figure 14) shows that the current capacity of hard engineering solutions will reduce the area of the floodplain 896 km^2 by 40% in the middle diagram. In order to take care of the other 60%, the government of Westminster proposed five years ago to build a tunnel under the Thames River at a cost of 10 billion pound sterling, a significant fiscal burden to the community. That plan has not been put into practice due to many objections from many institutes and organizations. Of course, expanding hard infrastructure defense along the river would also create a significant disruption, if not irreversible damage, to the lives of local habitats and to local ecology. Many species of local birds and fishes would be endangered by manual-controlled water cycle, and water quality will be negatively affected as well (Bohannon 2006). That is to say, the economic price and ecological costs associated with the hard solutions is far from what we can afford.

Can we provide adaptive solutions, rather than holding the water or building higher and higher hard barriers which isolate urban life from the river as a natural resource? Could we identify and provide a win-win solution, supporting central London both economically and ecologically? Soft infrastructural interventions, in conjunction with current hard approaches, offer a new strategy for addressing urban flooding (Figure 15).



Source: Environment Agency of the Government of Great Britain

Figure 14 Phasing of Floodplain of London

Figure 15 Design Concepts

2.2 Technical Studies

2.2.1. Current Civil Engineering Solution

A standard civil engineering approach to flood control in an urban floodplain entails building two channels at each edge of the area and a levee along the riverbank. One channel is at the foot of an adjacent uphill slope, to collect storm water from the watershed and streams; the other channel is at the edge of the riverbank, next to the levee, to handle overflow from water level rises of the river (Figure 16). Many systems include filtration vortex machines, installed in the intersection of drainage pipes and distribution joints, to cleanse the water.

2.2.2 Study of Hydraulics

In the study, On the Water: Palisade Bay (Seavitt 2009), hydraulic analysis was included to define the river level tidal movement within a diurnal and seasonal periods, and the water movement both on edge of the riverfront and within the water body. The diagram in page 18 represents the speed and energy of water flow and how to reduce the flow of water (Figure 17).

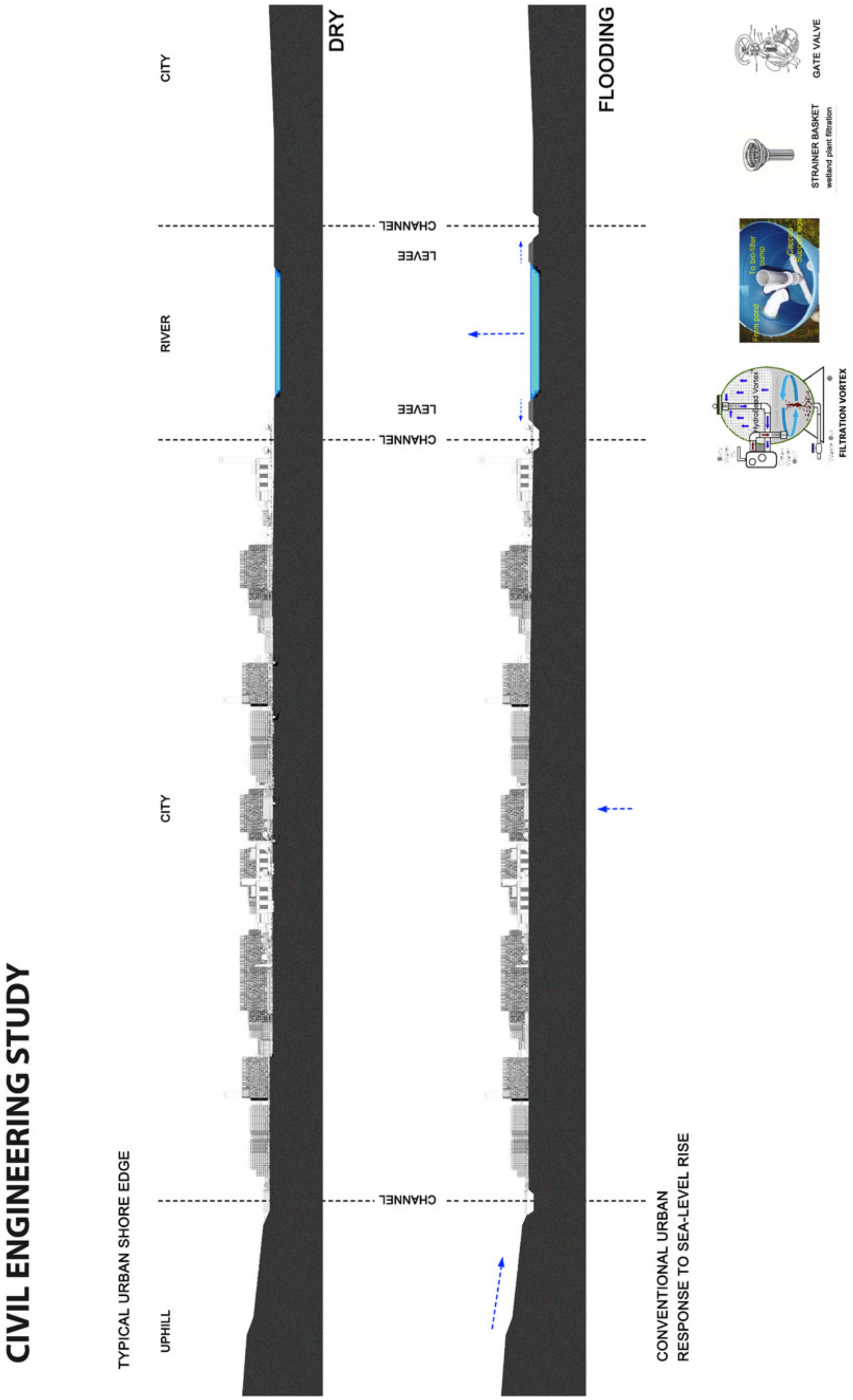


Figure 16 Civil Engineering Sections and Vertex

Diagrams

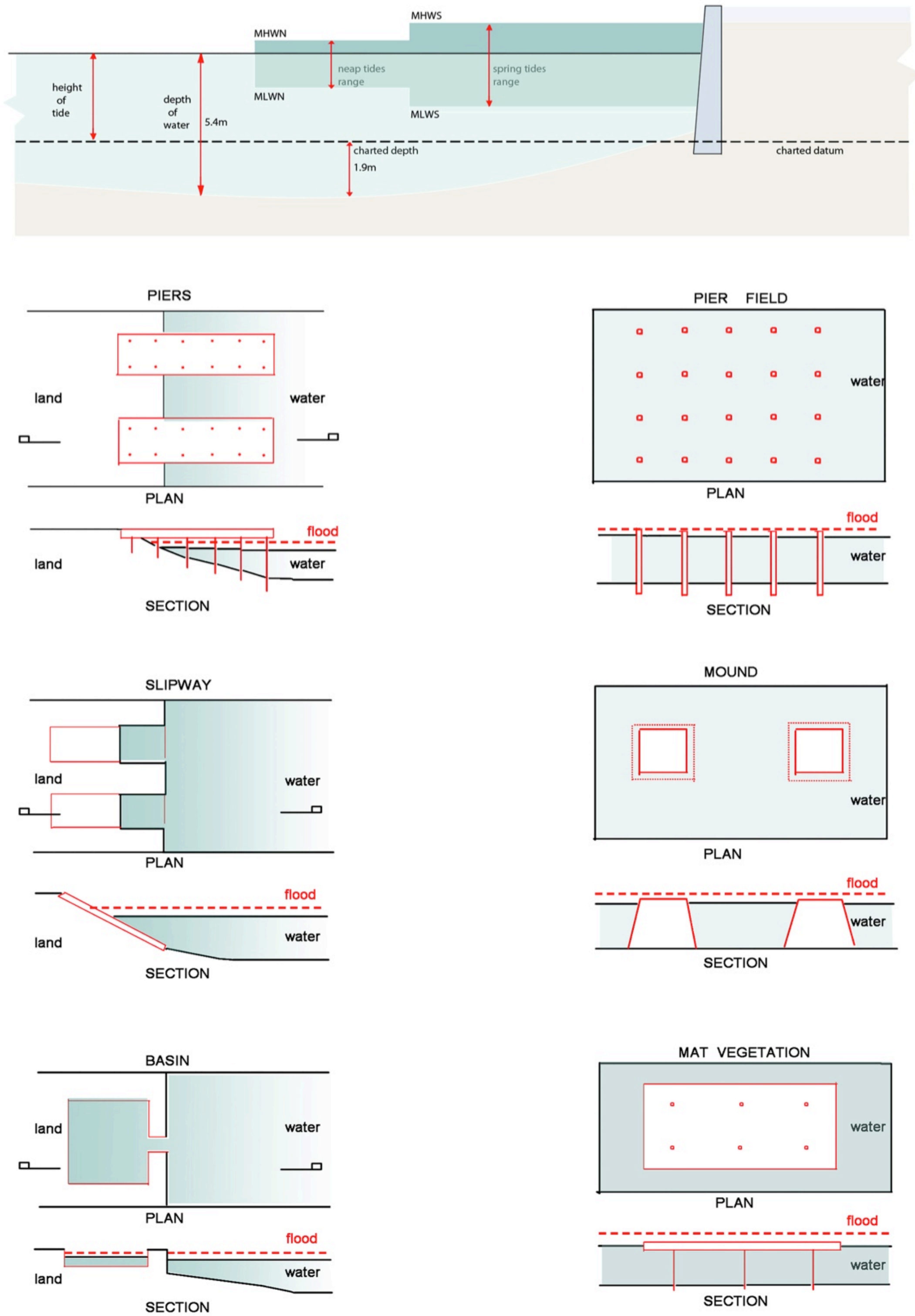


Figure 17 Hydraulic Studies

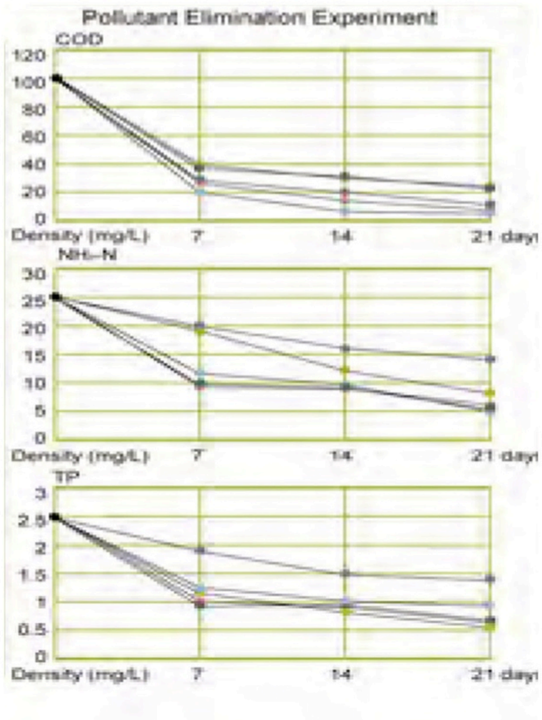
Source: "Rising Tides," Exhibition, MoMA, April, 2010

These diagrams represent two factors: the river level fluctuation and alternative solutions for reducing water-flow movement along the edge of the water body (illustrated on the left) and the middle of water body (illustrated on the right). The first diagram demonstrates river level rises during different period of time, according to tidal periods and seasonal periods. The series of diagrams on the left illustrates solutions to reduce water flow along the edge of the water body through piers, slipway, and basin approaches that reduce flow energy and restore part of water surge on the edge condition. The series of diagrams on the right demonstrates the water movement on the center of the water body, through a field of piers, around mound structures, and through mat vegetation.

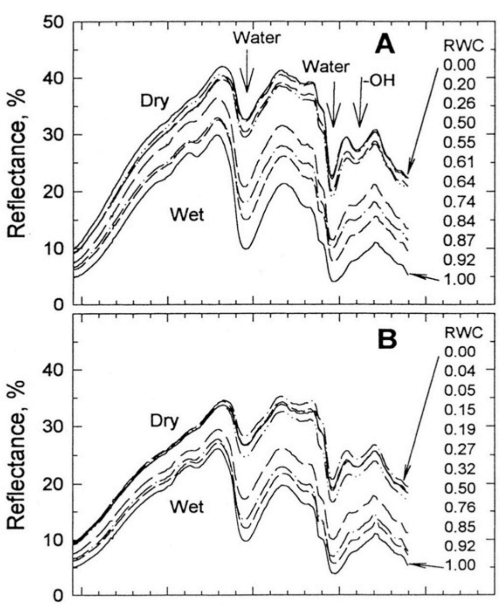
We can conclude that there is potential to build ponds within the urban fabric to restore the flooding and storm water and reduce the water flow energy along the urban riverbank. Also, soft structures in the water body can make the water flow follow wandering routes rather than straight ones, thereby reducing the speed of water flow and absorbing the flooding at the same time.

2.2.3. Study of Soft Material-Living Systems of Vegetation

As the primary material in soft infrastructure solutions, vegetation species selections fall into part of my study. The selection of vegetation is based on two parameters: pollutant elimination capacity (i.e., to what degree it can clean the storm water) and water absorption capacity (i.e., how much water it can absorb, to help mitigate the surge) (Figure 18). The differences among the three charts are to show different performance to eliminate pollutant of three typical vegetation species. The number of chart in Water Absorption Capacity is their reflected concentration of water within body of two selected compared vegetation species. Taking those two factors and various set parameters into account made it possible to identify species suitable for the central London area (Figure 19). We choose vegetation species based on higher capability of water absorption and better performance of pollutant elimination within north Europe region.



Pollutant Elimination Capacity



Water Absorption Capacity

Source: Planting Science

Figure 18 Vegetation Parameters

Figure 19 Vegetation Selections

2.3 Related Projects

In a recent research and design project, On the Water: Palisade Bay, an effort funded by the 2007 Latrobe Prize, five teams of engineers, architects, planners, landscape architects, professors, and students came together to imagine the transformation of New York-New Jersey's Upper Bay in the face of certain climate change. The Palisade Bay proposal provided an opportunity to rethink the relationship between infrastructure, ecology, and society in urban environments, exploring "soft infrastructure" strategies to buffer or, alternatively, absorb flooding while also creating a new destination on the water. In the proposal, new types of adaptive infrastructure, such as reef-like barriers formed from dredged materials, breakwater towers of densely planted material and constructed wetlands in the ocean, are imagined not only to protect the New York-New Jersey region from sea level rise and storm surge flooding, but also to provide habitat for the ocean ecosystem, a power station harvesting tidal energy, and open spaces for urban recreation. In such way, the proposals reconcile the relationship between stewardship of the environment and infrastructural development (Seavitt 2009).

The studies in Palisade Bay, which also were exhibited at MoMA in 2010, suggest ways to begin rethinking the relationship between coastal cities and oceans through adaptive infrastructures that support sustainable ecological and social processes. That framework represents an important opportunity for landscape architects to become involved in the development of landscape infrastructure in coastal urban contexts (Mossop 2003).

Examples of adaptive soft infrastructure, such as wetlands, algae beds, bio-swale soil canals, or synthetic elements, such as super-absorbent polymers or living buoys, are well suited to Palisade Bay project (Seavitt 2009). In addition to their flexible character in form and construction, they have excellent performance in buffering and absorb water, while providing urban habitat as well. They also have other valuable features when we address the issues of urban coastal infrastructure as follows.

2.4 Related Theories

1) Urban Ecology — As places where saltwater and freshwater meet, estuary ecosystems, such as that of the lower Thames River, are typically abundant with habitat for fish, birds, and even invertebrates, all of which contribute to productive and bio-diverse systems. But losses of marine diversity are highest in coastal areas, largely as a result of their urbanization and consequently conflicting uses of coastal habitats (Gray 2004). In urbanized estuaries, re-establishment of habitat depends on restoration and management of wetlands and the development of soft infrastructure. Also, in the context of urban areas, biodiversity matters not only for ecological function but also for human use, aesthetic style, and ideology (Hill 2002). Therefore, green space as new type of urban infrastructure in high-density urban settings could promote urban ecological health by providing potential space for urban habitats, recreational space, and living amenities in a sustainable manner.

2) Supplement to Urban Infrastructure — In large, urban-scale contexts, when we use the term "Infrastructural Urbanism" coined by Stan Allen in his book, Points + Lines: Diagrams and Projects for the City in 1999, contemporary public practices should be concerned primarily with performance—that is, what they can do. In addition to providing solutions to buffer and absorb flooding and coastal habitat, the proposed soft infrastructure will provide living machines or turbines to cleanse urban storm water and reduce urban heat as well as collect energy. For example, algae species can be a good source of fuel while cleaning nitrogen from wastewater and

carbon dioxide from power plants. The living systems of vegetation could help absorb urban heat, creating comfort for people living in the city during summer. When combined with existing grey urban infrastructure, such as highways, bridges, and buildings, these soft, green infrastructures become a refined, functional supplement to current urban hard infrastructure.

3) Consideration of Human Uses—The intelligent reconsideration of infrastructure should take into account not only climate change but also changing, urban, social conditions. Thus, considering human uses and the recreational opportunities of coastal environments is important in this thesis. In the process of generating new urban open space, it envisions the coastal area as a common ground. By providing new opportunities for social programs, such as coastal transportation and pedestrian systems, adaptive soft infrastructure may form a new geography of economy and society within coastal areas (Seavitt 2009).

4) New Urban Aesthetics—Stan Allen has suggested that public practice should not be concerned only with form or aesthetic issues. STOSS LU Studio, under the direction of Chris Reed, has reconceived the city as a hybrid matrix involving economy, ecology, and social context, all of which are consolidated through a promising picture of landscape as the medium of urban order. Whereas Allen and STOSS LU/Reed have prioritized performance or function of landscape, I would argue that the form and aesthetic values of landscape should be concerned as well with performance in sustainable design. Sustainable designs are more valued when people recognize, love, engage, and therefore care about the environment (Meyer 2008). In her essay, "Messy Ecosystems, Orderly Frames," Joan Nassauer argued that landscape design should use cultural values and traditions for appearance of landscape to place ecological function in a recognizable context. In such way, both of these factors, ecological function and human intention, could be mutually beneficial. Developing a new aesthetic types in urban contexts combining functional soft plus hard infrastructures with traditional aesthetics of landscape, a type of sustaining beauty (Meyer 2008), is critical in my study and proposed urban design model.

2.5 Conclusion

Understanding how extreme urban flooding in the City of Westminster could be caused by sea rise, storm surge, and extreme precipitation, the limitations of current hard-only solutions—not to mention the ecological damage caused by the latter, should be apparent. Drawing upon current standard civil engineering approaches, the hydraulics of water body edges and centers, and living systems-vegetation as soft solutions to absorb and clean storm water, this thesis addresses flooding while balancing ecological value and social benefits in a sustainable way, introducing new soft living systems into current civil engineering solutions and allowing them to work collectively (Figure 20).

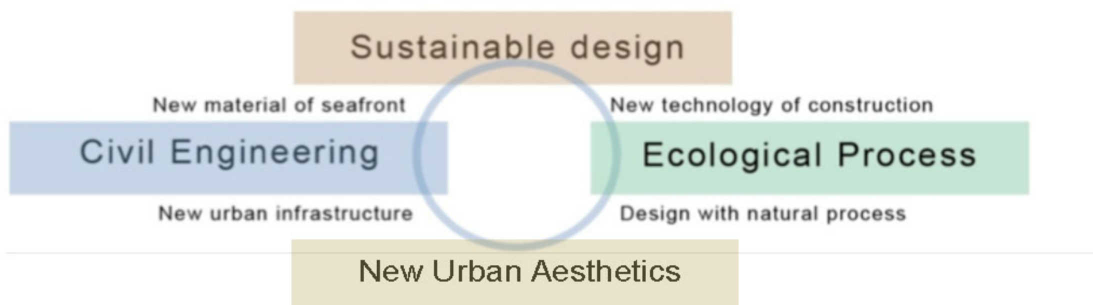


Figure 20 Theoretical Structures

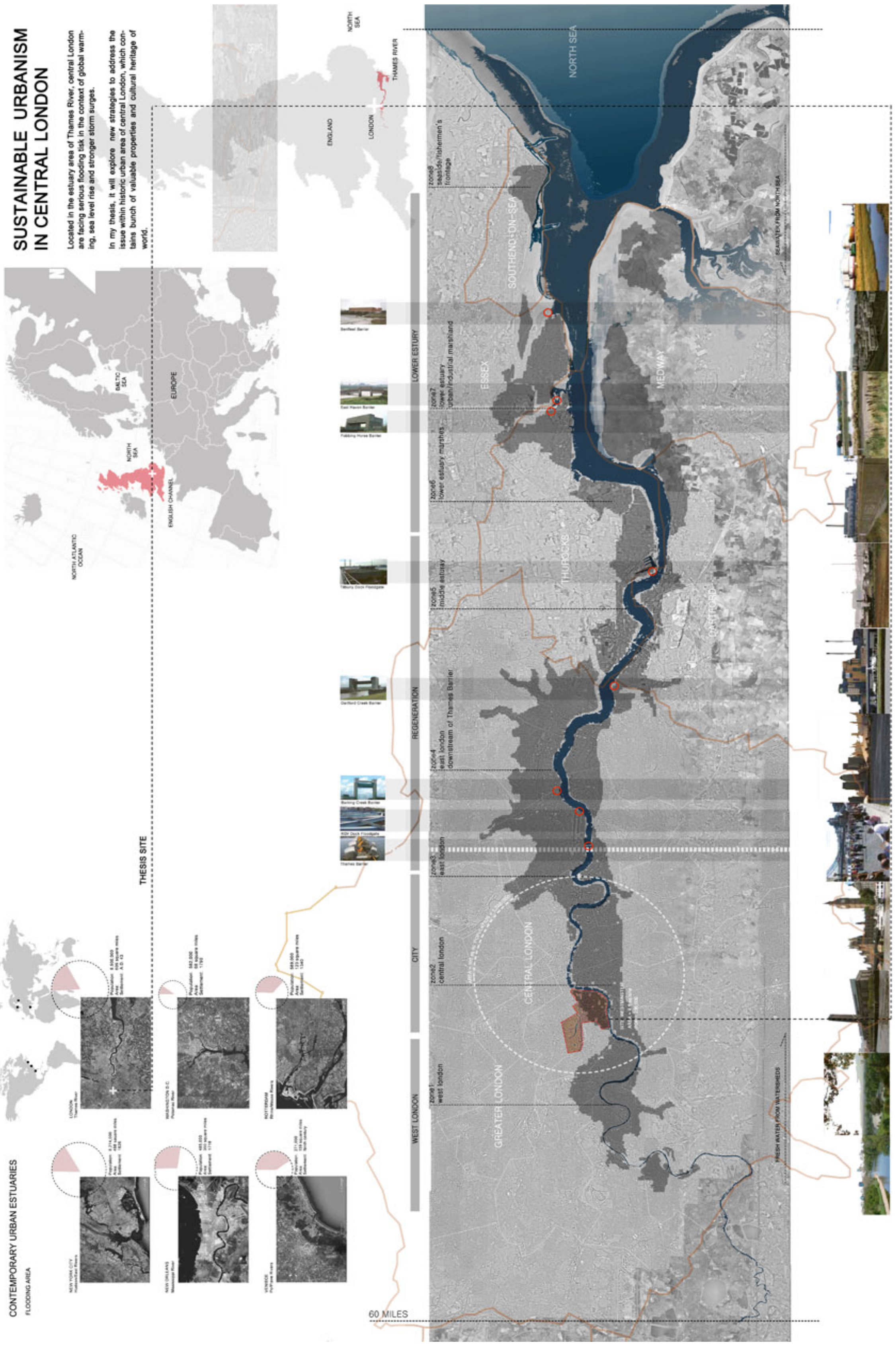


Figure 21 Scenario of London

Chapter 3: Design Research

The design research for the sample site included six stages: site description, site analysis, urban conditions, conceptual design, statistical phasing, and design details, all as components of an urban design model for a high density of coastal city: the City of Westminster in central London.

3.1 Site Description

This research focuses on Westminster as a sample historical area in central London, where urban patterns and infrastructures need to be addressed along with tangible forms of cultural heritage, such as buildings and public works of art (Figure 21). Westminster occupies 3.8 square miles and represents nearly 1,000 years of urban development. Figure 20 shows the elevation of the Thames River within the Westminster area. The width ranges from 680 feet to 850 feet. And the depth is between 8 feet to 28 feet by tides (Figure 22, The River Thames 2009).

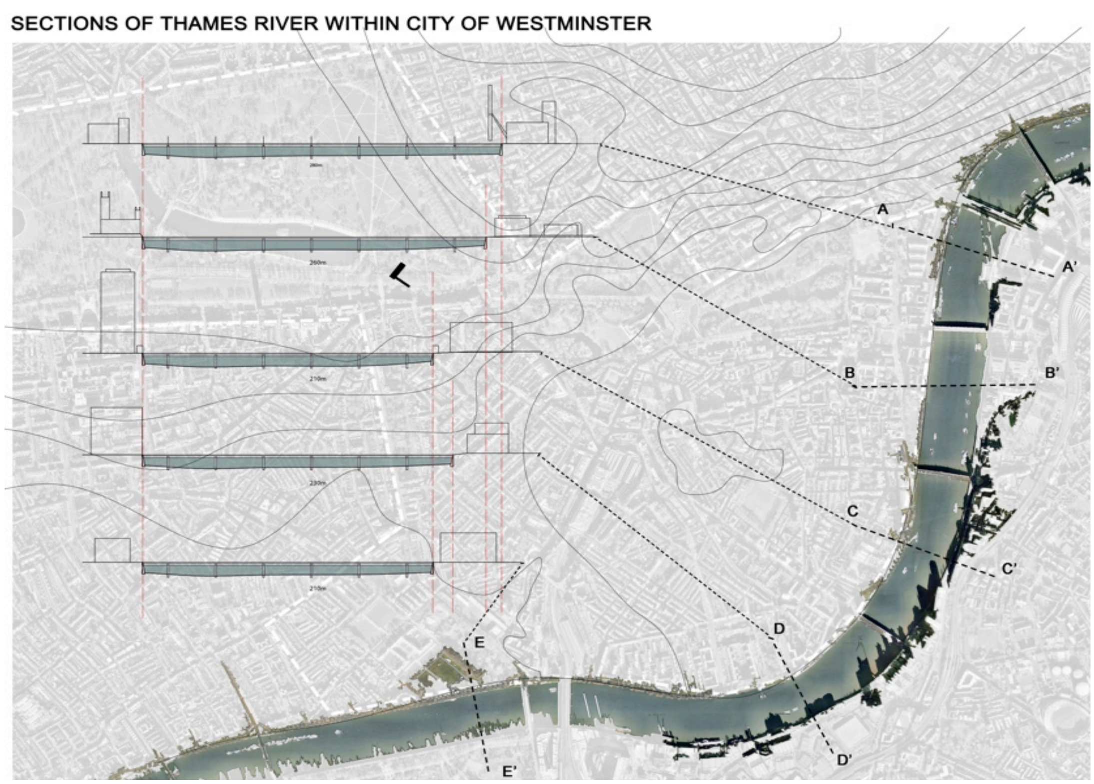
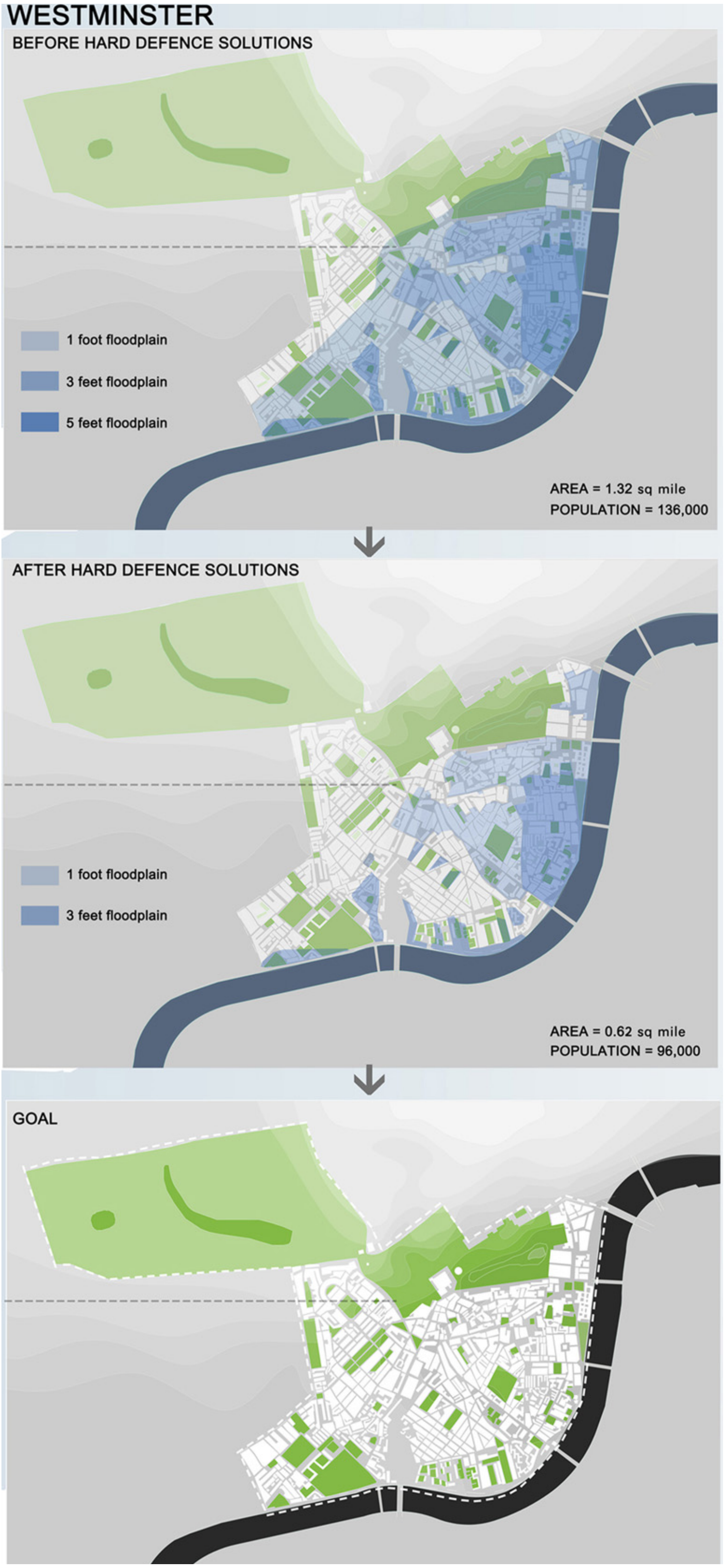


Figure 22 Sections of Thames River within Westminster



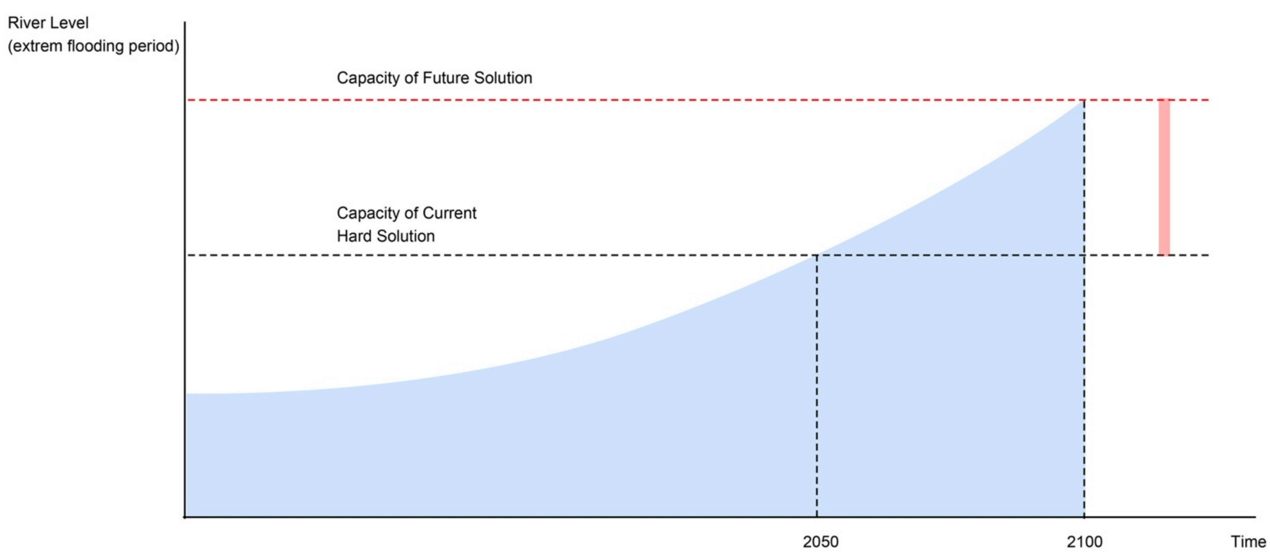
Source: Environment Agency of the Government of Great Britain

Figure 23 Floodplain of City of Westminster by estimated

These mappings of the floodplain within Westminster (Figure 23) show the most extreme floodplain scenario anticipated in next 100 years. I collected the shapefile of GIS from Environment Agency of the Government of Great Britain, and render them. There are three floodplains, distinguished by elevation: 1 foot high, 3 feet high and 5 feet high; floodplain after current hard civil engineering solutions by 1 foot high and 3 feet high of flooding levels; and floodplain after combination of civil engineering and soft green infrastructure solutions. In this case, the proposed strategy of urban green infrastructure is a supplementary to the existing civil engineering solution, which can handle the remaining 40% of flood volume within Westminster, in the middle of these three steps exceeding capability of civil engineering. And if that system works efficiently, handling the remaining water in blue area in the diagram, then the sample approach could be applied on a large scale to the whole floodplain along the Thames River.

3.2. Solution Analysis

The next stage of design research entailed a comparison of hard defense and soft living systems in terms of economic and ecological value. The red bar in Figure 24 represents the estimated height of flood water out of current control in the next fifty years. That is the target amount to be dealt with by my research and proposal. According to research reports published by the local Nature Environment Research Council, a traditionally engineered solution will cost 2.4 billion pounds and provide no ecological benefits. An exclusively soft, green infrastructure solution will cost 0.9 billion pounds but only deal with 60% of flooding, albeit with full ecological value (Figure 25). Red circles represents hard civil engineering solutions, and green circles means soft green solutions. Therefore, I propose a strategy of combining these two perspectives, which is represented in the third arrow of the diagram. In that way, it will be possible to minimize costs and maximize environmental benefits when dealing with floods.



Source: Environment Agency of the Government of Great Britain

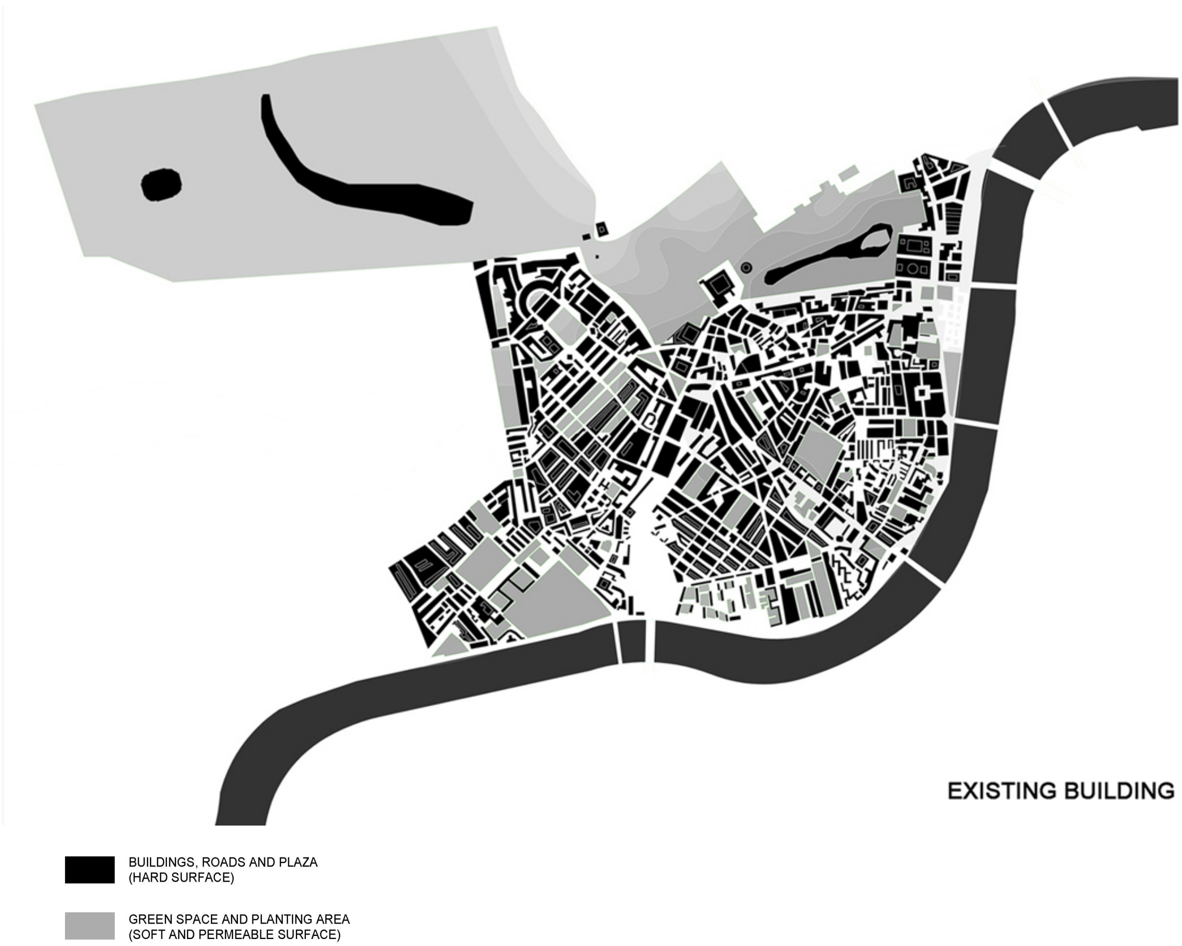
Figure 24 Flooding Estimation

Source: Nature Environment Research Council, City of London, 2010. 100% indicates full efficiency.

Figure 25 Comparisons of Two Solutions

3.3. Urban Condition

Considering next the site scenario, this thesis focuses on the urban fabric (Figure 26), land use (Figure 27), drainage systems (Figure 28), and lost rivers (Figure 29). The latter were covered by the mid-nineteenth century through urban development.



Source: City of London, 2010

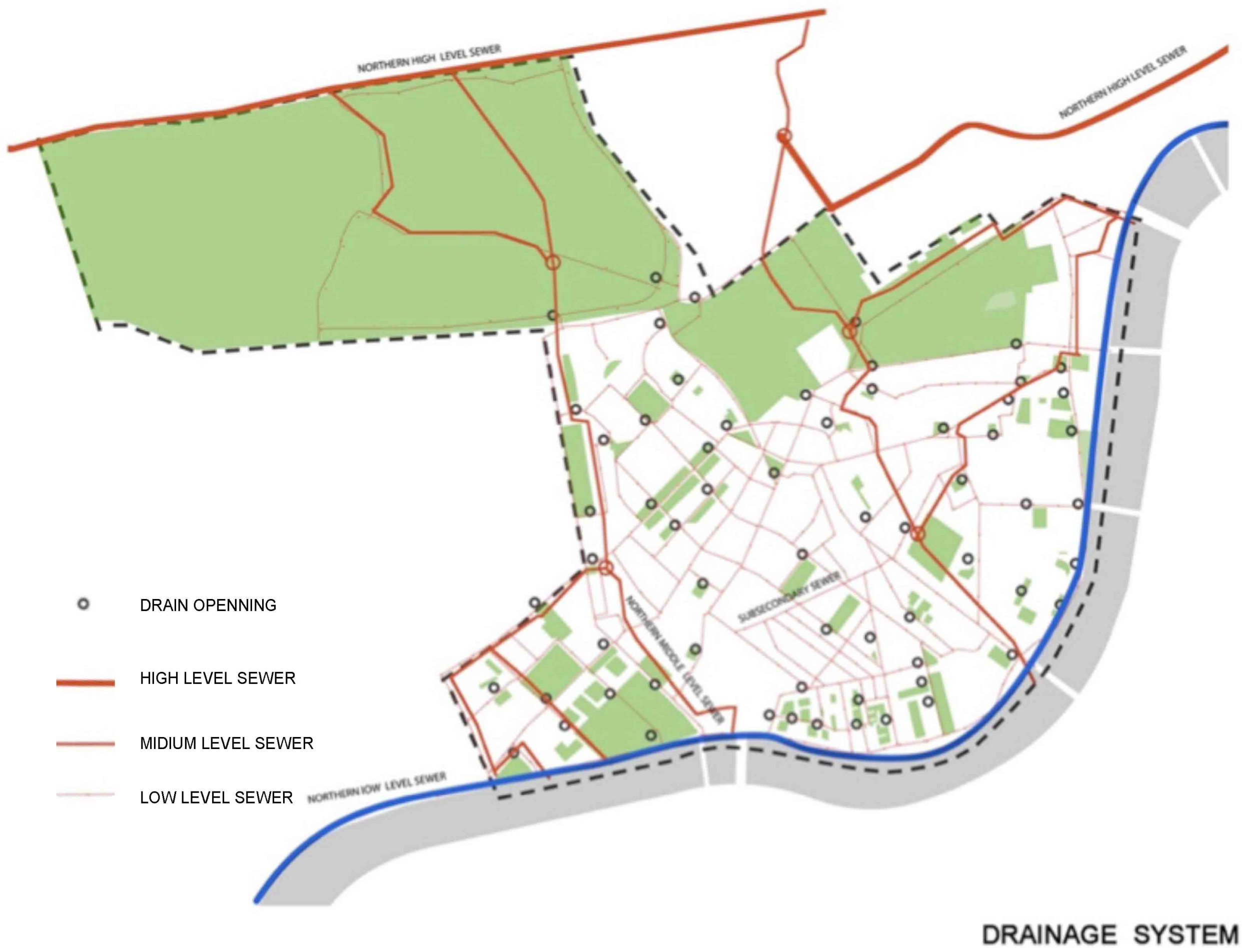
Figure 26 Urban Fabrics

Westminster is a high-density urban area represented in dark area (Figure 26), and hard surfaces occupy about 72% of the total area, excluding Hyde Park. There are some green spaces showed in grey color, such as courtyards and marginal spaces along buildings and urban infrastructures, within the urban fabric and potential green corridors such as green strips of streets connecting these tiny spaces and urban public parkland (Figure 26).

Source: City of London, 2010

Figure 27 Land Use of Westminster

Working with shape files for Arc GIS from the City of London, the study mapped out the land use of the City of Westminster based on formal color-coding. Except the most important cultural and economic sites—including palaces, government buildings, religious buildings, museums and public halls, business buildings, hotels along the bank, and public stations along the main circulation routes (i.e., Victoria Street and Buckingham Road, which are mostly located in the northeast of the site with only little marginal green spaces)—the another land use of the site is a residential area located in the south and west portion of the site. It occupies almost 60% of the whole area, sharing many comparatively large green courtyards, green streets, and open green spaces (Figure 27).



Source: City of London, 2010

Figure 28 Drainage System of Westminster

According to the topography of the city, with northwest sloping into southeast, the drainage system design is divided into a hierarchy of three systems: the Northern High Level Sewer, the Secondary Middle Sewer, and the Sub-secondary Sewer, to collect storm water and waste water into the same drainage system. They are represented in bold red lines and slim red lines accordingly. The dark circle means openings of drainage. The three systems come together into the blue pipe system along the bank of Thames River before they flow into the river. That is the forementioned, underground channel used to collect flooding and storm water. We can see from the diagram that those high-level drainage routes are almost direct and follow the main streets of the city. The sub-secondary sewers are along the small streets, and, at each intersection of the pipe routes, there are servicing silos and openings (Figure 28).

Figure 29 Two Lost River of Westminster

Two rivers, the Westbourne and the Tyburn used to flow through the City of Westminster to the main Thames River. Their location is identified by the blue lines in Figure 29. They were two main tributaries of Thames, collecting storm water from uphill, to the northwest of the city. But they were covered as an underground drainage system by urban fabric and circulation development in the mid-eighteenth century. However, with the new sustainable development of the city, those two lost rivers hold significant practical potential relative to new adaptive ecological urban drainage system design.

3.4 Conceptual Design

All in all, equipped with technical support and understanding the conditions of the site, this study proposes a conceptual approach. Considering the hydraulics and current urban drainage system, using wandering routes rather than direct drainage is a way to reduce speed of water flow, which can also be enhanced by potential detention ponds on the angle of said routes to reduce the speed and energy of water flow. With two civil constructed water channels to collect overflow of river floods and uphill floods, the proposal combined with two green channels on each edge of the city, as seen in Figure 30, at the foot of the uphill and the edge of the river, to function in the same way. Applying those elements into actual urban fabric and green open spaces is the implemental structure of the proposal. The intervention will occupy about 40% percent of the area of current green space (Figure 30).

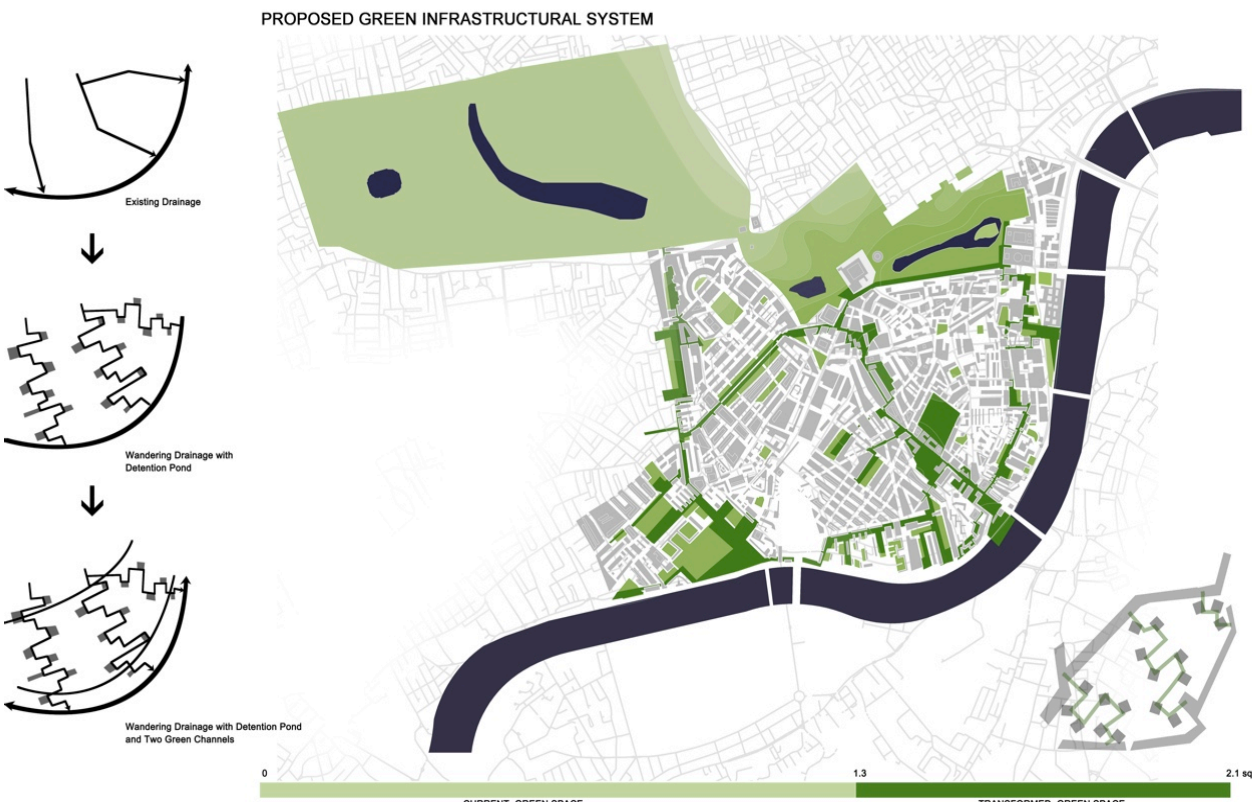


Figure 30 Proposed Green Infrastructure Network

(Dark Green indicates proposed green space; light green indicates current green space in this diagram)

Other than urban hydrological function, for an urban setting, consideration of human use and programming is essential. When dry, the proposed sites must also serve as public spaces accommodating the needs of city dwellers, such as sports, gardening, and social gathering. All such uses will apply to the site according to the current land use condition (Figure 31). Transformed green space takes up about 30% and recreational space takes up to 18% of the proposed area, which is showed in the diagram that dark green area means proposed area and light green means the left.

Figure 31 Programing

3.5 Statistical Analyses and Phasing

Conceptual development is not enough. This thesis included some statistical analysis of the study site. Educing the area of water restoration by calculating the floodplain with different levels (Figure 32), it calculates out the proposed area indicated in blue (Figure 33) with a 100-year event scenario. In these calculation systems, we define the flooding water volume Va and Vb by estimates. Then, we get the whole volume of extreme flooding, about 1.42 billion gallons. Four proposed, distinct phases respond to different flooding levels over time according to an economic development plan (Figure 34). Each phase includes how much current land area will be co-opted and transformed into water restoration uses, how many buildings will be adapted or removed, and how much the interventions will cost (Figure 34). With that financial model, we can process the operation wisely.

Figure 32 Proposed Master Plan of Floodplain of Westminster

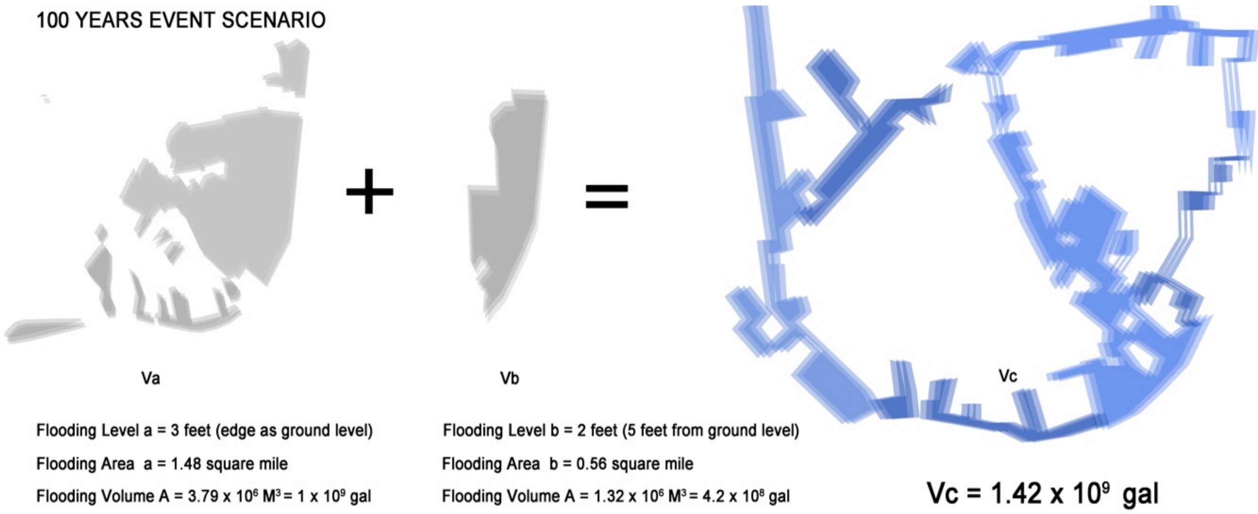


Figure 33 Calculation of flooding

In these calculation systems, we defined the flooding water volume by estimation. We divided the most intensive flooding scenario into four phases: 2050, 2080, 2100, and 2110, according to climate change phases. In terms of replacement of buildings, we would first prefer replace or utilize the basements of the existing building to store water to minimize the cost. Otherwise, we would take away some portion of them to use as water detention ponds when during flooding. When it is dry, those spaces still can function as green open space surrounded by buildings.

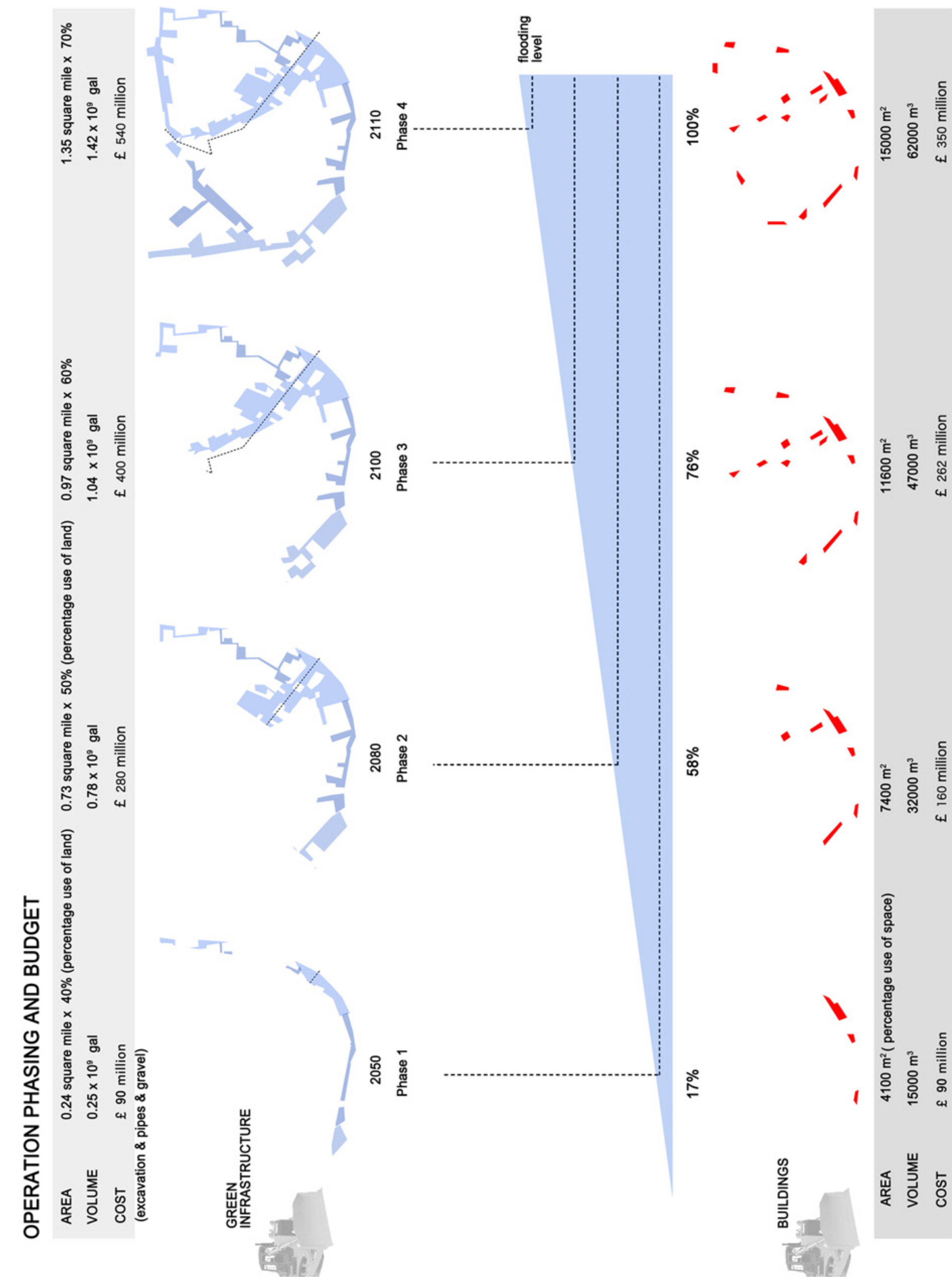


Figure 34 Phasing

3.6 Master Plan

With all of these considerations made and operations completed, I address the master plan of the proposed new strategic intervention for Westminster fifty years out with hybrid systematic detail approaches according to the real physical context of each part of the city.

The specific approaches that I propose include potential water detention ponds, green street soil channels, day lighting covered drainage, basement flood storage, sunken water gardens on the bank, and living systems structures on the river body surface. Those interventions work collectively with a cleansing system, which is composed of living systems of vegetation throughout the routes of the proposed drainage system (Figure 35).

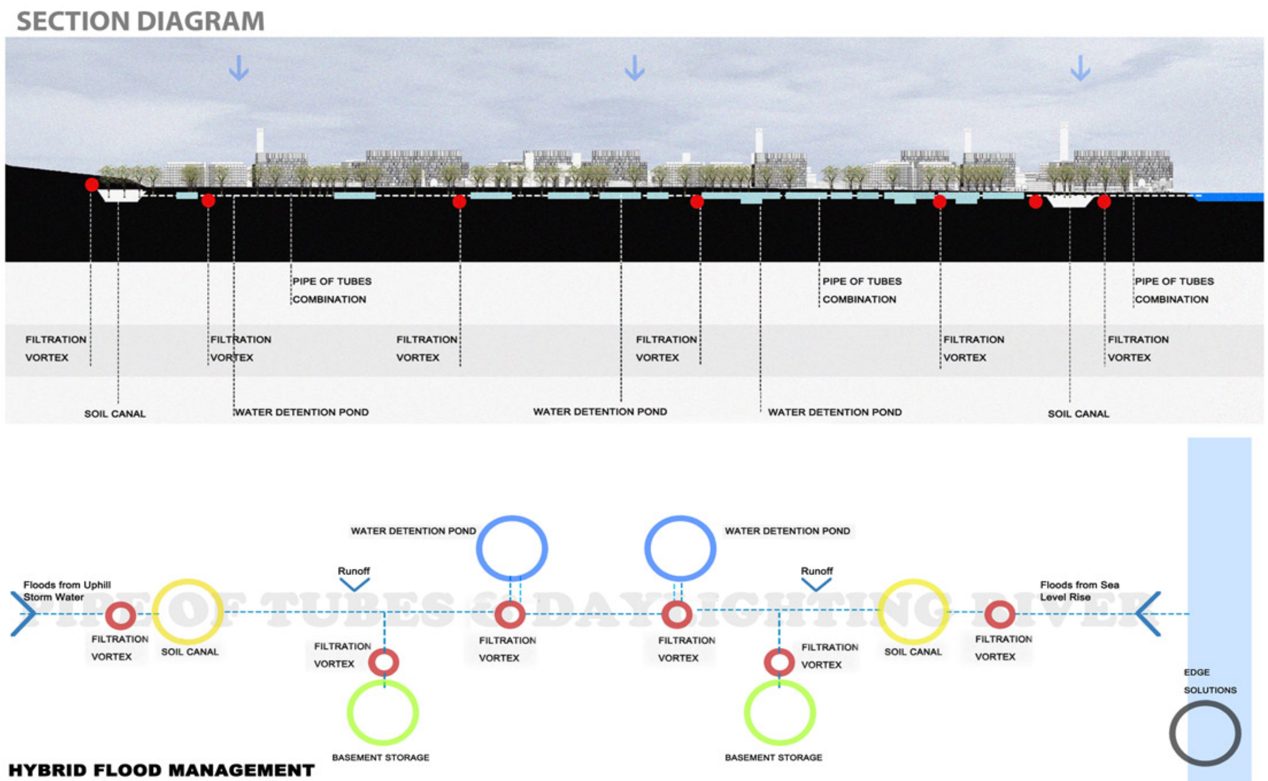


Figure 35 Section of Proposed Network

Then the design converts the systemic section design into a final proposed master plan (Figure 36) to define the specific locations of all these green infrastructure interventions network which is indicated in green.

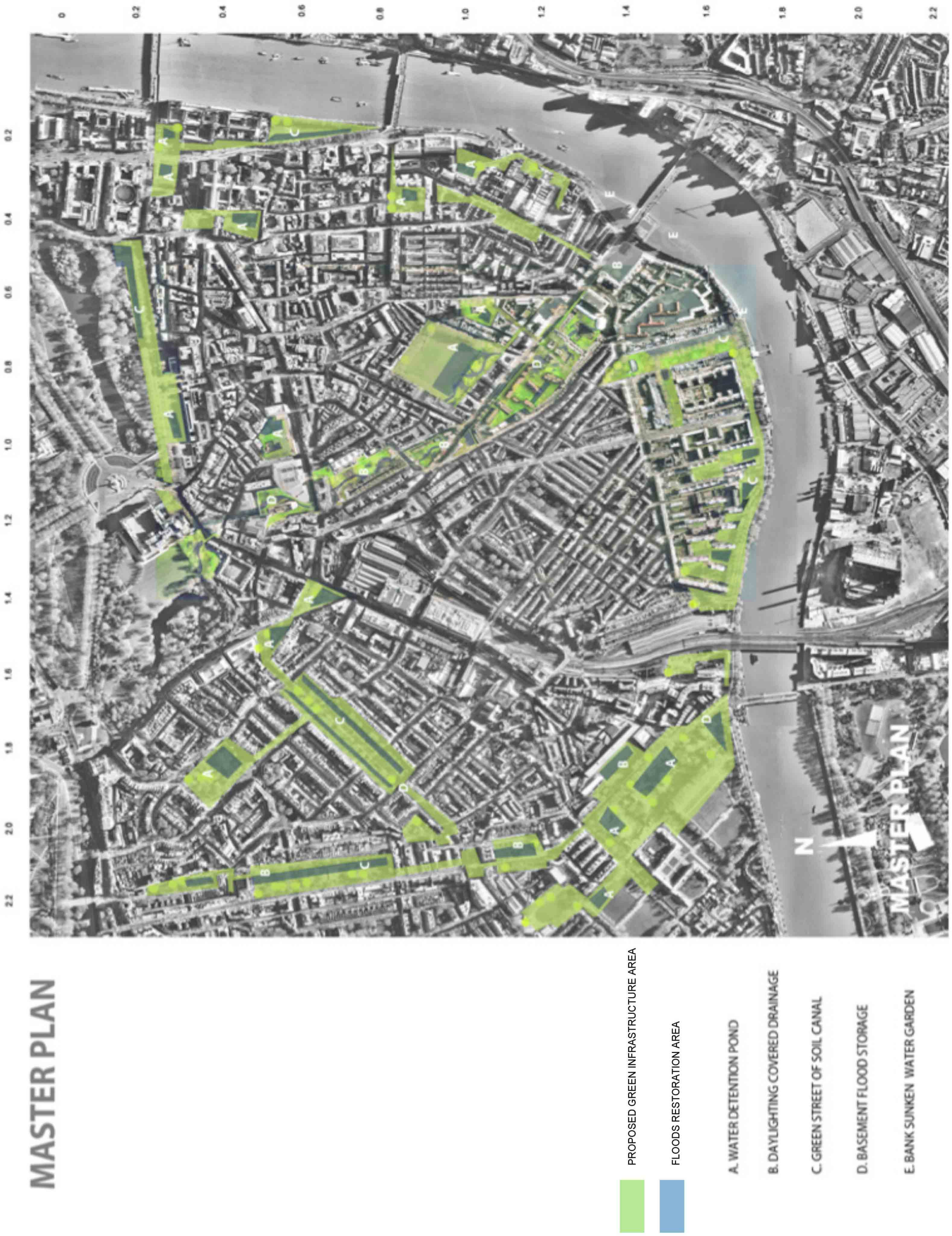


Figure 36 Master Plan of Proposed Network

3. 7 Detail Design

For specific approaches this thesis researched detailed technical solutions for each typical site design. The detailed, combined design solutions included design for "new channels", approaches for potential water detention ponds within buildings when flooding, and approaches for the lost Thames tributary rivers. There is also a clustered pipe system to filter, cleanse, and store drainage and flood water and eventually to distribute them through irrigation.

3.7.1 Bioswale Channel

A soil canal of bio-swale within Green Street, in the southwest sector of the proposed system, links King's Road to the north and Grosvenor Road to the south, near the riverbank. (Figure 36) The soil canal works as a civil engineering channel to hold flood water. The material of the soil canal is composed by mixing soil of clay and organic material. The gravel on the bottom of the canal is used as storage space during flooding. Connected by geotextiles to an outlet, when the surge overflows, flood water will flow into next three parts (Figure 37).

3.7.2 Basement Storage

The first of those are building basement storage rooms with living material cleansing layers. This operation will take place in the southwest sector of the network, at Sloane Street (Figure 38). Utilizing current building basement as storage of storm water during flooding (Figure 38), layered, living vegetation will filter and clean water as it flows into the storage tanks.

3.7.3 Courtyard Water Detention Pond with Wetland Vegetation

The second part, involving water detention ponds, is a storm water management facility, a low lying area that is designed to temporaly hold a set amount of water while slowly draining to another location. Detention ponds are used for flood control when large amounts of rain could cause flash flooding if not dealt with properly. They will be introduced into courtyards which meet the criteria of having a minimum area of 100 square feet and of being close to drainage pipes (Figure 39).

Figure 37 Soil Canal

Figure 38 Basement Storage

Figure 39 Courtyard Potential Water Detention Pond

3.7.4 Daylighting Covered Drainage

The third part involves daylighting covered drainage. This operation includes a pipe system I proposed along the Vauxhall Bridge Road (Figure 40). Uncovering some sections of the lost rivers, these pipes will be reused for drainage of storm water during flooding and to provide waterscape and urban constructed wetland habitat and recreation for people. The three chambers of the pipe system proposed here works as cleansing, storage, and irrigating processes in sequence, depending on the flood season and degree. Figure 40 shows this component in dry, storage, and flooding phases.

3.7.5 Cleansing Tubes System

Fourth, water purification and distribution are important operations of storm water management. . Figure 41 shows two areas connected by the pipe systems. They transform the current drainage pipes into ecologically functional pipe system with self-cleaning by living vegetation and waste water cleaning ponds at certain current intersections and vertex points (Figure 41). This system implements the current drainage system and builds additional concrete pipes with holes to allow water flow through one to one pipe. The whole new system will be along the routes to meet need.

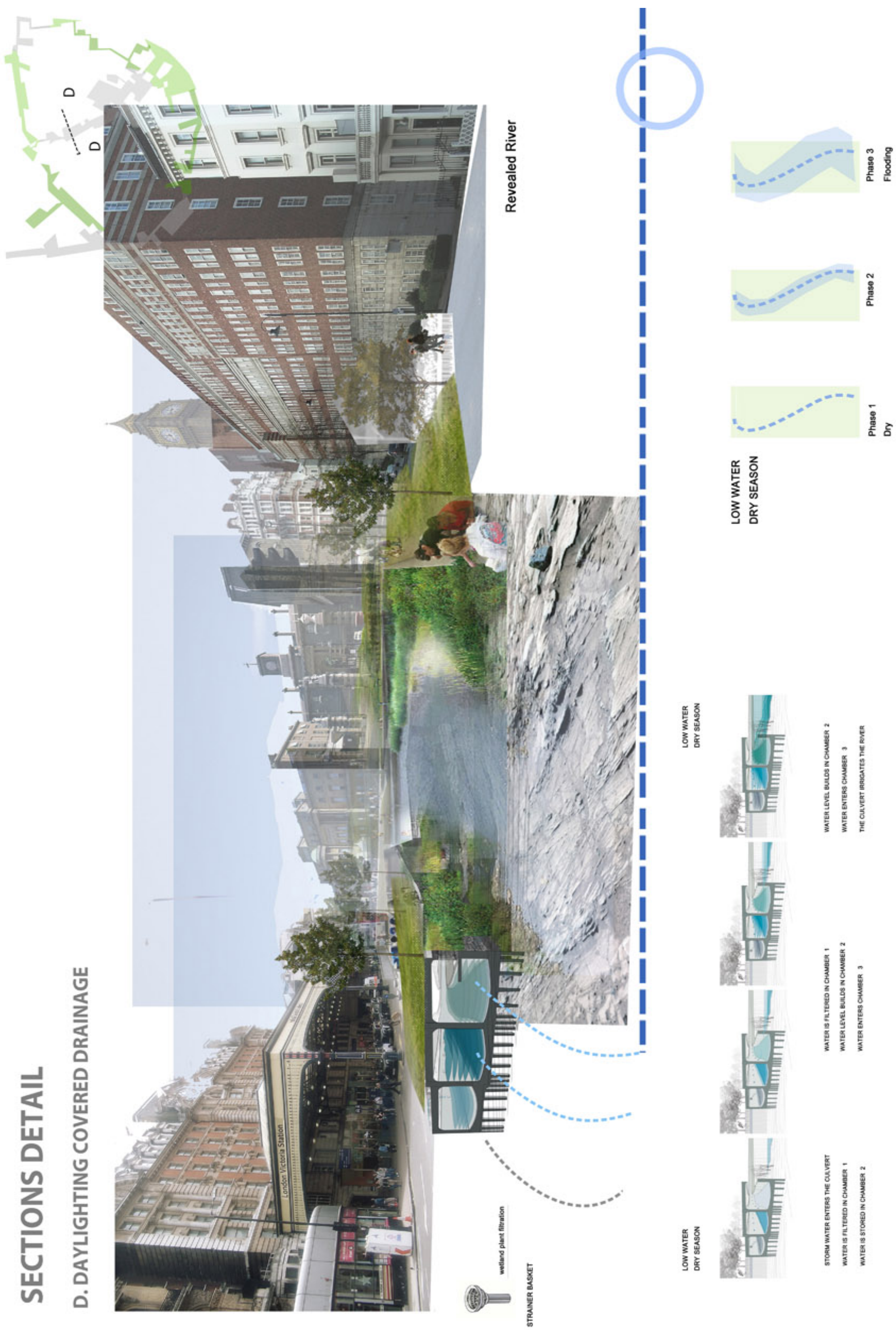


Figure 40 Daylighting Covered Drainage

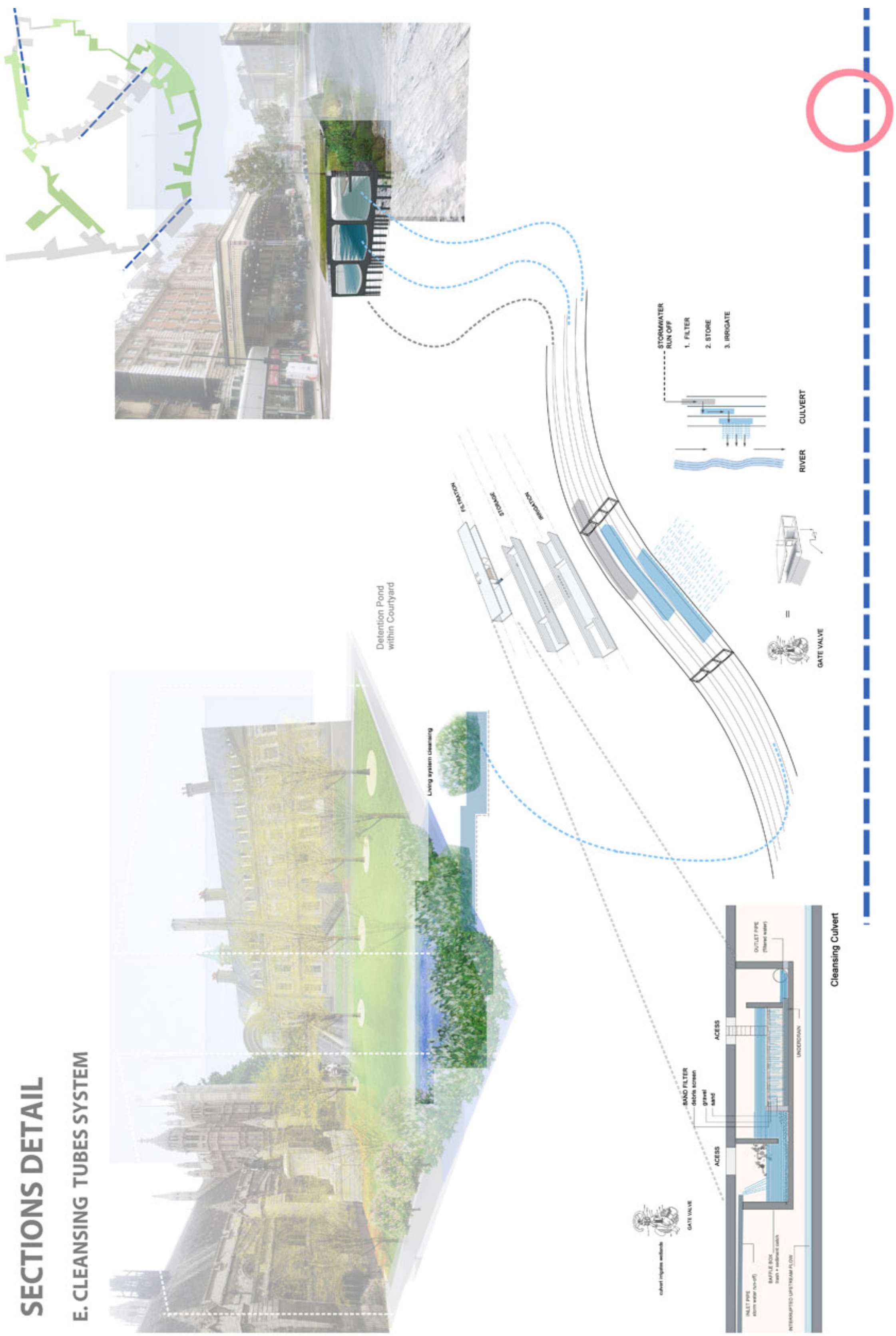


Figure 41 Cleansing Tubes System

3.7.6 Edge Solutions I

After those operations, the overflow of flooding will come to the edge of the city, the bank of the Thames River. The design proposes a sunken garden on the edge (Figure 42). There additional floodwater from the riverfront will be absorbed. Gradual changes of water level modulate the landscape and its form in that area over time (Figure 42). At the same time, it creates diverse riverfront programming opportunities for residents and visitors.

3.7.7 Edge Solutions II

Lastly, within the middle of the Thames River, the concept is to provide soft cubes with living system climbing and sponge material as a defense to reduce the speed and energy of river surge. The objective is to deploy the barrier structure in the highest speed spots of the river surge to slow the flow (Figure 43). But due to limited access to bathymetric and hydraulic data, the proposal presented here is conceptual and schematic.

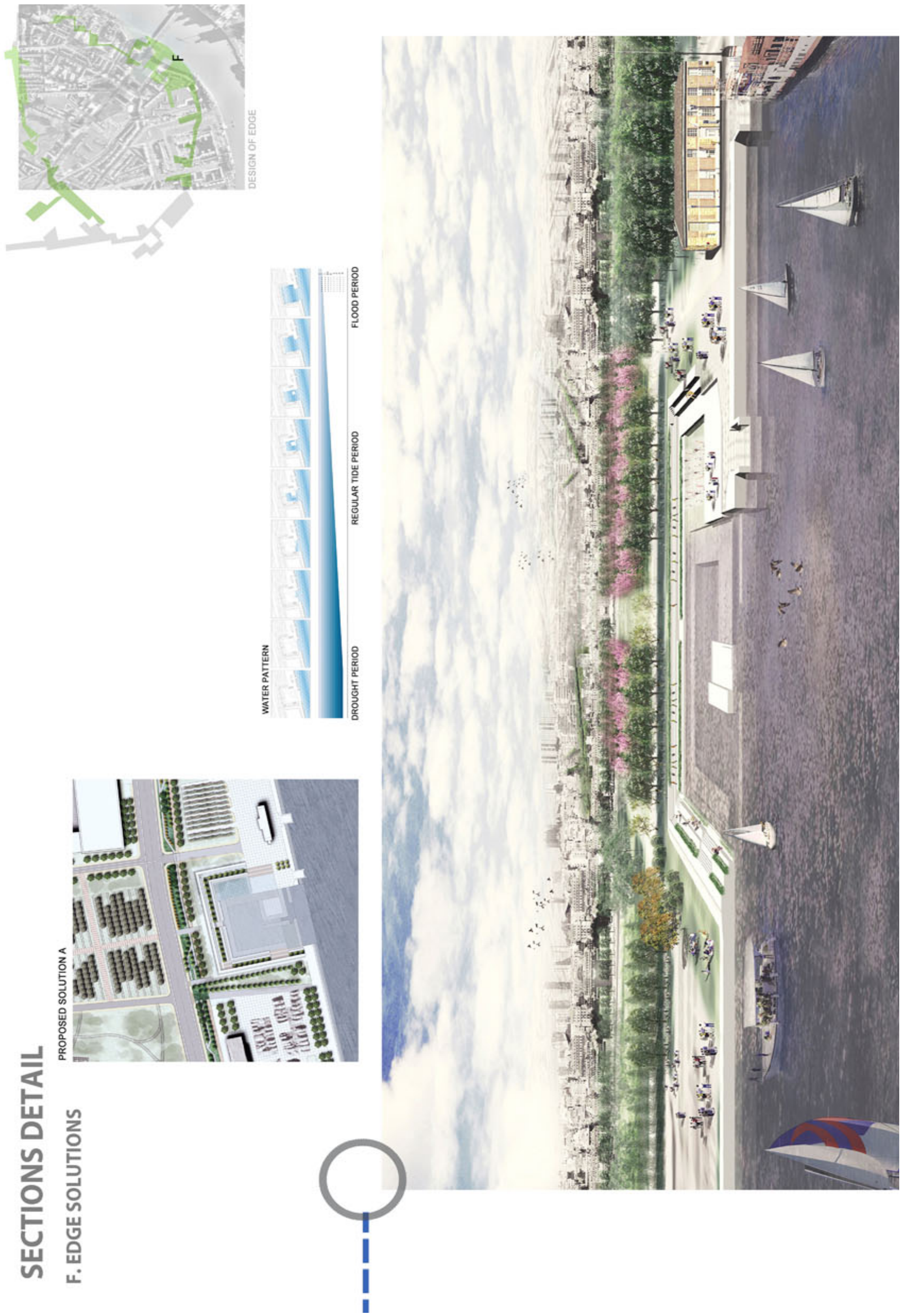
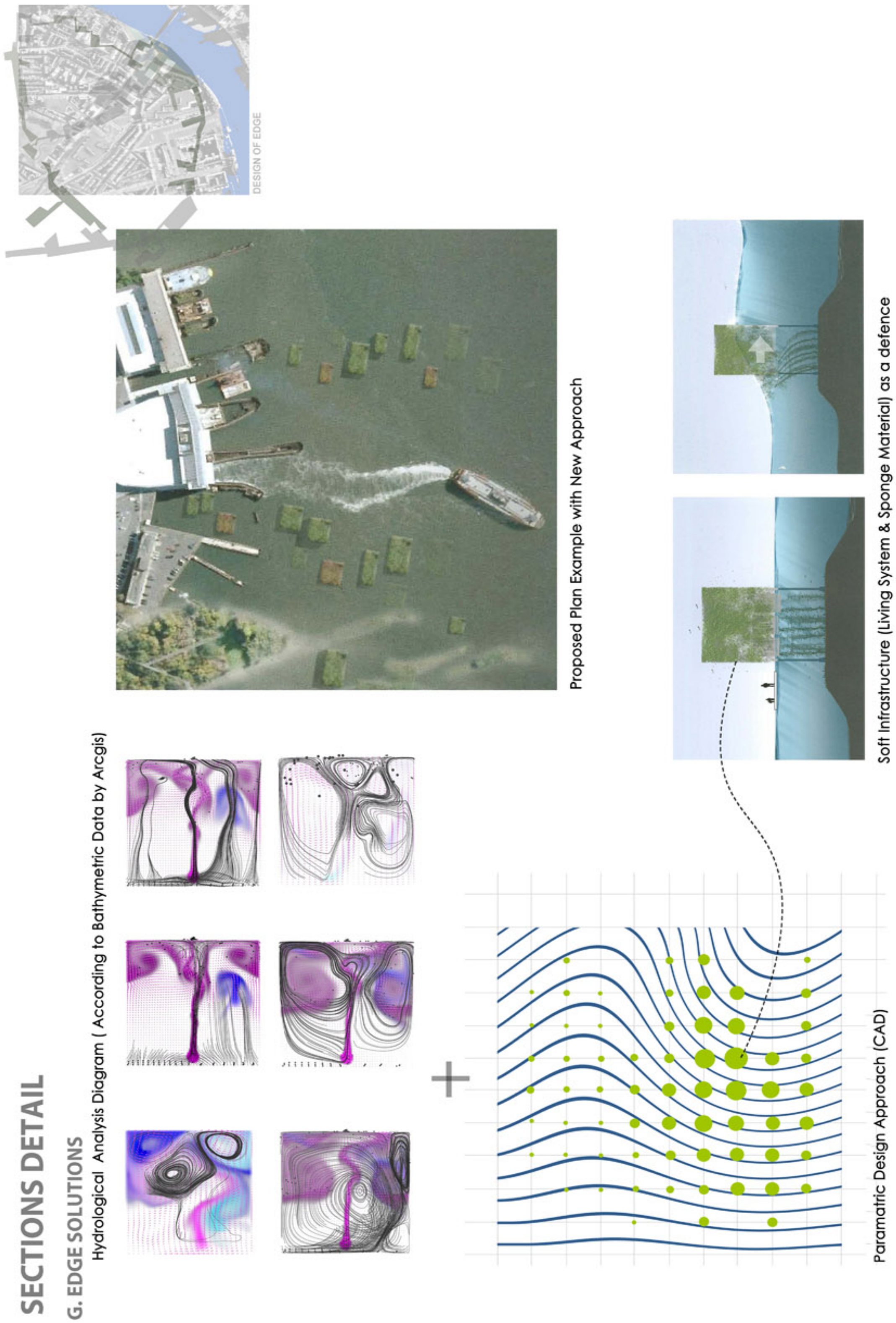


Figure 42 Edge Solution of Sunken Garden



Source: Rising Currents Exhibition

Figure 43 Edge Solution of Living Structure

SYSTEM

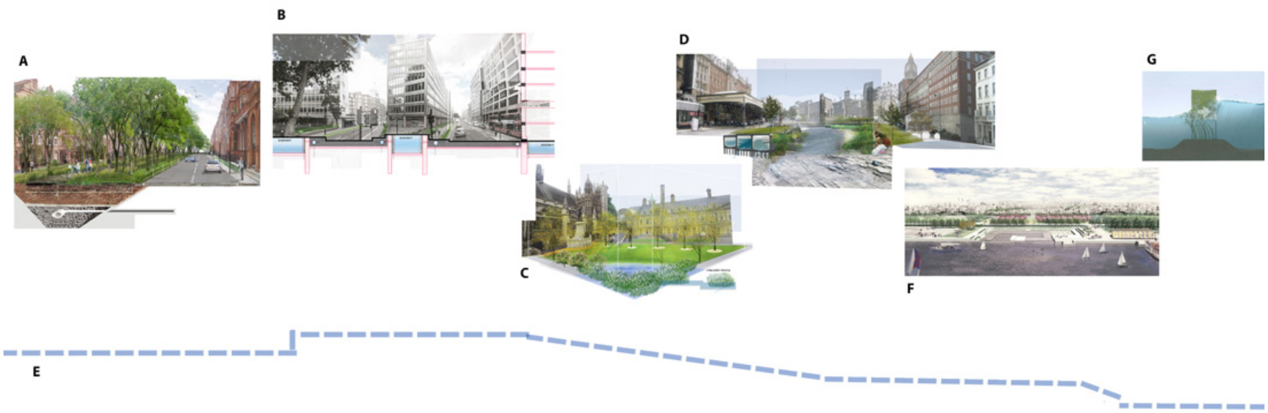


Figure 44 Systemic Solutions

Engaging hybrid, systematic approaches to dealing with storm water runoff, river surge, and sea rise collectively in central London (Figure 44), this thesis set up a study and design model for urban flood prevention and urban refinement adaptive strategies without eliminating existing civil engineering solutions. Combining soft and hard solutions makes possible more environmental and sustainable solutions. Soft solutions can find their home on or adjacent to hard solutions to meet a collective goal of sustaining beauty for the city in the future and providing more amenities for people. Water is treated not as an enemy but as a welcome friend, transforming the character of the city.

Chapter 4: Conclusion

Although the research in this thesis focused on the context of central London and the local portion of the Thames River, it provides potential solutions for coastal urban areas globally, and particularly for those in estuaries. Urbanization is not only a global phenomenon of physical and cultural restructuring. It has become a spatial effect of the distributed networks of communication, resources, finance, and migration that characterize contemporary life. Urban landscape systems, such as soft infrastructure, are part of that process.

At the same time, soft infrastructure is a new direction for the disciplines of landscape architecture and civil engineering. It entails exploring new strategies for combination of two types of solutions in order to reduce the impact of flooding within urban areas. The results are neither cold and unfriendly to people, as well as ecologically unsound, as are most traditional civil engineering solution, nor are they incapable of handling expected volumes of water, as would be the case if one were to rely exclusively on green infrastructure. The sense of sustaining beauty will be built on this basis.

If it is possible, this research will extend beyond the refinement model proposed here to further study of the local drainage system and a more specific implementation design for each component site. At that point the approach could be promoted to architecture, landscape architecture, and urban design firms, as well as to ecological agencies. Individual firms can practice detail design for each specific component site as a real implementation. Those could then be combined as a system to realize the big picture of sustainable urbanism to which this thesis aspires to contribute.

References

Allen, Stan. 1999. Infrastructure Urbanism. In *Points + Lines: Diagrams and Projects for the City*. 48–57. New York, NY: Princeton Architectural Press.

Barnett, Jonathan and Hill, Kristina. 2008. Design for Rising Sea Level. *Harvard Design Magazine*, Fall: 14-21.

Benjamin, Stanley. 1986. Some effects of surface heating and topography on the regional severe storm environment. Part I: Three-Dimensional Simulations. *Monthly Weather Review* 114: 307–329.

Bohannon, John. August 25, 2006. Running Out of Water-and Time. *Science* 313: 1085-7.

City of London. City of London Unitary Urban Development Plan 2002. http://www.cityoflondon.gov.uk/Corporation/LGNL_Services/Environment_and_planning/Planning/Planning_policy/udp_2002.htm (accessed September, 2010).

Climate Risk Management Limited. January 2007. *Rising to the Challenge: The City of London Corporation's Climate Adaptation Strategy.* London, England: City of London Corporation. <http://www.cityoflondon.gov.uk/NR/rdonlyres/ECD1C5D2-A645-4D5F-AD03-F9B17BC1D14C/0/SUS_AdaptationStrategyfinal_2010update.pdf>.

Corner, James. 2006. Terra Fluxus. In *Landscape Urbanism Reader*, ed. Charles Waldheim, 23-35. New York, NY: Princeton Architectural Press.

Crooks, Stephen. September 2004. The Effect of Sea-Level Rise on Coastal Geomorphology. *Ibis* (*The International Journal of Avian Science*) 146: 1, 18-20.

Hill, Kristina. 2002. Urban Ecologies: Biodiversity and Urban Design. In *Case: Downsview Park Toronto*, ed. J. Czerniak. 90-101. New York, NY: Prestel and Harvard Graduate School of Design.

Landscape Infrastructures Symposium. DVD. Organized by Pierre Bélanger, Speaker: Stan Allen, George Baird, Pierre Bélanger, Julia Czarina, Herbert Dreiseitl, Kristina Hill, Michael Jakob, Nina-Marie Lister, Kate Orff, Jane Wolff. Oct. 25, 2008; Cambridge, MA: Graduate School of Design, Harvard University, 2008.

Meyer, Elizabeth. 2008. Sustaining beauty: The performance of appearance - A manifesto in three parts. *Journal of Landscape Architecture*, Spring 2008: 6-23.

Mossop, E. 2006. Landscapes of Infrastructure. In *Landscape Urbanism Reader,* ed. Charle Waldheim. 163-178. New York, NY: Princeton Architectural Press.

Nassauer, Joan. 1995. Messy Ecosystem, Orderly Frames. *Landscape Journal* 14 (2): 161-170.

Nicholls, Robert; Frank Hoozemans and Marcel Marchand. 1999. Increasing floods risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environmental Change*, Vol. 9, Suppl 1, October: 69-87.

Pachauri, R.K. ,A. Reisinger, eds. 2007. *Climate change 2007: Synthesis Report.* Geneva, Switzerland: IPCC (Intergovernmental Panel on Climate Change).

Pfeffer, W.T.; J.T. Harper and S. O'Neel, Sep 2008. Kinematic constraints on glacier contributions to 21st-century sea-level rise. *Science* 321 (5894): 1340–1343.

Reed, Chris. 2006. Public Works Practice. In *Landscape Urbanism Reader,* ed. Charles Waldheim, 268-235. New York, NY: Princeton Architectural Press.

River Thames. Thames Waterway Plan 2006-2011. http://www.visitthames.co.uk/text/1930/thames_waterway_plan_2006_2011.html (accessed September, 2010).

Seavitt, Catherine. April 2010. On the Water: Palisade Bay. In *Sustain and Develop: 306090 Books*, ed. Joshua Bolchover and Jonathan D. Solomon, Vol. 13: 249-257. New York, NY: Princeton Architectural Press.

Seavitt, Catherine. April 2010. Rising Tides, Exhibition, MoMA. New York, NY: Princeton Architectural Press.

The Environment Agency of the Government of Great Britain. The Thames Barrier. http://www.environment-agency.gov.uk/homeand leisure/floods/105002.aspx (accessed September, 2010).