Adapting to Uncertainty: Re-thinking Critical Infrastructural Systems

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Key words:
Critical infrastructure, risk management, risk analysis, deep uncertainty, adaptive design, decision-making under uncertainty

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CONTENT

Figure 1 Transitional Territories studio field trip towards the North Sea, photo by author

1.0 Introduction

"Climate change is considered as a main cause of increase in frequency and intensity of hydro-meteorological hazards. Extreme climate related hazards are now commonly noticed in every part of the world" (Uitto & Shaw, p.40, 2016).

Presently, deltas and coastal regions have become magnets for urbanization and economic development. Future predictions indicate that by 2050, more than 650 million people will inhabit these regions. Flourishing delta economies are a result of their strategic locations to fertile soils, water and their ideal position for trade and commerce Deltas have also been identified as stimulator for national economic growth and contain the highest national GDPs. However, these regions are also susceptible to growing flood risks and ecological and economic damage. In particular, the Thames Estuary, one of the most significant political and economic urban zones in the UK, has also been deeply impacted by massive land erosion. Growing pressures from environmental issues such as the sea level rising have caused significant damage to coastal towns, harbors and infrastructure. As a result, deep uncertainties relative to future conditions have rendered many cities to question how to address the growing frequency of these 'extremities' and the risks at play in relation to critical infrastructure and systems.

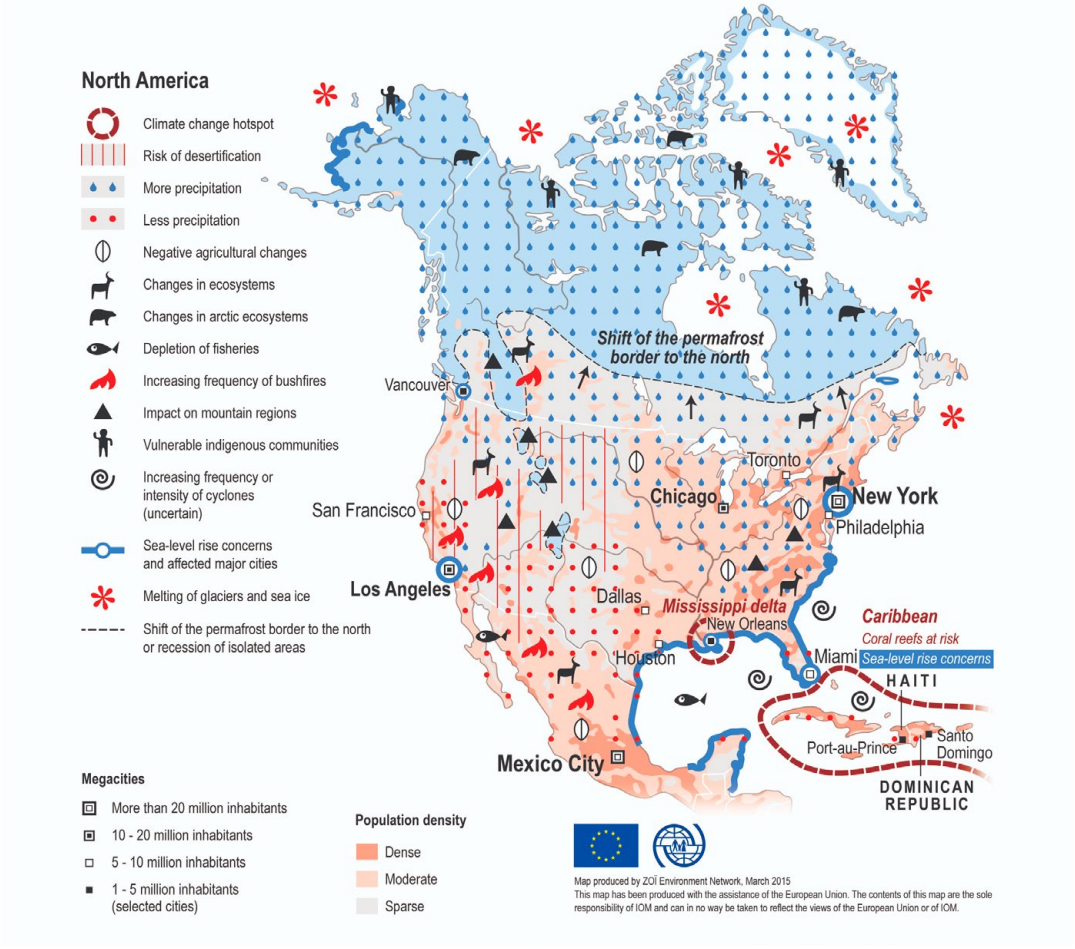


Figure 2 A regional map based in North America on migration, environment and climate change (Network, 2015)

1.1 Motivation & Relevance

Over the years, I have developed an interest in the topics of disaster relief and risk mitigation. In alignment with my interests, the Transitional Territories studio has a thematic emphasis on the altered state of nature based on extreme events. The studio offers an insight into working with different scales while providing a method of exploring the complexity of these large-scale issues (social, economic and ecological extremities).

Posing an example of a recent extreme event in North America, Hurricane Sandy inflicted over $70 billion in damage in the U.S. Governments are constantly hindered by the adverse effects of climate change and have been typically under prepared for these situations. Generally, strategies and investments tend to focus short-term solutions or address the impacts of disasters after-the-fact rather than funding preventative measures. Thus, if systems begin failing, how are vulnerable communities supposed to cope?

Personally, I have resided in three major cities within Canada (notably Toronto, Ottawa and Vancouver). It is notable that Canada has a long history of facing large climatic issues and geohazards. Majority of the economic hubs and highly urbanized cities are situated along a waterfront and are subjected to flash flooding, droughts or forest fires. There have been several cases where cascading risks and energy failures have spread across cities. Toronto, the most populous city in Canada is vulnerable to a series of climate related shocks including rainfall flooding, blizzards and heat waves. One of the most cost-intensive disruption was in 2013 when over 4,579 homes were flooded, and 750,000 people lost power. There was a rising concern amongst officials that power disruptions would continue to impact the region but also disproportionately affect the city's neediest.

On August 14, 2003, portions of southeastern Canada and northeastern United States suffered a massive cascading failure in the electrical grid. The failures immediately impacted other interdependent infrastructure including communications, water and sewers. The single blackout began with an energy system in Ohio and rapidly infected other neighbouring systems. In Ontario, Canada, the blackouts lasted for more than a week before full power was restored. Additionally, health and security risks compounded with the shortage of electricity. Overall, the event affected over 50 million people and cost over $2.3 billion, with a net loss of 18.9 million work hours.

TORONTO'S SHOCKS & STRESSES

- Blizzards
- Economic inequality
- Energy insecurity
- Extreme cold
- Extreme heat
- Inadequate public transportation services
- Infrastructure failure
- Insecure municipal finances
- Lack of affordable housing
- Poor governance/regulatory climate
- Power outage
- Rainfall flooding

> We pay a lot of attention to building harder/tougher infrastructure and not enough attention on how people engage with the system so that they can bounce back. How do we ensure we maintain power, water, transport, communications but also have access to health and food?
>
> **Peter Chamley,** Director
> Chair of Arup's Global Infrastructure Practice

Figure 3 South East England, satellite image (https://www.sciencephotogallery.com/south-east-england-satellite-image-9208515.html)

1.2 Executive Summary

The starting point of the thesis began with examining uncertainties in the future and the impact of extreme unforeseen conditions of flood risk on critical infrastructure systems. It is important to note that risks towards the viability of communities and economies are closely linked to the resilience of local infrastructure. Specifically, lifeline systems such as energy, transportation and communication systems.

> "Projected sea level rises of 50-100 centimeters by 2100 will exacerbate flood risks and accelerate the process of coastal change for exposed communities" (Climate Change, p. 3, 2017).

Direct climate-change related risks in the UK have increased in frequency over the years and have endangered wildlife, natural ecosystems and infrastructure. It is also evident from the IPCC report (2017) that warmer temperatures would lead to heavier rainfall and more frequent flooding, even in regions outside recognized specified flood risk areas (Climate Change, 2017). Since the 1900s, sea levels within the UK have risen by 15-20 cm. Although natural variability in the climate will continue to effect weather related events, more severe and sustained projections of these events will occur (Climate Change, 2017). At the national level, efforts and approaches to adaptation could offset increases in annual flood damage if global warming is limited to the 2°C projection. However, local impacts will vary substantially, and risks will also impact areas unevenly.

The strengthening of infrastructure has been identified as an important field of disaster risk reduction. "However, CI and DRM terminologies have not been fully integrated and results in inconsistent labeling, conceptualization and implementation of disaster risk-related CI activities and governance approaches" (Bach et al., 2016). The integration of flood risk management alongside spatial planning to transform urbanized landscapes are of utmost importance. There is also an aim towards a shift of thinking in how critical infrastructure sectors such as is to be designed, delivered and operated (Mian et al., 2018).

The thesis also critically analyzes the existing paradigms of protecting vital urbanized landscapes and the adaptive measures taken. The approach of the thesis looks at the impact of flood risks on lifeline systems and how the system could be rendered obsolete. These problematic issues have also been evident in other cities around the world and many local governments and utility providers are exponentially dealing with the consequences of aging and failing infrastructure. The pitfall of designing without considering an extreme or radical way of how we plan or develop cities can result in more risks compounding in the future.

White cliffs of Dover, photo by author

PROBLEM FIELD & CONTEXT

Problem Fields:

- Climate Trends and Economic Impacts
- Risks to Critical Infrastructure & Interdependencies
- Flood Risk for the Thames Estuary and Growing Deep Uncertainties
- Environmental Degradation & Flood Risk Protection Conflicts
- Aging Flood Defences

Problem Statement

Research Question & Sub-research questions

Hypothesis

2.1 Problem Field

Climate Trends & Economic Impacts

With the increasing frequency of extreme weather events and large-scale disasters, extensive societal and economic losses occur every year. This can be seen with damages in infrastructure, private properties, business disruptions, homelessness and health-related issues. A significant contributor to the increase in the occurrences, magnitude of natural hazards and weather variability is due to climate change, water practices and land use. The number of people effected by hazards will continue to grow as increasing trends such as population growth, urbanization, land shortages and poor conditions of flood protection and drainage infrastructure persist (United Nations, p. 2, 2018).

Further disruptions from winter storms between the years 2013-2016 have established long-lasting disruptions and caused complete losses of essential services such as water, energy supplies, and transportation and community networks. In addition, storm surges continue to have mounting impacts on changing coastal environments. Despite advances in risk management and technology such as flood defences and warning, coastal flooding continues to be a growing threat due to climate-induced sea level rise, land subsidence and rapid population and economic growth in flood exposed areas (Haigh et al., 2017).

"Coastal flooding in the UK occurs during storm surges, which are mainly caused by strong onshore winds, and the higher the tide at the time the more likely flooding will be (Pugh and Woodworth 2014). Large-scale fluctuations in weather also affect sea level variability: for example, the decadal scale changes of the North Atlantic Oscillation influence sea level variability in the North Sea"(Edwards, p. 9, 2017).

Assets across multiple sectors are susceptible to flooding and the number is predicted to double by 2080 with projected changes to the UK climate. Historically, the UK has encountered severe coastal flooding which is considered the second highest risk of civil emergency as ***over 5 million people***, and ***£150 billion of assets*** are threatened (Haigh et al., 2017). In combination with fluvial and coastal flooding, there has been ***£0.25bn in annual economic damages***. The impacts of climate change on water is expected to have cascading effects to various sectors of the economy, human health and well-being. The benefits and coordination of risks related to water management cannot be achieved through unilateral developments (United Nations, 2018) and this is especially emphasized in the Sendai Framework.

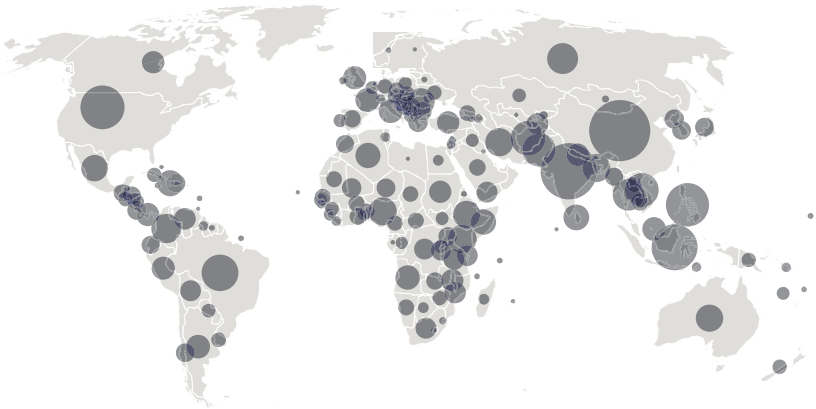


Figure 4 Flooding events and number of occurrences from 1996-2015 around the world (Source: CRED)

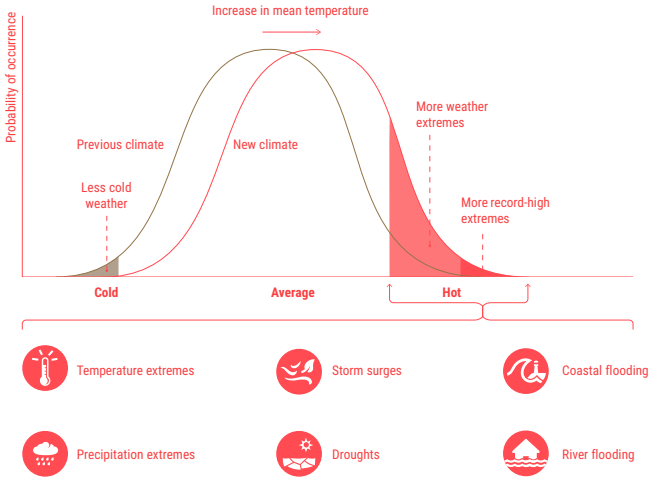


Figure 5 Diagram showing a shift in mean conditions and impacts of extreme weather conditions. These extreme conditions are occurring more frequently and becoming more 'extreme'. Adapted from (Source: CRED)

Estimated coastal flood damages by 2090s under different scenarios of sea level rise by 2100 to current adaptation and high population increase (Sayers et al, 2015; 2016)

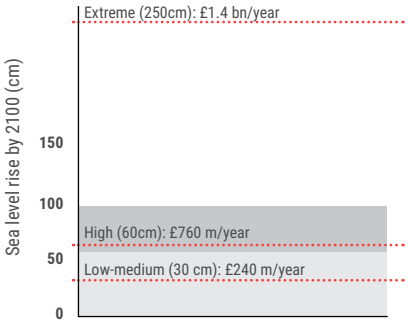


Figure 6 Chart showcasing coastal flood damages and sea level projections. An increase in expected annual damages relative to present day (£540 m/year) using the UK Climate Change Risk Assessment 2017 and IPCC sea level projections.

Relative Sea Level Rise

This map illustrates the extreme effect of climate change in the case of a +1m sea level rise (SLR) in regards to an 8.5 RCP scenario in the absence of interventions. The relative SLR projection is for the period between 2081-2100. The map renders the flood risk areas in the North Sea region and provides information about when those events are expected to be formalised: as extreme event (flood) or constant condition (sea level rise). Considering relative sea level rise, large portions of the coastline needs to be redesigned and planned in terms of water defence systems and urban strategies. The entire seascape is expected to fully reshape, with Netherlands, Germany, Denmark, but also part of England being the most vulnerable to the changes.

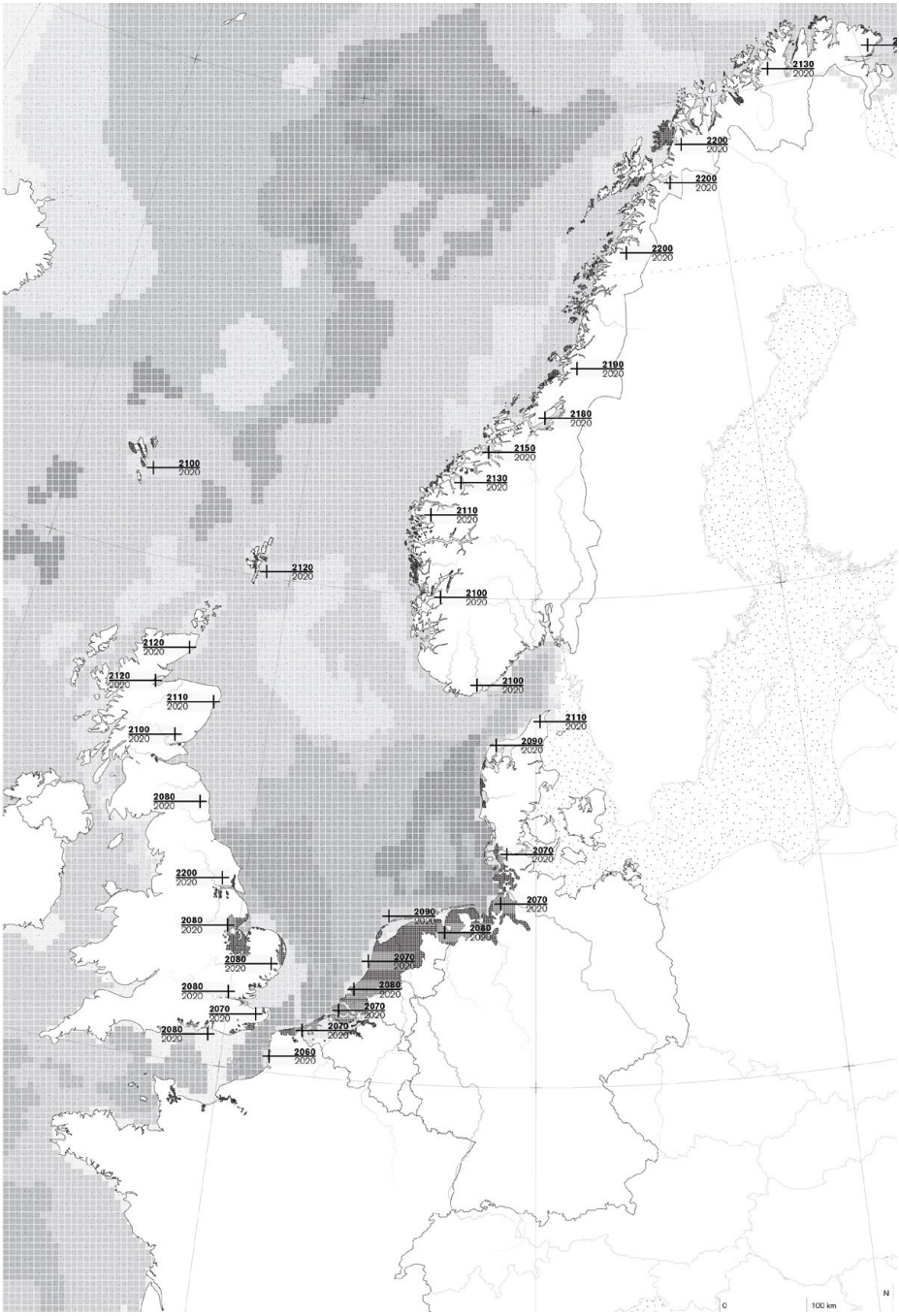
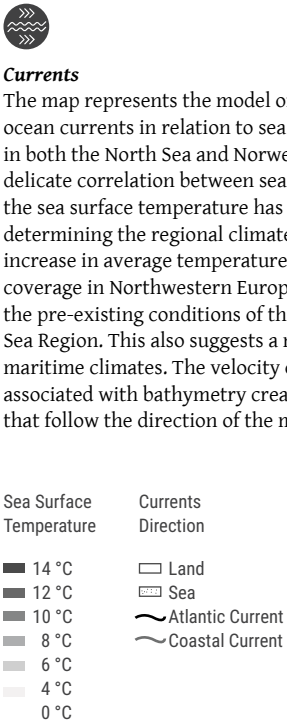


Figure 7 North Sea Scale - SLR (Collective Studio thematic explorations)

Currents

The map represents the model of the sea/ ocean currents in relation to sea temperatures in both the North Sea and Norwegian Sea. The delicate correlation between sea currents and the sea surface temperature has a great impact in determining the regional climate. The expected increase in average temperatures and cloud coverage in Northwestern Europe will redefine the pre-existing conditions of the entire North Sea Region. This also suggests a major shift in maritime climates. The velocity of the sea currents associated with bathymetry creates rapid corridors that follow the direction of the main currents.



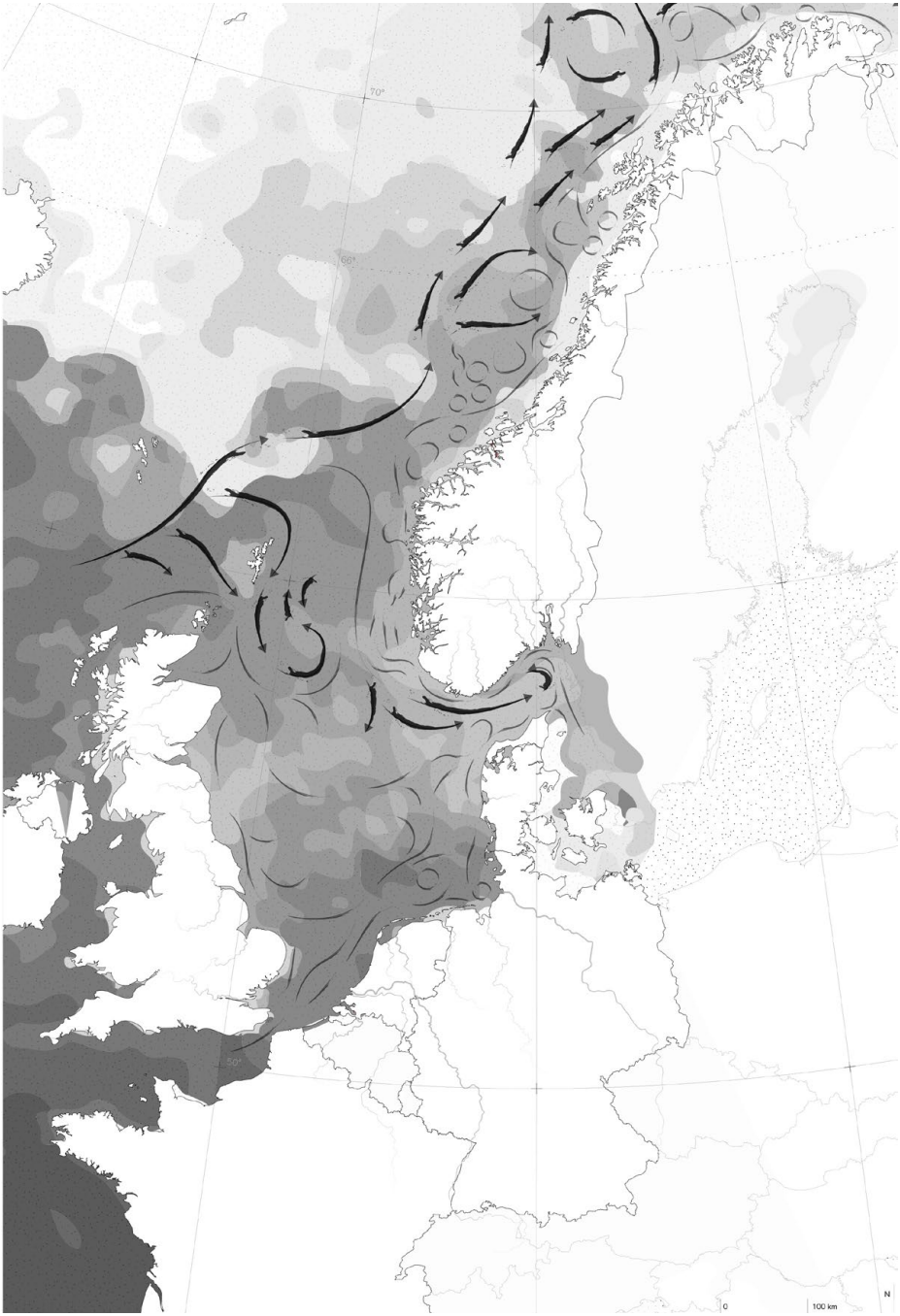
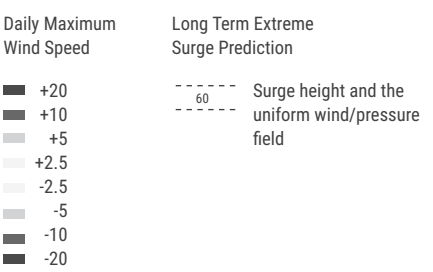


Figure 8 North Sea Scale - Currents (Collective Studio thematic explorations)

Extreme Winds and Storm Surge

This map represents the extreme scenario during wintertime for wind speed and air pressure in the future. The frequency of winds will increase up to 7% in the North West (Sari Kovats et al., 2007). These conditions will create more storms along the coastal regions of Holland, the UK, Germany and Denmark. This will result in storm surges where high winds will push water towards the coast (Sari Kovats et al., 2007)and will transport moisture onto northern Europe and Scandinavia. Storm surges can raise sea levels up to 3m in European seas and can last from hours to days. This can cause significant economic and environmental damage and loss to areas spanning hundreds of square kilometres ("What are storm surges? | National Tidal and Sea Level Facility," 2018). The combination of high tides, storm surges and wave conditions can breach coastal defences.



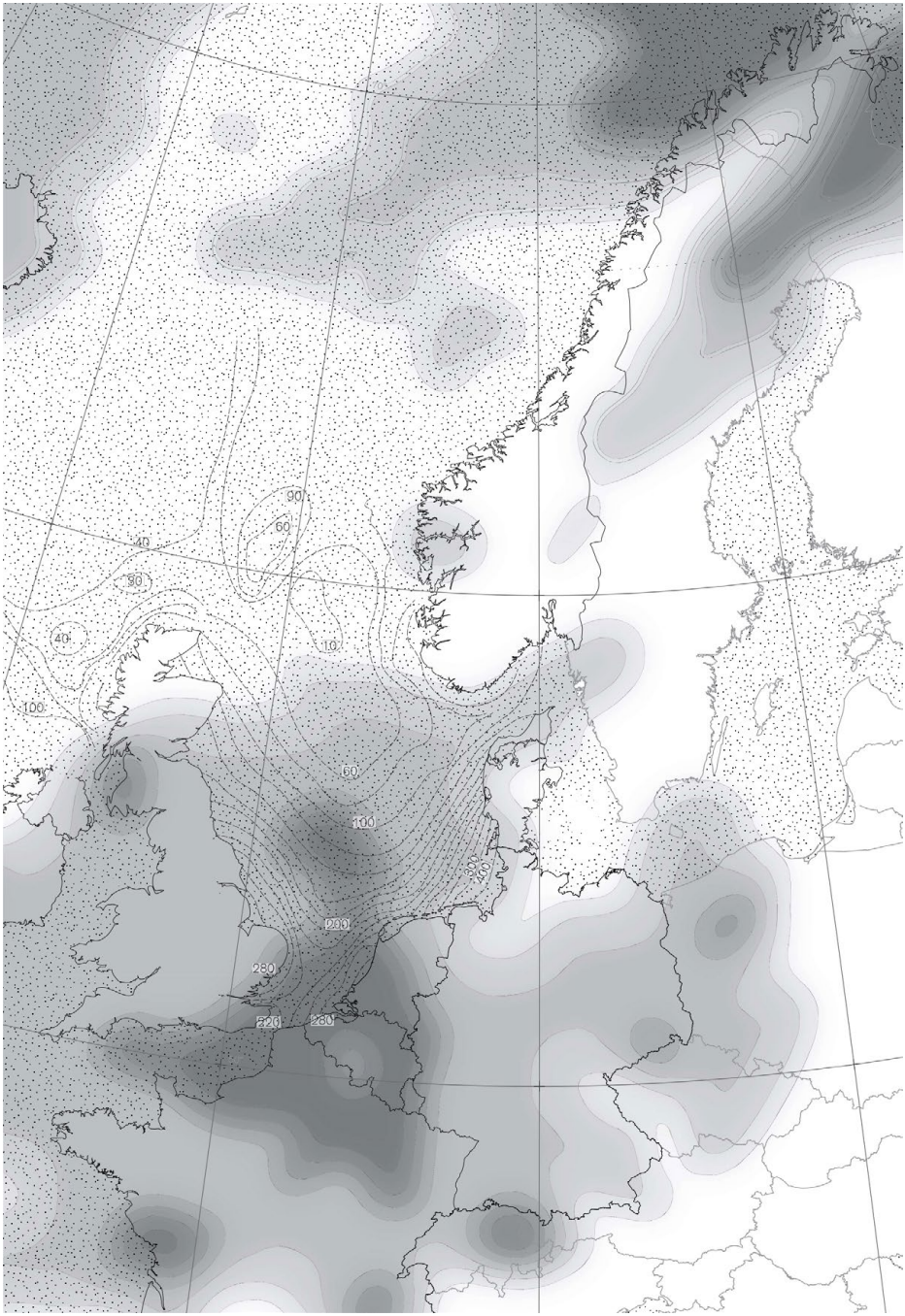


Figure 9 North Sea Scale - Extreme Winds and Storm Surge (Collective Studio thematic explorations)

Evident in the climate projections, the maps show areas with substantial increase in precipitation during both the non-frost and frost seasons. The Thames Estuary is an area subjected with frequent and intensifying flood risk. Coastal developments will also need to be prepared for a decrease in water availability and an increase of flooding severity simultaneously. Vulnerability assessments also conclude that “higher absolute costs are sustained by larger and richer EU countries (the biggest looser is UK with $ 871 million GDP losses on average in 2050, followed by Italy and France). This is due to the higher value and “density” of agriculture and capital assets at risk” (Flörke et al., p. 92, 2011).

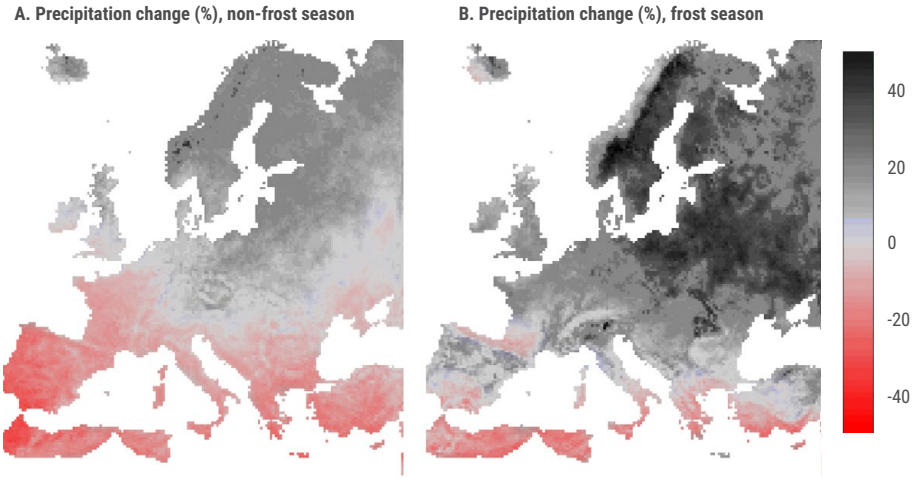


Figure 10 Change in average precipitation using climate projections for the 2050s (Flörke et al., 2011)

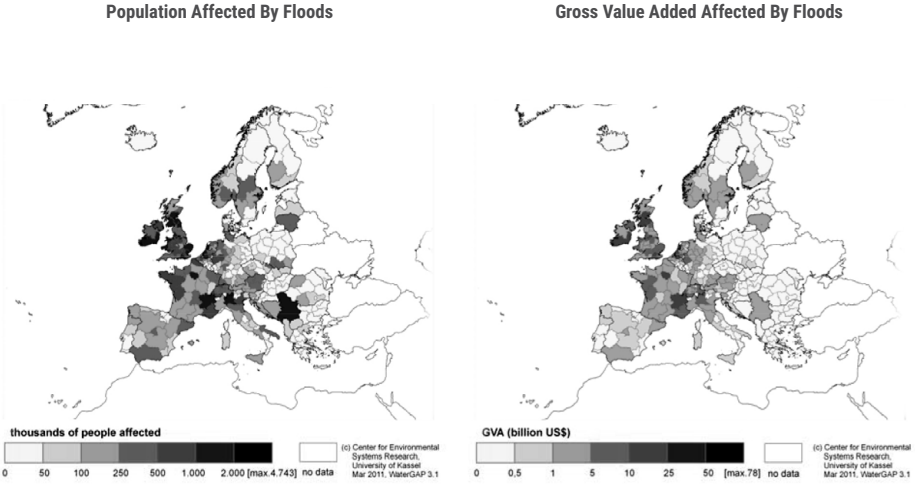


Figure 11 (a) Number of people affected by 100-year flood events in the EcF scenario for the 2050s. In (b) the amount of manufacturing gross value added (GVA) affected by the 100-year flood events (Flörke et al., 2011)

Risks to Critical Infrastructure & Interdependencies

As cities are rapidly urbanizing around the world, many altered states of extremes are becoming more pronounced. Flooding is the most significant climate change risk to UK infrastructure and affects all sectors. There is the potential for lengthy disruption and high costs of repair. In addition, with the rise of impervious areas, civil infrastructure and roadways are particularly becoming more vulnerable to flooding (Kim et al., 2017). Sudden events can cripple infrastructure which assists in operation and functionality of transit, electricity, water and other crucial services. Not only does this exacerbate vulnerabilities but certain groups such as those with low socioeconomic status would be disproportionately affected. In addition, current policies lack the foresight in integrating interdependencies and being prepared for cascading risks. Long-term climate trends will continue to disrupt and reduce the capacity and efficiency of some infrastructure (Dawson et al., 2018). In addition, due to the unpredictability and uncertainty of future weather events, there is a suggestion that even large and redundant infrastructure may be vulnerable to future rainfall events or storm surges (Kim et al., 2017).

Currently, discussions have revolved around fail-safe design strategies such as strengthening infrastructure against more intense environmental conditions. But there has been less of an emphasis or fewer studies developing 'safe-to-fail' strategies within the realm of adaptation and resilience in urban areas. This includes strategies that allow "infrastructure to fail in its ability to carry out its primary function but control the consequences of the failure" (Kim et al., p. 398, 2017).

There is a growing concern that many large-scale redevelopments in London are in flood risk areas. However, this poses an opportunity to "reduce the risk by ensuring that the new developments have a far better layout and design that recognises the current and future flood risk" (The Environment Food and Rural Affairs Commitee, p. 9, 2006). London is an important case study, because it is one of the most interconnected cities in the world, with a concentration of businesses that are highly dependent on stable supplies of electricity. An example of how interconnected the systems are can be evaluated through an instance of electricity grid failure in the city. In 2003, a power failure of 40 minutes affected more than one million people which in turn overburdened the emergency services (Korkali, Veneman, Tivnan, Bagrow, & Hines, 2017).

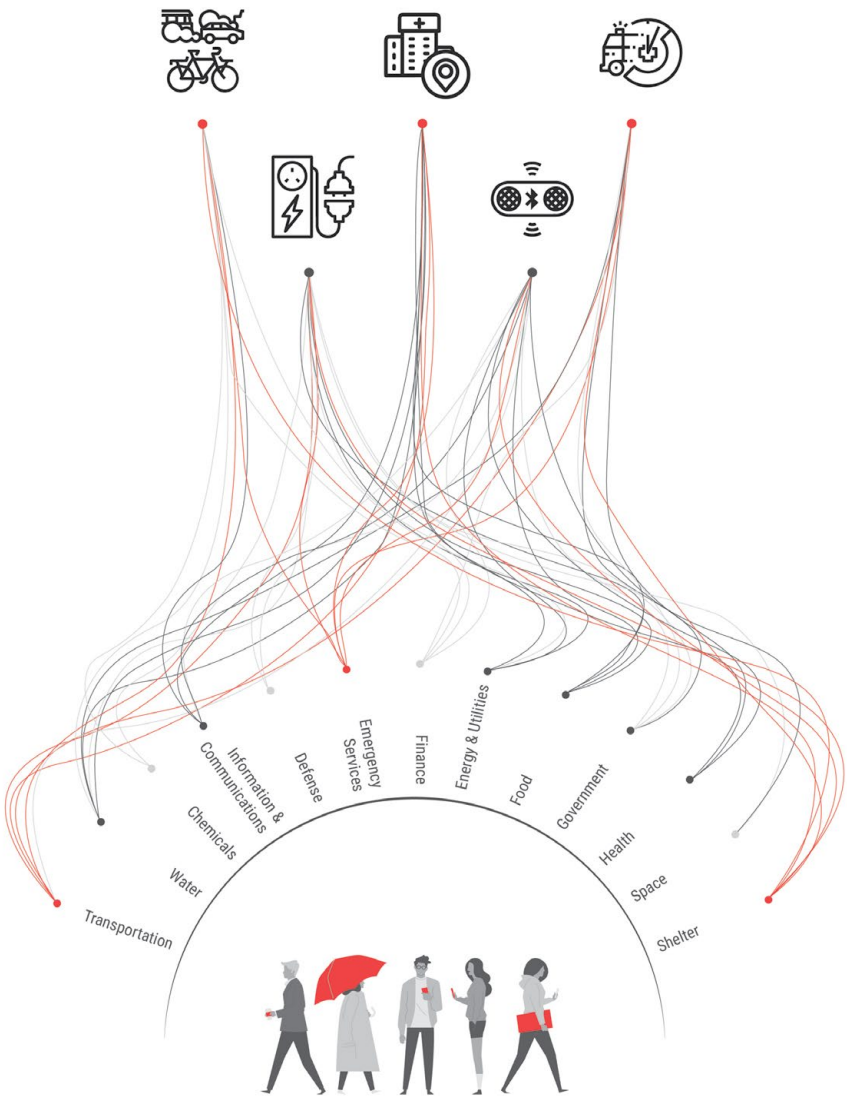


Figure 12 Diagram representing the interdependencies within critical infrastructure systems (drawing made by author)

Figure 13 Map of UK - areas with highest density of critical infrastructure at risk to floods. The Flood Risk Areas show areas where the risk to flooding has the greatest impact on residential buildings and critical infrastructure i.e. the largest cities where there are the most residential properties and infrastructure in relation to the risk of flooding (Adapted from Environment Agency, 2017).

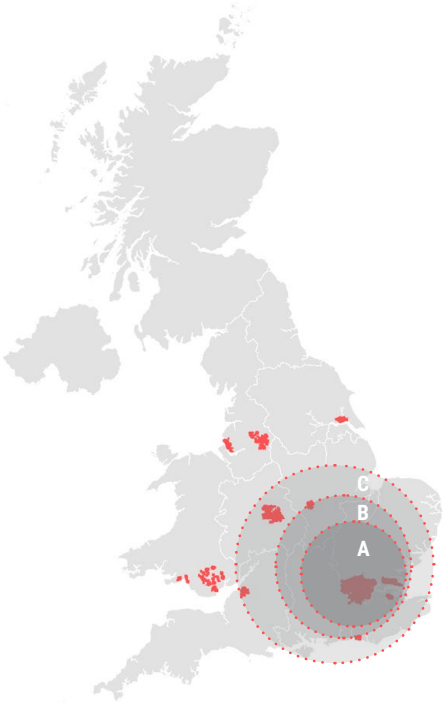
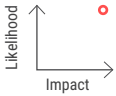
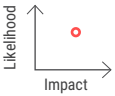


Figure 14 Map of UK with flood risk matrix; areas with likelihood of surface water flooding and potential impacts (Adapted from Environment Agency, 2017)



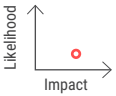
A

In Area A, there is a high likelihood of severe impacts from surface water flooding in Greater London. Impacts can include: flooding of whole communities, loss of life, widespread disruption to infrastructure and large scale evacuations.



B

In Area B, there is a medium likelihood of severe impacts from surface water flooding in Greater London. Impacts can include: flooding of multiple properties, possible endangerment to life and some disruption to infrastructure.



C

In Area C, there is a very low likelihood of significant surface water flooding. Impacts can include: some disruption to infrastructure.

More adaptation action needed over next 5 years above those already planned

- Risks to infrastructure services from river, surface water and groundwater flooding
- Risks to public water supplies from drought and low river flows
- Risks to infrastructure services from coastal flooding and erosion
- Risks of sewer flooding due to heavy rainfall
- Risks to transportation networks from embankment failure
- Risks of cascading failures from interdependent infrastructure networks

Sustaining current adaptation action to manage risks

- Risks to transport, ICT and energy infrastructure from extreme heat
- Opportunities for water, transport, digital and energy infrastructure from reduced frequency of extreme cold events

Research needed to enable assessment of the need of action

- Risks to bridges and pipes from high river flows and bank erosion
- Risks to infrastructure services from coastal flooding and erosion
- Risks to energy, transport and ICT infrastructure from high winds and lightning
- Risks to offshore infrastructure from storms and high waves

Maintain a watching brief of monitoring and review of need

- Risks to hydroelectric generation from low to high river flows
- Opportunities for water, transport, digital and energy infrastructure from reduced frequency of extreme cold events
- Risks to electricity generation from drought and low river flows
- Risks to offshore infrastructure from storms and high waves

Figure 15 Chart summarizing adaptation urgency for climate change risks to UK Infrastructure (Source: royalsocietypublishing.org)

Ports

Inventory: UK has 52 major ports – 40 million passenger journeys per year.

Disruptions can have substantial consequences for local businesses and cargo.

Example: After a few days of flooding in 2013, Immingham which specializes in petrochemical and biomass fuel remained inoperable for several days.

Projections: SLR exceeding 0.5m by 2080. The IPCC (2013) reports it is likely to occur with a 1-in-5 chance.

Energy

Inventory: UK has 19 nuclear plants, 12 oil and gas terminals and 6 oil refineries situated on the coasts.

Long Disruptions as electricity stations are generally less protected than power stations. Estimations of 86 major sub-stations have 1-in-75 annual chance of flooding.

Projections: 12/19 of nuclear plants would be risk of flooding by 2080*. Plants are required to be defended up to a 1 in 10,000 year event but there is a deep uncertainty of rare events.

Transportation

Inventory: Over 300km of roads and 150km of rail is at flood risk.

Disruptions : If coastal defences fail, over 15 per cent of UK major road network is at risk
Examples: In 2014, the seawall at Dawlish which costs £2.1m/year to maintain severed main rail connection to south-west England for two months and direct costs were £50m (Dawson, D. et al. 2016)

Projections: Systemic adaptation not evident in railway network. Severe backlog in sustained investment over 40-50 years. Amount of investment for the future has not accounted for projected changes in climate and not sufficiently embedded climate resilience into design. Length of roads at significant risk to increase up to 63%. Whereas length of railway networks with annual chance of flooding is to crease by 26-39% across SLR and population scenarios.

Water, Waste and Care Facilities

Inventory & Disruptions:
130 Water and Wastewater treatment sites
40 landfill sites
30 hospitals
140 emergency services
370 GP surgeries
380 Care homes
440 schools

Sea Defences

Inventory: Includes hard and soft shoreline structures (engineered and natural) and tidal barriers (flood or storm surge) encompasses 4,500km of defences.

Disruptions 110km of defences are vulnerable to failure. Thames closed 50 times in 2013/14, past maximum recommended number (Environment Agency, 2016)

Projections: Length of defences as highly vulnerable and failure would increase by around 70% 0.5m SLR. In the extreme scenario, it would rise to 490%

Figure 16 More in-depth analysis of sea-level rise impacts on critical infrastructure and systems in the UK (Edwards, 2017)

Figure 17 Diagrams of how the surge enters the Thames estuary, Source: Drawn by author, adapted from the Environment Agency 2100 Plan

Flood Risk for the Thames Estuary and Growing Deep Uncertainties

Transitioning from the problem field of the largest territorial scale - the North Sea and the UK, as highlighted in Figure 14, the Thames Estuary contains the most prominent area of flood risk and damage to critical infrastructure. Flood risk in the Thames Estuary occurs from a variety of sources from high surges in the North Sea to fluvial flooding on the Thames (Gouldby, Sayers, & Tarrant, 2008). However, due to location of the Thames estuary being the meeting place of the freshwater River Thames along with tributaries within the North Sea, the highest potential risk comes from tidal surges. It is notable that twice a day, the freshwater in the Thames flows across west of London and is met by an incoming tide of the North Sea. Based on statistics and the TE2100 report, the Thames has an average daily rise and fall of water levels of 7m. In addition to the increasing risk from the tides, the Thames is prone to storm surges and an increase in water levels due to the North Sea. Storm surges and tides occur when a "band of low pressure or depression moves across the Atlantic towards the British Isles, the sea under it rises above the normal level creating a hump of water" (Ranger, Reeder, & Lowe, 2013). From here, the 'hump' passes through the north of Scotland and south of the North Sea and funnels at the Thames estuary.

In addition, strong northerly winds and currents can increase the height of the surge and this can increase up to 3m. This is especially concerning during the spring tide season when normal tide levels are significantly higher. The Thames tidal floodplain has been identified as the corridor that passes through London and eastwards through North Kent and South Essex, which is identified in the adjacent page. The flood risk presented does not only include vulnerable populations but also vital services, transportation links and emergency services. In the upcoming chapters, issues regarding critical systems and services located along the floodplain which are situated in the high urbanized and dense areas of London will be elaborated upon. As previously mentioned, estimations of the future changes in precipitation and extreme weather events are still highly uncertain. The limited data on these projections also provide limited support to future infrastructure design. Deep Uncertainty poses a difficult problem for decision makers as it is the position in which analysts do not know or the parties to a decision cannot agree upon (Walker, p.3, 2014):

1. The appropriate models to describe interactions among a system's variables
2. The probability distributions to represent uncertainty about key parameters in the models
3. How to value the desirability of alternative outcomes

By having limited or inadequate information, it is another factor to consider on top of risk mitigation and vulnerability assessments.

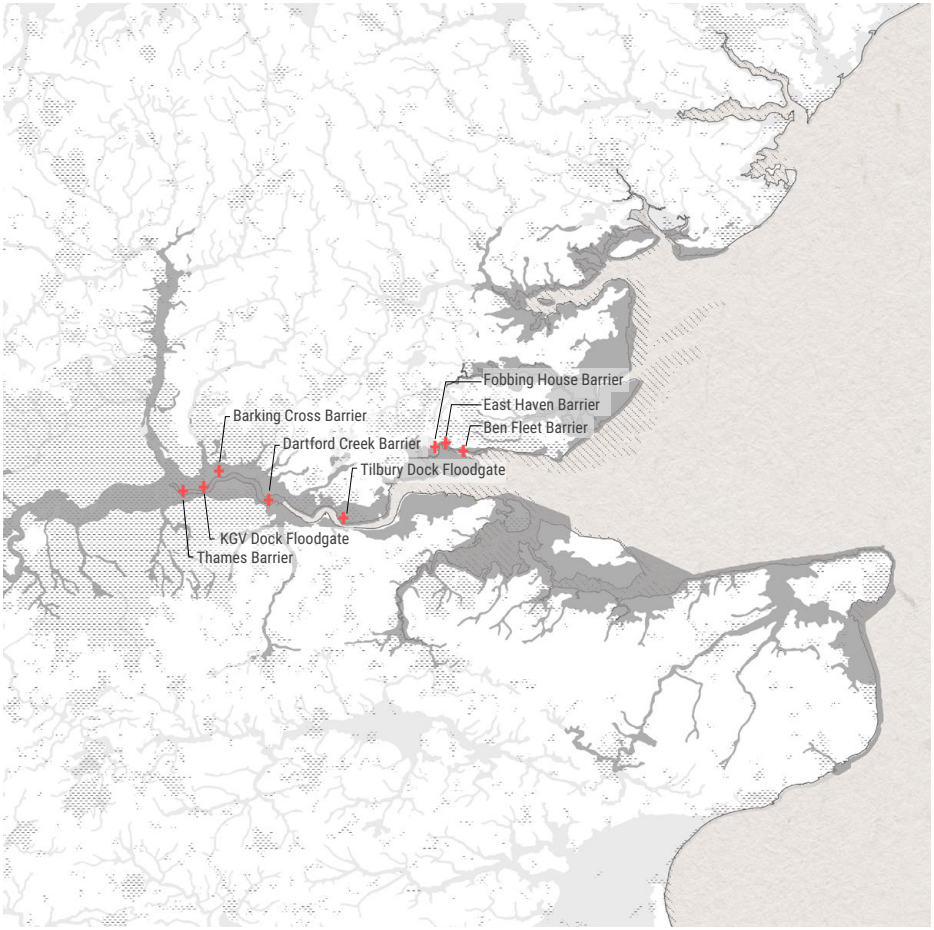


Figure 18 Flood risk and defences along the Thames Estuary

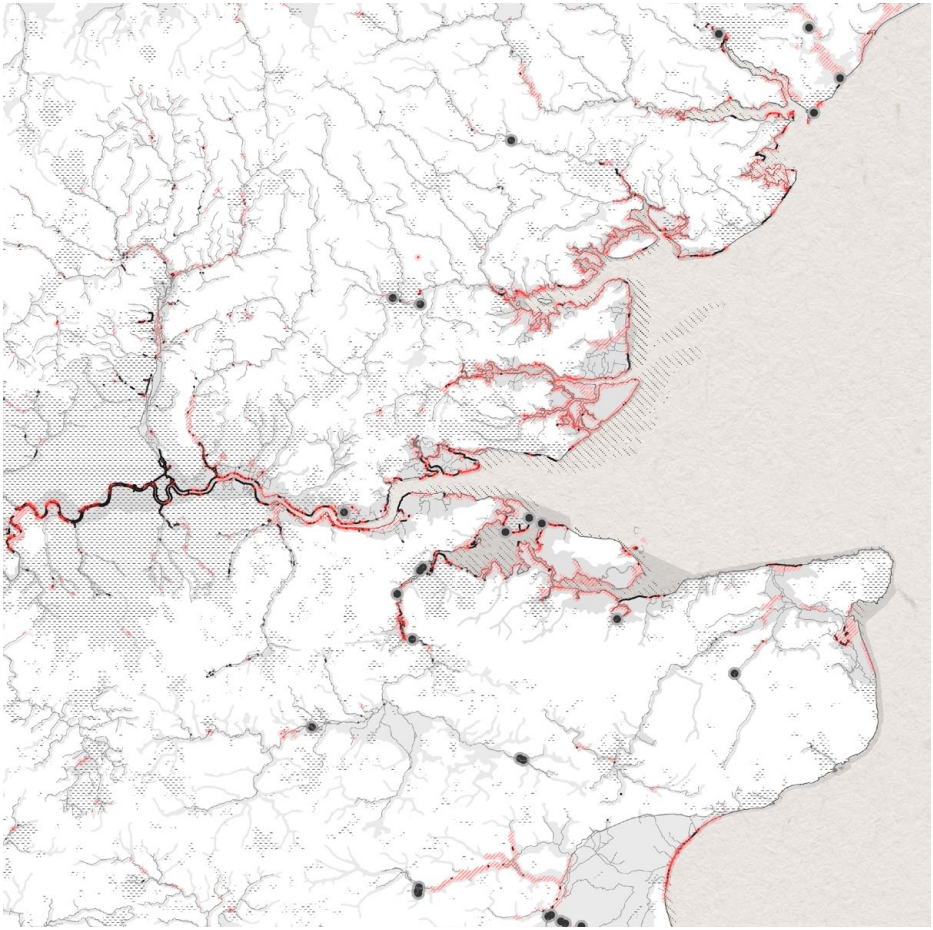


Figure 19 Classification of flood defences along the Thames Estuary

Environmental Degradation & Flood Risk Protection Conflicts

It is estimated by the year 2100, around 1,200 ha of internationally designated habitats will be lost as a outcome of tidal flooding in the Thames Estuary. This is a result from a coastal squeeze where sea levels rise but habitats are prevented from migrating inland due to the presence of flood defences and existing development. The Thames Estuary 2100 (TE2100), the Environment Agency's action plan for responding to mitigating flood risk, proposes to replace over 876 ha of inter-tidal habitat lost by sea level rise. Estuarine mudflats and salt marshes that provide the feeding and breeding ground for commercial fish and shellfish will be lost. There are also plans to undertake localised environmental enrichments in specific locations to enhance wetland areas as well as greater public access to the natural and estuarine environments.

Figure 20 The Thames Barrier (photo by Author)

Aging flood defences

Many of the current defences were constructed over 30 years ago and are reaching the end of their life. They will all need replacement or enhancement between 2030 to 2060. The Thames Estuary is and will remain susceptible to tidal flood. The current flood management system includes over 330 km of walls and embankments, alongside the Thames Barrier and eight smaller barriers.

2.2 Problem Statement

There are prevailing issues regarding major altered states of extreme weather events. For instance; storm surges, sea-level rise, and droughts have all resulted in many regions left with critical systems and interdependencies exposed. The impact and risk of modern disasters have caused substantial adverse socio-economic bearings. In particular, the damage and disruption inflicted on infrastructure services that modern societies have become heavily reliant upon. Further disruptions from winter storms between the years 2013-2016 have established long-lasting disruptions and have had impacts of complete losses of essential services such as water, energy supplies, and transportation and community networks.

The frequency of these extremities is considered to be the new norm (Dawson et al., 2018). With that in mind, critical infrastructures play a crucial role in supporting society, and if major systems were to fail by a sudden shock, the resultant devastation would cause a ripple effect. A single failure in the system can easily cascade across a network of critical infrastructure that would render otherwise unaffected sectors inoperable. Presently, there are a myriad of issues in the UK governmental system, as there is little action being done to ensure service continuity and security of supply. Nor is there an agency that has an overall responsibility for defence against system failure.
Recently, the UK government announced a six-year capital program from 2015-2021, to provide greater certainty and efficient planning in response to water defense infrastructure. However, the current model has no clear long-term objective for the level of flood resilience that the government is seeking to achieve. Although it will be impossible to prevent all types of flooding, the current planning system is too piecemeal, reactive and have been disjointed. Current levels of adaptation are also projected to be insufficient to avoid flooding and coastal erosion risk. In addition, there is an estimation that with 4°C of warming and population growth, a significant number of households will encounter the effects of flooding. It is predicted that 860,000 to 1.9 million homes by 2050 could be affected. We need to ensure that our systems are able to cope with future shocks and threats especially in light of increasing interdependencies of infrastructure systems.

As a response, there is an urgency to develop a spatial risk assessment framework along with dynamic adaptive pathway strategies that would assist decision-makers to identify potential vulnerabilities and to prioritise systems that require attention. The core of the project should implement future long-term plans while accounting for uncertainties and to provide emergency capacities to endure disruptive changes. The reliability of infrastructural components and combinations should be able to operate no matter the hazard so that basic services such as shelter, water, evacuation and electricity are maintained. This would enable incremental planning strategies that would be flexible and adaptable which would then translate into long-term resilient planning for regional growth and risk.

What is at Risk?

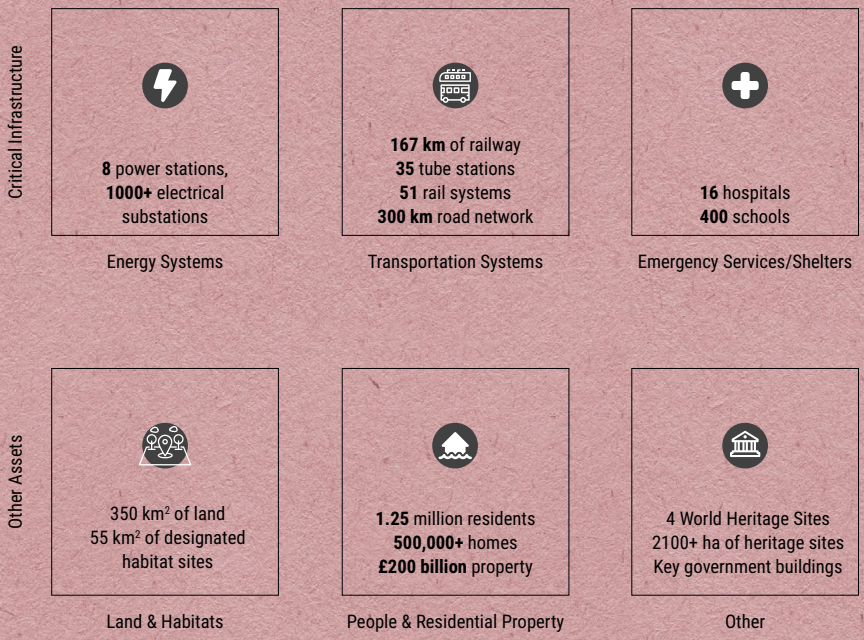


Figure 21 Critical infrastructure, Assets and people at risk in the tidal Thames floodplain Source: Environment Agency, 2009, TE2100 plan: consultation document

2.3 Research Question

How to develop dynamic and adaptable strategies for vulnerable critical systems to address deep uncertainty and flood risk for the Thames Estuary Region?

Sub-Research Questions:
The following are a series of sub-research questions that are listed to compliment and help examine the main research question. In addition, they offer supplementary guidance in the construction of the provided frameworks.

Conceptual & Theoretical Framework S.Qs

- What is critical infrastructure and what are the interdependencies in critical urban infrastructure systems?
- What is the risk cycle and how does each factor influence one another? And how does flood risk impact critical infrastructure systems?
- How does risk compound and cascade across critical infrastructure systems?
- How are social and physical vulnerabilities distinguished?
- What is the role of spatial planning on mitigating flood risks from hazards and designing for uncertainties? What is currently being done in the UK?
- How can dynamic adaptive pathways assist in developing incremental strategies in light of deep uncertainty?

Analytical & Spatial Framework S.Qs

- How will a trans-scalar approach assist in understanding deep uncertainty and flood risk in the Thames Estuary?
- What are future urban expansions, climate trends and predictions that would exacerbate hazards and risks?
- What are the current adaptation and spatial strategies to combat flood risk and deep uncertainty in the Thames Estuary? And do the strategies integrate both social and physical vulnerabilities?

Strategic & Design Framework S.Qs

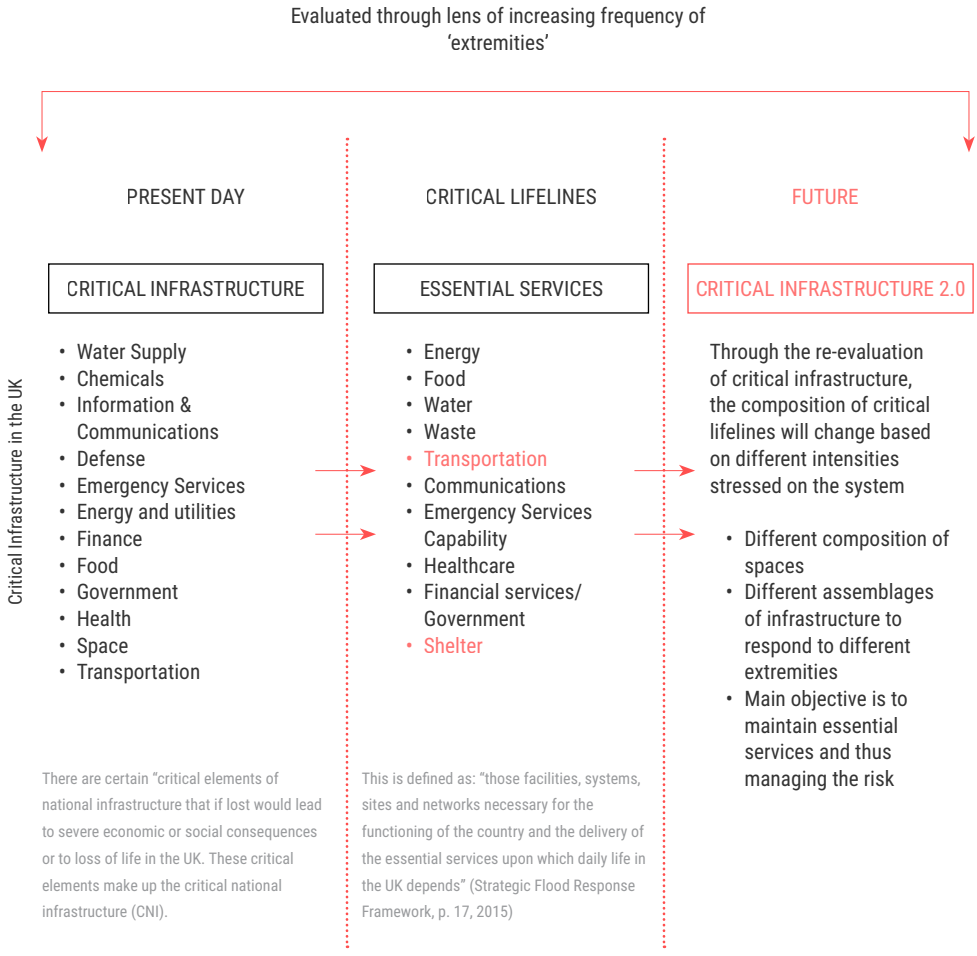
- How can the arrangement/hybridity of certain assemblages or combinations of critical systems be used to deal with different extremities of flood risk?
- How to improve the reliability of infrastructure components so they are able to operate under flood risk?
- Can the functionality of critical infrastructure operate differently depending on the intensity of the event? And if so, how to ensure service continuity and supply for the region?
- How to provide emergency relief and response under deep uncertainty?

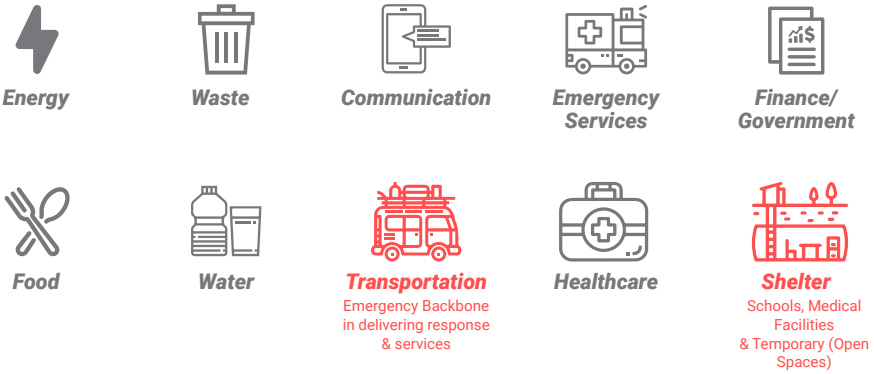
Research Aims

A large portion of the studio focused on examining uncertainties in the future and the impact of extreme unforeseen conditions from flood risk. As previously stated, direct climate-change related risks to the UK have increased in frequency and have severely impacted natural ecosystems and infrastructure. This has also increased risks in relation to critical infrastructure and systems. Thus, the integration of flood risk management alongside spatial planning to transform urbanized landscapes are of utmost importance.

The following are research aims of the thesis:

1. To develop a methodology and framework to understand how to assess and develop resilient critical infrastructure and services.
2. To advance an understanding of the risk cycle and to create strategies that would translate risk management into space while improving safety and living standards.
3. To develop a set of propositions based on research-by-design with insight on upscaling or replicability of the project.
4. To critique the 'gaps' in current practices related to flood risk management and designing and planning for uncertainties for urbanized landscapes.


Evaluated through lens of increasing frequency of 'extremities'
PRESENT DAY
CRITICAL LIFELINES
FUTURE
CRITICAL INFRASTRUCTURE
ESSENTIAL SERVICES
CRITICAL INFRASTRUCTURE 2.0
Critical Infrastructure in the UK
• Water Supply
• Chemicals
• Information & Communications
• Defense
• Emergency Services
• Energy and utilities
• Finance
• Food
• Government
• Health
• Space
• Transportation
• Energy
• Food
• Water
• Waste
• Transportation
• Communications
• Emergency Services Capability
• Healthcare
• Financial services/ Government
• Shelter
Through the re-evaluation of critical infrastructure, the composition of critical lifelines will change based on different intensities stressed on the system
• Different composition of spaces
• Different assemblages of infrastructure to respond to different extremities
• Main objective is to maintain essential services and thus managing the risk
There are certain "critical elements of national infrastructure that if lost would lead to severe economic or social consequences or to loss of life in the UK. These critical elements make up the critical national infrastructure (CNI).
This is defined as: "those facilities, systems, sites and networks necessary for the functioning of the country and the delivery of the essential services upon which daily life in the UK depends" (Strategic Flood Response Framework, p. 17, 2015)

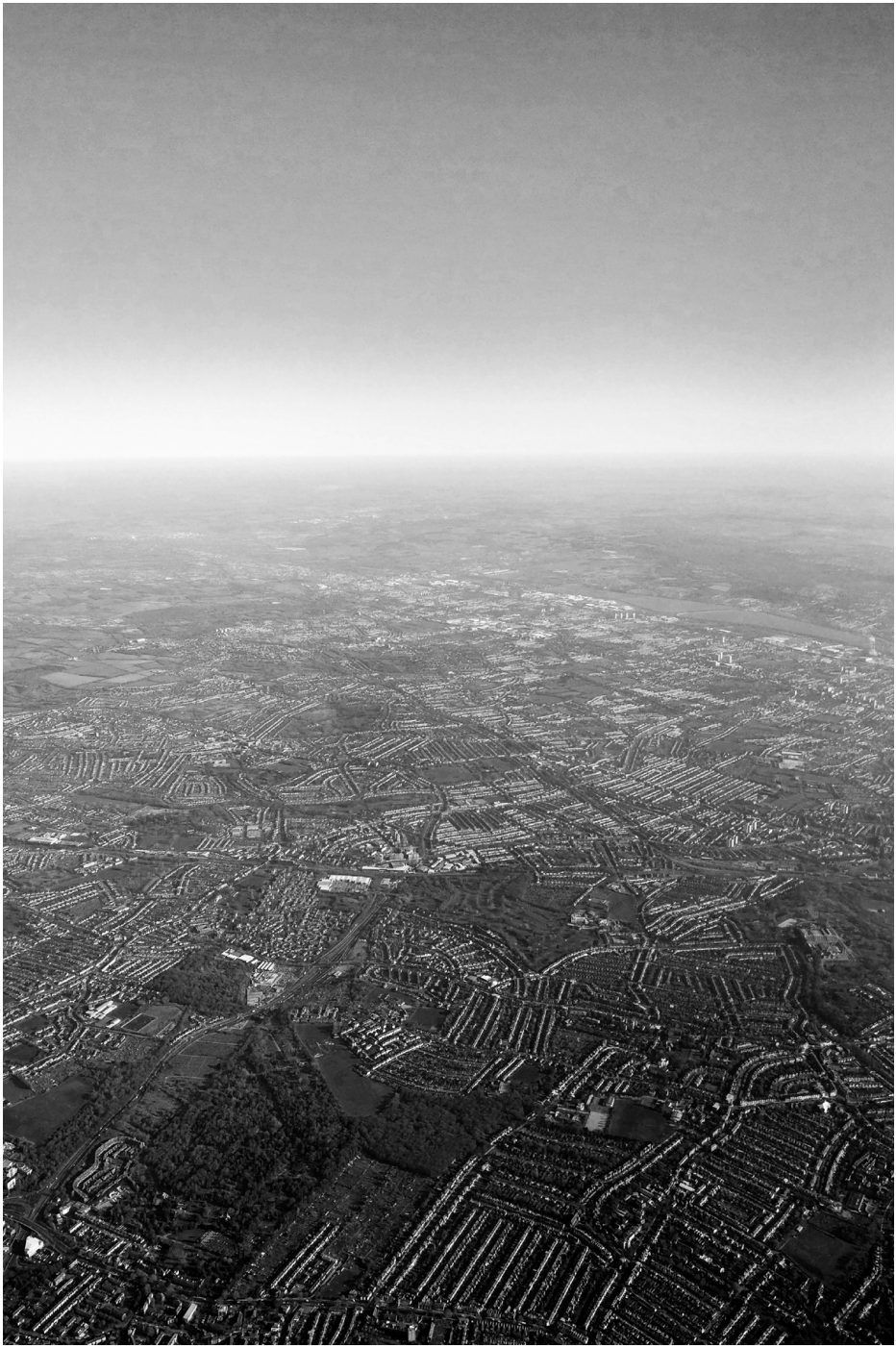


2.4 Hypothesis

The intensification of urban and economic land use has been proportionate to the disappearance of delta's ability to resist natural hazards and increasing effects of climate change. To ensure a sustainable future for urbanized coastal areas, new integrative frameworks need to be implemented to decrease risk and improve living conditions. Several mechanisms and strategies need to be put at the forefront to have successful prevention and mitigation measures to reduce hazards.

Through the evaluaton of critical infrastructure systems based on the increasing frequency of extremities, the composition of critical lifelines will change based on different intensities stressed on the system. Below are a series of key factors that should be considered and integrated into the project:

1. Improve the reliability of infrastructure components so they are able to operate under a range of possible conditions.
2. Provide redundancy to increase the capacity, number of alternative connections and diversity of backup systems.
3. Build capacity in organizations and communities to deliver a fast and effective response to, and recovery from, climate disruption.



Aerial photograph of neighbourhoods north of the Thames River, Photo by Author

METHODOLOGY

Research Framework

Methodology

Road map

Summary of:

- Theoretical Framework
- Conceptual Framework
- Analytical & Spatial Framework
- Strategic and Design Framework
- Evaluation & Assessment Framework

Research Methods & Processes

3.1 Research Framework

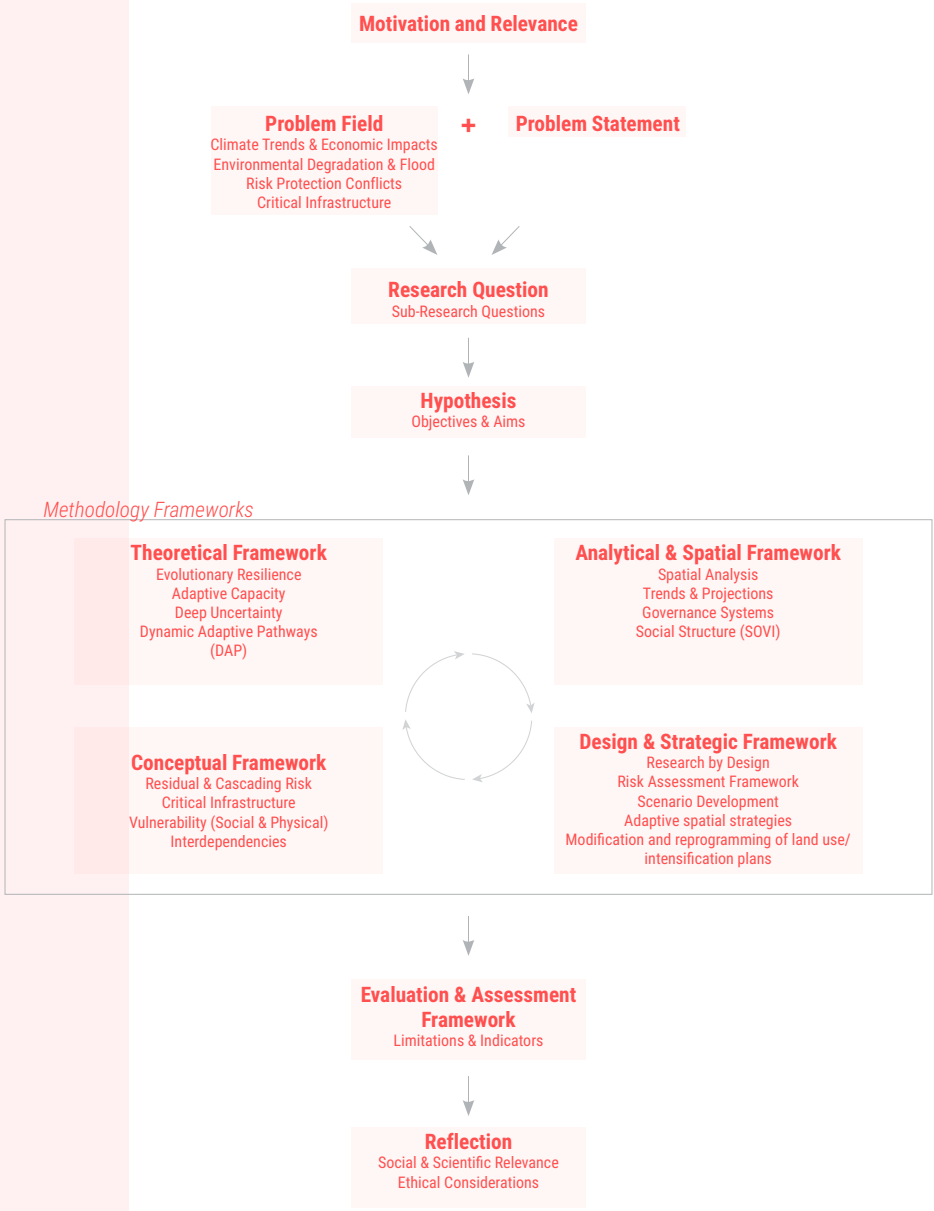


Figure 22 Research Framework

3.2 Methodology

The research framework (figure 22), offers a general overview of the process of the thesis. Within the overall research framework, a defined set of frameworks which were created as a backbone for the research. The following frameworks that will assist in guiding the thesis are:

- Theoretical Framework
- Conceptual Framework
- Spatial & Analytical Framework
- Strategic & Design Framework
- Evaluation & Assessment Framework

The designated frameworks and body of theories will then inform the strategies, design and the final evaluation stage. The narrative of each framework will be further elaborated in this chapter and section 4.0. The chapter also further elaborates the initial approaches, methods, techniques and analysis necessary to explore the research questions.

Road map
The road map (figure 23), showcases a more detailed strategic plan of the thesis. All the major steps, methods and 'milestones' are defined within the diagram. In addition, it serves as a guiding document to communicate both the plan and goal of the thesis.

Theoretical Framework Summary
The theoretical framework describes a set of definitions of theories and models to give direction to the research. In addition, it lays a foundation for the body of knowledge required to build upon throughout different stages of the project. This also offers a more grounded perspective tied to scientific theory and of existing practices. In order to have a deeper understanding of the initial discourse proposed in the problem statement, a literature review was conducted to explore in detail the following notions:

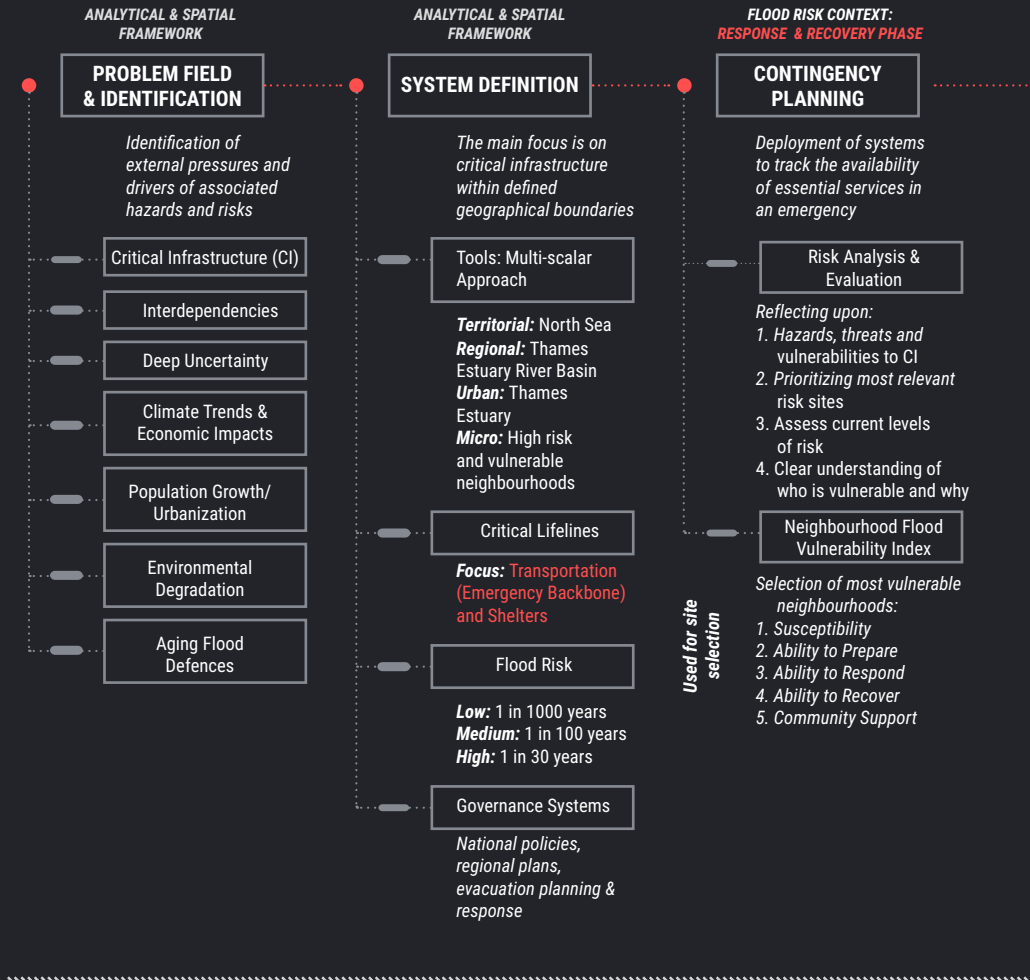
- Deep Uncertainty
- Evolutionary Resilience
- Dynamic Adaptive Systems
- Risk Cycle
- Adaptive Capacity

The literature review seeks to explore the notions of critical infrastructure and vulnerable systems and how they are embedded in the key theories stated above. A more detailed elaboration of the theories and their relationships are found in the next chapter.

Conceptual Framework Summary
The conceptual framework is defined as a, "network of interlinked concepts that provide a comprehensive understanding of a phenomenon or phenomena" (Jabareen, p. 51, 2009). By articulating the concepts in the framework, they possess ontological, epistemological and methodological assumptions that play a key role. Each concept plays an integral role and as per defined by Jabereen, the conceptual framework should lay out the "key factors, constructs or variables and presumes relationships among them" (Jabareen, p. 51, 2009). The conceptual framework will be utilized as a platform that helps guide and develop a general understanding of the key concepts throughout the report. The framework also offers a starting point for the initial quantitative analysis of the different scales to offer a broader scope of how areas are at risk. Below are the key concepts that will be further explored:

- Residual & Cascading Risk
- Critical Infrastructure
- Vulnerability (Social & Physical)
- Interdependencies

3.3 ROAD MAP



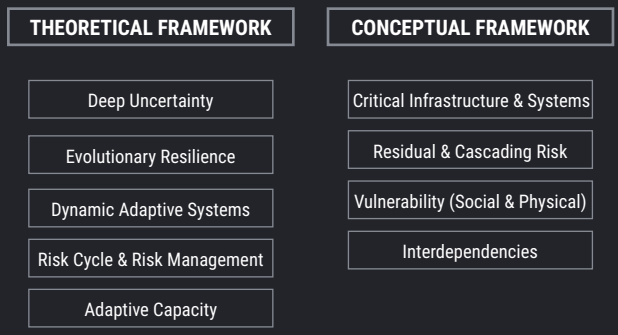
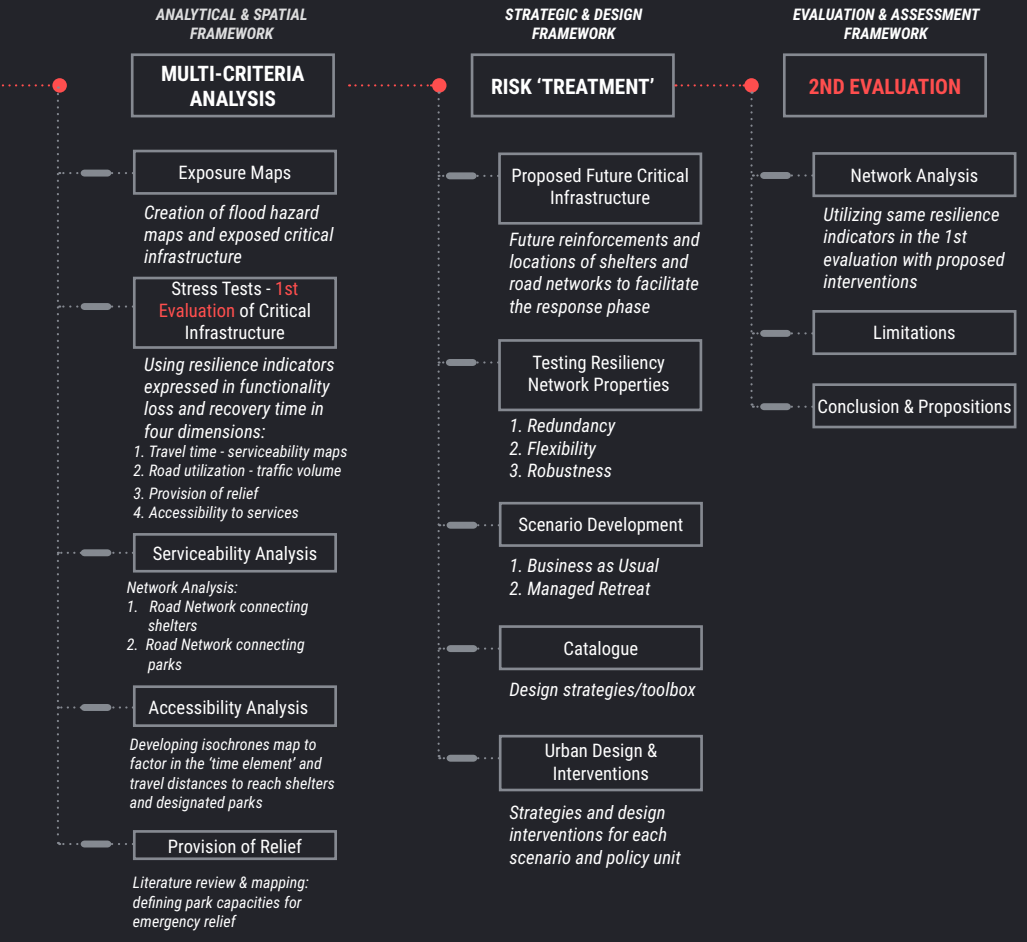


Figure 23 Thesis road map


ANALYTICAL & SPATIAL FRAMEWORK
MULTI-CRITERIA ANALYSIS
Exposure Maps
Creation of flood hazard maps and exposed critical infrastructure
Stress Tests - 1st Evaluation of Critical Infrastructure
Using resilience indicators expressed in functionality loss and recovery time in four dimensions:
1. Travel time - serviceability maps
2. Road utilization - traffic volume
3. Provision of relief
4. Accessibility to services
Serviceability Analysis
Network Analysis:
1. Road Network connecting shelters
2. Road Network connecting parks
Accessibility Analysis
Developing isochrones map to factor in the 'time element' and travel distances to reach shelters and designated parks
Provision of Relief
Literature review & mapping: defining park capacities for emergency relief
STRATEGIC & DESIGN FRAMEWORK
RISK 'TREATMENT'
Proposed Future Critical Infrastructure
Future reinforcements and locations of shelters and road networks to facilitate the response phase
Testing Resiliency Network Properties
1. Redundancy
2. Flexibility
3. Robustness
Scenario Development
1. Business as Usual
2. Managed Retreat
Catalogue
Design strategies/toolbox
Urban Design & Interventions
Strategies and design interventions for each scenario and policy unit
EVALUATION & ASSESSMENT FRAMEWORK
2ND EVALUATION
Network Analysis
Utilizing same resilience indicators in the 1st evaluation with proposed interventions
Limitations
Conclusion & Propositions

Analytical & Spatial Framework

Territorial/North Sea

- Thematic studies on: future projections on SLR, temperature increases, precipitation and urbanization trends
- Impacted critical infrastructure and economic risks

Regional Scale - Thames Estuary River Basin

- Flood risk levels
- Identification of critical infrastructure
- Policy and frameworks related to flood risk management
- Social vulnerabilities
- Lack of standardized flood resilience

Urban Scale - London

- Network Analysis: accessibility and serviceability
- Investigation and implementation of TE2100
- Lack of defined spatial emergency routes and shelters
- Lack of foresight on maintaining essential services

Neighbourhood: Isle of Dogs, Wandsworth, Royal Docks

- Investigation on disconnected roads, lack of defined shelters, and public spaces
- Investigation on planned urban and economic growth
- Defining land-use and building ages
- Investigation and implementation of TE2100

Figure 24 Division of scales (note levels of analysis may overlap or be more detailed at smaller scales)

The analytical and spatial framework forms the quantitative and qualitative analysis in order to answer the theoretical research question and sub-questions. This framework also draws upon notions defined in the theoretical and conceptual framework. In addition, the following section will elaborate on the detailed steps taken in the road map.

Hierarchies and Limitations of Utilizing Different Scales

Each scale has a different set of objectives as they offer varying levels of analysis (political, economic and social realms) and clarity within each geographical boundary. In each scale, the spatial location of critical infrastructure should be identified along with the exposure to different flood risk intensities. At the territorial scale, the main objective was to identify areas that had the highest density of critical infrastructure. Other valuable information gained at this scale would inform areas that had the highest impacts to emerging risks, hazards and vulnerabilities. This would also assist in transitioning to smaller scales and determining neighbourhoods within the Thames Estuary that are exposed to highest forms of flood risk in relation to critical infrastructure.

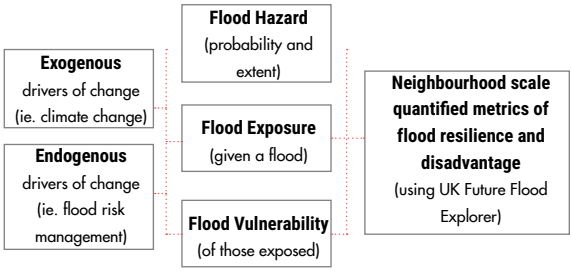


Figure 25 Analyzing climate disadvantage (Diagram by author, interpreted (Sayers, P.B., Horritt, M., Penning Rowsell, E., and Fieth, 2017)

In figure 24, a set of defined limitations, level of detail and set of initial conclusions have be made in each scale. The intent of working with different scales would be identifying priority areas that had the highest amount of vulnerable critical infrastructure at risk to floods.

Spatial Layered Analysis Approach
One of the main objectives of working at multiple scales was to understand and visualize the variations of vulnerabilities within different geographic boundaries. This was determined by using a spatial layered analysis approach which pinpointed vulnerabilities in the system relative to critical infrastructure and vulnerable populations. By overlaying critical infrastructure systems exposed to different flood intensities, this will assist in identifying key locations that will be prioritized for the spatial and design framework.

Overview of Analysis:
Within the framework, majority of the components listed in the adjacent column were mapped spatially and were further investigated through literature. A deeper understanding of critical infrastructure systems, deep uncertainty, patterns of flood risks and vulnerabilities through a literature review is required to help inform additional spatial analysis necessary. The four primary aspects taken into consideration are broken down into the following categories:

- ***General context spatial analysis related to flood risk and critical infrastructure***
  - Flood risk boundaries and intensities: low, medium and high
  - Spatial inventory of critical lifelines
  - Climate trends and projections
  - Environmental restrictions and hazards
  - Historical flood map and causes for flooding
  - Flood alert areas
  - Existing flood defences
  - Population density relative to flood risk

- ***Multi-criteria analysis***
  - Flood hazard mapping and exposure maps for all critical infrastructure networks
  - Network analysis: serviceability and destination accessibility maps
  - Emergency relief capacities

- ***Governance systems***
  - Flood related plans in the UK
  - Regional plans related to evacuation planning and response
  - Overview of existing governance related to flood mitigation and corresponding responsibilities
  - TE2100 Plan

- ***Social systems and structures***
  - Neighbourhood flood vulnerability index
  - Deprivation Index

Based on the road map, the main spatial analysis began with creating a spatial inventory of all external pressures and drivers associated with risks within the North Sea. This also accounts for trends and projections that will impact the Thames Estuary region. The primary tool and method used in the spatial analysis was mapping through geographic information systems (GIS) in order to gather, manage and analyze data. Mapping allows for a greater understanding of the terrain under a complex and dynamic set of social and natural processes. GIS as a geographic and spatial platform integrates many types of data and analyzes it based on spatial location and organizes layers of information into visualizations using maps and 3D infrastructure.

This was accounted for in several categories of using GIS as a platform for:

- Mapping all the 'lines/systems': transportation systems (road networks, rail networks, tunnels), energy, water, communication lines
- Mapping 'points': transportation (airport, ports, stations), energy (substations and towers), water treatment facilities, shelters (education facilities, leisure, sports center, places of worship), and emergency services (police, medical services, fire station)
- Mapping 'polygons': boundaries: Thames River Basin District, census wards, open space, flood defenses
- Mapping 'constraints': greenbelt, climate trends and projections, flood risk areas (zone 2 and 3), historic flood zones, flood alert areas, flood defenses, predicted urban growth

Resources/Data Sources

- Flood risk assessments: climate change allowances
- Thames river basin district sea level rise boundaries and local authorities
- Thames Catchment Flood Management Plan
- London Data Store (data.london.gov.uk)
- UK CPNI
- EU Floods Directive
- Climatejust.org.uk
- OS Open Data: Ordnance Survey Mapping
- MAGIC Datastore
- Environment Agency GeoStore

Network Analysis

The selected policy units along the Thames River Corridor were further analyzed using network analysis in ArcGIS. The two tools used within this system were the route analysis tool and drive-time areas. As part of the literature review and focus of the project, the main intent was to focus on improving the resiliency of the existing critical lifeline network (primarily the road network and designated safety shelters). The route analysis tool was used to determine the quickest and best routes that should be maintained during a disaster. The maps would also show a distinction between roads that would be impacted by the different flood zones (marked as the barriers). In order to use the tool, a road network database had to be constructed with only the primary, secondary and tertiary road systems. The destination points used in the program would be marked shelters which were classified as medical facilities and schools. A secondary set of maps would be created to show connections between temporary shelter spaces (open spaces) that would accommodate for larger populations until emergency relief would be provided.

In contrast, the serviceability maps were created from the drive-time areas tool in ArcGIS, the network analysis showcases a series of isochrones with pre-defined time or distance restrictions. This showcases the differences in modalities between pedestrians and automobiles in having service within the vicinity of designated safe shelters.

GOVERNANCE SYSTEMS

Predominantly, this section involves understanding the existing resilience plans for London and the Thames Estuary in response to critical infrastructure systems and flood risk. Reports established by the government at the national (UK) and local (Thames/London) provide an overview of objectives. Objectives and aspects obtained from the reports are:

- How the UK classifies emergent flood risk, hazards and vulnerabilities. In addition, how they are currently being addressed in frameworks and plans.
- To learn and distinguish lifeline services that need to be maintained during extreme events ie. water, power, telecommunications
- To understand the role of spatial planning and disaster risk management regarding uncertainty and floods.
- To understand national coordination policies and how these are delegated to local levels.

London has a predefined set of emergency plans and frameworks. The main objectives of the plans were created after assessing the risk of emergencies in the London area and were developed to either reduce, prevent or control the impact of emergencies ("Planning for emergencies in the capital | London City Hall," 2018). It is important to note that London executes a series of frameworks and plans during an adverse weather event. Only frameworks and emergency plans that were relevant to flood risk or impacting critical infrastructure are highlighted below.

Resources/Data Sources

- IPCC
- Sendai Framework
- 100 Resilient Cities
- World Economic Forum: The Global Risk Report 2018
- Eklipse - Establishing a European Knowledge and Learning Mechanism to Improve the Policy-Science-Society Interface on Biodiversity and Ecosystem Services
- World Bank
- UNISDR (United Nations Office for Disaster Risk Reduction
- Thames River Basin District Flood Risk Management Plan
- ICE Report: Defending Critical Infrastructure (UK)
- Thames Estuary 2050 Growth Commission
- Thames Estuary 2100 Plan
- National Infrastructure Assessment 2018
- Centre for the Protection of National Infrastructure
- National Planning Policy Framework

EXISTING EMERGENCY PLANS

	Purpose
London Strategic Flood Response Framework	Information for local responders to assist in decision making and planning for a flood incident
London Structural Collapse Response and Recovery Framework	Guidance for planning for and responding to large scale structural collapse
London Mass Evacuation Framework	Guidance for managing a mass evacuation of displaced persons
London Mass Shelter Framework	Guidance for sheltering large numbers of people affected by emergencies
London Power Disruption Framework	Guidance for planning for and responding to a large scale power outage

SOCIAL SYSTEMS & STRUCTURES

To have a more realistic picture of the distribution of vulnerabilities in the Thames Estuary, the consideration of social vulnerabilities would offer an alternative perspective. Often at times, research and practice primarily focuses solely on physical vulnerabilities. To have a broader scope and understanding of the context, the social structure section relies on mapping and literature review.

The literature review offers a more informative perspective of different vulnerability indexes that can be used in order to analyze the sites. This will than inform the series of maps and variables that would need to be considered for the analysis. In conjunction with understanding the evacuation and recovery frameworks, it poses the question of how the Thames Estuary area is addressing social vulnerabilities.

The main priority of developing an understanding and a series of maps related to social vulnerabilities is to put an indication in determining priority locations that would require additional services and assistance in the response and evacuation phase of a disaster. This also includes placing priorities to neighbourhoods that would require improved risk awareness, creation of more shelters and additional contingency plans. However, due to the limited scope of the project, this section of the analysis is primarily used to determine neighbourhood project locations.

The chosen indexes used is the Neighbourhood Flood Vulnerability Index (NFVI) and Social Flood Risk Index (SFRI) which correspond to a series of indicator and variables to evaluate the existing system.

The NFVI is structured into five characteristics:
- Susceptibility
- Ability to prepare
- Ability to respond
- Ability to recover
- Community support

Resources/Data Sources

- SOVI Index
- Climate Just (https://www.climatejust.org.uk/resources?type=download&theme=All)
- UK Census Tracts
- Flood disadvantage data and maps (UK)
- Neighbourhood Flood Vulnerability Index (NFVI)
- Social Flood Risk Index (SFRI)

Strategic And Design Framework Summary

The thesis aims to produce an incremental and transformative strategy to deal with flood risk management in the Thames Estuary region through spatial interventions and re-programming of space. The primary focus would be to reconsider the use of a set of networks ie. road systems and position of shelters to respond to the frequency of extreme events. There needs to be a shift in thinking towards developing a standard for critical infrastructure resilience alongside flood resilience. With the use of the strategic and design framework, a method would be created to extract lessons learned from the analytical, spatial and theoretical frameworks in order to formulate the final deliverables which includes:

1. Producing a spatial risk assessment framework that could be used to understand the Thames Estuary Area with a modifiable set of variables. This would result in a product that exhibits a risk gradient in understanding the extent of risk from tidal and surface flooding.
2. Embedding resilient growth in the system by understanding priority development areas with a set of adaptation measures/spatial strategies in response to high flood risk areas and future urban intensifications which would be informed by the risk assessment framework
3. Developing a modified dynamic adaptive policy pathways strategy that would assist decision-makers with dealing with uncertainty

Evaluation & Assessment Framework Summary

In the final evaluation, the same set of multi-criteria analysis indicators will be used to assess the proposed strategies. The set of resilience indicators that will be used in the evaluation are: travel time, time for recovery (duration of support), provision of relief and access to lifesaving services. The same parameters used for the creation of the serviceability and accessibility map will be reconfigured to see if areas that were lacking were improved. The set of spatial strategies will also have a set of quantified land use modifications in the proposed scenarios.
In addition to the evaluation, an assessment framework would include a timeline on the level of importance and a series of metrics of the benefits of each strategy. The matrix will be utilized to become a comprehensive tool that would assist communities/regions to understand the dynamics and holistic performance of the overall system. Overall, the assessment should evaluate and highlight options, constraints, and limitations on the proposed solutions. In the final evaluation, an integrative performance assessment framework will be developed to quantify and evaluate the strategies proposed.

3.4 Research Methods & Processes

The following chart breaks down how the proposed sub-research questions would explored and addressed. In many instances, each question overlaps with multiple frameworks and scales. The chart strives to provide a coherent overview of the methods, tools and rationale used in the project.

Scales: (MI) Micro (ME) Meso (MA) Macro

Frameworks: (CT) Conceptual and Theoretical Framework (SD) Strategic and Design Framework (AS) Analytical and Spatial Framework (EA) Evaluation and Assessment Framework

Sub-Research Questions	Frameworks	Scale	Method
What is critical infrastructure and What is critical infrastructure and what are the interdependencies in critical urban infrastructure systems?	CT AS	MI	Data analysis, literature review,
What is the risk cycle and how does each factor influence one another? How does risk compound and cascade across sectors?	CT AS	All	Literature review
How does risk compound and cascade across critical infrastructure systems?	CT	All	Literature review
How are social and physical vulnerabilities distinguished?	CT AS	ME MA	Literature review
What is the role of spatial planning on mitigating risks from hazards and designing for uncertainties? What is currently done in the UK?	AS	All	Literature review, case studies
How can dynamic adaptive pathways assist in developing incremental strategies in light of deep uncertainty?	CT AS SD	ME	Literature review, case studies
How will a trans-scalar approach assist in understanding deep uncertainty and flood risk in the Thames Estuary?	CT AS SD	All	Data analysis, systems method
What are future urban expansions, climate trends and predictions that would exacerbate hazards and risks?	AS SD	MA	Data analysis, literature review
What are the current adaptation and spatial strategies to combat flood risk and deep uncertainty in the Thames Estuary? And do the strategies integrate both social and physical vulnerabilities?	CT AS	ME	Data analysis, literature review
How can the arrangement/hybridity of certain assemblages or combinations of critical systems be used to deal with different extremities of flood risk?	SD EA	ME MI	Research-by-design
How to improve the reliability of infrastructure components so they are able to operate under flood risk?	SD EA	MI	Research-by-design
Can the functionality of critical infrastructure operate differently depending on the intensity of the event? And if so, how to ensure service continuity and supply for the region?	SD EA	ME MI	Literature review, research-by-design
How to provide emergency relief and response under deep uncertainty?	AS SD EA	ME MI	Literature review, research-by-design

Figure 26 Methods and processes chart with sub-questions

Tools	Product	Rationale & Aims
GIS, online database and reports	Analysis and maps	To understand the location of critical areas, vulnerabilities and hazards.
Reports, journal articles	Series of maps and diagrams	To understand the scope and variables that constitute risk. This is essential to further develop interventions and strategies.
Reports, journal articles	Series of maps and diagrams	To develop a greater theoretical and scientific background of risk. This will also place a priority on critical lifelines systems.
Reports, journal articles, GIS	NFVI maps Deprivation Index maps	Enabling a classification of risk and to determine site locations.
Reports	TE2100 critique, revised DAP	Comprehending challenges associated with deep uncertainty and practical solutions.
Journal articles, references	TE2100 critique, revised DAP	To understand existing practical and theoretical measures dealing with deep uncertainty.
GIS	Series of maps and interventions	To understand and reflect upon the iterative approaches needed to impact the existing system.
GIS, reports	Series of maps and diagrams	To develop and understand future scenarios for the determined project areas.
Journal articles, reports	Analysis and maps	To understand and critique the existing governance schemes. Opportunities and constraints for interventions could be observed.
GIS, network analysis, 3D modelling	Resilience indicators and maps	To develop a series of spatial strategies to deal with different intensities and extremities for CI.
Network analysis, 3D modelling	Resilience indicators and maps	To understand and develop dynamic and flexible interventions.
Network analysis, 3D modelling	Urban design, spatial interventions	To develop a series of spatial strategies to deal with different intensities and extremities for CI.
Network analysis, 3D modelling, journal articles	Revised DAP, spatial interventions	Assist in developing a regional and spatial plan with knowledge (+ DAP)

Elaboration On Research Methods & Tools

Dynamic Adaptive Pathways

As a means to deal with deep uncertainty, dynamic adaptive pathways (DAP) offers a range of adaptive and flexible solutions for future risks. The aim is to develop a system to look at developing a DAP for critical infrastructure systems.

Adaption Pathways are a sequence of promising actions in conjunction with a monitoring system to ensure the plan is on track to meet a pre-defined set of goals and objectives set by the decision-making body (Haasnoot et al., 2013). The action of monitoring decision-relevant principles is also vital "as it establishes a link between risk assessment and action that many adaptation approaches lack" (Kingsborough et al., p.387, 2016). Pathways can be designed, evaluated and consists of a series of polices. The sequencing of these pathways are comprised of a series of possible actions in the form of adaptation trees, which can be seen as a decision tree or road map (Haasnoot et al., 2013) These come into play when a series of policy actions are deemed inadequate. The set of preferred pathways can also be improved through a series of trigger-event actions.

Existing DAP documents that were referred to were:

- TE2100
- Delatares

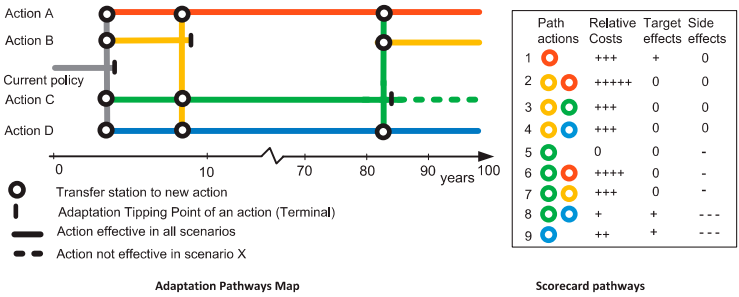


Figure 27 A diagrammatic example of the final Adaptation Pathways Map (Haasnoot et al.,p. 488, 2013)

TIME PLANNING // PROGRESS

The chart defines major deadlines and phases of the thesis. The frameworks defined in the methodology guide the overall timespan necessary for each deliverable.

Photo by Author - City of London & Thames River

THEORETICAL & CONCEPTUAL FRAMEWORKS

Theoretical Framework

- The Risk Cycle & Risk Management
- Evolutionary Resilience
- Adaptive Capacity
- Deep Uncertainty & Dynamic Adaptive Pathways

Conceptual Framework

- Critical Infrastructure & Systems
- Interdependencies
- Residual & Cascading Risk
- Vulnerabilities

4.1 Theoretical Framework

Due to the limited scope of the report, this section will briefly describe the main theories used. The following theories identified lays the foundation of the body of knowledge required to understand the scope of the thesis and theoretical narrative.

Main Theories Used As Drivers of Knowledge

1. The Risk Cycle & Risk Management
2. Evolutionary Resilience
3. Adaptive Capacity
4. Resilient Critical Infrastructure
5. Deep Uncertainty & Dynamic Adaptive Pathways (Theory Paper)

Understanding the Risk Cycle & Risk Management

According to the Sendai Framework, there are several priorities which encompass:

1. Understanding risk
2. Strengthening risk
3. Investing in risk reduction for resilience
4. Enhancing preparedness for effective response to build back better in recover, rehabilitation and reconstruction.

To understand the scope of risk, it is described as a function of hazards and vulnerability. Risk research aims at underpinning the conditions that generate disasters while addressing the prevention or reduction of disaster impacts (Sobiech, 2013b). The scientific scope of the theory involves several disciplines such as geography, economy, meteorology, sociology or historical and political science.

Experts measure risks by the probability of "occurrence of a disaster and evaluate the effect of risk reduction strategies in cost-benefit analyses. They follow the objective risk concept which is characterized by probability, intensity and the potential impacts of a disaster. Risk can be defined as the probability of harmful consequences due to conditions of a natural hazard and social vulnerability which together can lead to a disaster" (Sobiech, p.1, 2013). It is also important to note that risk is a social construct and refers to the perspective shaped by a body of individuals, human cognitions and is influenced by a variety of other social factors. This can lead to subjective preferences and estimations on creating risk reduction strategies.

By identifying where and understanding how particular socially vulnerable communities may be affected, allocated resources can be more effectively managed during the different patterns of the disaster cycle. Breaking down the risk disaster cycle, it transitions through different phases of mitigation, preparedness, response and recovery. The overall goal is to improve each phase of the disaster cycle, but the main focus or concentration will be focused on mitigation. Risk management does not only involve looking at impacted areas, but also the reduction and mitigation strategies to combat extreme events.

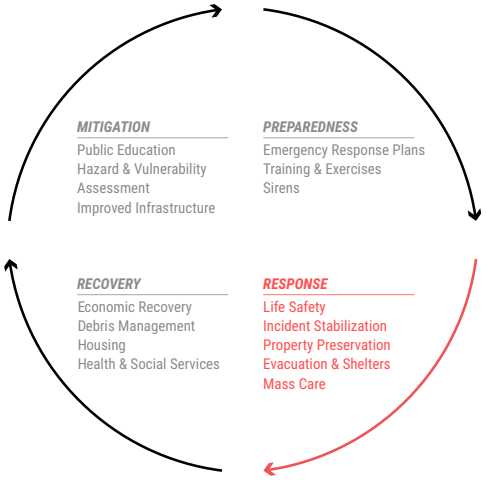


Figure 28 The risk cycle (Source: made by author)

To summarize the other cycles of risk management:

1. **Mitigation:** focuses on preventing a disaster event from occurring.
2. **Preparedness:** involves a set of measures to reach an appropriate level of readiness to respond to any emergency situation. Government initiatives, organizations and communities are set with a certain capacity to respond to the event.
3. **Response:** a set of activities and measures to provide immediate assistance to affected populations. The main priority is to maintain life, provide basic necessities and ensure the safety of people during an emergency phase.
4. **Recovery:** as the last phase of the risk cycle, these are a set of activities aimed to restore livelihoods and supporting infrastructure. There is also an opportunity window for communities to reconstruct areas for future prevention and preparedness (United Nations, 2018).

The goals of disaster management include:
1. Reducing or avoiding losses from hazards
2. Assure prompt assistance to victims
3. Achieve rapid and effective recovery

Flood Risk Context: Response & Recovery Phase
As part of the disaster risk management cycle, it is important to analyze, reflect and evaluate the current system of risk. To gain a better understanding of risk management in the spatial context, a literature review and a series of multi-criteria analysis maps were conducted. As indicated in the following diagram (figure 28) , a pre-defined set of measurements needs to be taken under consideration when designing for the response phase in addition to ensuring that the main critical infrastructure defined are protected.

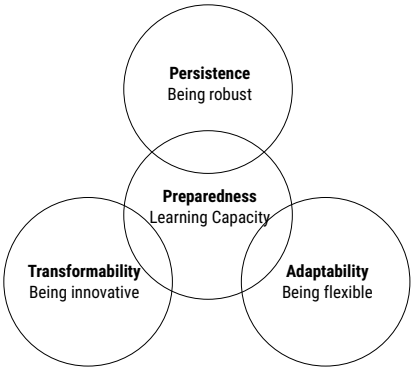


Figure 29 Four dimensional framework for resilience building

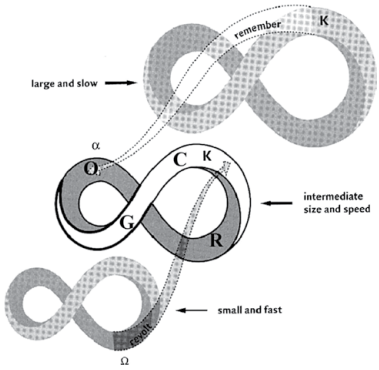


Figure 30 The adaptive cycle, adapted from Gunderson & Holling (2002) and Berkes et al. (2003).

Evolutionary Resilience

A large ripple effect can be triggered in systems when there are structural failures. Thus, the aspect of evolutionary resilience needs to be considered and is beyond the definition of the "capacity to survive, adapt, and flourish in the face of turbulent change" (Siemens, 2017, p. 9). Although resilience has become a contested concept and has become a danger of "becoming a vacuous buzzword' as a result of its overuse and ambiguity" "(Davoudi, Brooks, & Mehmood, p. 307, 2013), it is still a significant term integrated in disaster management and planning. Resilience has gained traction in the past decades and has been used as a response to climate change uncertainties and future socio-economic trends. Through a series of literature reviews, the term is often referred to as the capacity to bounce back to the previous state from an external shock. The term was further developed in the 1960s by ecologists (Holling, 1961; Morris, 1963; Lewontin, 1969). As a point of departure, it is important to understand that there are three perspectives on resilience which are framed as engineering, ecological and evolutionary.

As one of the pioneers of the term, Holling states that stability is the "ability of a system to return to an equilibrium state after a temporary disturbance" (Davoudi et al., p. 381, 2013). From the engineering resilience standpoint, there is a larger focus on returning back to the original state for efficiency, consistency and predictability. After, the term ecological resilience was defined as the ability of systems to absorb changes and continue to persist. There was an emphasis of not only analyzing the duration of the system to bounce back after a disturbance but also how much the system can take and persist before changing functions (Davoudi et al., 2013). However, the major criticism of the two types of resilience is that rather than conceiving resilience as a "return to normalcy, evolutionary resilience calls for the ability of complex socio-ecological systems to change, adapt or transform in response to stresses and strains" (Davoudi et al., p. 381, 2013). The notions behind evolutionary resilience is that the structure and function of the systems undergo four distinct phases of change as seen in figure 30 called the adaptive cycle.

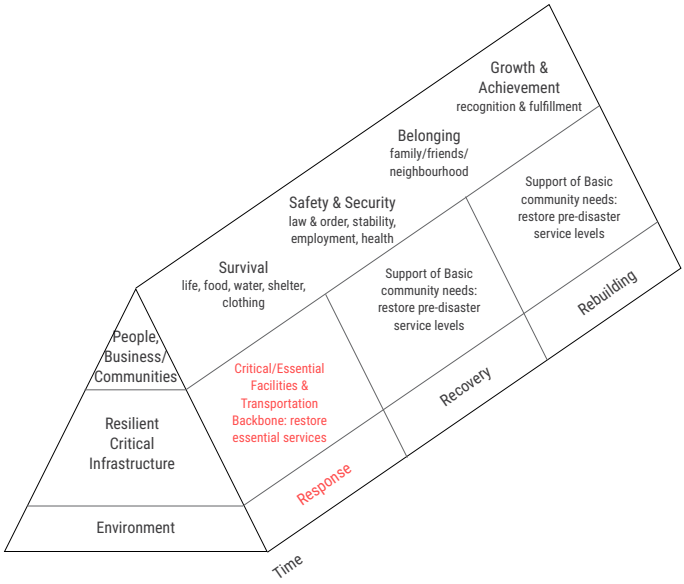


Figure 31 Resilience prism (modified from Wang and Yu, 2014)

To elaborate:

- The growth phase (r) deals with the "rapid accumulation of resources or capital, competition, seizing of opportunities, rising level of diversity and connections" (Davoudi et al., p. 310, 2013).
- The conservation phase (k) shows that growth begins to slow down and the resources used in the growth phase are stored for system maintenance. This is the state at which the phase tries to stabilize, with reduced flexibility and low resilience
- The creative destruction phase (v) is seen as the "chaotic collapse and release of accumulated capital" (Davoudi et al., p. 310, 2013).
- Finally, the reorganization phase (a) is the period where there is innovation, restructuring and highest point of uncertainty but also high resilience.

It is important to note that the phases defined do not necessarily run in sequential order and operates in a series of nested adaptive cycles. These adaptive cycles can operate in a multi-scalar system. These complex systems are in a constant flux and is always in a state of continually shifting in order to adapt and change (Davoudi et al., 2013). Evolutionary resilience broadens the scope of the existing definition of resilience of maintaining and conserving what you currently have and to restore itself to the previous state. The concept incorporates a "dynamic interplay between persistence, adaptability and transformability across multiple scales and time frames in ecological (natural) systems" (Davoudi et al., p. 311, 2013).

One of the main differences in evolutionary resilience in comparison to the engineering or ecological resilience is the aspect of transformability. The moment the system is disturbed and experiences a 'regime shift', a rapid phase of renewal and reorganization

takes place and leads to a new arrangement. The unpredictable nature and process of transformation can immediately shift to something new, whether it is considered desirable or undesirable. Thus, the adaptive cycle can also be seen as a major strength or opportunity to transform socio-ecological processes. Taking this into consideration for design thinking and practice, the system can be directed through a series of desired pathways.

Bridging this concept to practical implication, resilient cities need to share "core capabilities such as constant learning rebounding rapidly from shocks, limiting the effects of failure, adapting flexibly to change, and maintaining spare capacity" (Siemens, 2017, p. 198). There is also a need to adequately address infrastructural and non-spatial interdependencies, so a series of resilience metrics will need to be developed in order to be applied to the region. In relation to London's road map strategy to resilience, the transformative potential of climate change is not explicit or evident (Davoudi et al., 2013). The dominant mindset in the framework is to return to normality with a larger emphasis on the physical robustness and continuity of the city. However, there needs to be a shift in thinking for adaptation strategies to engage with communities, researchers and other stakeholders to pursue alternative futures.

Importance of Adaptive Capacity and Capacity of Response

Situations impacted by environmental change need to factor in human agency as a notable component in how individuals respond. Several reports and policy approaches emphasize on resource and infrastructure to support adaptation measures but do not completely address agency or psychosocial factors related to environmental stressors. Human development, well-being and disaster literature provide insights to support more integrated and human-centered approaches to understanding environment change. In order to grasp a greater understanding on adaptive capacity, below are several definitions:

Adaptive Capacity: defined as "the preconditions necessary to enable adaptation to take place, it is a latent characteristic that must be activated to effect adaptation" (Brown & Westaway, p. 322, 2011). Whereas capacity looks to generate an outcome or perform a task and also to learn, and the potential for growth and development.

Capabilities: "the alternative combinations of functioning a person is feasibly able to achieve. A capabilities approach emphasizes functional capabilities and understands poverty as capability deprivation" (Brown & Westaway, p. 323, 2011) Human Security: "a state that is achieved when individuals and communities are able to end, mitigate or adapt to threats to their human, environmental and social rights" (Brown & Westaway, p. 323, 2011)

Several of the above terms highlighted are areas of uncertainty and the thesis need to remain objective in measuring capacity in understanding that these issues are reflective and dynamic (Brown & Westaway, 2011).

Adaptive capacity is intrinsically tied to the notions of resilience and vulnerability in a number of ways:

- Biological, economic, cultural diversity
- Social learning concerning the system and how it changes
- Experimentation and innovation
- Selection, communication, and implementing appropriate solutions

These key factors interact across temporal and spatial scales and is necessary for building resilience and adaptive capacity in social-ecological systems to deal with dynamics and change. In gaining a better understanding of how adaptive capacities and resilience can work together, they can be utilized to strengthen and find linkages, question areas related to capacity, determining who is responsible for initiating change, and contributing and shaping governance.

AR3U023 Theories of Urban Planning and Design

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Adapting to Uncertainty: Planning with Deep Uncertainty for Resilient Critical Systems

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Major altered states of extreme weather events such as storm surge, sea-level rise, droughts and heatwaves have resulted in many regions left with critical systems exposed. The impact and risk of modern disasters have become more pronounced with extensive societal and economic losses every year with damage to infrastructure and linked socio-ecological systems. Adding to the concern is the development of future policies as they come with a set of limitations and challenges with the mounting impacts of changing environment. Deep uncertainty has also added an additional layer for decision-makers to consider on top of risk mitigation and vulnerability assessments. In light of increasing uncertainties, a new planning approach, Dynamic Adaptive Policy Pathways (DAPP) will be analysed in this paper. The two complementary approaches for planning under deep uncertainty – Adaptive Policymaking and Adaption Pathways, will be further elaborated to ground a better understanding of how to plan for unforeseeable conditions. The case study of the Thames Estuary (TE2100) will be used as a large-scale practical example of how DAPP has been implemented. Overall, the aim of the paper strives to understand how DAPP confronts deep uncertainty and how that knowledge translates into designing future critical systems.

Key Words: Dynamic Adaptation pathways, Risk Management, Decision-making under uncertainty

1.0 Introduction

Estimations of the future changes in precipitation and extreme weather events are still highly uncertain and provide limited support to future infrastructure design. Classified as deep uncertainty, decision makers (governments, NGOs, and businesses) are pressured to reach robust decisions that have satisfactory performances across a large range of plausible futures. As indicated in the journal article, Fail-safe and safe-to-fail adaptation: decision-making for urban flooding under climate change (Kim et al., 2017), novel approaches are needed for the future of infrastructure planning and design which also incorporates uncertainties in climate model predictions. Especially with the difficulties in predicting the frequency and intensity of future weather extremes; climate risk projections are increasingly becoming more difficult and "problematic for planning large-scale, long-lived and costly adaptation projects" (Reeder & Ranger, p.1, 2011). Large scale investments tend to be cost-intensive to reverse, have a limited life span and designs are typically dependent on the assumptions made in the present. Consequently, if the current forecasts are incorrectly made, "the project can become maladapted to climate, exposing society to greater risks, wasted investments or unnecessary retrofit costs"(Reeder & Ranger, p.2, 2011). Infrastructure systems inherently carry a risk when it is used as a strategy to cope with the effects of the changing climate. As infrastructure systems are typically designed and commissioned by the thought process of 'predict then build' approach, this comes with a significant cost if expectations are not met.

Adaptation has risen in domestic policy agendas but there are uncertainties over long-term mitigation policies which can conflict with planning. To note, emerging long-term decision making models and approaches have sprouted over the last decades from dynamic adaptive policy pathways, adaptive policy-making, real options analysis, info-gap decision theory, decision scaling, robust decision-making and many object robust decision-making (Kwakkel, Haasnoot, & Walker, 2016). In addition to these decision making models, other tools and techniques have supported these approaches such as scenario planning, assumption-based planning, and exploratory models (Manocha & Babovic, 2018). As the focus of this paper, there is a necessity to address deep uncertainty with a set of strategies and plans that support flexibility and can react strategically compared to conventional planning approaches. Thus, the chosen method that will be further analysed is Dynamic Adaptive Policy Planning (DAPP) and how can it be further developed in planning critical systems and services under deep uncertainty. DAPP is of the main methods aims to ensure that adaptation decisions today are resilient in the uncertain climate. The Thames Estuary 2100 project will be highlighted as an example of a real-life application of adaptation pathways in the realm of flood risk management. To conclude, several lessons learned and challenges of further development using this approach will be addressed.

2.0 Policymaking as a Dilemma of the Future: Limits and Challenges

Decision-makers are continually confronted with unpredictable dilemmas of deep uncertainty. Part of the ongoing conflict is due to the diverse set of options that are available. As a consequence, this can drastically produce multiple consequences which are considered far-reaching but also difficult to anticipate (Walker, 2014). There is a heavy responsibility for decision-makers to develop and implement a set of policies that has the best output for the population related to health, safety and well-being. For countries like the Netherlands who continually look at flood mitigation strategies, the method of choice tends to be scenario planning. Future predictions are a result of scenario planning and would then develop into a presumed robust 'optimal' plan. This method utilizes predictions and extrapolates a set of trends to develop an acceptable outcome in the most plausible future (Haasnoot, Kwakkel, Walker, & ter Maat, 2013). The major downfall in relying on scenario-planning is its static nature of not being able to respond or adapt. If the future prediction is largely different in comparison to the hypothesized future, established plans are more likely to fail and decision-makers fall back on the practice of ad-hoc planning.

There are several limiting factors and challenges that need to be considered in developing successful plans (in addition to being accepted and interpreted while considering uncertainty) as referred to by Walker (2014):

1. Not all uncertainties about the future can be eliminated or accounted for.
2. If uncertainty is ignored in future plans, it could limit the ability to accommodate or take corrective action in the future. This could possibly lead to situations that could be easily avoided.
3. Leaving uncertainty as an after-thought can result in missed chances and opportunities or worse, a failure of the long-term plan.

In the traditional sense, scientific work in other fields such as engineering, social and natural sciences defines uncertainties as lacking information. Larger efforts are emphasized through stochastic processes and statistical analysis (Walker, 2014). In contrast, decision makers in the field of strategic planning are faced with uncertainties about the future that "cannot be reduced by gathering more information and are not statistical in nature" (Walker, p. 3, 2014). To summarize, uncertainties can appear from a range of external developments and only appropriate future system models that can address future fluctuations should be developed.

3.0 Infrastructural Risk in a Rapidly Urbanizing World

As cities are rapidly urbanizing around the world, many altered states of extremes are becoming more pronounced. With the rise of impervious areas, civil infrastructure and roadways are particularly becoming more vulnerable to flooding (Kim et al., 2017). The majority of urban growth around the world, specifically in North America, is comprised of asphalt and concrete based 'grey infrastructure' such as roads, buildings, and parking lots. With urban expansion progressively moving to more impervious surfaces, large amounts of runoff occurs. Infrastructural systems tend to be overloaded and when drainage structures exceed their capacity, water accumulation may occur on roadways which in turn can lead to further potential damages and disruptions to surrounding infrastructure and ultimately service disruptions. Sudden events can cripple infrastructure which assists in operation and functionality of transit, electricity, water and other crucial services. Not only does this exacerbate vulnerabilities but certain groups such as those with low socioeconomic status would be disproportionately affected. In addition, current policies lack the foresight in integrating interdependencies and being prepared for cascading effects as a consequences to these risks. In addition to the unpredictability of future weather events, there is a suggestion that even large and redundant infrastructure may be vulnerable to future rainfall events or storm surges (Kim et al., 2017).

Currently, discussions have revolved around fail-safe design strategies such as strengthening infrastructure against more intense environmental conditions. But there has been less of an emphasis or fewer studies developing 'safe-to-fail' strategies in light of adaptation and resilience in urban areas. This includes strategies that allow "infrastructure to fail in its ability to carry out its primary function but control the consequences of the failure" (Kim et al., p. 398, 2017). In the future sections, suggestions related to how flood mitigation has been practised due to the uncertain future will be discussed.

4.0 Grounding Deep Uncertainty

Deep uncertainty has been defined as:

> A situation in which analysts do not know or the parties to a decision cannot agree upon (1) the appropriate models to describe interactions among a system's variables, (2) the probability distributions to represent uncertainty about key parameters in the models, and/or (3) how to value the desirability of alternative outcomes (Walker, p. 3, 2014).

Overall, the term essentially means having limited or inadequate information. Often, deep uncertainty involves a range of decisions that are made over time with interventions made to the system that are dynamic or adaptive. In order to grasp a better understanding of deep uncertainty, one must understand that there are different levels of uncertainty and also how it is addressed at different extremities. In current literature reviews, there are several methods dealing with deep uncertainty in a sustainable manner. The following often overlap and are not mutually exclusive (Walker, 2014):

1. Resistance: planning for the worst possible case or situation
2. Resilience: the capacity for a system to recover
3. Static Robustness: aims at reducing vulnerability in a wide range of conditions
4. Dynamic Robustness (or adaptivity): plans that can adapt or change over time depending on the condition

In the grand scheme of the paper, dynamic adaptive plans is chosen as it that can adapt to changing conditions is suitable for dealing with deep uncertainty in order to create long term robust plans.

5.0 Theoretical Framework – Dynamic Adaptive Pathways & Policies

A new paradigm for planning has been established under the conditions of deep uncertainty. For the context of this paper, Dynamic Adaptive Policy Pathways (DAPP) will be explained. The approach combines two bodies of literature on planning under uncertainty which are: Adaptive Policy-Making (Kwakkel et al., 2010; Walker et al., 2001), and Adaptive Pathways (Haasnoot et al., 2012). To simplify, the integrated framework includes transient scenarios which represents a variety of relevant uncertainties and development over time (Haasnoot et al., 2013). The strength of the model comes from being able to handle vulnerabilities (how it might fail) and developing a series of actions to protect these weaknesses.

These adaptive plans have received a lot of attention in various policy domains and have been predominantly applied in the field of water management. Dynamic flexible plans have been incorporated in plans from New York, New Zealand, the Rhine Delta to the Thames Estuary. In essence, "DAPP aims at developing an adaptation pathways map that contains a set of possible pathways that serves as input to a conversation between stakeholders" (Kwakkel et al., p. 179, 2016). The system also establishes a series of indicators to monitor the uncertain vulnerabilities (Walker, 2014). This assists in determining if these markers would achieve predetermined critical levels. The adaptive plan is reassessed if the essential components or anticipated objectives cannot be achieved. The DAPP model (Fig. 1) is enabled to deal with deep uncertainty by incorporating the elements of flexibility, adaptability, and learning while adjusting to new forms of information and data (Walker, 2014).

Figure 1. Dynamic Adaptive Policy Pathways approach (Haasnoot et al.,p. 488, 2013)

To elaborate on the DAPP method, it occurs in two different phases. First, the design phase encompasses the dynamic adaptive plan, monitoring program and then a series of pre- and post-implementation actions are designed. The second major step is the implementation phase. In this phase, all the pre-established steps including the monitoring program and adaptive actions are implemented.

5.0.1 Adaptive Tipping Points

To assess vulnerabilities and opportunities of the status quo, adaptation tipping points assist in establishing these conditions. Adaptation tipping points are defined as "conditions under which the status quo starts to perform unacceptably for the relevant uncertainties, using expert judgment and/or model simulations" (Kwakkel et al., p. 171, 2016). The tipping point which is also classified as the use-by date, similar to an expiry date, is scenario dependent. The performative aspect and timeline relies on transient or semi-static model simulations. This crucial component reveals the strategic timeframe when policy actions should be enacted upon to obtain a desired outcome. Once a tipping point has been reached, additional actions are needed which transitions into Adaptive pathways.

5.0.2 Adaptive Pathways

Adaption Pathways elaborates on a sequence of promising actions in conjunction with a monitoring system to ensure the plan is on track to meet a pre-defined set of goals and objectives set by the decision-making body (Haasnoot et al., 2013). The action of monitoring decision-relevant principles is also vital "as it establishes a link between risk assessment and action that many adaptation approaches lack" (Kingsborough et al., p.387, 2016). Pathways can be designed, evaluated and consists of a series of polices. The sequencing of these pathways are comprised of a series of possible actions in the form of adaptation trees, which can be seen as a decision tree or roadmap (Haasnoot et al., 2013) These come into play when a series of policy actions are deemed inadequate. The set of preferred pathways can also be improved through a series of trigger-event actions. Through contingency planning and the mentioned monitoring system, the below are classified actions that can be taken:

1. Defensive actions – Actions taken after the initial implementation to assist in clarifying plans. This essentially leaves the basic plan unchanged.
2. Corrective actions – Adjustments that are made to the initial plan in response to specific triggers.
3. Capitalizing actions – Actions that are taken after the initial implementation. This takes advantage of the timeframe in which the performative aspects of the plan can be improved.
4. Reassessment – This process is initiated when the analysis and assumptions critical to the plan's success has lost validity. This is the case when unforeseen events have caused a significant shift in the fundamental goals established.

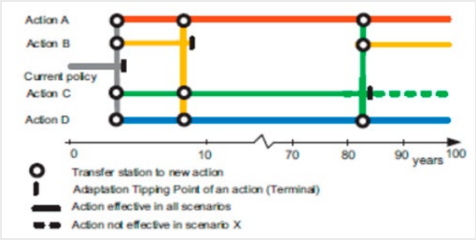

Figure 2. The map starts with the current situation. The grey lines indicate the current policy and the four other options present are the estimated targets for the next 100 years in all climate scenarios. If the actions or tipping points (terminal stations) are shifted, then the action is shifted (transfer stations) or a combination of actions are required (Haasnoot et al.,p. 488, 2013)

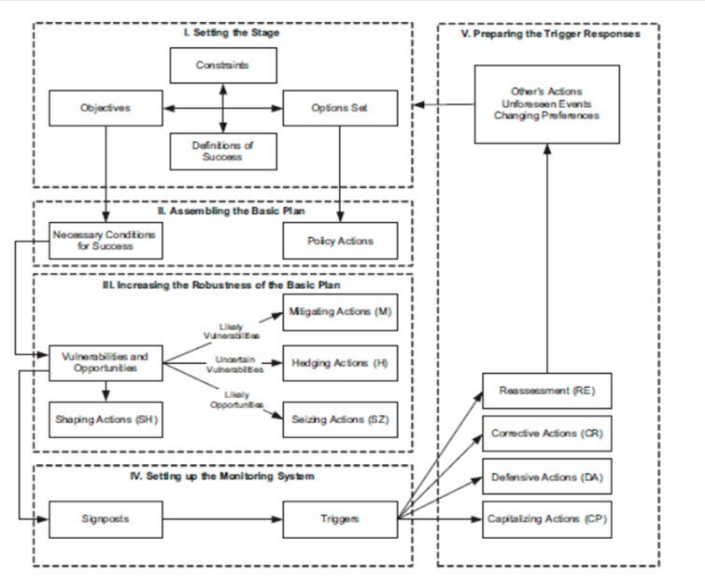

Figure 3. Adaptive Policymaking approach for designing a dynamic adaptive plan (Haasnoot et al.,p. 488, 2013)

A diagrammatic example of the final Adaptation Pathways Map can be seen in (fig. 2). The map showcases a series of actions that can be made along with indicators of which developments should be monitored or implemented. An alternative set of pathways are always presented in a way that the same desired point is achievable for the future. The pathways are set at a "minimum performance level, such as a safety norm (a threshold that determines whether results are acceptable or not)" (Haasnoot et al., p. 487, 2013).

Not only does the pathways approach sequence the implementation of actions over a timeline, they enable the system to adapt to changing social, environmental and economic conditions. This essentially will continue to build flexibility into the overall adaptation strategy (Kingsborough et al., 2016)

5.0.3 Adaptive Policymaking

Conceptually, Adaptive Policymaking stems from Assumption-Based Planning (Marjolijn Haasnoot et al., 2013). In addition, the construction of Adaptive Policymaking is defined as a structured approach for designing dynamic robust plans. The general outline of the Adaptive Policymaking approach is outlined in (Fig. 3) and is be broken down into the following:
Upon the implementation of the plan, a series of actions can be constructed (Walker, 2014):

1. Mitigating actions – Actions that can reduce adverse impacts on a plan which are from likely vulnerabilities
2. Hedging actions – Actions that reduce adverse impacts on a plan, spread or reduce risks that stem from uncertain vulnerabilities
3. Seizing Actions- These actions take advantage of opportunities that may be beneficial to the overall scope of the plan
4. Shaping Actions – Proactive actions that would affect external events or conditions that can mitigate or alleviate failure

In the initial steps of establishing a DAPP, the setting, objectives, constraints and major uncertainties are defined.

Once the complete plan has been formulated, the steps shown in the diagram can be executed and the monitoring system seen in Step IV is established. From here, actions can start or begin to respond to new information. The set of actions seen in Step V is postponed until a trigger event occurs (Marjolijn Haasnoot et al., 2013)

5.0.4 Comparison Between Adaptive Pathways and Policymaking

The main aim for both approaches is to support decision-makers in handling uncertainty with long-term decisions. There is also a heavier emphasis for the need to integrate adaptivity and flexibility in plans in order to cope with deep uncertainty (Haasnoot, 2013). The two continually offer support in short-term actions while abiding to the ability to modify, extend or alter plans in respond to the changing environment or future.

In comparing the two approaches, they mostly differ in the decision support system. Adaptation Pathways offers a perspective of "sequencing of actions over time, taking into account a large ensemble of transient scenarios". The transient scenarios allow for a wide variety of uncertainties about future developments to be taken into account in the planning process" (Marjolijn Haasnoot et al., p. 489, 2013). In this aspect, future trends, system modifications and uncertainty due to natural variability are included. The downfall of the Adaptive Pathways is no actual guidance of how the decision maker can translate these into an actual plan. In contrast, Adaptive Policymaking provides support through the means of developing a plan. Through the identification of a series of opportunities and vulnerabilities, a specific course of actions can be delegated to be taken during a specific timeframe. The negative aspect of this approach is that there is no guidance beyond these notions. The lack of guidance negatively impacts how decision makers can identify vulnerabilities, how actions should be sequenced or the steps into developing a monitoring system (Marjolijn Haasnoot et al., 2013). To summarize, the DAPP system offers a more comprehensive and complex range of options than just scenario planning (Haasnoot et al., 2013). Not only do these approaches allow for more flexibility in planning with deep uncertainty but also enables advisors to set a time frame for when new strategies need to be executed.

6.0 Adaptive Planning Paradigm in Practice: Thames Estuary

As part of a competitive and global economy, London is expected to be a low-risk and desirable place to live. However, London has been classified as a water-stressed city and already faces water scarcity challenges due to large population growth. In response, adaptation has risen in the domestic policy agenda. A legislative framework was initiated due to the UK Climate Change Act 2008 which required the government to have a programme for adaptation. Additional concerns were compounded by "additional scientific and socioeconomic uncertainties, particularly at a local level"(Reeder & Ranger, p.1, 2011). Investments tend to be costly to reverse and assumptions made of the future can come at great risks.

In the case of the Thames estuary, a significant number of approaches and computational techniques have been used to support decision making under deep uncertainty. A prime example of this was the Thames Estuary 2100 (TE2100), a project designed for London which utilizes a decision tree to analyze sequential decisions for flood management for the next 100 years. The concern stems from the impacts of what storm surge could potentially do to properties, create economic disruption and loss of lives. Currently, the Thames Barrier protects Central London which was created in the 1980s for the 1-in-100 year return period storm surge (Reeder & Ranger, 2011). However, since the system was built to last until 2030, the goal of the TE2100 project was to analyze if the system needed to be modified.

The project understood that it was fundamental to incorporate flexibility and adaptation into long-term plans. To simplify, the project began with a context-first approach as it was deemed to be less resource intensive and focused on streamlining information. With this initial strategy, policy makers could think more broadly of other risks and seek co-benefits in other areas. First, the project identified and structured the problem based on understanding the current vulnerabilities in the system (ie. Flood risk and protection). Second, when mapping out the sensitivities related to climate change, the model suggested that there would be a potential increase of 2.7m in 2100 (Reeder & Ranger, 2011). Third, assessing known thresholds and identifying

feasible adaption response options that would be able to support the capacity. Fourth, creating a set of adaptive pathways would begin to break down the thresholds that have been identified. From here, a preferred route is chosen with a set of key variables that can be assessed for any future changes. Each package as identified in (Fig. 4) was then evaluated through a different set of scenarios to comprehend its robustness. The key to the adaptive pathways is having the flexibility of having interchangeable set of actions interchangeable depending on the actual rate of change.

6.0.2 Lessons Learned from TE2100

The plan established a 'no-regrets' motto when creating fundamental actions in the early stages of the project. This includes extending the lifetime of existing infrastructure and detailing a 40 year investment plan on upgrading existing flood management. The approach was also regarded as a method that would not require a lot of time in developing adaptive pathways. TE2100 highlighted the avoidance of taking 'inflexible' decisions. It was important to lay out a set of decision points that are conditional and can be observed based on sea level rise (Reeder & Ranger, 2011). However, one of the key downfalls of applying flexibility into the plan is that it could result in a greater cost or reduced productivity such as providing larger foundations for sea walls. If an urgent public infrastructure project (ie. sea defence) was delayed, it could severely expose populations and other critical infrastructure to extreme weather events. This would result in costly repairs to not only damaged infrastructure but an increased frequency repair to older infrastructure.

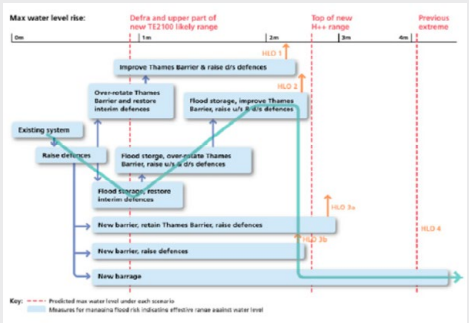

Figure 4. The route map of TE2100 presents high-level adaption options with four different levels that were designed to accommodate for extreme weather levels in the Thames by 2100 (Reeder & Ranger, p.8, 2011)

7.0 Discussion

Predictions of the future are likely to be proven wrong. As noted by Walker (p. 3, 2014) "the performance of plans optimized for a most likely future can deteriorate very quickly due to small deviations from the most likely future, let alone in the face of surprise". Methods like scenario planning can offer an insightful perspective of certain trends and outcomes but can still often limit the full scope of the dilemmas of the future. They also are unable to provide systematic measures to examine their implications. The adaptive pathway approach, as seen in the TE2100 project establishes a beneficial relationship between water management and mid-long term planning. As governments can apply the DAPP framework to long-term adaptation planning, there are still a series of recommendations that need to be considered such as:

1. Considering a risk-based approach pertaining to critical infrastructure and planning
2. Identifying and monitoring risk-based decision triggers (Kingsborough et al., 2016)
3. Robustness and flexibility metrics should be included in existing decision appraisal
4. Developing transient scenarios to inform the timing of adaptation pathways and actions
5. There should be a priority in developing, identifying and exploring long-term adaptation pathways

In relation to the aim of the paper, there is still the need to address a design paradigm that "rigorously considers uncertainty in climate predictions during the decision-making process and primes infrastructure to be resilient to unforeseen climate risks" (Kim et al., p. 410, 2017). A perspective to consider for planning future critical systems is using DAPP and safe-to-fail infrastructure systems. This includes the benefits for dynamic adaptive pathways but also adapts to uncertain and unpredictable infrastructure failures. (Kim et al., 2017). The strategy also focuses on strengthening the resilience and capacity of infrastructure systems while minimizing the impacts of systematic failures (Kim et al., 2017). Countries like the Netherlands have established resilient infrastructure systems by deliberately increasing flood-prone areas to land-uses such as farmland. By targeting farmlands as flood paths, local risk management can delegate where urban damages would occur to less socially and economically vital regions (Kim et. al, 2017).

As cities are rapidly expanding, there is a need to continue developing and to also be critical about adaptive pathways. Adaptive pathways have been proven to be an effective means of informing long-term adaptation planning. However, there needs to be further investigation on how these approaches can respond to different shortcomings, barriers and utilized in information adaptation planning in different contexts.

8.0 Conclusion

The paper outlines an analytical approach of the successes behind dynamic adaptive policy pathways (DAPP) in the presence of deep uncertainties. The compounding risks that come with extreme weather scenarios, storm surge, urbanization and so forth put forth an added layer of uncertainty. Policymakers and decision makers are always conflicted with presenting policies even with deficient knowledge. Although there are many possible scenarios for the future, a single policy should not be expected to capture or perform well in all aspects. However, policies should be highly adaptable – not just to be optimal for the best estimated future but to be set up systematically in a way to be robust across a range of plausible futures.

It is notable that adaptive planning has gained traction but the commitment to develop the methods have been relatively constrained due to the scale of institutional financial and methodological barriers. But the trade-offs of using adaptive pathways include: significant benefits of reconciling multiple decision timescales and is comprised of medium and long-term adaption planning for stakeholders to understand. The flexible approach is essential in risk management while working with uncertainty and has demonstrated to be effective in the decision-making process (Kingsborough, Borgomeo, & Hall, 2016). Utilizing DAPP as a method for policy formation and implementation can '"explicitly confront the pragmatic reality that policies will be adjusted as the world changes and as new information becomes available" (Walker, p. 10, 2014). The approach forms a framework that enables policymakers to deal with a range of uncertainties by allowing policies to respond and adapt to changes over time while creating a learning feedback loop. The entirety of the system is fundamental and forms a larger holistic process rather than developing short-term plans on an ad-hoc basis. TE2100 showcased a series of lessons learned from a practical and large-scale operation in the face of deep uncertainty. The plan created a framework that ensured adaptation strategies were not only cost-efficient but were also flexible and adaptable. With the advantage of not being heavily resource intensive or reliant on a single form of climate modelling. The approach also showcased that it can be adopted into other fields of interest such as critical infrastructure systems.

The aim of the study was to understand and analyse a decision-making model when confronted with large uncertainty and the implications it may have for critical systems. It has also been highlighted that adaptation still needs to consider solutions that "in the event of failure, do not compromise the entire urban system" (Kim et al., 2017). The development of a long-term plan for critical systems and infrastructure would require a more extensive study and consideration of a broader range of literature. However, DAPP provides a promising outlook in supporting a wide variety of uncertainties in a dynamic way while striving to connect short-term targets with long-term planning.

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4.2 Conceptual Framework

The conceptual framework will outline the primary concepts that play an integral role in establishing notions, variables and relationships that will help guide the report. The following are a series of terminology that will be defined:

Main Concepts & Terminology

1. Critical Infrastructure & Systems
2. Interdependencies
3. Residual & Cascading Risk
4. Vulnerability (Social & Physical)

Defining the Importance of Critical Infrastructure & Systems

As defined by the IPCC (2018), critical infrastructure are "assets (physical or electronic) that are vital to the continued delivery and integrity of essential services on which a country relies, the loss or compromise of which would lead to severe economic or social consequences or to loss of life" (Sari Kovats et al., 2018).

Critical infrastructure systems include energy systems, water systems, transportation systems, health facilities, schools, emergency evacuation shelters, information and communications technology, security, and financial services – underlie the economic prosperity of every society (Mukherjee & Hastak, 2018; "Themes & Issues - PreventionWeb.nest," 2018.)

Critical infrastructure systems are threatened with the risks of climate change with frequent extreme weather events such as coastal flooding due to sea level rise, droughts and heat waves owing to increasing global mean temperatures. These induced hydro-climatological events causes extensive damage to infrastructure and communities (direct impacts) or might create unwanted shifts in the end-use demand patterns (indirect impacts) (Mukherjee & Hastak, 2018). For example, there were massive disruptions in the last 'North Sea flood' (2013), where there was an estimate of 20,000 houses that lost power in Scotland, 20,000 in Northern England, 6,500 in Ireland, and 50,000 in Sweden.

Interdependencies

Many interdependencies are evident in key infrastructure sectors. The reduction of performance or failure in one sector can lead to multiple direct or indirect effects for other sectors. The effects of the energy sector are increasing with the electrification of transport, personal device mobility and any technology associated with electrical devices. Cascading effects following the disruption of any of these services need to be recognized.

Residual and Cascading Risk

Residual risks are classified as the threat remaining after a series of mitigating actions have been applied. This amounts to the risk or danger that is associated with an event after all forms of preventative actions have been applied. A general formula or understanding is residual risk= (inherent risk) – (impact of risk controls). This could also include instances of a severe flood event that exceeds a flood management standard or intense rainfall event where the drainage system cannot fully cope with the amount of water. Thus, areas located behind flood defences are at most risk from extreme rapid fast-flowing and deep water flooding with little or no warning if defences are over topped or breached ("Flood risk and coastal change - GOV.UK," 2018).

Cascading risk involves a process where parts of a highly connected network could trigger the failure of other components. This can easily occur in many critical infrastructure systems due to the high reliance in interdependent systems. When failures occur, other portions of the system may compensate for the failed element, but this may prompt additional elements to fail after one another.

Hazards

Geo-hazards (such as forest fires, flooding and earthquakes) may be quickly dismissed as localized but they quickly cascade into long term effects such as emotional distress, loss of life and significant property damage. In both short-term and long-term events, disasters can have significant impacts on economic, health and social systems.

Exposure

The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected (Field et al., 2013).

Vulnerability

As per the conceptual framework, vulnerability needs to be termed in two different aspects: vulnerability in relation to natural and physical variables and vulnerability in relation to social variables. Majority of disaster management cases and research often focuses on physical hazards whereas social vulnerability is frequently disregarded and neglected (Flanagan, Gregory, Hallisey, Heitgerd, & Lewis, 2011).

Human vulnerability defined by (C. B. Field et al., 2014) states that it is a combination of physical vulnerabilities (in the built environment and vital networks) and social vulnerabilities (experienced by people and their social, economic and political systems). This is essential to explore both issues as there has been large critiques on primarily focusing on physical vulnerability without attention to social or political dimensions.

Traditionally, in both research and practise, there is a larger focus and scope on physical vulnerability. This is more fundamentally dependent on exposure to hazard and spatial distribution to the hazard. There is a general assumption that aspects of vulnerability to exposure could be looked at through the lens of land-use planning, zoning and structural engineering. However, there is an illusion to "assume that reducing physical vulnerability through managing exposure would not be political in nature" (Uitto & Shaw, p.44, 2016).

Social Vulnerability

Breaking down the relationship of these concepts, there are a series of variables in how vulnerability is classified in relation to hazards such as: age, income, strength of social networks and neighbourhood characteristics. As previously stated, disaster-stricken areas do not affect people equally. Vulnerability is not an independent variable, as in most cases it is a combination of variables. As defined by Flangan "Social vulnerability refers to the socioeconomic and demographic factors that affect the resilience of communities" (Flanagan et al., p. 1, 2011).

Constructing the SOVI

The Social Vulnerability Index (SOVI) developed by Susan Cutter is a model (the index includes 32 variables and includes a broad multi-variate assessment) that examines potential value and impacts for disaster management. This specific model was used in a case study of Hurricane Katrina on local populations (Flanagan et al., 2011).

Many of the aspects that should be considered in mapping and creating a framework from the referenced SOVI are:

1. Socioeconomic status
    - This includes income, poverty, employment and education variables
    - "Economically disadvantaged populations are disproportionately affected by disasters" (Flangan et. al., p. 4, 2011). For example, the poor are less likely to have income or assets to prepare or recover from a disaster.

2. Household composition and disability
    - Age, single parenting and disability variables
    - For children, they lack the necessary resources, knowledge or life experiences to effectively cope with the situation
    - People in any of these categories are likelier to require financial support, transportation, medical care, or assistance with ordinary daily activities during disasters.

3. Minority status and language
    - Comprising race, ethnicity, English language proficiency
    - Social and economic marginalization of certain racial and ethnic groups have rendered these populations more vulnerable at all stages of disaster

4. Housing and transportation

Geographically mapping specific aspect and demographics can show potential population vulnerability that can be used in the different phases of the disaster risk cycle.
*data analysis is usually compiled by using census tracts, usually these are designed to be demographically homogeneous.

Importance of SOVI

Analyzing the components of the Social Vulnerability Index can largely assist in the governance aspect at all levels that are tied to all the phases of the disaster cycle. By understanding the general locations of socially vulnerable communities, planners are able to specify and effectively determine mitigation efforts to these communities. Local responders can determine a faster response route for those who need transportation or special assistance. Especially in situations where the local health system may be in a detrimental state after a disruption along with poor living conditions. In addition, the local government can also provide additional services to hasten the recovery phase to prevent the need for higher upfront costs associated with post-response efforts (Flanagan et al., 2011).

Photo by Author

CRITICAL INFRASTRUCTURE: SYSTEM DEFINITION

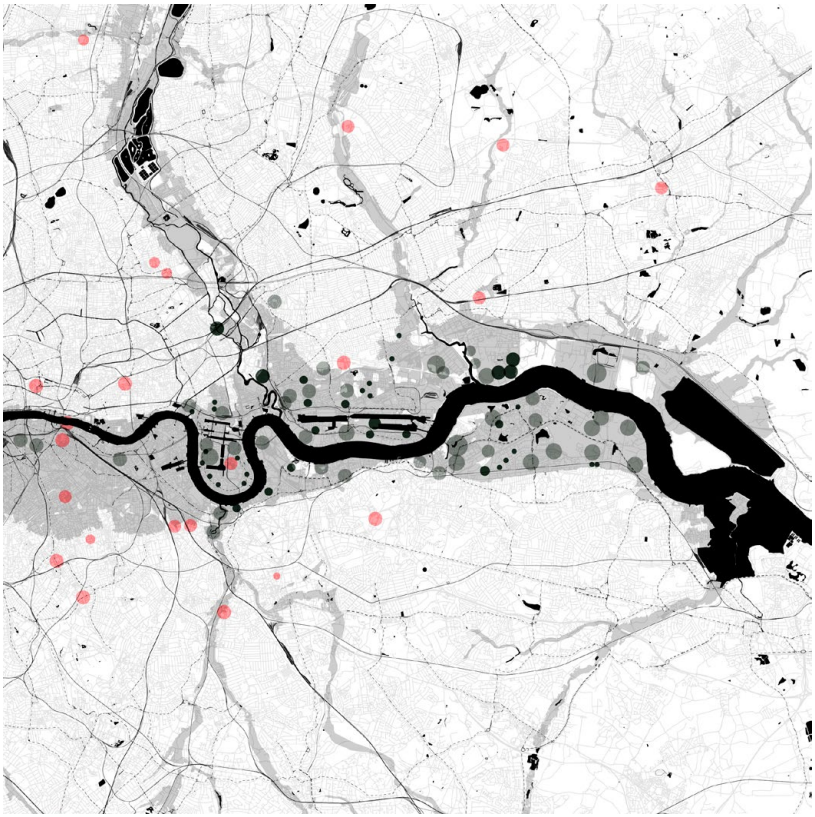


Figure 32 Speculative drawing of critical infrastructure 'pressure points' (Drawing made by author)

5.1 Flood Risk Intensities

Based on the reports from the Environment Agency, three different risk intensities are defined by combining tidal, fluvial and surface water flood risk as seen below.

Flood Risk Intensities

1. **Low-Med:** The area is has a chance of flooding between 1 in 1000 (0.1%) Zone 2
2. **Medium-High:** The area has a chance of flooding between 1 in 100 (1%) Zone 3
3. **High:** The area has a chance of flooding greater than 1 in 30 (3.3%)

Based on the reports from the Environment Agency, three different risk intensities are defined by combining tidal, fluvial and surface water flood risk as seen below.

The Environment Agency in 2016 also released a set of climate change allowances in anticipation for: peak river flow by river basin district, peak rainfall intensity, sea level rise and offshore wind speed and wave height. The most significant risks to the City of London is surface water flooding as well as fluvial and tidal flood risk. The increased rainfall intensity will also increase volumes of water in the sewer system which needs to be accounted for when coping with any future changes. It is important to consider all the different stages of intensities for flood risk in future scenarios.

There is also evidence that fifty percent of those living in flood risk areas in the United Kingdom are oblivious to flood risk and only 10% actually take any action to prepare or be informed about flood risk.

Recommendations:
Further efforts are needed to communicate risks to the public in an easier and digestible way. In addition, there is no way to fully guarantee t hat all the uncertainties against flood risk can be addressed or avoided with built infrastructure against flood risk can be addressed or avoided with built infrastructure.

Assets Above Population Threshold within Extreme Flood Outlines

1. **In all sectors (clean water, electricity, gas, oil, health):** 1640
2. **Total number of potential vulnerable sites:** 820
3. **Net number vulnerable to flooding:** 530

Next 100 Years, central allowances for increases in peak rainfall intensities:

1. **5%** in the 2020s (2015-2039)
2. **10%** in the 2050s (2040-2069)
3. **20%** in the 2080s (2070-2115)

Peak river flows in the Thames River Basin District is expected to increase by:

1. **25%** in the 2020s (2015-2039)
2. **35%** in the 2050s (2040-2069)
3. **70%** in the 2080s (2070-2115)

Sea level rise allowances are expected to increase by 1.21m between 1990 and 2115. Increases per epoch are listed below:

1. **4mm/year** (1990-2025)
2. **8.5mm/year** (2026-2055)
3. **12mm/year** (2056-2085)
4. **15mm/year** (2086-2115)

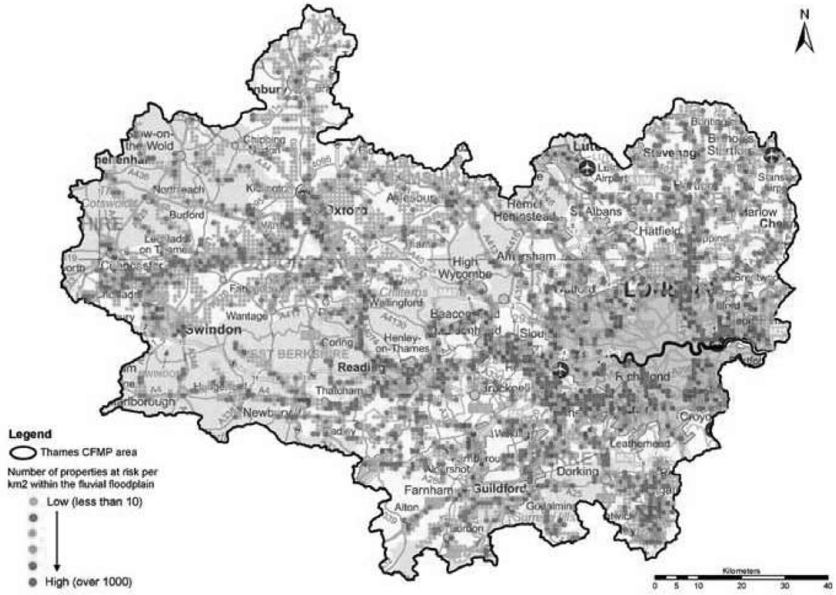


Figure 33 Disruption of properties at risk from flooding from rivers in the Thames CFMP area (assets.publishing.service.gov.uk)

5.2 Thames River Basin Catchment Area

London and the Lower Thames have the greatest total number of people and property at risk. The number of properties in the floodplain in these areas represents 60% of the total at risk in the Thames CFMP area (The Environment Food and Rural Affairs Commitee, 2009). Over 18,000 marked properties are found to be exposed in the Lower Thames and over 19,000 in the Lower Lee.

Flooding in the Thames CFMP area can occur from: rivers (fluvial flooding), urban drainage systems (surface water and sewer flooding) and rising groundwater levels. The Thames CFMP focuses on the risks from river flooding, as there is limited existing data available on flooding from surface water and groundwater within the region. The future management of tidal flood risk in London is being addressed in the Thames Estuary 2100 Flood Risk Management Plan (TE2100). It's also important to note that more frequent, short duration, intense storms in summer have caused more widespread and regular 'flash flooding' from overwhelmed drainage systems and some rivers.

It is estimated that the number of properties at a 1% risk of flooding from rivers in the Thames CFMP area will increase by approximately 20%, as a result of climate change. Most predominantly, properties that reside within flat floodplains will be at higher risks of flooding.

Flood Zone	Definition (Provided by Environment Agency, 2016)
Level 1 Low Probability	Land having a less than 1 in 1,000 annual probability of river or sea flooding. (Shown as 'clear' on the Flood Map – all land outside Zones 2 and 3)
Zone 2 Medium Probability	Land having between a 1 in 100 and 1 in 1,000 annual probability of river flooding; or land having between a 1 in 200 and 1 in 1,000 annual probability of sea flooding.
Zone 3a High Probability	Land having a 1 in 100 or greater annual probability of river flooding; or Land having a 1 in 200 or greater annual probability of sea flooding

5.3 Thames Estuary: Hazards & Risks

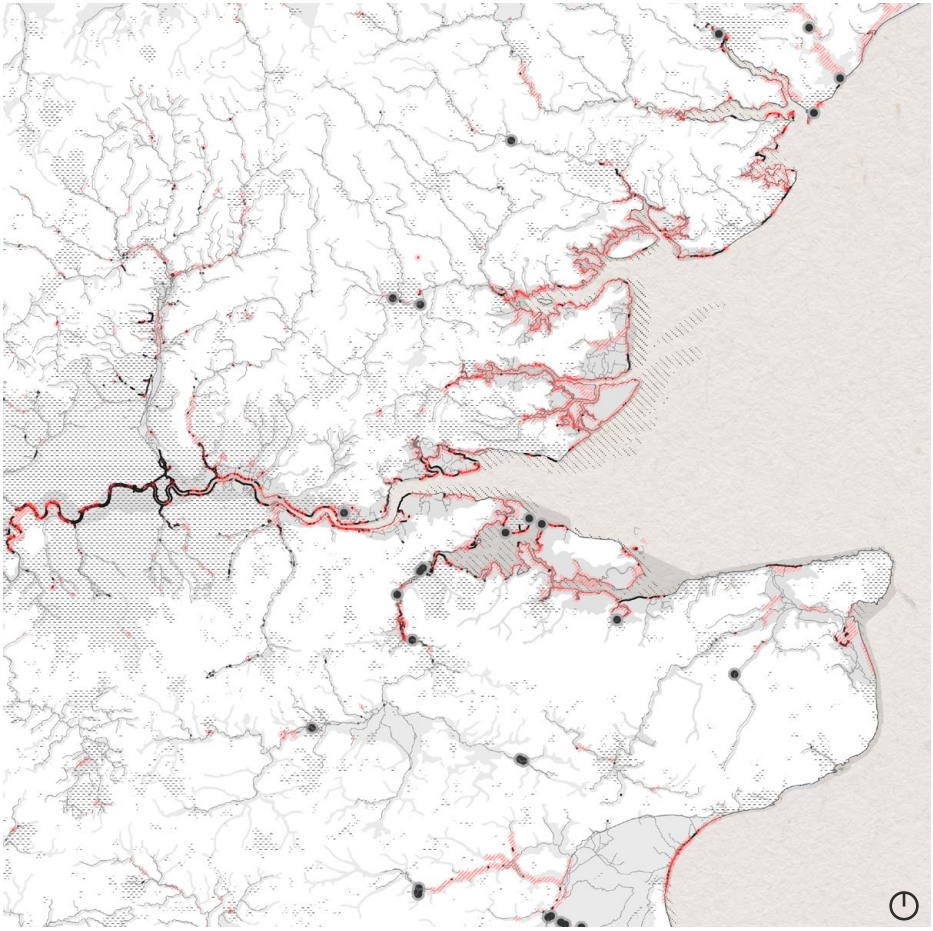


Figure 34 Existing flood defences (Map by Author)

Urbanized Area
Dunes
High ground
Wall
Demountable defence
Flood gate

The next series of maps were used to build a spatial body of knowledge related to flood risk in the Thames Estuary. This is essential as it will formulate and assist in assessing current levels of risk and exposure present in the Thames.

Relative to the existing flood defences, as mentioned earlier in the report, as SLR begins to increase, the performance levels of existing defences begin to lower. It is important to consider that the urbanized regions along the Thames have more artificial and higher forms of hard defences such as the Thames Barrier.

Figure 35 Flood Alert Areas (Map by Author, Source: Ordnance Survey)

Urbanized Area Flood alert areas

The following flood alert areas are geographical areas defined by the Environment Agency. Along with the flood alert map, the historic flood map, flood defences and flood risk zones give a better scope of what is currently at risk along the Thames. Flood alert areas may cover floodplains and also multiple catchment areas with similar characteristics. Typically, flood alerts are issued to warn populations of a possibility of flooding.

The flood alert areas predominantly cover majority of the regions are along the coastal areas of the UK and covers a large portion of the Greater London Area.

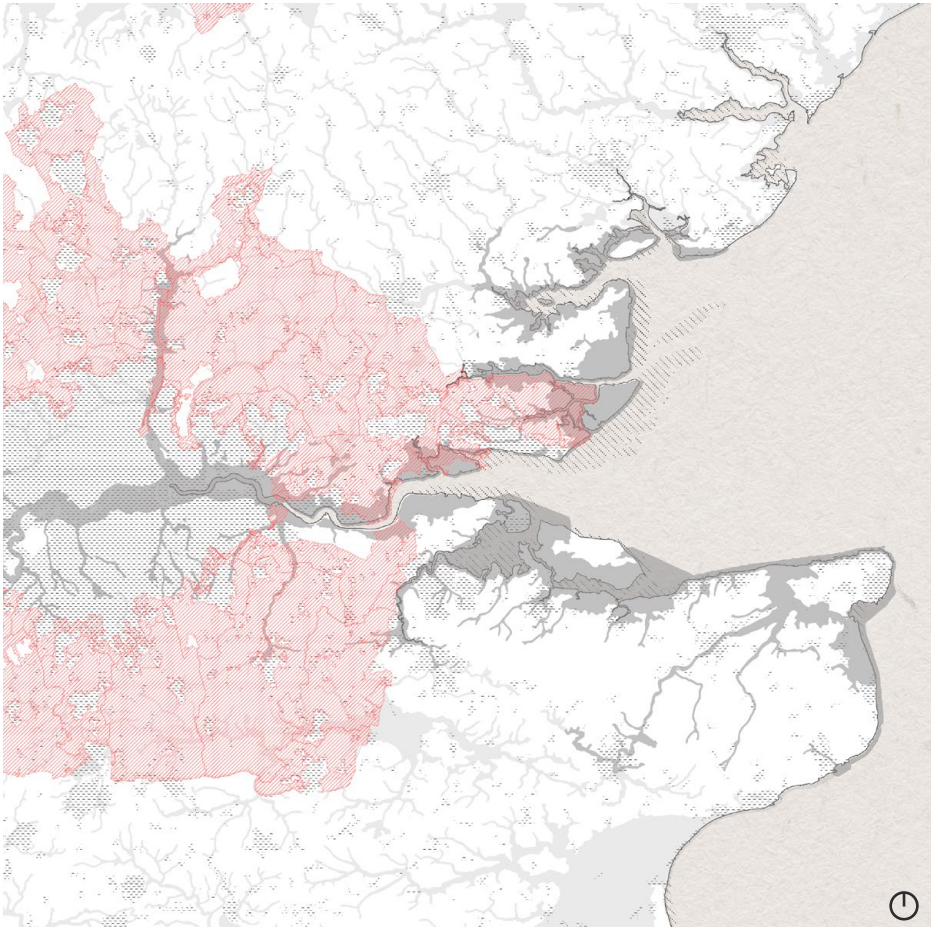


Figure 36 Environmental Restrictions/Hazards (Map by Author)

The green belt land areas are commonly reserved for open space and tends to be located around large cities, in this case, London. The main purpose of implementing the green belt policy is to prevent urban sprawl, maintain a designated area for forestry, agriculture as well as to provide habitat to wildlife. It also offers an additional reassurance to have open space for water drainage and capacity. However, the green belt is also primarily outside of the flood risk zones and flood warning areas. In addition, with the proposal of the TE2100, more habitats may be at loss with the upcoming hard defence infrastructure to be implemented.

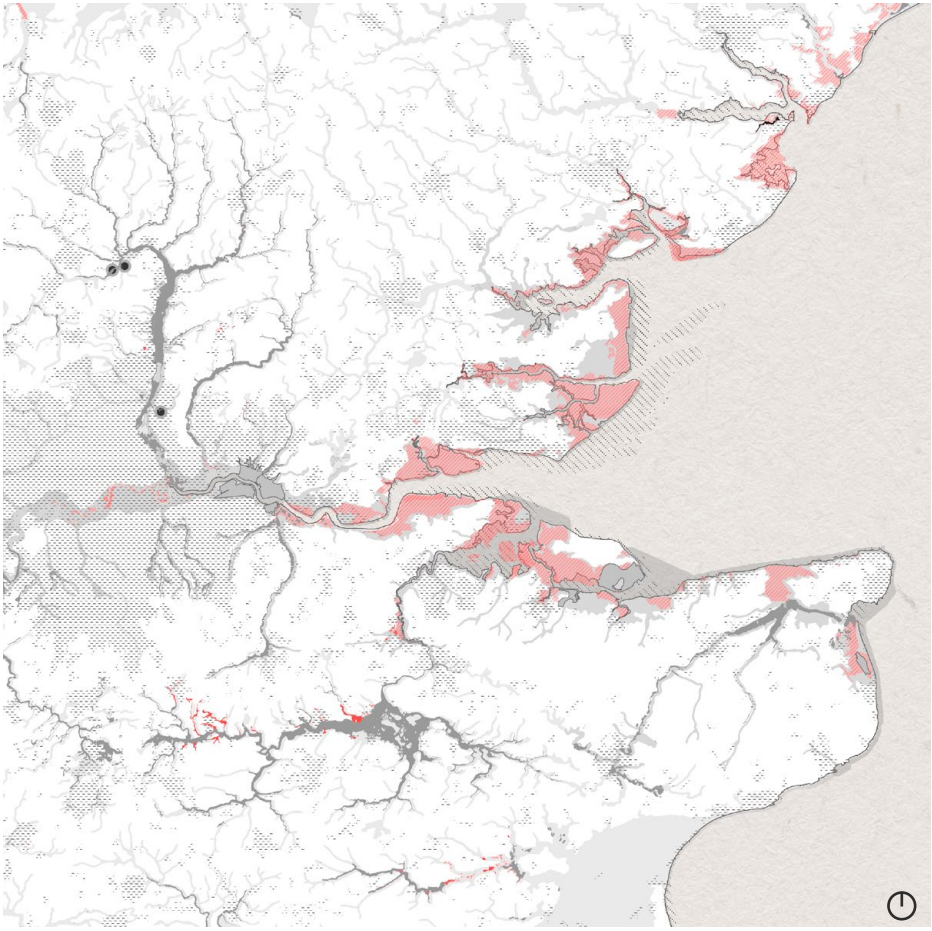


Figure 37 Historic flood map and causes for flooding (Map by Author, Source: Ordnance Survey)

Based on the historic data provided by the Ordnance Survey, previous causes of floods were the result of over topping of defences or the channel capacity had been exceeded. As SLR increases, this will put even more pressure on the capacity of the water infrastructure systems as well as failure in defence systems. Areas with previous history with flood risks are still exposed to increasing frequencies and intensities of floods. Based on the climate scenarios, coastal locations and the Thames Estuary can experience floods 10 to 20 times more frequently. Historically, the flood of 1953 also catalyzed the construction of the current Thames River tidal defences, which has provided substantial flood defences for the UK for over 20 years.

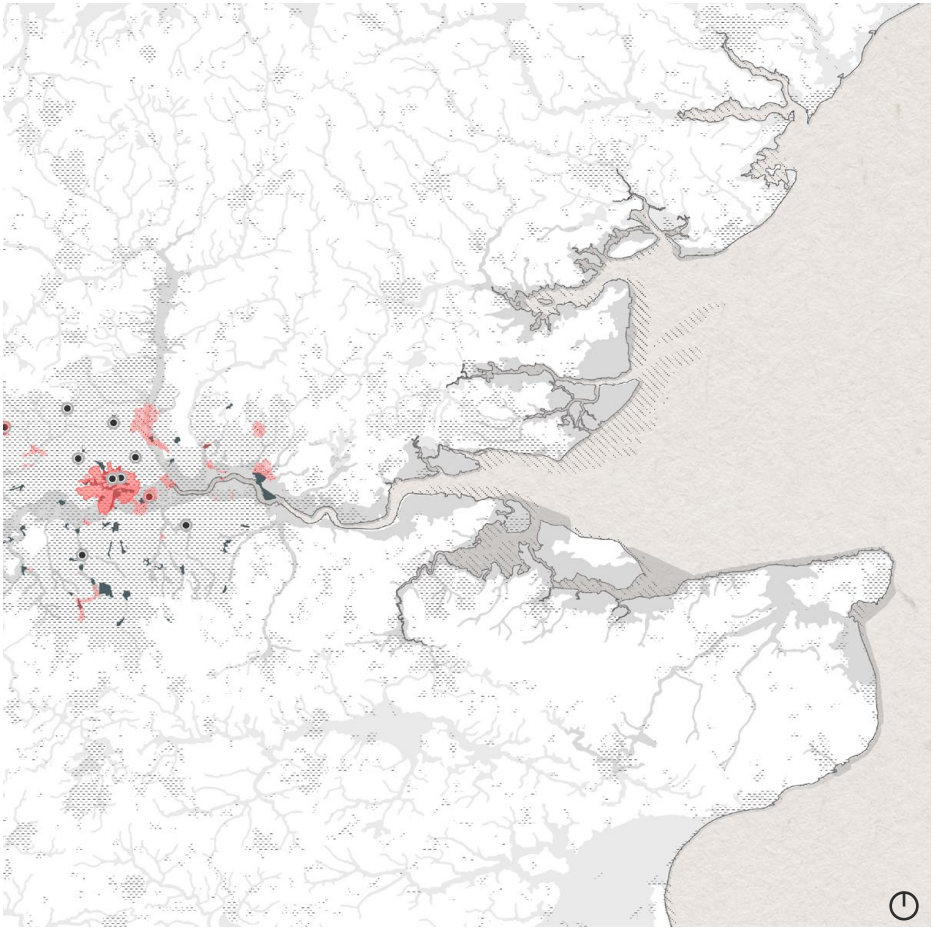


Figure 38 Intensification areas in relation to current flood risk (Map by Author)

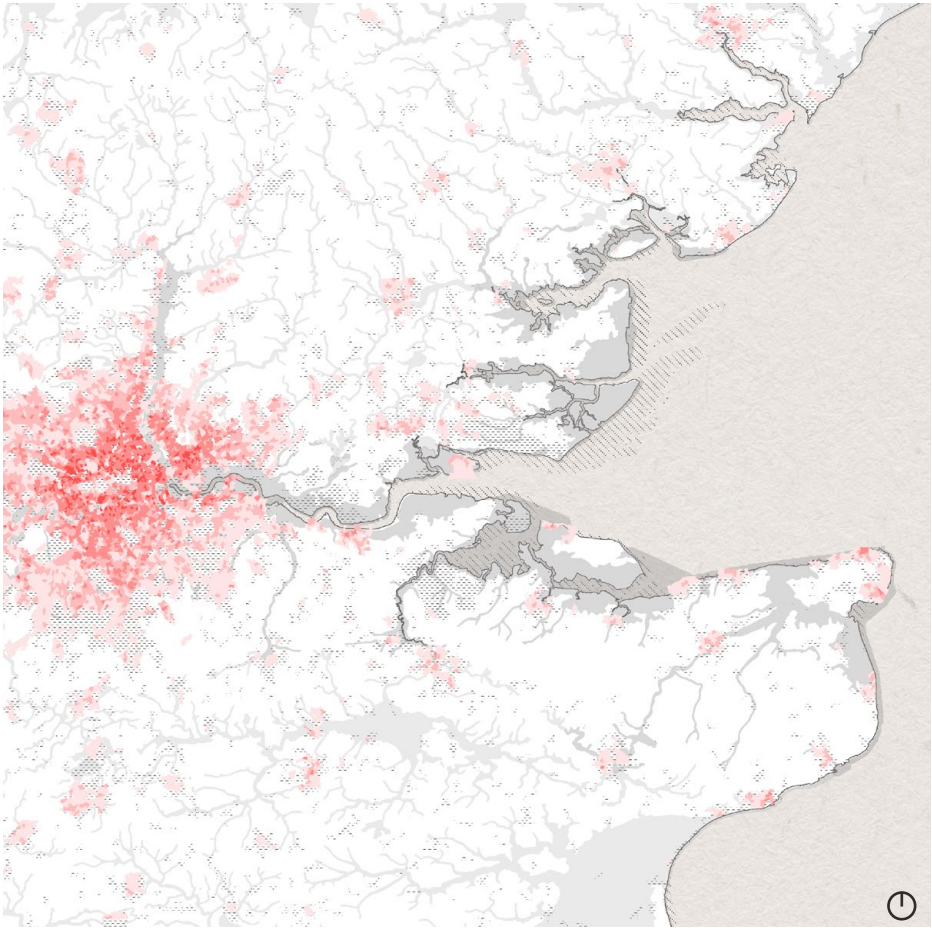


Figure 39 Population density relative to flood risk (Map by Author, Souce: Ordnance Survey)

The Thames Flood Risk Management plan covers over 17 catchments stretching over 1487km², which is treated as a relatively small region. However, the largest challenge is that it contains the largest population of any management catchment. This also results in many complex and conflicting socio-economic pressures and interests.

5.4 Critical Lifelines in the Thames Estuary

Flood Hazard Mapping & Exposure Maps
In the macro scale, the purpose is to identify risk zones with a high density of critical infrastructure networks and systems. As part of the first phase in the multi-criteria analysis, this section is directed to find and prioritize the most relevant risk sites, assess the current levels of risk and have an understanding of which neighbourhoods are most vulnerable. However, in order to do so, a spatial analysis needs to be conducted for each system. This includes identifying flood risk hazards that impact the CI at three different likelihoods of flood events.

To conduct the spatial analysis, a projected set of flood risks and hazards are placed upon the major infrastructure systems. Hazards can have severe disruptions to loss of livelihoods, services, economic disruptions and environmental damage (United Nations secretariat of the International Strategy for Disaster Reduction, United Nations Office for Coordination of, & Humanitarian Affairs, 2008). The susceptibility of these hazards and frequency of flooding should be considered for future planning. Using ArcMap and the spatial analysis tools, all systems (points and lines) that intersected the flood risks are emphasized.
The following data of critical infrastructure systems were analyzed:

1. Rail networks & subway stations
2. Road networks
3. Medical facilities /hospitals
4. Emergency services
5. Schools & leisure facilities
6. Utilities Infrastructure
7. Waste & Water Infrastructure

**Statistics were gathered from the regional flood risk appraisal conducted in 2018.*

The previous set of maps were developed to have a better understanding of the impact and historical patterns of flooding in the Thames Estuary. In the next series, an additional layer of social vulnerability is accounted for.

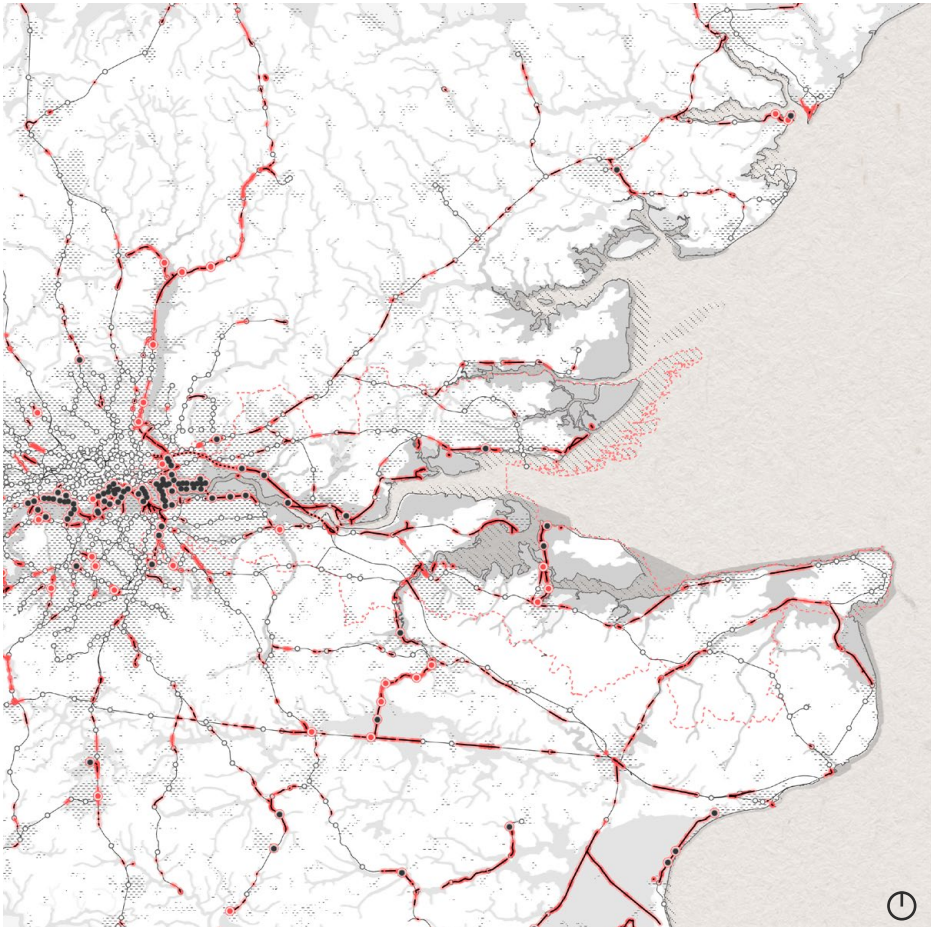


Figure 40 Rail network at flood risk, Source: Made by author, Data from Ordnance Survey, 2017

Urbanized Area
Flood Zone 3
Flood Zone 2

All stations outside of flood zone
Stations in Flood Zone 3
Stations in Flood Zone 2

All other rail tracks
Rail in Flood Zone 3
Rail in Flood Zone 2

Thames Estuary 2050 Growth Boundary

Flood Event	Rail stations in flood area	Rail stations outside flood area	Total rail stations	Portion in flood zone
1 in 30 flood	85	275	360	24%
1 in 100 flood	106	254	360	29%
	Rail length in flood area (km)	**Rail length outside flood area (km)**	**Total rail length (km)**	**Portion in flood zone**
1 in 30 flood	87	740	827	11%
1 in 100 flood	111	715	827	13%

Data adapted from (Greater London Authority, 2018)

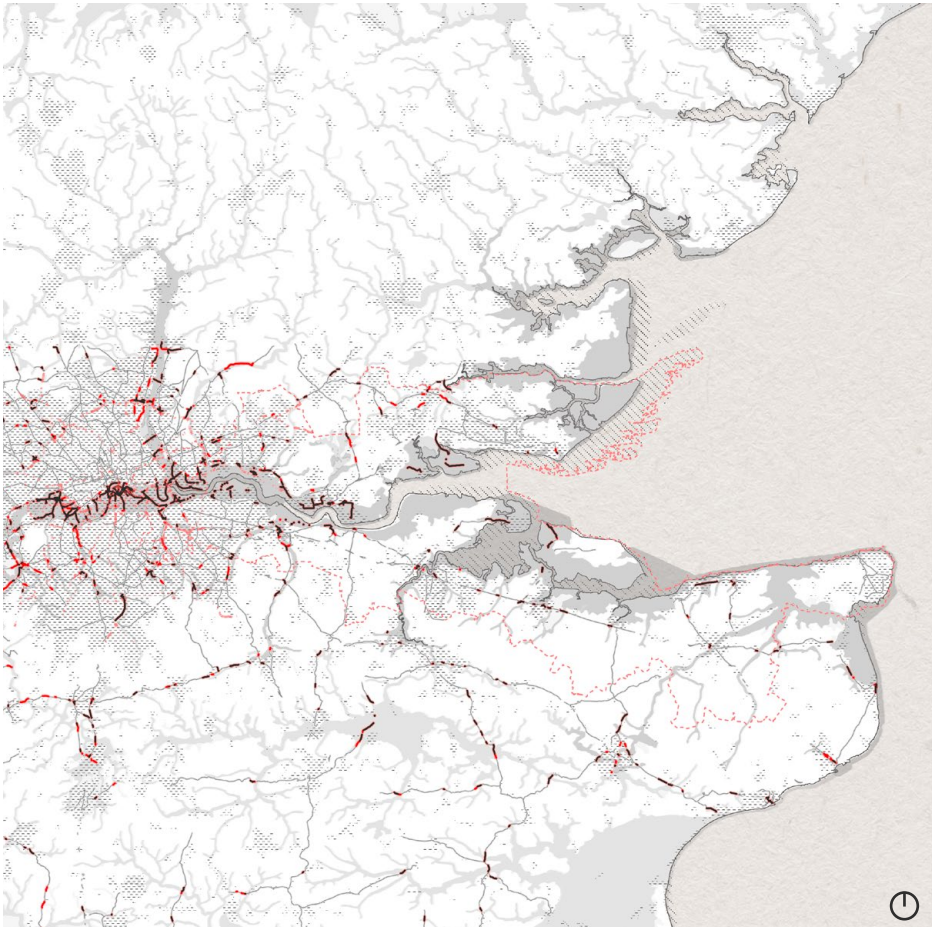


Figure 41 Road networks at flood risk, Source: Made by author, Data from Ordnance Survey, 2017

Flood Event	Roads length in flood area (km)	Roads length outside flood area (km)	Total road length (km)	Portion in flood zone
1 in 30 flood	125.2	1007.4	1132.7	11%
1 in 100 flood	163.3	969.4	1132.7	14%

Data adapted from (Greater London Authority, 2018)

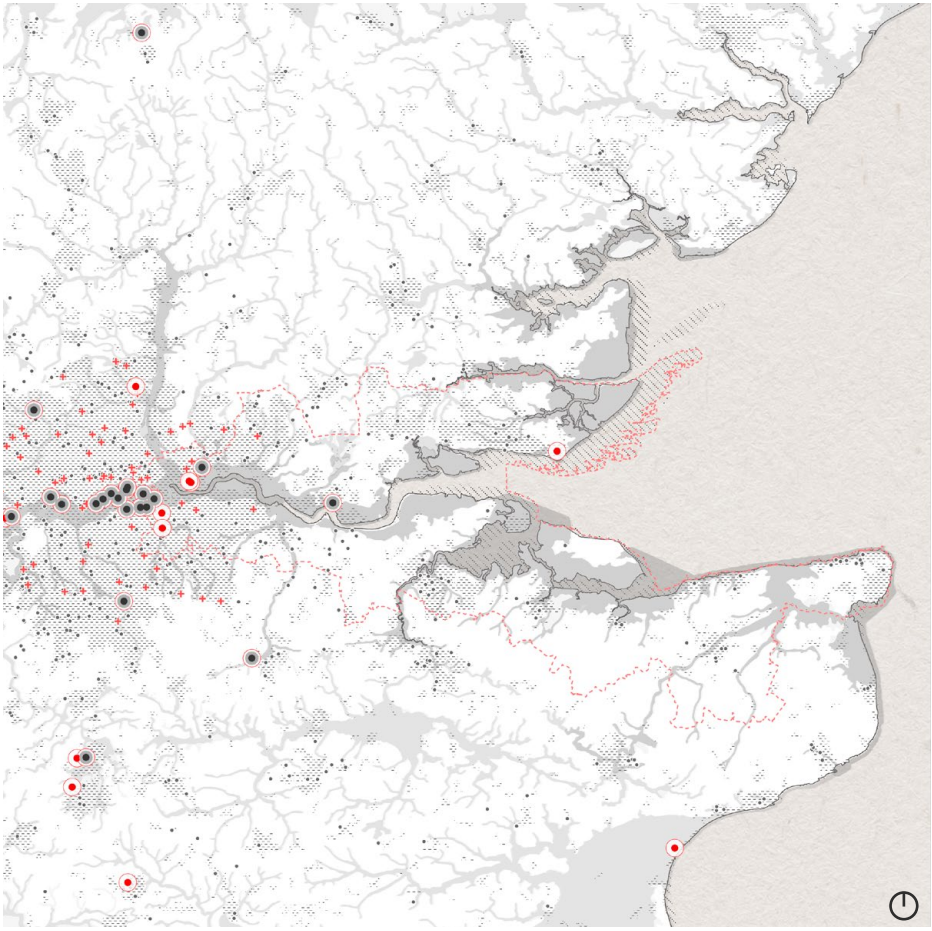


Figure 42 Hospitals at flood risk, Source: Made by author, Data from Ordnance Survey, 2017

Urbanized Area
Flood Zone 3
Flood Zone 2
All medical facilities outside of flood areas
Medical facilities in Flood Zone 3
Medical facilities in Flood Zone 2
Medical facilities in 1 in 30 year risk
Thames Estuary 2050 Growth Boundary

Flood Event	Number in flood area	Number outside flood area	Total number in greater London	Percent in flood area
1 in 30 flood	82	111	193	42%
1 in 100 flood	92	101	193	48%

Data adapted from (Greater London Authority, 2018)

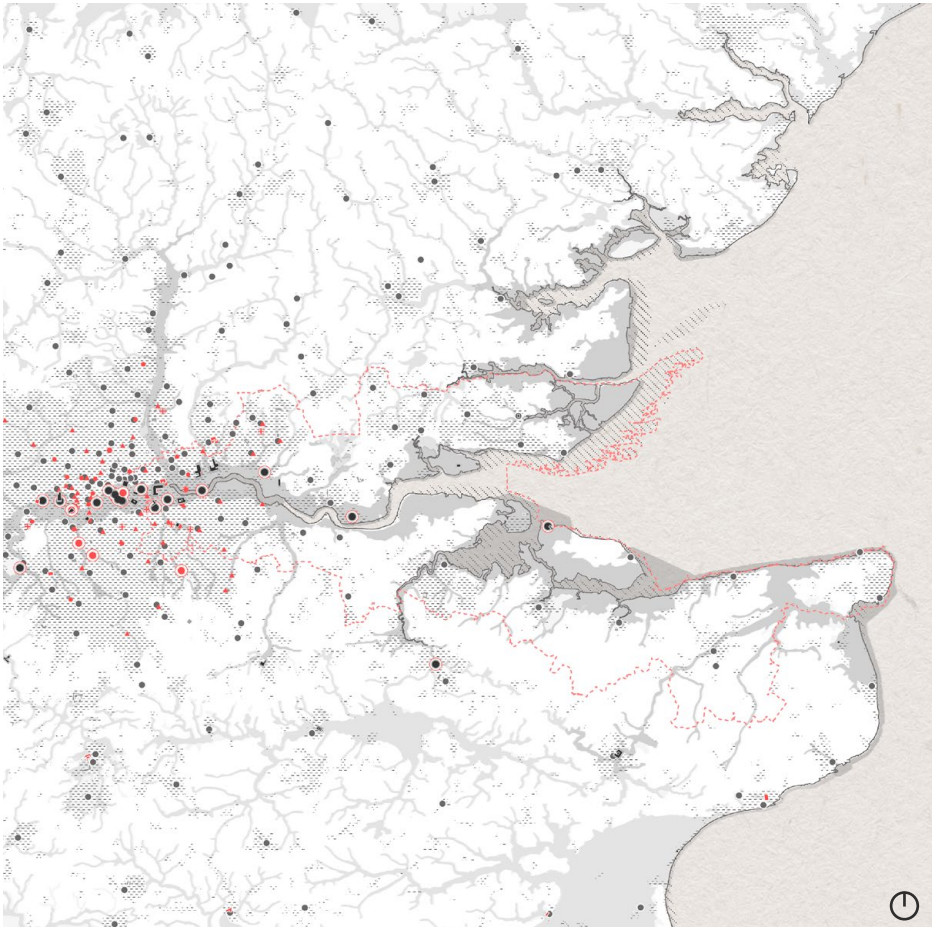


Figure 43 Emergency services at flood risk, Source: Made by author, Data from Ordnance Survey, 2017

Flood Event	Ambulance	Fire Stations	Police
1 in 30 flood	12	28	58
1 in 100 flood	13	38	68
% in flood (1 in 30)	19%	24%	25%
% in flood (1 in 100)	20%	27%	29%

Data adapted from (Greater London Authority, 2018)

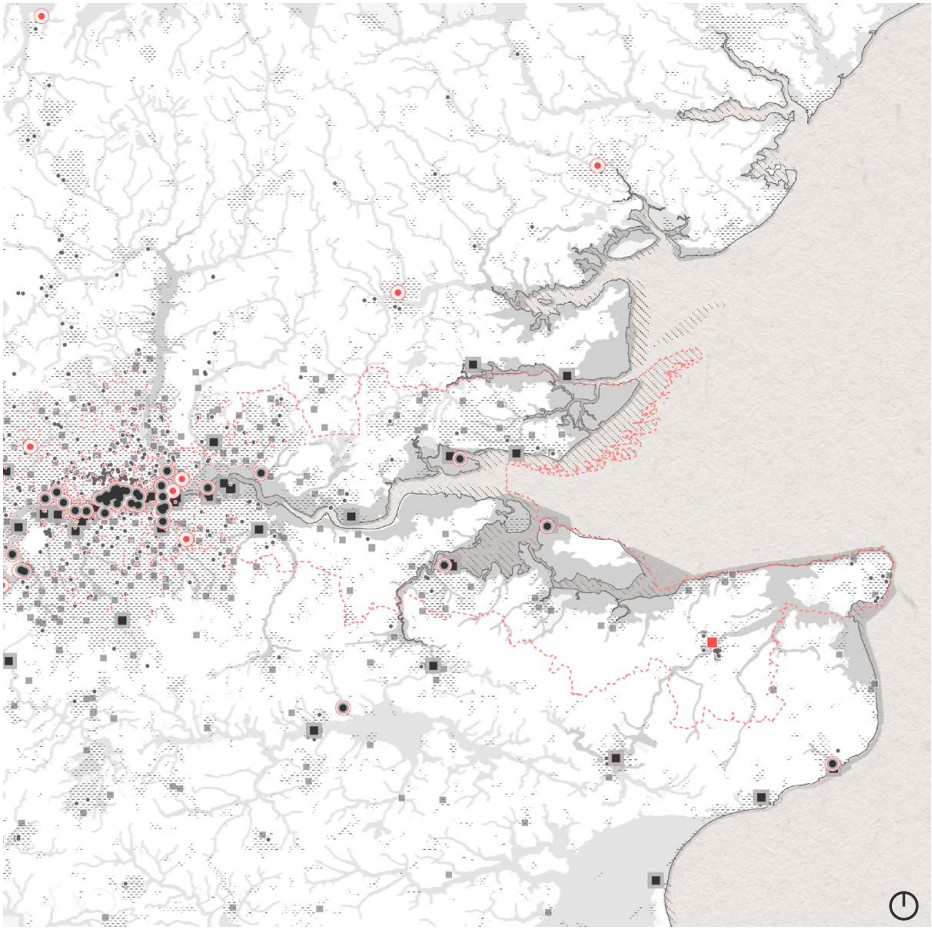


Figure 44 Schools and leisure areas at flood risk, Source: Made by author, Data from Ordnance Survey, 2017

Flood Event	Schools in flood area	Schools outside flood area	Total in GL	Percent in flood zone
1 in 30 flood	643	2252	2895	22%
1 in 100 flood	781	2114	2895	27%

Data adapted from (Greater London Authority, 2018)

Figure 45 Utilities infrastructure at flood risk (includes electricity supply, gas, telecommunications, sewage and water supply), Source: Made by author, Data from Ordnance Survey, 2017

Flood Event	Number in flood area	Number outside flood area	Total in GL	Percent in flood zone
1 in 30 flood	261	326	587	44%
1 in 100 flood	286	301	587	49%

Data adapted from (Greater London Authority, 2018)

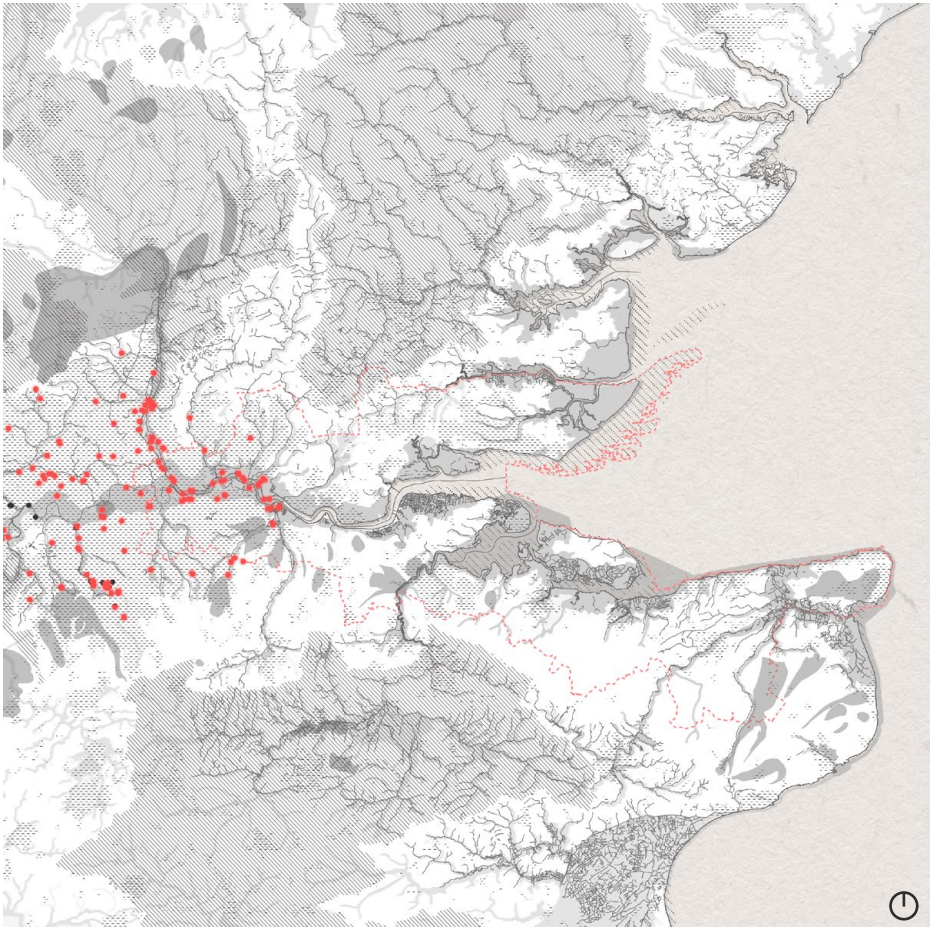


Figure 46 Water and waste treatments at risk, Source: Made by author, Data from Ordnance Survey, 2017

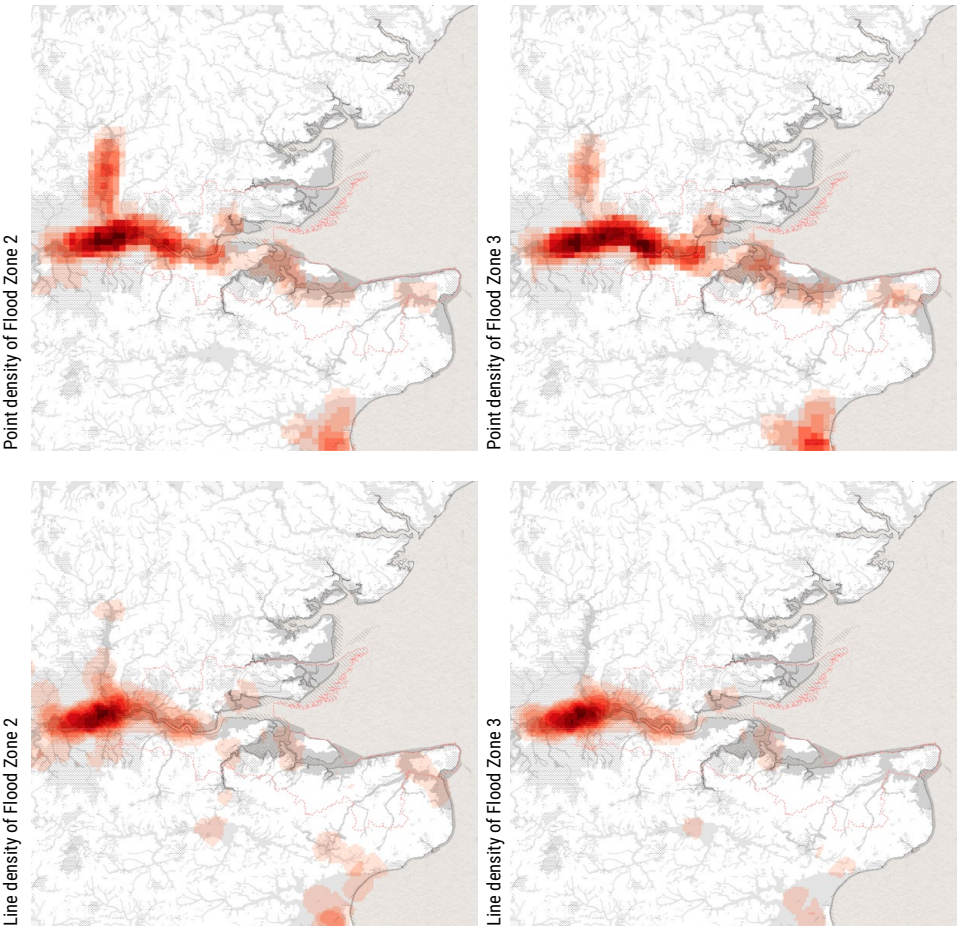


Figure 47 Point and line densities of critical infrastructure. Source: Made by author

Critical Infrastructure Density Maps Relative to Flood Risk Intensities

The initial step of creating the density maps included spatial intersections of critical infrastructure systems with the flood intensities (flood zone 2 & 3). The same parameters were defined to include sq.km buffer areas to perform the point and line density spatial analysis. This allowed for the comparison between the 4 maps. Once the rasterized maps were produced, high density areas were calculated to showcase the magnitude per unit area that the points and line segments were located in per neighbourhood.

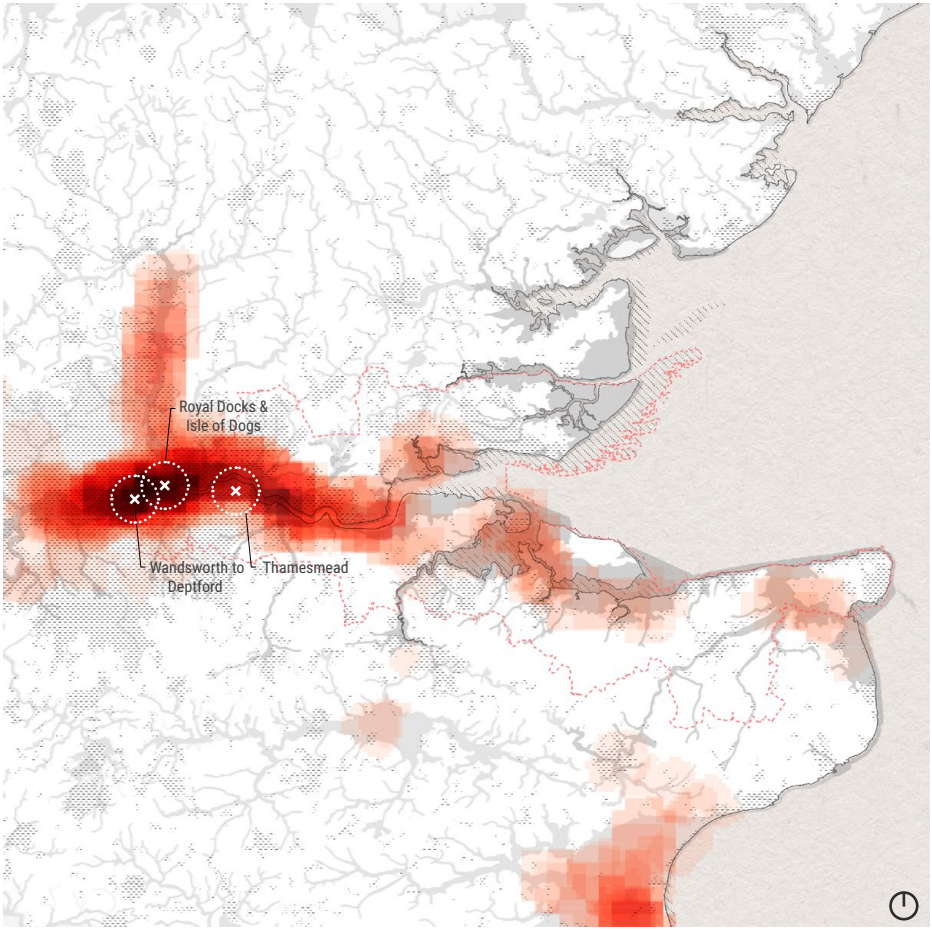


Figure 48 Combined flood risk intensities. Source: Made by author

Combined Flood Risk Intensities & TE2100 Policy Units

The identified areas with the highest magnitude of critical infrastructure also correspond with the TE2100 policy units.

1. Wandsworth to Deptford
2. Thamesmead
3. Royal Docks & Isle of Dogs

5.5 Social Vulnerabilities

Traditionally, in both research and practise, there is a larger focus and scope on physical vulnerability. To paint a more realistic picture of the uneven distribution of vulnerabilities in the existing system, a Neighbourhood Flood Vulnerability Index (NFVI) and Social Flood Risk Index (SFRI) was used. However, due to the limited time frame of the project, the outcome of the analysis was only used in determining the neighbourhood project locations.

The main asset of the maps would be determining the areas that require an urgency of adaptation alongside areas with higher levels of flood vulnerability. These specific areas would also prelude to an indication of additional services required to assist in the response and evacuation phase of a disaster.

The Neighbourhood Flood Vulnerability Index (NFVI) was used to compare risks between more and less flood vulnerable neighbourhoods (where vulnerability is characterized in terms of communities experiencing a loss in wellbeing when floods occur) and a Social Flood Risk Index (SFRI) is used to identify where vulnerability and exposure coincide to create flood disadvantage.

"The results highlight significant variation in flood disadvantage across the UK. For example, ten local authorities account for fifty percent of the most vulnerable people that live in flood prone areas (those living in the 5% most vulnerable neighbourhoods according to the NFVI). Coastal areas, declining urban cities and dispersed rural communities are also highlighted as representing the greatest concentrations of disadvantage (as measured by the Social Flood Risk Index, SFRI)" (Sayers, P.B., Horritt, M., Penning Rowsell, E., and Fieth, p. 2, 2017). Also, By the 2080s more and less vulnerable neighbourhoods will both experience more frequent floods.

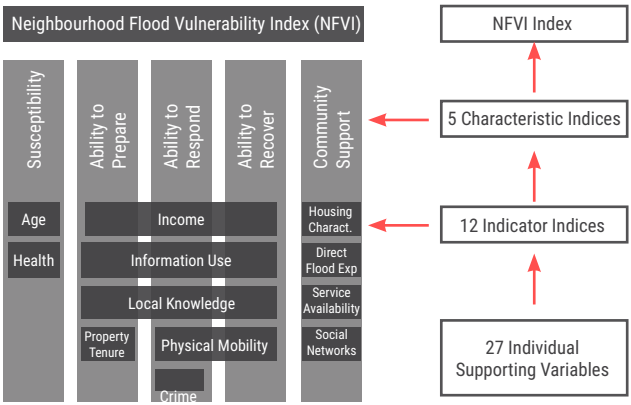
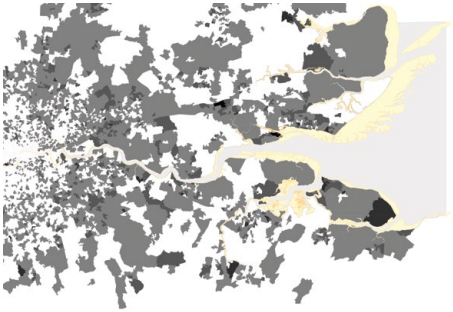


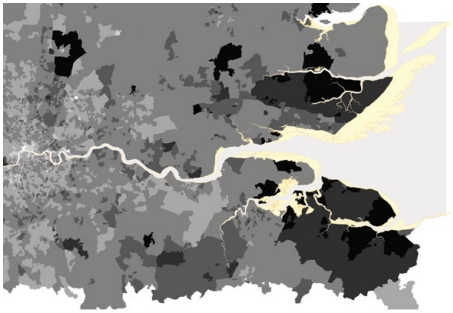
Figure 49 Structure of social vulnerability according to Neighbourhood Flood Vulnerability Index (NFVI) - 12 indicators and 27 supporting variables make up the structure (Present and future flood vulnerability, risk and disadvantage A UK assessment EXECUTIVE SUMMARY Prepared for Joseph Rowntree Foundation, Climate Change and Communities Programme, 2017)

Dimension	Indicator	Supporting variable (%)		Explanation
Susceptibility	Age	a1, a2	Young & old (% people under 5 years and % over 75)	Describing the predisposition of an individual to experience a loss of well-being when exposed to a flood. The dominant characteristics that influence susceptibility to harm relate to the age (the old and very young) and health of the individuals exposed.
	Health	h1, h2	Disabilities & household with at least one person with limiting illness	
Community Support	Housing Characteristic	hc1	Caravan or other temporary shelters in households	Recognizing how the availability and quality of services provided by health and emergency services as well as broader care and social services influence the severity of harm caused by a flood . A formal representation of community cohesion and its influence on flood vulnerability is not available. However, the following are considered to gauge the nature of this support: housing characteristics; the collective experience of past floods; the likely availability of community services in a flood (including emergency service
	Direct Flood Exposure	e1	No. of properties exposed to significant flood risk	
	Service Availability	s1-4	Emergency services exposed to flooding	
	Social Networks	n1-3	Single pensioner household, lone-parent household with dependent children, children of primary school age	
Ability to Prepare Index	Income	i1-5	Unemployed, long-term unemployed, low income occupations, households with dependent children, people income deprived	Reflecting the actions taken by an individual during normal conditions (i.e. in the absence of a forecast or actual flood) that are likely to reduce the harm they suffer when a future flood occurs. Although an area of continued research, an individual's ability to prepare is influenced by their income, capacity to act, local knowledge and property tenure.
	Information use	f1, f2	Recent arrivals to UK and proficiency in English	
	Local knowledge	k1	New migrants from outside the local area	
	Property tenure	t1-2	Private renters and social renters	
Ability to Respond Index	Income	i1-5	(%) Unemployed, long term unemployment, low income, dependent children, people income deprived	Reflecting the underlying reasons why some individuals act more effectively in the run up to and during a flood. Although this is an area of continued research, there is broad agreement that an individual's ability to respond is influenced by their income, capacity to access and use formal and informal information, local knowledge and physical mobility.
	Information Use	f1-2	Recent arrivals to UK and proficiency in English	
	Local knowledge	k1	New migrants from outside the local area	
	Physical Mobility	m1-3	High levels of disability, people living in medical and care establishments, lack of private transport	
	Crime	c1	High levels of crime	
Ability to Recover Index	Income	i1-5	Unemployed, long-term unemployed, low income occupations, households with dependent children, people income deprived	Reflecting the degree to which an individual can aid their own recovery is influenced by several factors, particularly their income, capacity to use information, and physical mobility. Many flood events have highlighted the length of time it can take for individuals and communities to recover from a flood.
	Information Use	f1-2	Recent arrivals to UK and proficiency in English	
	Physical Mobility	m1-3	High levels of disability, people living in medical and care establishments, lack of private transport	

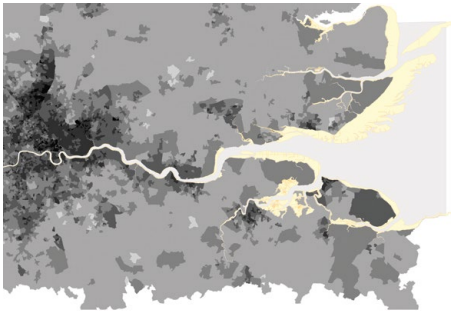
Figure 50 Domains and explanation of metrics used for social mappings of vulnerability (Adapted from Sayers, P.B., Horritt, M., Penning Rowsell, E., and Fieth, J. (2017). Present and future flood vulnerability risk and disadvantage: A UK scale assessment. A report for the Joseph Rowntree Foundation published by Sayers and Partners LLP. Table 3.2 (page 27)



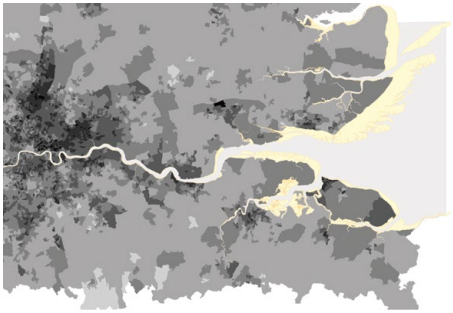
NFVI_Susceptibility



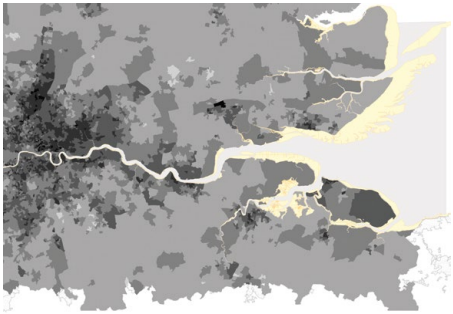
NFVI_Community Support



NFVI_Ability to be Prepared Index



NFVI_Ability to Recover Index



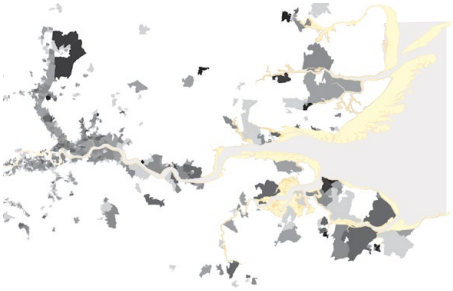
NFVI_Ability to be Respond Index

Legend

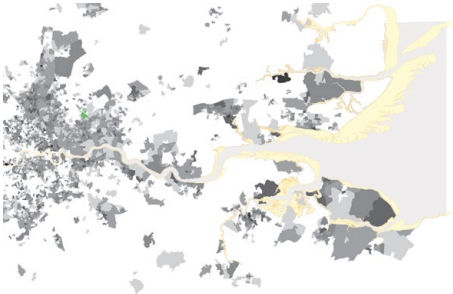
- Slight
- Very Low
- Relatively low
- UK Average
- Relatively High
- Very High
- Acute

To gain a better understanding of the set of data from Climate Just (University of Manchester, the Joseph Rowntree Foundation, 2017), 5 vulnerabilities are considered and the scores given from each indicator was used with different weightings. From here the Neighbourhood Flood Vulnerability Index was created.

The maps of social vulnerability to flooding show and explain how social and environmental factors can have uneven impacts impact particular neighbourhoods. “The Neighbourhood Flood Vulnerability Index (NFVI) provides insight into the social vulnerability of a neighbourhood should a flood occur. It estimates how far individuals may experience a loss in well-being if exposed to a flood as well as their ability to prepare, respond and recover from a flood (without significant emergency support from the authorities). A neighbourhood is defined by census geographies (i.e. Lower Super Outputs Areas (LSOAs)” (Sayers, P.B., Horritt, M., Penning Rowsell, E., and Fieth, p. 13, 2017)

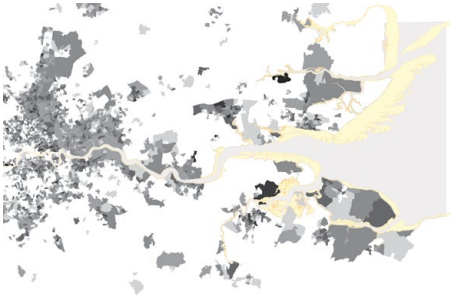


SFRI_Fluvial_Present Day



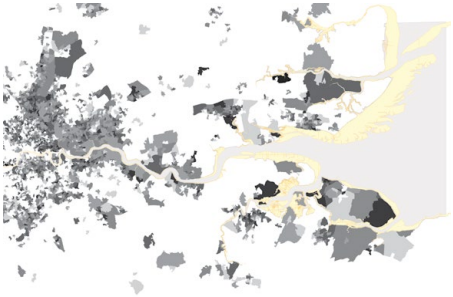
SFRI_Surface Flooding_Present Day

SFRI_Fluvial_2 Degrees Rise



SFRI_Surface Flooding_2 Degrees Rise

SFRI_Fluvial_4 Degrees Rise



SFRI_Surface_4 Degrees Rise

Legend

- Exposed
- Low
- Moderate
- High
- Very High
- Acute
- Extreme

Future scenarios were used to assess present day flood risks (climate change, population growth and adaptation) the climate projections 2°C and 4°C rise in Global Mean Temperature (GMT) by the 2080s .

5.6 Governance Systems - Mitigating Flood Risk

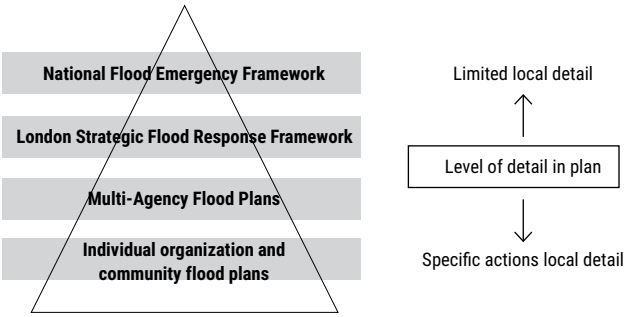


Figure 51 Current flood related plans from the UK (National Framework) to individual community plans (Strategic Flood Response Framework, p. 5, 2015)

The following diagrams (figure 51-53) outline the complicated governance structure from the national flood emergency framework to individual organizations. Each governing body, whether public or private, has their own set of objectives. This also helps visualize the coordination and execution of the stakeholders involved in spatial planning, risk management and the execution of the projects. The main issue outlined is that the administrative governing bodies roles and responsibilities becomes more fragmented from the planning to the delivery of flood plans.

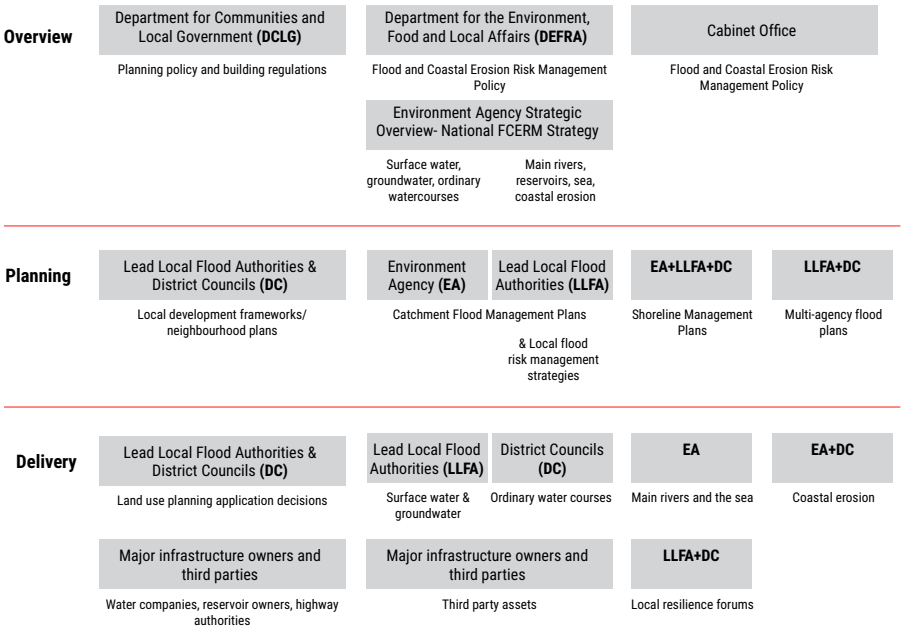


Figure 52 Existing overview of governance adapted from (Strategic Flood Response Framework, p. 5, 2015)

Flood Risk Type/ Organization	Main rivers (large rivers)	Watercourses (small rivers)	Surface water	Groundwater	Sewer Flooding	Road drainage	Canals and artificial waterways
Environment Agency	X						
London Boroughs (Lead local flood authorities and highways authorities)		X	X	X		X	
Highways England						X (M Roads)	
Transport for London (TfL)						X (Red route roads TLRN)	
Utility Companies					X		
Canal and Rivers Trust							X

Figure 53 Flood Risk types and organization responsibilities(Strategic Flood Response Framework, p. 15, 2015)

5.7 Existing Thames Estuary 2100 Dynamic Adaptive Pathways

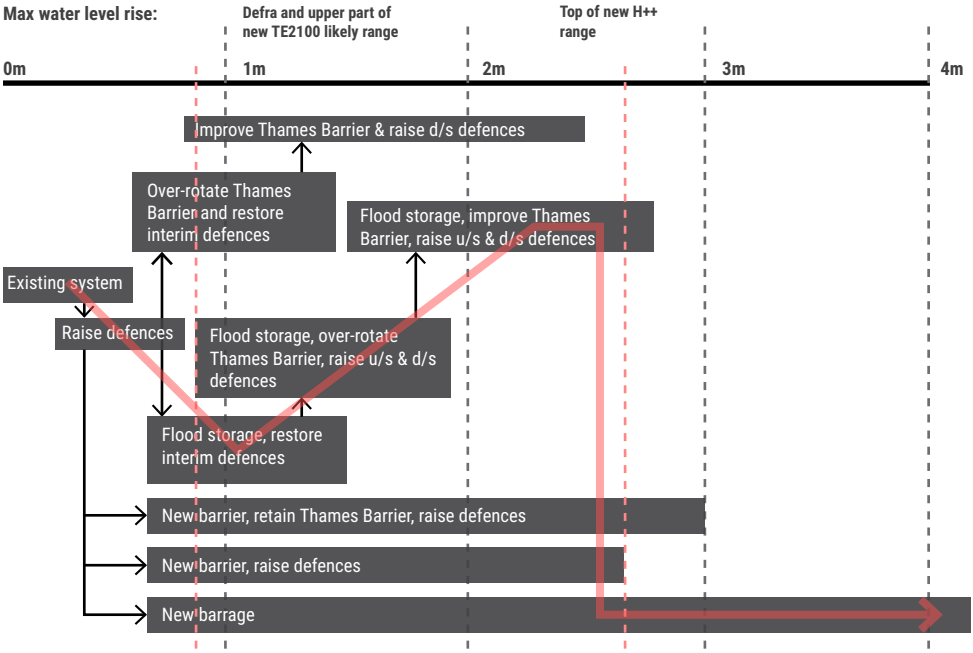


Figure 54 Adaptation pathway map for the Thames Estuary as shown in the TE2100 (Ranger et al., 2013)

The plan predominantly focuses on mitigating future flood risks with continued renewal and reliance on hard structured defences. As mentioned previously, the other phases of risk management are not addressed within the current Dynamic Adaptive Pathways (DAP) diagram nor was it designed with those intentions. However, there are several notable innovations and strengths born from the construction of the TE2100 plan which includes built in flexibility through a combination of methods:

A. ***Low regret measures*** being implemented in the new term. To reduce risks effectively and immediately with cost-efficiency under a wide range of climate scenarios ex. raising existing flood defences. This allows for the reduction of residual risks and also buys time for the monitoring before any major investments.

B. ***Structural flexibility*** - engineering in flexibility so infrastructure can be adjusted or enhanced in the future at minimal additional cost. The goal was to also increase safety margins and there is an expectation that over engineered infrastructure would be able to cope with future changes and also expect greater damage.

C. ***Pathway flexibility*** - DAP - plans are implemented iteratively and designed to be adjusted based on learning about the future. The timing of new interventions and interventions themselves are adjusted over time.

Critique on the TE2100: Decentralized Implementation of Flood Resilience Measures

Within academia and policy-makers around the world, the Thames Estuary 2100 plan has been applauded and has gained vast attention for its innovative methods of developing a long-term estuary wide approach (Restemeyer, Van Den Brink, & Woltjer, p.1, 2018). The plan currently promotes a dynamic spatial planning method of flood resilience, the city continues to expand into its floodplains (Restemeyer et al., 2018). There are several issues that need to be highlighted:

1. There has yet been an actual evaluation of the implementation and development from a practical and research point of view. As stated by Restemeyer (p. 62, 2018), there is a divide between "policy-on-paper and 'policy-in practice', in particular when an ambiguous term like resilience is involved".
2. Lack of local ownership and responsibilities in the execution of floodplain management. This is due to the shift in dissolving responsibilities to local level governance authorities. The shift in a decentralized governance system has caused a public-public divide (Restemeyer et al., 2018)
3. The implementation process is proving to become difficult with having multi-level and multi-actor governance. This is also due to the fact that the plan was developed at the Environment Agency, meanwhile the execution requires the participation of several levels of governing bodies, citizens and stakeholders.
4. Continues to perpetuate a false sense of security by maintaining traditional flood defence approaches.
5. As per the response phase, flood warnings and evacuation "only work when citizens in flood-prone areas know what to do and where to go in case of an emergency" (Restemeyer et al., p. 64, 2018). Which is not defined in the TE2100 or mass evacuation plans. There is also the factor
6. The 'watering down' of regulations in new developments (Restemeyer et al., 2018). As per the Royal Docks, which is situated in flood zone 3. New developments are required to undergo assessments and only developments are accepted through exceptions. The EA has prohibited habitable units on the ground floor but regulations throughout redevelopment phase were modified. The EA eventually permitted the developers and architects to have ground units as long as they had an emergency plan. The architect also put the site risk as residual (Restemeyer et al., 2018) which has enabled the mentality of continuing to build upon these areas with the reliance on the tidal flood defences.
7. Public awareness has also pushed upon local boroughs and is not clarified or stated in the TE2100 plan.

5.8 Critical Areas In Focus

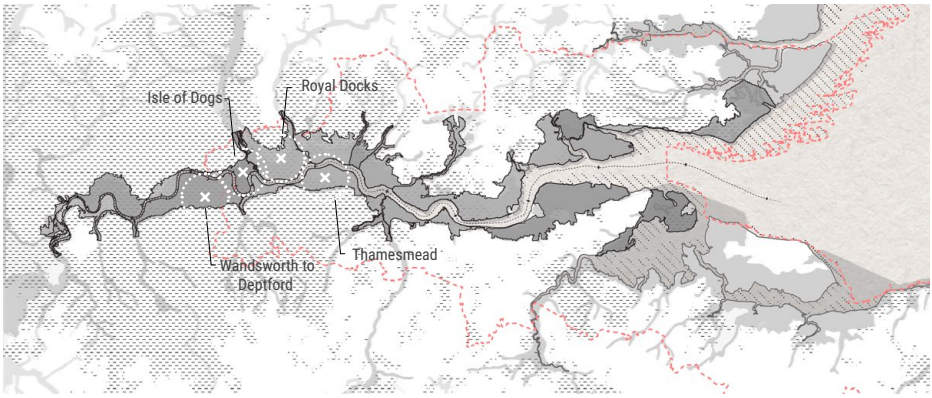


Figure 55 Highlighted TE2100 policy units that will be further analyzed. Policy units refer to the TE2100 plan (Environment Agency, 2012)

Historical Context- City Level Scale

Referring back to the historical developments of London, much of it was established adjacent to the Thames River in the low-lying marshland. Over the last two millennia, the area has been increasing in severity of tidal flood conditions. With the advancements in tidal defence technology, the thriving city of London continued to flourish with large-scale reclamation of marshes and mudflats. Development continued into the seventeenth century and the main tidal defences utilized today were constructed from the 1970s and 1980s. These are also proving have an expiry date as the infrastructure is nearing half a century. The flood-plains eventually became abundant for industrial and agricultural development. The land use in these areas has gradually shifted in more residential and business-oriented development. Substantial re-development and growth are continuing through the Thames with the UK's regeneration initiatives such as the Thames Gateway Project. As urban growth is directed towards the east of London, more pressure will be placed upon the Thames tidal floodplain. In addition, the Environment Agency will continue to have increasing responsibilities and challenges for planning future defence mechanisms, environment and ecology designations and locations of new buildings upon the tidal flood-plain.

Thames Estuary- Further Context

As part of the long-term national priority area for growth, the Thames Estuary spans from East London to Southened-on-Sea in Essex for 64 km. The population catchment area encompasses over 3.58 million people with 18 local authorities. The total area spreads across a significant portion of cities and towns as well as populated suburban and rural areas. To service these areas, significant transport infrastructure has been constructed, including three major motorways which are M25, M2 and M20. Aside from the large road infrastructure, the existing transit lines are made up of the London Underground and Overground lines with a significant number of radial rail routes, high speed rail links and cross-rails.

In addition to the amount of large scale infrastructure project, it is deemed to be an environmentally sensitive area with a large number of internationally and nationally designated sites, habitats and specifies. However, this area is also accustomed to high vulnerability to flood risk. The area is still seen as a place of opportunity, economic growth and continues to supply short and long term benefits to the UK economy and local populations. However, in order to support this vision of economic and environmental sustainability, it is crucial to continue developing dynamic adaptive plans and strategies for the growing deep uncertainties.

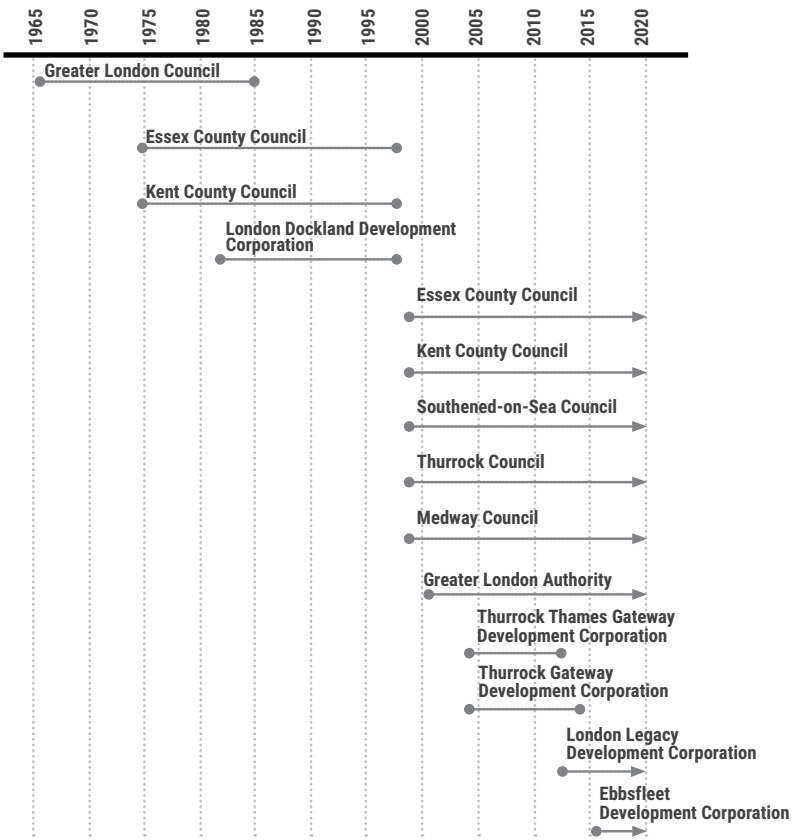
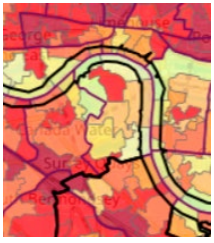


Figure 56 Administrative fluctuations in the Thames Estuary

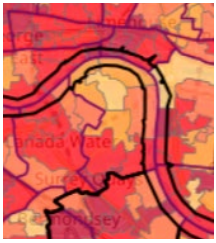
Above is a time line of major changes in governance over the past decades. Presently, there are 18 local authorities but due to the administrative complexity and other governing bodies, this has led to a fragmented approach. Strategic planning and prioritizing interventions have become more challenging due to the decentralized nature of the governance system.

Neighbourhood - Policy Units
Wandsworth to Deptford

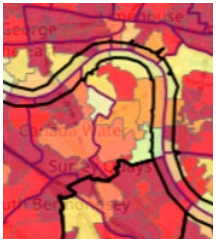
10% most deprived to least



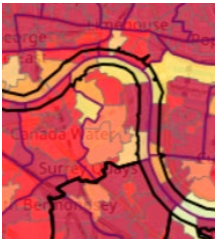
Index of Multiple Deprivations map (UK)



Living Environment Deprivation map



Deprivation Affecting Children Index



Deprivation Affecting Older People Index

Map source: http://dclgapps.communities.gov.uk/imd/idmap.html

Based on the flood risk intensities, the identified areas with the highest density of critical infrastructure were also chosen to correspond with the TE2100 policy units.

Major CI at risk:

- 10 underground stations
- 3 major railway termini
- 93 schools
- 200+ electricity substations

Out of the TE2100 policy units, Wandsworth to Deptford also has the largest developed area. ***The area is also defined by:***

- major urban centres
- residential areas
- industry
- commerce and
- London's major transport terminals

The unit is considered to be the most vulnerable relative to flood risk in the event of failures or the collapse of flood defences. Not only is the area low-lying and contains predominately a residential and business population, the area is also prone to surface water flooding through heavy and prolonged rainfall.

The probability of flooding from the tidal water of the Thames River is (0.1% per annum) but the flood depth can exceed up to 4m if the barrier fails. A secondary risk comes from fluvial flooding from the River Wandle (3% per annum). The third risk is from pluvial (heavy rainfall) and the drainage capacity being exceeded.

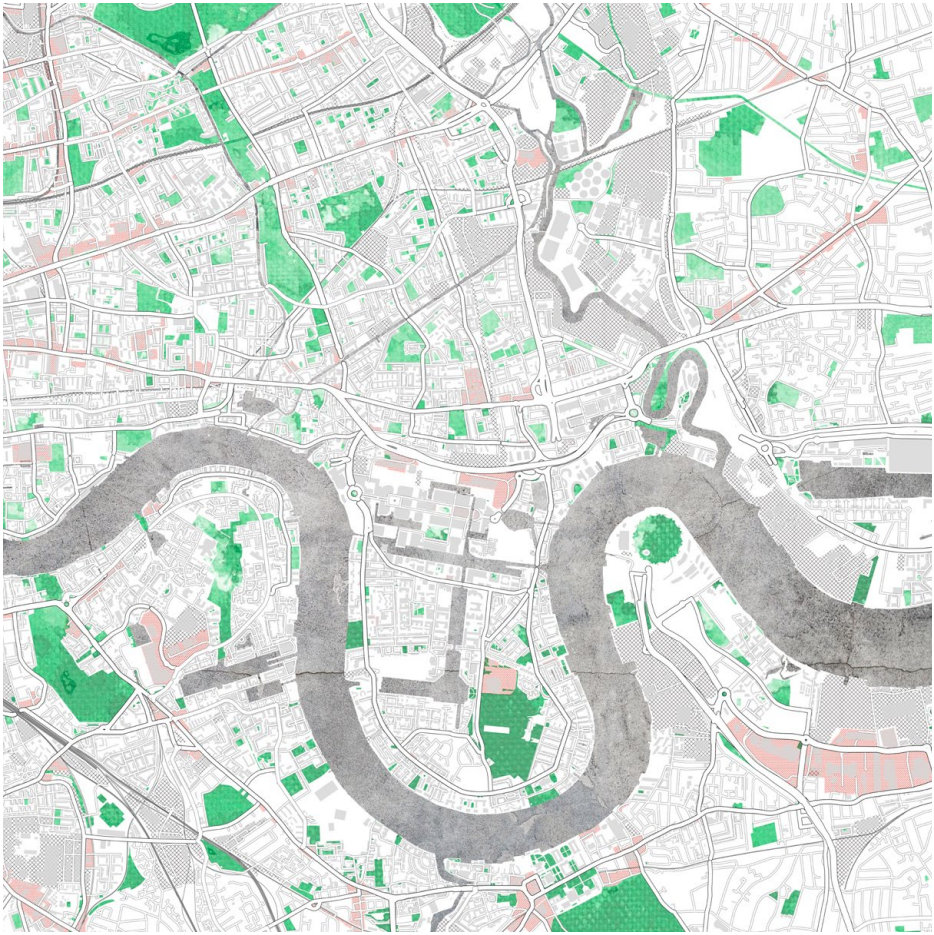
CONSTRAINTS

- The neighbourhoods are already well established and redevelopments are occurring at a smaller scale
- Historical sites vulnerable to flood defences include: Battersea Power Station, the Albert Embankment, Lambeth Palace, National Threatre and Tower Bridge
- Ground level of the policy unit is low at 2m AOD (above ordnance datum), high difficulty of evacuating floodwater
- Overall area is large, flat and in a low-lying area

OPPORTUNITIES

- With new development projects being planned within the vicinity of the Estuary, these projects also provide additional opportunities to enhance areas along with defences
- Future flood defences to be integrated into the landscape
- Improvement of riverside amenities and habitats with the combination of defence realignment and floodplain management An example of this approach can be seen with Tate Modern at Bankside

Neighbourhood - Policy Unit
Isle of Dogs



10% most deprived to least

Index of Multiple Deprivations map (UK)

Living Environment Deprivation map

Deprivation Affecting Children Index

Deprivation Affecting Older People Index

Map source: http://dclgapps.communities.gov.uk/imd/idmap.html

The Isle of dogs is comprised of former industrial lands that has seen large development through the Canary Wharf Docklands commercial areas. With the Olympic site set in place, further investments and regeneration will most likely occur.

Major CI at risk:

- 19 schools
- 100+ electricity substations
- Docklands Light Railway
- Canary Wharf underground station

The Isle of Dogs area is defined by:

- High density of development
- Canary Wharf business district and Olympic Park
- Extensive residential and industrial areas

The Thames Barrier acts as the highest defence for the area. The tidal risk has a probability of 0.1% per annum in this area and flood depths can range up to 3m if the barrier failed. The highest fluvial risk comes from the Lea River at 1.5 to 3% per annum. However, the risk from pluvial and urban drainage is lower in comparison to the previous policy areas. The area is also experiencing some erosion on the river bed on the south east corner of the Isle of dogs.

Recommendations:
Development occurring near Estuary frontage has opportunities to enhance the area with additional defences being integrated into the landscape. One of the areas that can benefit is the old East India Dock site. In addition, the communities should be more informed about flood risks in the area.

According to the deprivation maps, even though there is a strong perception that the Isle of Dogs is a strong economic hub, it showcases that it has high levels of deprivation. It is classified also as one of the most deprived boroughs in the UK. The deprivation maps show deprivation maps for children, elderly, overall index and living environment. However, due to the buildings being mixed developments with social rent, affordable and private sales in the same building.

The area is also sub-divided by docks and large greenery like Millwall Park and Mudchute Farm. This limits east-west connects and there is a heavy reliance on three key roads:

- A1206 – Manchester and Westferry Roads which loops around the island
- Marsh Wall – which connects the island east to west at the top of the island
- Eastferry / Limeharbour road which runs north to south up the middle of the island

All other roads are residential in nature. All roads have a 20mph speed limit. There is also no dedicated cycle lanes and the Thames riverside path is blocked along large sections. Due to the rapid growth rate of the areas, there is also limited roads and two access points in and out of the site.

CONSTRAINTS

- High density development with the Olympic Park and Canary Wharf business district
- Low amount of open space
- River frontage is highly developed

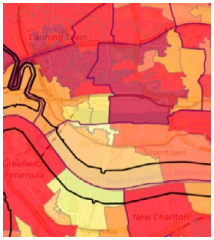
OPPORTUNITIES

- Docks can provide additional support and pathway for tidal flooding (fluvial floodwater)
- Area is part of the Thames Gateway Parklands vision and Thames Strategy East

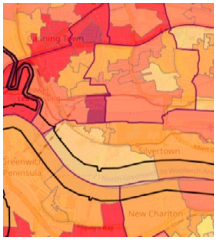
Neighbourhood - Policy Units

Royal Docks

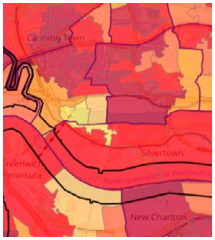
10% most deprived to least



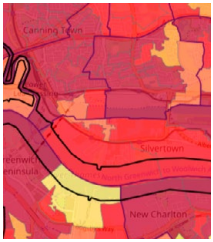
Index of Multiple Deprivations map (UK)



Living Environment Deprivation map



Deprivation Affecting Children Index



Deprivation Affecting Older People Index

Map source: http://dclgapps.communities.gov.uk/imd/idmap.html

The Royal Docks is adjacent to the Isle of Dogs policy unit. Similar to the other policy units, it is a large low-lying areas with higher risks to pluvial and urban drainage flooding. It contains a major arterial route that splits the site from west to east.

Major CI at risk:

- 5 underground stations
- 36 schools
- 1 Hospital
- 2 power stations, 200+ substations

Royal Docks policy area is defined by:

- Extensive residential and industrial areas.
- Contains three royal docks that will be raised parallel to the Thames River
- Jointly tied to the benefits of the Olympic site (in Isle of Dogs)

Much of this policy unit is at 1m AOD or less but the section at the Thames frontage ranges from 3 to 5m. Likewise to Thamesmead, there would be difficult in evacuating floodwater if it were to occur.

Similar to the other policy units, this area is extremely vulnerable to pluvial (heavy rainfall) flooding. During high tide, there is a difference of 2m on either side of the river. If the Thames barrier failed, the flood depth could reach up to 5m. Tidal flooding from the Thames has a 0.1% per annum probability.

The area also has a restricted capacity as the urban drainage system is quite low. Other issues that have been identified in the TE2100 report is that local flood risk management has not been designed or addressed into detail.

Suggestion:
Using the new areas of redevelopment, floodplain and flood risk management should integrate enhanced riverfront environment, defences and amenities. Additional public awareness is required to assist in emergency planning and response. Raising quay levels or closing docks in an event of a flood.

CONSTRAINTS

- Extensive areas of redevelopment planned in this area
- Limit on how often the existing flood gates can be closed due to the increasing sea level heights. These hard infrastructures also need to be replaced within the next 40 years at the docks

OPPORTUNITIES

- Part of the Thames Regeneration area
- Improve river frontages with regeneration areas to decrease erosion damage, increase ecological capacity and amenities

Battersea Power Station, Photo by Author

CRITICAL INFRASTRUCTURE: MULTI-CRITERIA ANALYSIS & EVACUATION PLANNING

Multi-Criteria Analysis

- Resilient Critical Infrastructure & Contingency Planning
- Summary of Indicators
- Serviceability & Accessibility Analysis

Aspects of Evacuation Planning: Organization

Understanding Early Response and Recovery in Planning

Classification and Capacity

- Performance Metrics

Life Cycle of Infrastructure

- Lifespan of Assets

Utilizing Resilient Network Properties

- Flexibility
- Redundancy
- Robustness

6.1 Multi-Criteria Analysis
Resilient Critical Infrastructure

Understanding and evaluating critical infrastructure using resilience metrics is one of the primary objectives of the project. Relative to transportation and contingency planning, frequent and uncertain trends need to be accounted for.

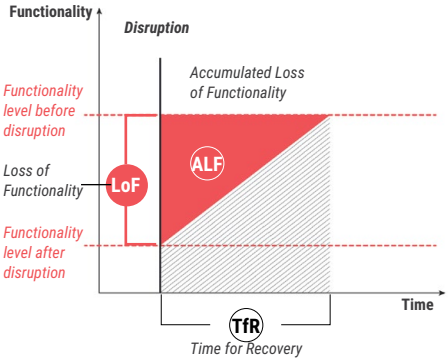


Figure 57 Incorporating resilience in functionality. Adapted from Incorporating resilience in infrastructure prioritization – application to japan's road transport sector (Raina,p. 7 2018)

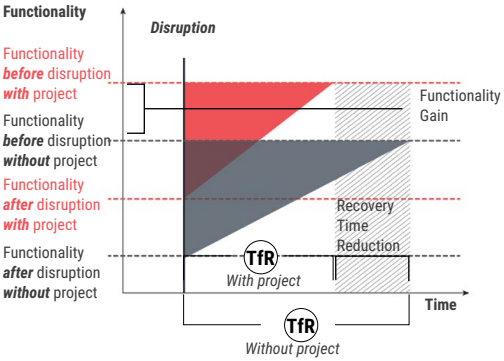


Figure 58 Accumulated loss of functionality with and without project. Adapted from Incorporating resilience in infrastructure prioritization – application to japan's road transport sector (Raina,p. 7 2018)

What is contingency planning and why investigate it?
Contingency planning is the deployment of systems to track the availability of essential services in an emergency. It is also used as a management tool to analyze the impact of potential hazard events in order to develop adequate arrangements in advance to respond in a timely, effective and appropriate way to affected populations.

What is infrastructure resilience? And how does this link to creating resilient road infrastructure networks that are able to adapt to different intensities of flood risk?
Referring to 'Incorporating Resilience in Infrastructure Prioritization: Application to Japan's Road Transport Sector' (Raina, 2018), several lessons were learned and adapted into the project such as the translation of the practical indicators to estimate 'resilience'. The report was also used as a guiding document as Japan has frequent climate extremities in relation to flood risk and tsunamis. In the current situation, the UK government does not have a set of indicators to evaluate critical infrastructure in the scope of resilience or enduring shocks.

If resilience is to be expressed in terms of functionality loss and recovery time; four dimensions need to be considered from: travel time, time for recovery, provision of life-saving services and provision of relief goods. To further develop this concept, it depends on the asset's capacity to withstand and recover functionality following a shock. This process is illustrated in the diagram and is expressed during an event of a disaster. For example, a critical infrastructure such as a road or bridge is susceptible to loss of functionality (LoF), it is more related to travel time (t), road utilization (u), provision of relief (p) and access to lifesaving services (l).

SUMMARY OF INDICATORS

TRAVEL TIME	***TIME FOR RECOVERY***	***PROVISION OF RELIEF***	***ACCESS TO LIFESAVING SERVICES***
Denotes travel time between an original and destination.	Denotes the estimated time for recovery for disrupted roads after an event and after the project implementation.	The affected population having accessibility to designated emergency shelters* (classified as medical facilities or schools) within certain time intervals under an ordinary state in comparison to a extreme event.	This relates to the accessibility and delivery of relief goods for isolated populations in a disrupted state.
Serviceability Maps	***Serviceability Maps***	***Accessibility Maps***	***Accessibility Maps***
Non- disrupted servicing for (automobiles and pedestrians)	Estimated time for evacuation for automobiles and pedestrians during an event	Position of shelters and accessibility and capacity of temporary safe grounds	Accessibility to shelters

Why is it important to develop resilience indicators for long-term planning?

Transportation systems and shelters are classified as the emergency backbone to providing relief to populations that are exposed to flood hazards. As flood hazards continue to increase due to the attraction of city developments, so does the rise in population and infrastructure which is especially seen in flood prone areas. As mentioned previously in the SOVI, the amount of damage and affected CI in the area are often heterogeneous and extent of damage depends on the vulnerability of the population and infrastructure. Typically, there is a heavy reliability placed on the safety and integrity of infrastructure, especially on instance for shelter and emergency relief.

Establishing a set of indicators

A crucial step as mentioned in the methodology is to identify a set of criteria, indicators and evaluation categories to be used. The above listed summary of indicators will be used as a means to set a multi-criteria analysis and should be able to correspond to the scope and scale of the system that is currently being analysed.

The following next set of maps were created with network analysis on ArcGIS using the route analysis tool. In addition, the selected policy units are adjacent along the Thames River Corridor. As the main intent is to focus on the resilience of the road network system and access to shelters, the route analysis tool was used to determine the quickest and best routes to access medical facilities and schools amongst the network.

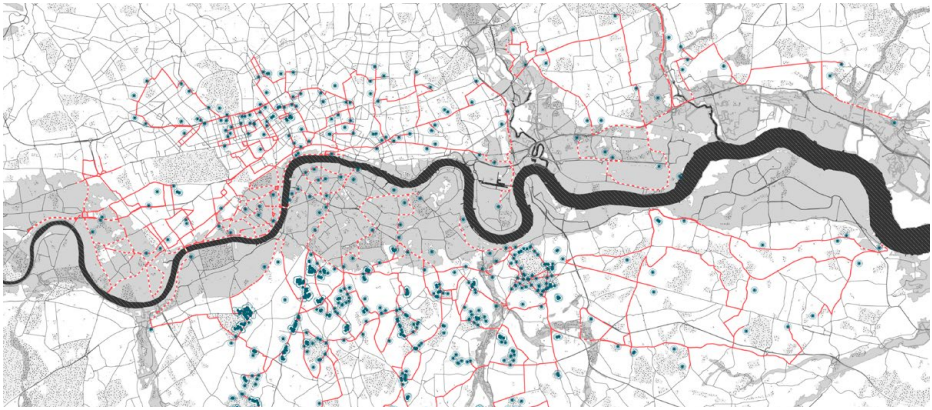


Figure 59 Accessibility Map: Present Condition - Shelters (Medical Facilities and Schools) with Flood Zone 2

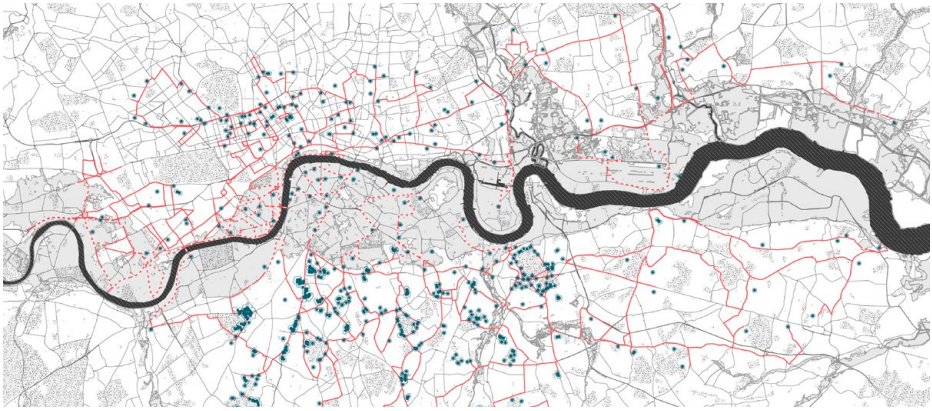


Figure 60 Accessibility Map: Present Condition - Shelters (Medical Facilities and Schools) with Flood Zone 3

- Road network impacted by flood zone
- Existing primary, secondary and tertiary roads
- Shelters (Medical Facilities/Schools)
- Road network outside of flood zone
- Parks

Destination Accessibility Maps: Designated Shelter Network

Currently, there is no suitable resilience indicator in UK documents for external shocks on the transportation network given the uniqueness of any incident that could occur. Information regarding alternative routes, multiple modes or transit or travel flows have not been modeled to have a change in behavior during a flood. In these series of maps, only the primary, secondary and tertiary road systems were considered. In theory, only the highlighted routes connecting the shelters should be maintained at all costs. This would provide an indication of providing rerouting, redundancy in the road network. The two above maps also compare two different flood intensities defined by the Environment Agency and their area of impact.

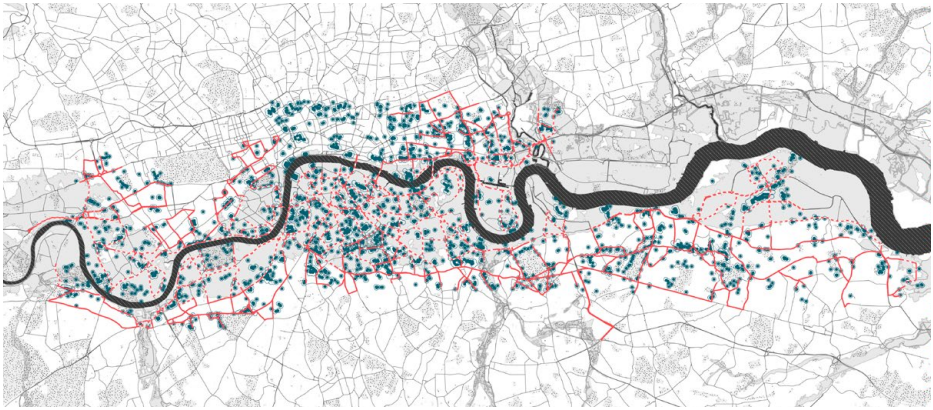


Figure 61 Accessibility Map - Park Entrances (Temporal Shelters) with Flood Zone 2

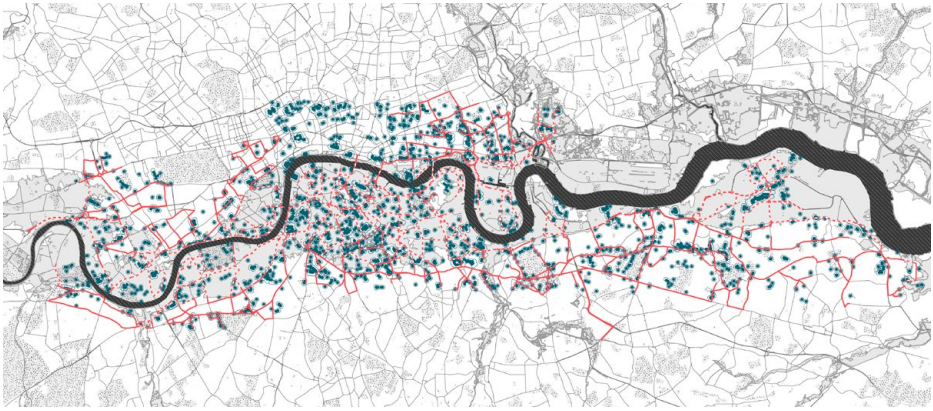


Figure 62 Accessibility Map - Park Entrances (Temporal Shelters) with Flood Zone 3

Road network impacted by flood zone
Existing primary, secondary and tertiary roads
Park Entrances
Road network outside of flood zone
Parks

Destination Accessibility Maps: Park Network

There is a need to maintain a strong open space network as a means of establishing temporary relief for affected populations. Open spaces are an opportunity to set up flexible temporary shelters until emergency services can alleviate flooded areas. As such, civilians should be able to have high accessibility to park entrances. It is notable that within the flood zones, there is a high concentration of access points to parks. However, the available amount of 'green space' is limited. Within the core of central London and highly urbanized areas along the Thames, there is a deficit in green areas. With the abundance of grey infrastructure, there is also a lack of capacity for infiltration and drainage in the area which increases pressures on the existing sewage system.

Utilizing the drive-time areas tool in ArcGIS, the network analysis showcases a series of isochrones with pre-defined time or distance restrictions. This showcases the differences in modalities between pedestrians and automobiles in having service within the vicinity of designated safe shelters.

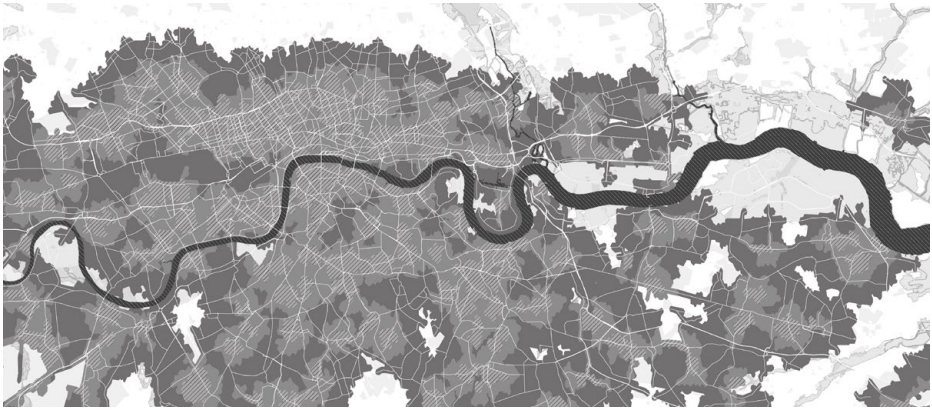


Figure 63 Service Map: present day accessibility to 'shelters' without barriers for vehicles

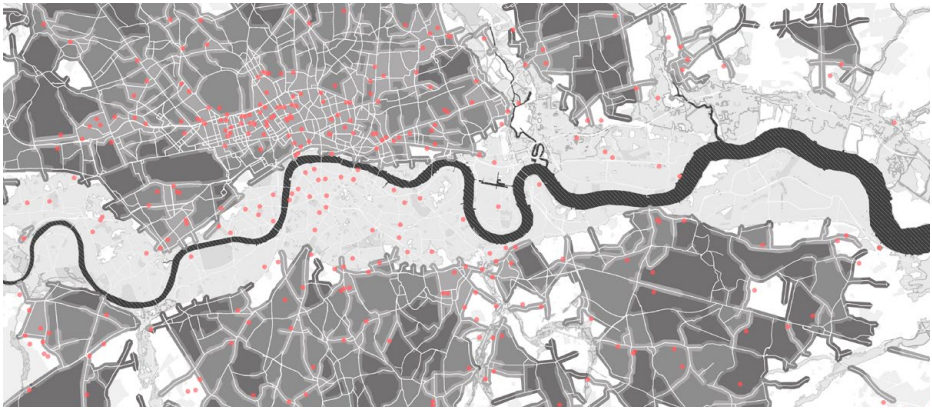


Figure 64 Service Map with Flood Zone 2 & 3 for vehicles

Existing primary, secondary and tertiary roads
Marked Shelters
Flood Zones
1km buffer from road
2km buffer from road
3km buffer from road

Serviceability Maps

The serviceability maps indicate the available emergency amenities within a certain distance. If areas are lacking within the primary network, these are shown in the darker regions or as 'blanks' because they are classified to be outside of the scope. These specific areas indicate high levels of risk and vulnerability as they lack accessibility to necessary emergency services.

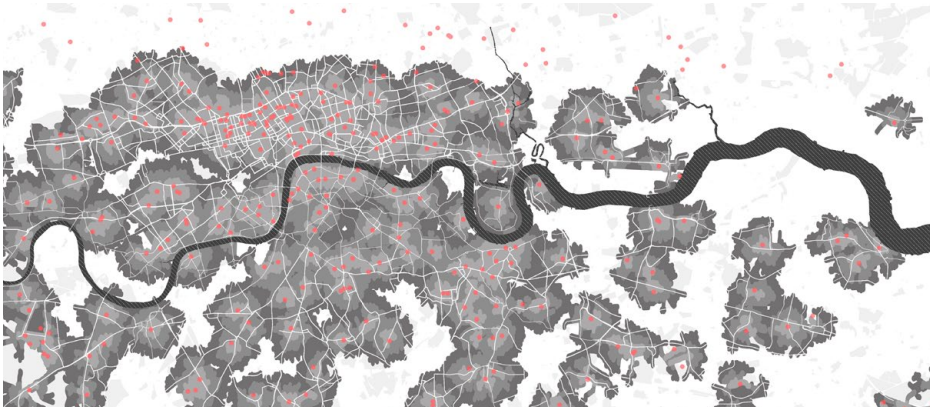


Figure 66 Service Map: present day accessibility to 'shelters' without barriers for pedestrians

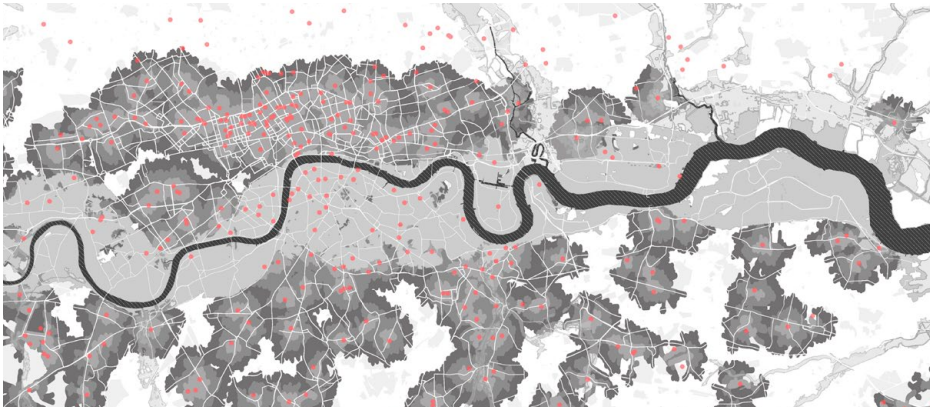


Figure 65 Service Map: present day accessibility to 'shelters' without barriers for pedestrians

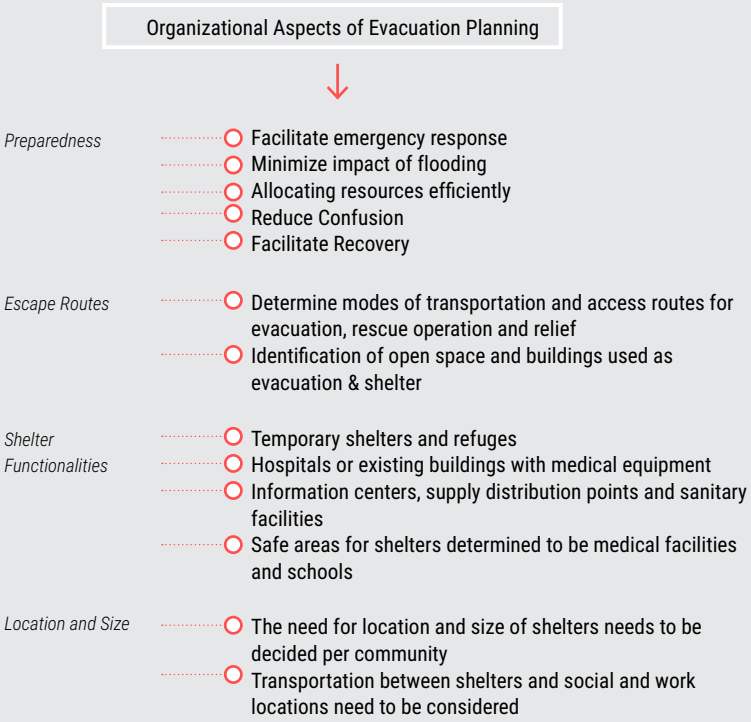
Existing primary, secondary and tertiary roads
Marked Shelters
Flood Zones
5 min from shelter
10 min from shelter
15 min from shelter

In contrast to the vehicle serviceability maps, the pedestrian maps use time intervals of 5, 10 and 15 minutes in accessing a shelter. There are obviously more patches and empty areas as pedestrians have a smaller area of reach in an event of an emergency. It is also notable that there is a higher density of classified shelters in the northern area of the Thames River. By overlaying the serviceability and accessibility maps, it is evident that within the chosen neighbourhood policy units, there are large areas at risk of isolation. This could be seen through either the fragmented nature of the networks (roads), the darkest zones (edges of 15 minutes) and the areas completely void are outside 15 minute accessibility mark) for pedestrians or vehicles.

6.2 Aspects of Evacuation Planning

ORGANIZATIONAL ASPECTS

- *Preparedness & Response*



In analyzing the planning assumptions as outlined in the London Risk Register, scenario requiring mass evacuation in the worst possible event needs to consider:

- Properties flooded: 50,000
- Potential total number of evacuees: 150,000
- People requiring assisted evacuation: 55,000
- People stranded requiring assistance in situ: 1,500
- People needed assisted sheltering (temporary): 50,000

Response Planning

To strengthen preparedness in response in disasters, there are two main objectives:

1. Increasing the capacity to predict, monitor and reduce or avoid possible damage or addressing potential threats
2. Strengthening preparedness for response to a disaster or assist those who have been adversely affected

Incorporating Early Recovery and Response in Preparedness Planning

1. Prepositioning of stocks in safe locations in high risk areas
2. Emergency relief is not designed to address underlying causes that result in a disaster, nor does it automatically stimulate rapid and sustainable recovery
3. May even exacerbate the underlying causes of vulnerability and increase risk
4. Needs to be a closer integration of recovery to reduce risk while simultaneously accelerate recovery process

Figure 67 Mile End Park with Canary Wharf in the distance, Photo by Author

6.3 Classification & Capacity Performance metrics

The defined standard values in the adjacent table will be used to classify the capacity and assets available in the current and proposed system. In particular, the area size, capacity and accessibility are important metrics to compare if the system will be improved and prepared for in the response phase. This is essential to see the size and scale of open space required for temporary safe shelter areas as well as understanding if there is sufficient capacity to accommodate the local population.

Criteria	Evaluation Variables	Data and Standard Values
Area Size	1st degree	>10,000m² +
	2nd degree	5000- 10,000m² +
	3rd degree	1000-5000m² +
	4th degree	100-1000m² +
Usability	Attributes	Existing land-use format
	Vegetation	Trees, shrub, no vegetation
Capacity	The first evacuation Area	Min. 1.5m2/ person
Sufficiency	Population Density	Neighbourhood
Accessibility	Walking time	5 minute 10 minute 15 minute

Figure 68 Analysis elements of shelter areas (Unal & Uslu, p.97, 2016)

6.4 Life Cycle of Infrastructure
Performance metrics

Figure 69 Regent's Canal in London, Photo by Author

Towards Transformation and Adaptation Using Life-cycle Based Planning: The Time Frame for New Opportunities & Understanding Lifespan of Assets

An important question to consider is how the actual process of ingraining evolutionary resilience into practice while translating risk management spatially. There currently is a lack of research and evaluation of the practical implementation of dealing with urban development and the uncertainty of climate change as a means of implementing adaptation strategies. In several scientific journals, there is an emphasis that any adaptation strategies should be incorporated into other policies, strategies and decision-making policies (Veelen, 2016). This has gained traction in several fields such as coastal zone management, risk management, community

	Functional Life	Technical Life
Infrastructure		
Refurbishment cycles of public spaces/streets	20-30	30-40
Highway and streets	45	100+
Sewer system	40-60	50-100
Quays and walls	30-50	30-100
Dikes and dams	30-50	50-200
Light and power	20-45	
Buildings		
Interior and equipment	11-14	10-30
Planned Maintenance	15-25	10-20
Renovation and Alterations	25-40	30-50
Residential buildings	80	100
Residential buildings (>4 units)	65	100
Non-residential buildings	30-40	20-60

Figure 70 Overview of average life cycles showcasing functional and technical lifespan of infrastructure and buildings. There is a limitation to understand the years due to the variation in maintenance, type, age of buildings and regulations on the infrastructure. The data has been adapted based on Statline/CBS in the Netherlands and from Table 7.1 (Veelen, 2016)

development and so forth. Several cities have begun integrating of these opportunities of merging and combining opportunities with adaptation such as Rotterdam and New York City.

Referring to the Rotterdam Climate Adaptation strategy, one of the main principles is to link "area development, network maintenance or the transformation of real estate" (Veelen, p.183, 2016). As part of the Dutch Delta Programme, it has been widely accepted that 'synergetic advantages' and by the 'coupling of mutual goals' is largely beneficial (Veelen, 2016). There has been a large focus in developing ingrained adaptation with the regular urban renewal and development processes. In comparison, New York City has begun to update the zoning and building codes to address climate change adaptation.

The general assumption of utilizing moments of urban renewal, retrofitting infrastructure and development of buildings and assets could offer a moment where the integration of proposed flexible and adaptive measures could be done at relatively lower costs. This could also be timed in phased developments and allow for the nature of responding to current needs while continuing to grow with resilience. Designers and planners could begin to think of these windows of opportunity to redevelop and reconfigure the design of critical infrastructure and networks.

01

Flexibility in design aims to respond more easily to a variety of potential changes (Veelen, 2016) and reconfiguration is possible. Imbedding flexibility in the system also reduces interdependencies in the systems by providing measures that allow change without negative effects on other areas of the system.

Flexible Adaptation Strategies/Design Principles:

Adjustability

- **Purpose:** Change of task
- **Definition:** "Incorporating modifications in the use or design of infrastructure in anticipation of future conditions and requirements" (Veelen, p. 117, 2016). This typically requires upfront costs but can remain beneficial when it has co-functionalities with other infrastructure or areas. This can also involve using alternative infrastructure systems to alleviate others.
- **Example:** the road network would focus on rerouting and assigning designated evacuation routes; this entails that alternate modes and routes are possible in any flood risk intensity.

Convertibility

- **Purpose:** Change of function
- **Definition:** Enabling economic, legal or physical changes in function of space, buildings and infrastructure in anticipation of changing conditions" (Veelen, 2016).
- **Example:** Sacrificial Infrastructure (Safe to Fail Infrastructure). To increase the survivability of the system, there may be a need to sacrifice some system subcomponents for the sake of maintenance (and necessary services) of greater functionality of the larger system. It is important to recognize that not all system functions or components can be protected at all times (Clark, Seager, & Chester, 2018)

Expandability

- **Purpose:** Change of size
- **Definition:** This allows for infrastructure to extend in response to changing conditions. Typically, this method regulates land uses that could also limit the ability to expand to expected design levels. The difficulty of using this strategy in highly urbanized areas such as London is that it can be expensive or lost overtime.
- **Example:** Engineering in structural flexibility to increase safety margins. Additional characteristics include raising elevations and heights of strategic CI.

02

A key component of redundancy is accounting for backup systems that would enable the overall system to survive if it was to be impacted. Redundancy also involves the ***spare capacity and diversity of pathways*** and options so that if one portion of the system fails, others that serves similar functions can substitute or take its place.

Diversity of Options

Multiple or diverse options are required for the system to survive (and for people to be provided essential services).
Example: autonomous, self-supporting or decentralized systems

Synergetic Advantages

Synergetic advantages need to be incorporated as well as the coupling of mutual goals. This includes two subsystems performing at the same time. For example, elevated roadways or bike paths can retain grey water and redirect it to nearby buildings.

03

Robustness of critical infrastructure strategically focuses on ***maintaining functionality no matter the intensity***. It is the ability of the CI and network to withstand stresses and shocks to a level that is designed to be tolerable and cost effective. Critical components should be protected, especially vulnerable sections of road and designated shelters. Although, majority of this strategy emphasizes the maintenance of the physical condition and strength of the infrastructure rather than the quality of services provided. With this strategy, it is also crucial to ensure that infrastructure resilience is not just considering the physical integrity of assets but also maintain service and operating performance.

Maintain Functionality

Only crucial aspects of functionality should be maintained. For example, water for hospitals and drinking water need to be maintained. This includes strategies such as elevating critical roads and designated shelters.

Maintain Performance & Service

Monitoring the performance and service of the system also requires the prioritization and identification of a minimum viable supply chain of infrastructure needed across sectors to ensure people have the most basic needs during a disaster.

Figure 71 O2 in the distance, Photo by Author

RISK 'TREATMENT'- RESPONSE, RECOVERY & ADAPTATION

7.1 Overview & Aims of Chapter

The chosen policy units along this corridor have the highest and densest concentration of critical infrastructure exposed to different intensities of flood risk. However, through further analysis these neighbourhoods also contain areas with:

- High forms of fragmentation which are the result of disconnected road networks that link to shelters and open spaces
- Poorly equipped and inadequate number of 'designated shelters' with basic necessities that are also located in the floodplain
- Significant forms of isolation with lack of large available areas for safe refuge (ie. temporary shelter spaces)
- Low lying flood plain with large difficulties of removing the accumulation of water if a breach in defences were to occur

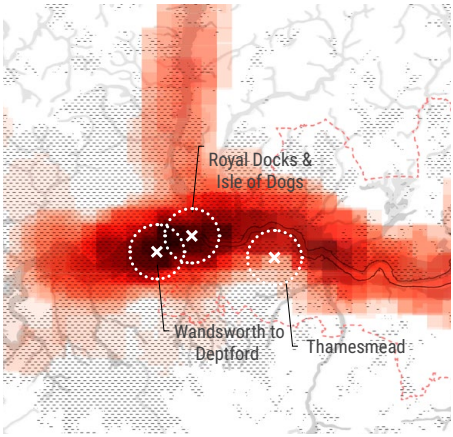
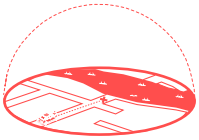
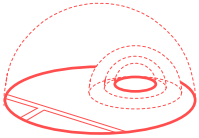


Figure 72 Specified policy units with the densest levels of critical infrastructure

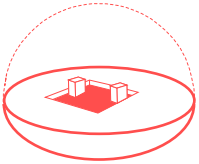


Insufficient accessible and alternative emergency road networks

Inadequate numbers and areas of safe refuge



Lack of accessibility to nearby shelters



Trapped volume of water

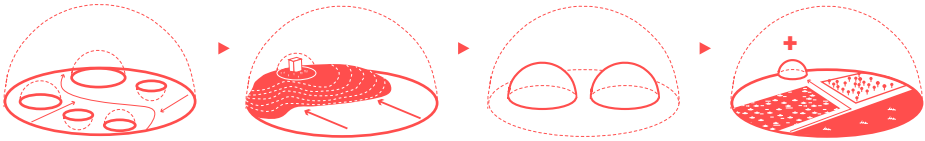
With these underlying issues, the specified policy units along the Thames River are at an even higher risk due to the lack of spatial risk management in relation to response planning.

Communities along the Thames Estuary can continue to developing robust structures to eliminate local failure points but to what extent can this continue to happen? And what are the priorities in the face of deep uncertainty?

In the pursuit of spatially translating a response framework to improve safety standards and maintain essential services, several questions arise with: how to 'grow resilience' within urban developments? Or does the mindset of how we develop intensive urban areas need to change?

The manipulation and arrangement of spaces, will be tested in two proposed extreme scenarios with the aim is to:

- Design areas that not only increase the safety parameters of the area but also to improve livability
- Rerouting and strengthening alternative means of accessing designated safety areas
- Establish safety grounds with backup systems
- Encourage a faster response and recovery time
- Integrate flexibility and adaptability into the system to improve



Manipulating connections & spaces

Creating access/higher porosity to designated safe areas

Allocating back-up services that can operate off grid

Increase safety margins & livable environment

7.2 Overview of Policy Units

Wandsworth to Deptford

DEFINING PRIORITY RESILIENCE AREAS

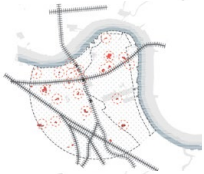
Differences in residual risks

Flood depth: 4m

Danger: Major London transit terminals exposed

DESIGNATING SAFE SHELTERS

Relationship between shelters and temporary shelters



Shelter & open space relationship: 2 large open spaces with majority of CI in between

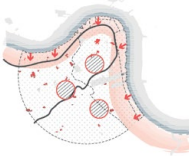
SCENARIO DEVELOPMENT

Business as Usual

Intensification: Core

SCENARIO DEVELOPMENT

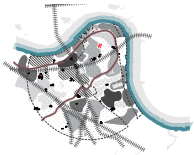
Managed Retreat



Phasing out infrastructure to allow for the intrusion of water and nature

OPPORTUNITIES

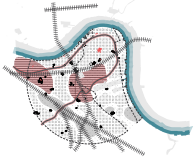
Life cycle-based planning



Patchwork nature of developments

OPPORTUNITIES

Land-use



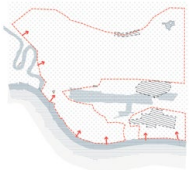
Land-use: Extensive residential, industry and commerce

Isle of Dogs

Royal Docks

Flood depth: 3m

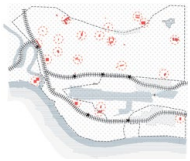
Danger: Limited in/out access



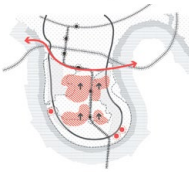
Flood depth: 5m

Danger: East/west divide

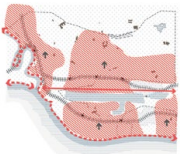
Shelter & open space relationship: 1 large open space with smaller scattered CI throughout site. CI also lacks connection to existing parks



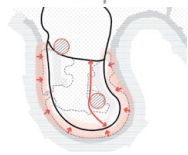
Shelter & open space relationship: Dispersed open spaces. CI are always adjacent to parks



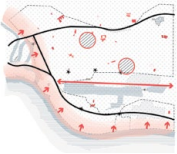
Intensification: Extension of Canary Wharf, transition into next business district



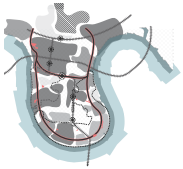
Intensification: Large urban renewal



Phasing out infrastructure to allow for the intrusion of water and nature

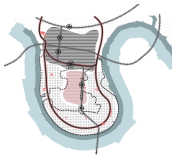


Phasing out infrastructure to allow for the intrusion of water and nature

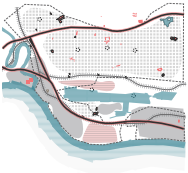


Patchwork nature of developments

Patchwork nature of developments



Land-use: Highly dense business district with residential units



Land-use: Residential and industrial

7.3 Scenario Development Summary

EXTREME SCENARIO

BUSINESS AS USUAL:
Increased pressures on the floodplain

The primary objective of this scenario is to work within the constraints of projected intensification on the floodplain. There is a larger focus on increasing the levels of safety while still working within the constraints of:

- Increased housing demands would be fulfilled in low lying areas at risk of flooding
- Continued asset deterioration
- Continued rise in population growth allocated per borough/policy district
- Constrained within a highly dense urban fabric

Additional Challenges

- Prolonged risk in area
- Increased issues related to critical drainage due to heavier development on site
- Increased difficulties to reduce flood waters
- Increased demand on water consumption and grey infrastructure
- Increased demand of short-term relocation sites in an event of an emergency
- Roads and public transportation would need to accommodate for larger capacities of people

Opportunities

- Expansion of smart grid
- Retrofitting Thames Pathway to trigger investment and change
- Conversion of surface parking to park infrastructure or porous infrastructure increase infiltration and water storage capacity
- Surface level infiltration on roads
- Improve accessibility and quality of river fronts to increase public amenities and deprivation index
- Creation of dual functionalities in urban developments

EXTREME SCENARIO

MANAGED RETREAT:
Intrusion of water and nature/ receding of the land

The primary objective of this scenario is to work within the narrative of the restriction and removal of infrastructure on the flood plain. Environmental risk would be placed at the highest priority. The constraints would consist of:

- Increased housing and development pressures would be pushed away from the floodplain
- Phasing in and integrating safety parameters
- The increased expenses needed to relocate, modify and retrofit areas

Additional Challenges

- Building intensity on the site decreases but pressures are re-allocated to other areas on the outskirts of floodplain
- Limited capacity for future growth
- High upfront costs and strategy is extremely costly due to demolition, relocation of people and material waste
- Convincing stakeholders and private investors the change of land ownership
- Re-location of large population

Opportunities

- Increase drainage capacity and park network
- Creation of back-up systems (redundancy)
- Increased recreational amenities and biodiversity
- Long-term reduction of costs with flood mitigation infrastructure
- Lowered water consumption patterns and demand
- Grey-water could be reused in a circular model
- Deprived neighbourhoods would have larger access to greener spaces
- Removal of infrastructure could enable trigger changes to the environment with tidal parks or flood-able areas

Presently, there is still has a high reliance on managing floods through the means of grey infrastructure such as sea walls and barriers. The scenarios account for the most extreme conditions such as a breach in defences (resulting in residual risks). In addition to sea level rise, as defined in the problem statement, there are issues with aging flood defences, changing socio-economics and extremely low public awareness of flood risks.

With the intentions of upscaling set strategies, the following must be identified:

1. Priority resilience areas (at most risk in breached defences) along with critical drainage areas.
2. Identification of affected shelters (classified as schools)
3. Critical transportation nodes and road infrastructure

Planning efforts should be able to address these concerns in designing for flexibility and adaptability over time even with the uncertainty of external conditions. In the following pages, the execution of these strategies with site specific interventions will be outlined.

What if we develop semi-autonomous infrastructure?

Can communities develop off-the-grid areas that detaches from centralized facilities to reduce risk exposure?

Which services can be set safe-to-fail?

The scenarios would affect:

1. Priority of elements and what is crucial to be maintained/require extra protection
2. Number and placement of connections, services and of shelters
3. Program of urban life and direction of development
4. The states of isolation and how it is relieved

7.4 Priority Safety Measures: Small and Large Scale Interventions

The proposed set of interventions have the objective of integrating higher safety measures within the urban fabric. The intent was also to facilitate discussions on having the dual purpose of ingraining safety parameters while improving the quality of spaces. Overtime, these layered strategies incorporate measures of manipulating land use, re-alignment of riverfront defenses, and infrastructure.

The emphasis of these elements is to increase redundancy in connections and to accommodate for accessibility to safe areas. Appropriate safe areas of refuge and maintaining essential services should be allocated to affected populations. Added community benefits include recreation, connections, social spaces, and assistance in mitigating other climate related risks.

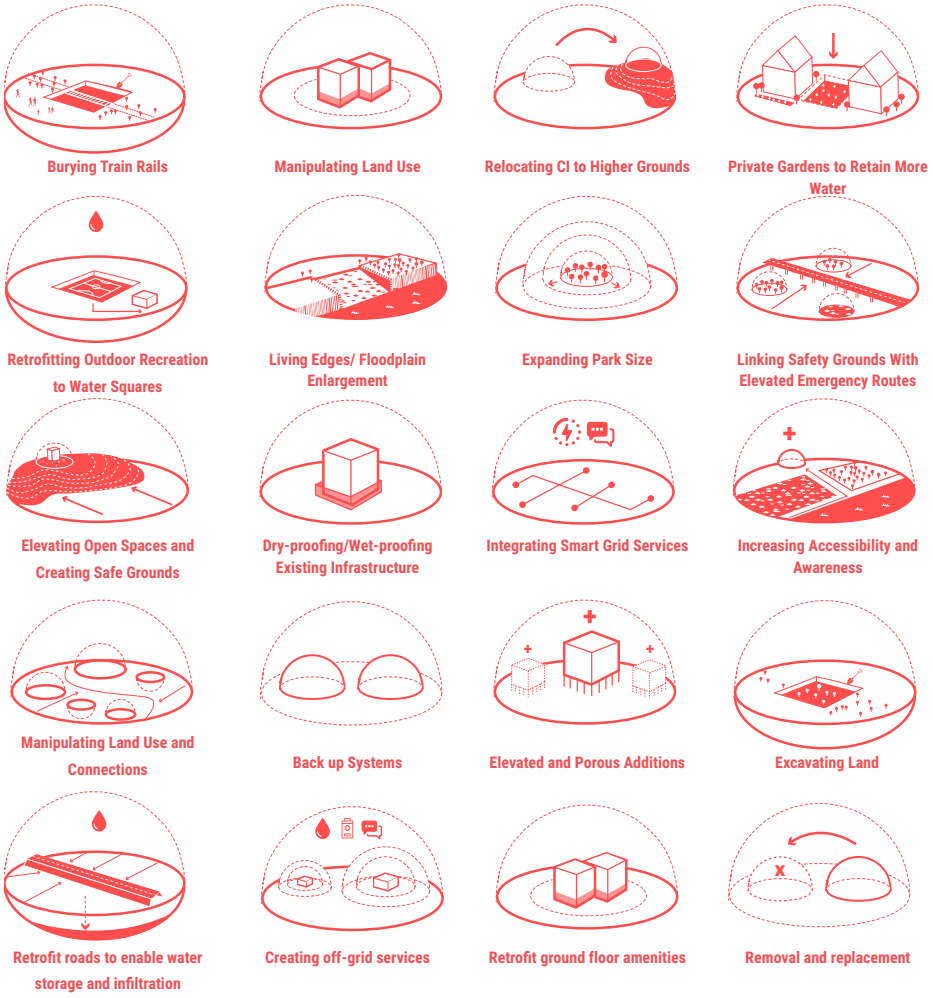


Figure 73 Summary of strategies and interventions from scenario development

Priority Safety Measures: Temporary Infrastructure in Public Spaces

Alongside embedding decentralized systems in the existing urban fabric, a series of temporary and flexible infrastructure should be allocated in designated safe areas. These can be designed in the form of public furniture that would require low maintenance and upfront costs. These systems can add mutual benefits to the existing urban fabric while providing a sense of awareness to local communities. In addition, this added amenity would be able to facilitate an off-grid communication, energy, sanitation and water supply in any emergency. Other benefits include a monitoring system for level of usage that could help the system to adapt and improve.

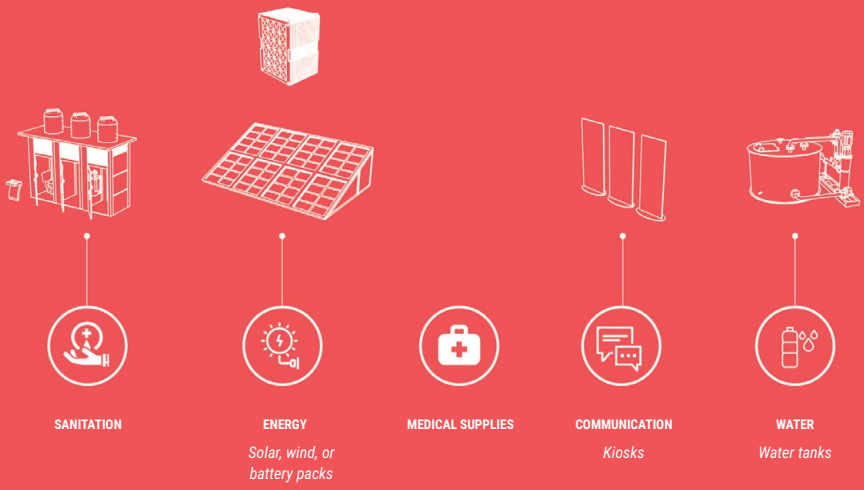


Figure 74 Required back-up services in new public furniture to be integrated in designated safe grounds

Increasing Accessibility to River fronts and Risk Awareness

Elevating Open Spaces and Creating Safe Grounds

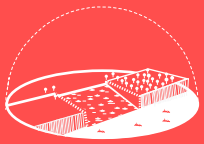
Back-up Systems

Manipulating Land-Use

Dry-proofing/Wet-proofing Existing Infrastructure

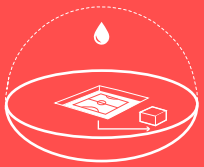
Private Gardens to Retain More Water

Linking Safety Grounds With Elevated Emergency Routes



Living Edges, Tidal Parks and Widening of Docks

Integrating Smart Grid Services



Retrofitting Outdoor Recreation to Water Squares

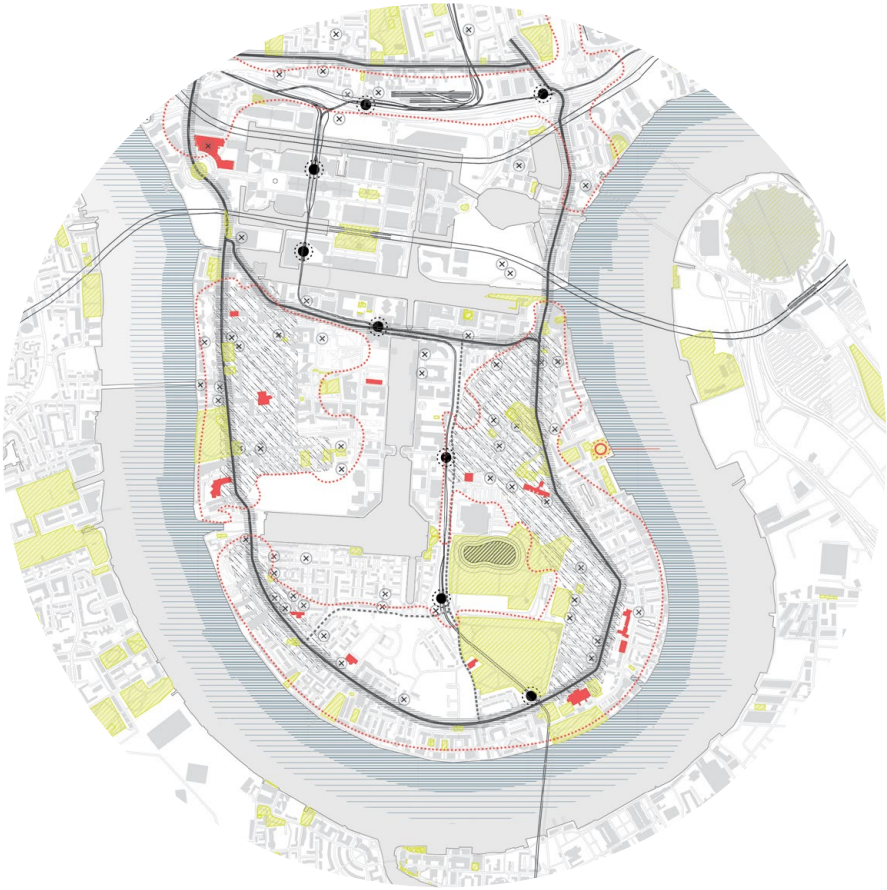
Relocating CI to Higher Grounds

▲

Interventions applicable in this policy unit

The diagram on the right breaks down the occupation of space within the boundary ▶

7.5 Zoom-In
Isle of Dogs



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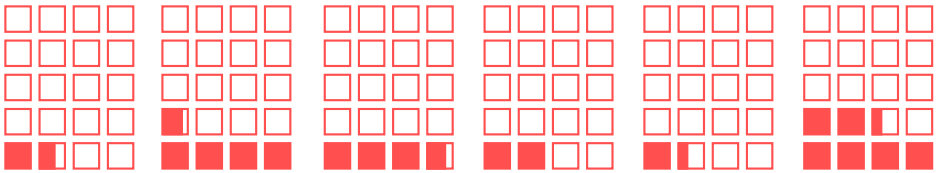


Public Space
- 284,997m²
- 80,619m² temporary shelter
- 211,936m² domestic gardens

Building Footprint
- 859,208m²
- 21,024m² Critical Infrastructure

Road
- 673,007m²

Water
- 342,597m²

Surface Parking
- 254,297m²

Hardscapes/Other
- 1,137,365m²

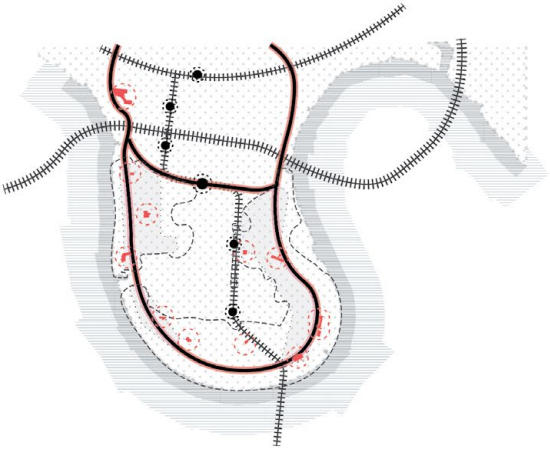
Isle of Dogs: Defining Priority Resilience Areas & Critical Infrastructure

The Disrupted State

Residual risks from failed defences

Critical Drainage Areas

Priority Resilience Areas

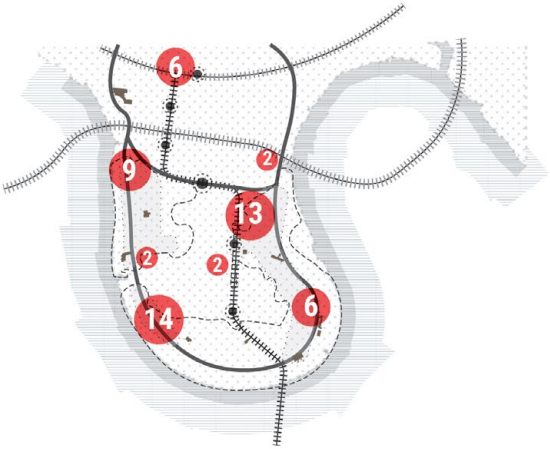


The Disrupted State: Place of Gatherings

Priority CI in affected area

Train Stations

Schools

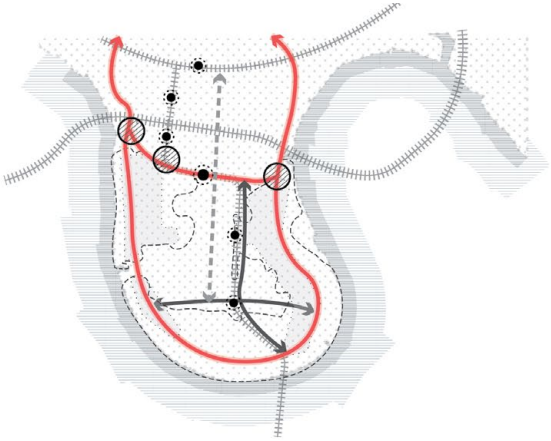


The Electrical Disrupted State

Affected electrical areas with >2m SLR

Electrical Substations

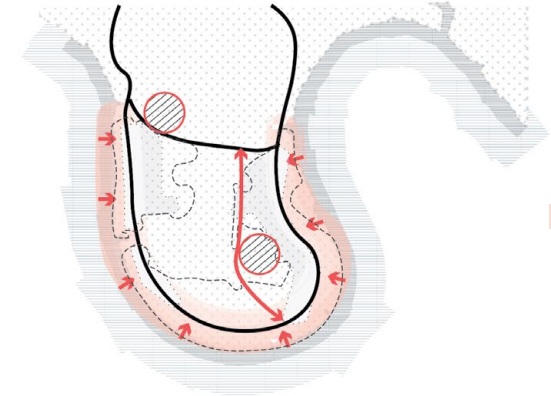
Isle of Dogs: General Strategic Interventions



Accessibility & Service

Proposed elevated areas and connections (automobile, pedestrians, water and cycling)

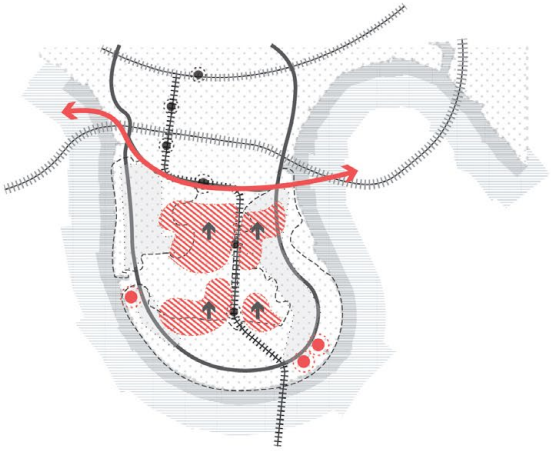
- Critical connection points
- Elevated roadway
- Elevated pedestrian/cyclist path
- Waterway (emergency relief)



Managed Retreat

Green buffer zone and green spine

- Removal of outer edge infrastructure
- Sacrificial edges or restricted development along corridors
- Primary elevated areas
- Relocation and allocation of growth outside of flood plain



Business as Usual

- Risk of islanding or separated from emergency relief
- Development pressure areas
- Increased wall height
- Relocated schools

Isle of Dogs: Proposed Shelters and Emergency Routes

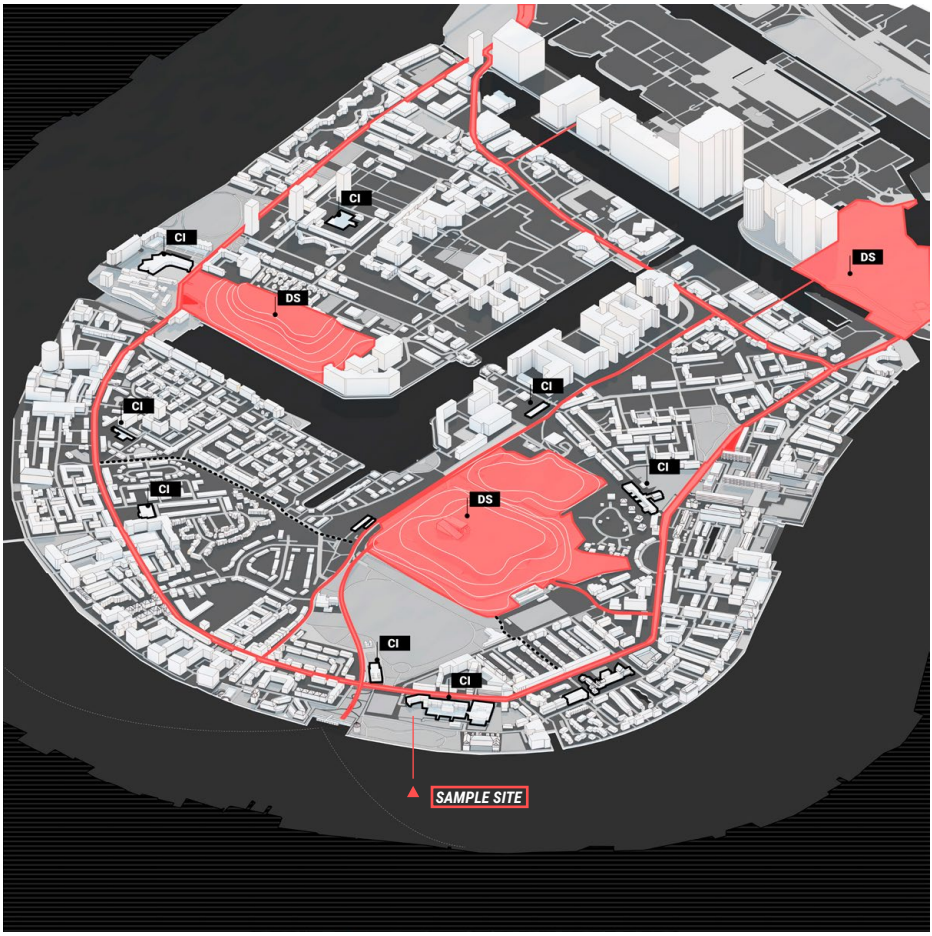
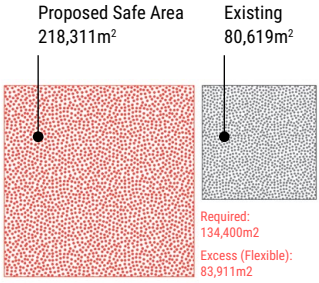


Figure 75 Proposed emergency routes, connections, and designated safe areas for Isle of Dogs

CI Priority Critical Infrastructure (Schools)

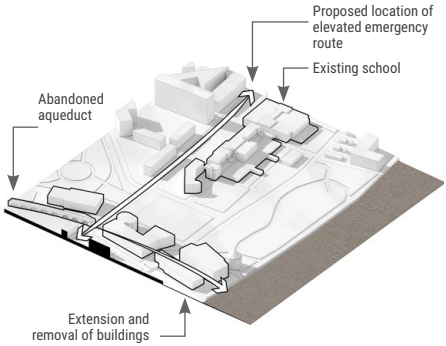
DS Designated Safe Grounds - Permanent Public Access



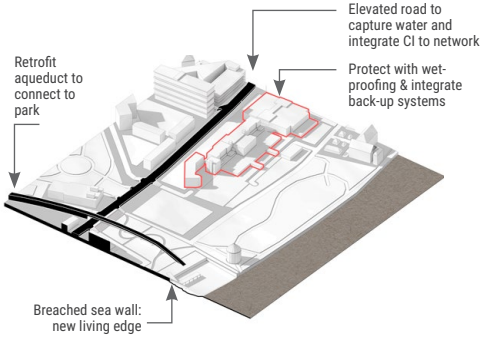
Isle of Dogs: Critical Infrastructure

BUSINESS AS USUAL

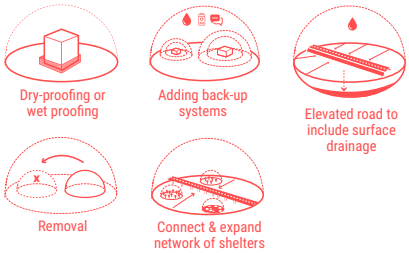
EXISTING



PROPOSED

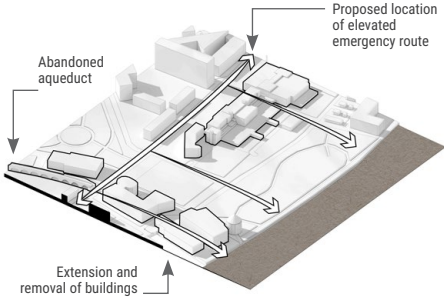


- Phasing in monitoring systems with smart grids and decentralized energy systems
- Integrated areas along corridor of evacuation routes act as areas for communication, gathering and basic provision of services

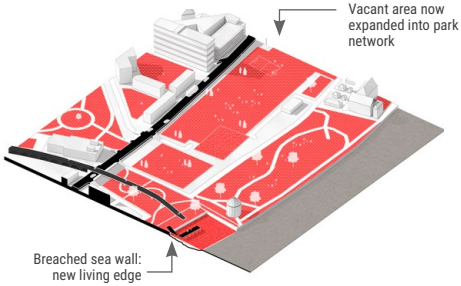


MANAGED RETREAT

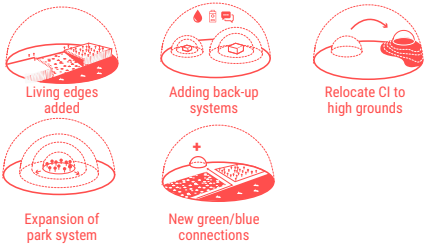
EXISTING



PROPOSED



- Relocation of CI and new infrastructure should embed semi-autonomous energy and water systems



Isle of Dogs: Land-use/Infrastructure Strategies

Working with the constraints of a highly intensified site, what if mono-functional sites were transformed into multi-functional?

Using life-cycle based planning, priority resilience areas could be transformed to multi-functional zones. The following are some benefits of phasing in the proposal:

- More mixed-use neighbourhoods to service the growing population
- Refurbishment of public spaces and streets
- Schools and medical facilities would be retrofitted to have higher safety standards. De-centralized systems could assist in reducing costs, and energy and water demands
- Higher accessibility to the riverfront and access to new safety shelters
- Integration of smart grid could adjust to future demands and uncertainties

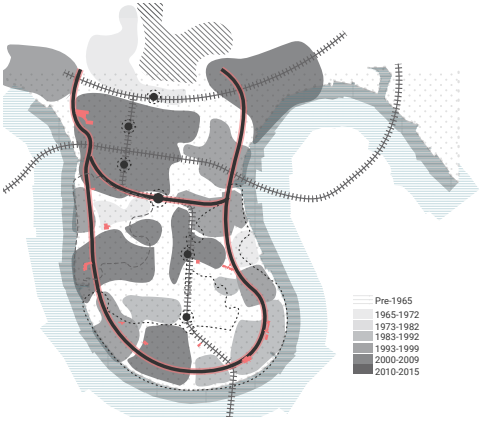


Figure 76 Compared to the other two policy units, the Isle of Dogs has more recent urban development towards Canary Wharf.

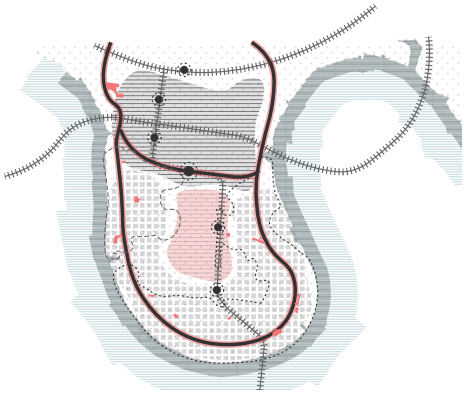


Figure 77 Isle of Dogs is characterized by a strong business district on the northern portion of the site and ringed by residential developments on the southern half.

Figure 78 Large mono-functional residential developments along the riverfront

Figure 79 Low-density residential district, one of the oldest and adjacent to the evacuation corridor

Figure 80 Dense residential development & storage facility

Figure 81 Dense development with poor access to riverfront

Figure 82 Old residential district with the highest deprivation index

Figure 83 Low access and backyards turned against riverfront

All above images are from Google Earth, 2019

Isle of Dogs: Business as Usual - Land Use

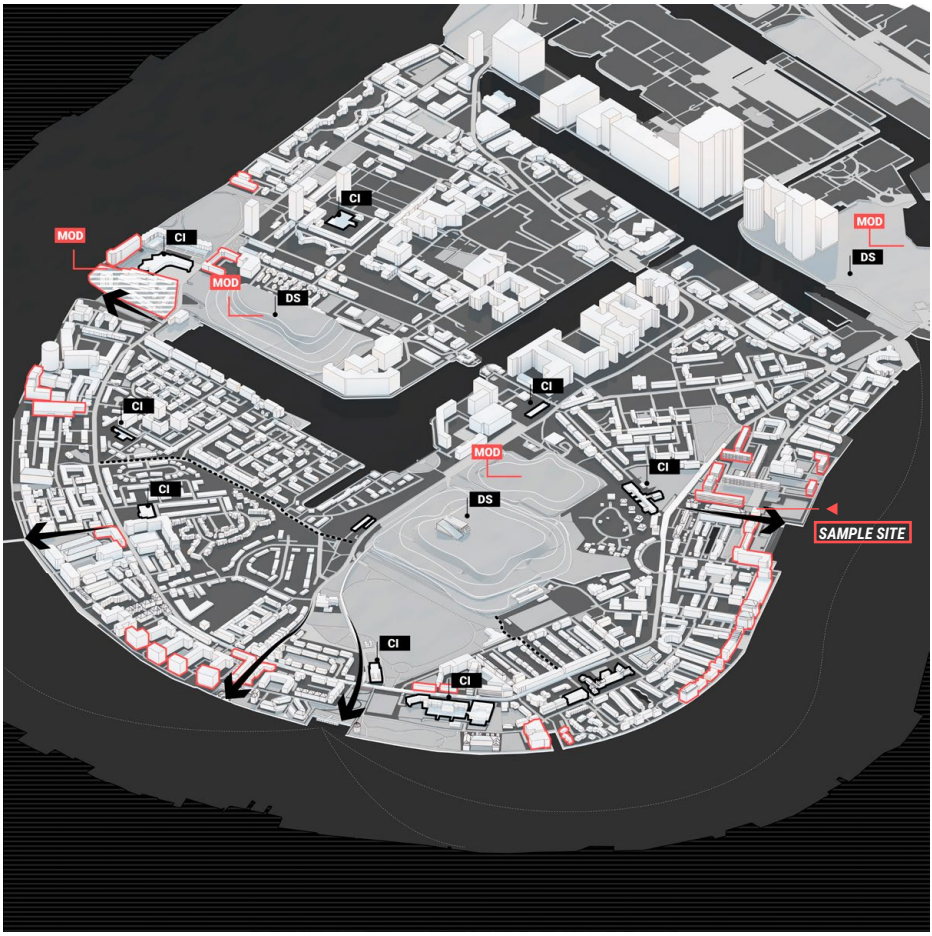


Figure 84 Proposed emergency routes, connections, and designated safe areas for Isle of Dogs

CI Priority Critical Infrastructure (Schools)

DS Designated Safe Grounds - Permanent Public Access

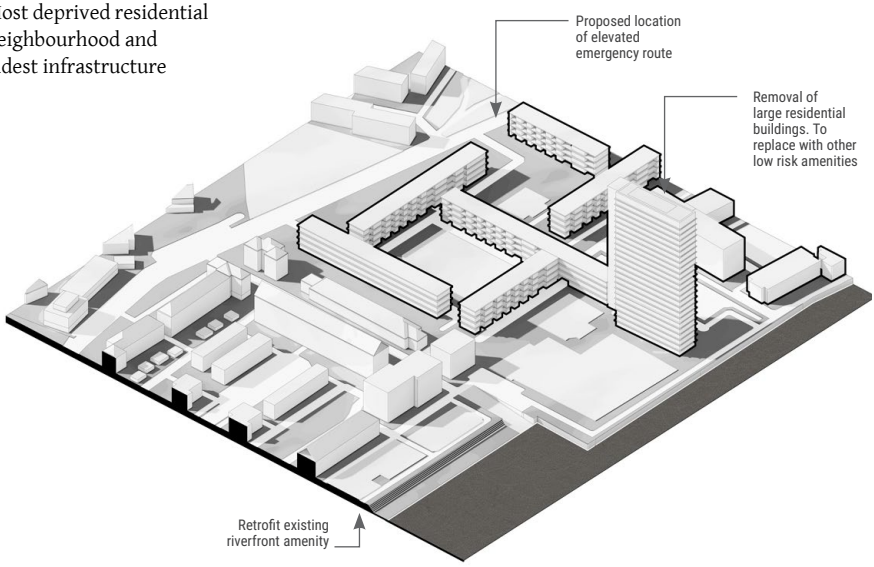
MOD Modified Industrial/Surface Parking

↔ Recommended permanent pedestrian access

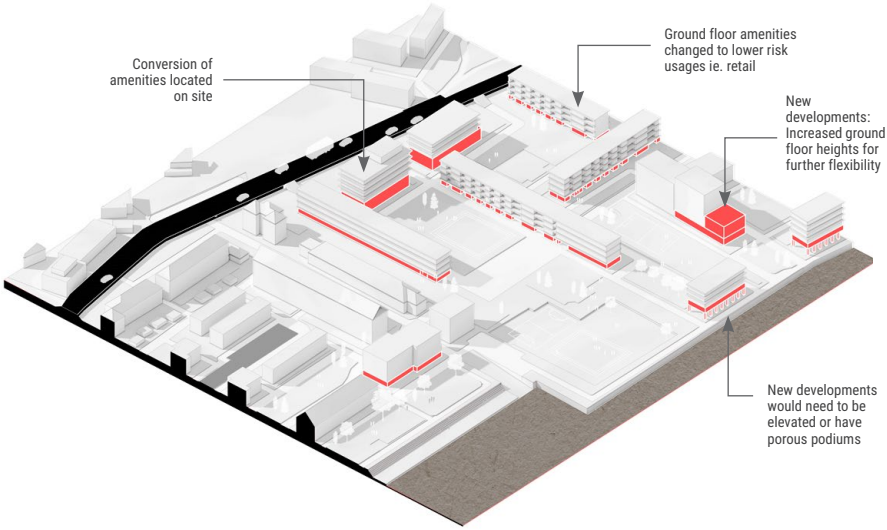
- Development and changes occur at the end of the functional life of infrastructure with retrofitting first floors
- Priority to infrastructure adjacent to river front and emergency corridor
- Increasing porosity, adaptability and flexibility throughout the site through stronger connections
- Stricter development regulations on elevating new buildings
- Strengthened connections to riverfront

EXISTING

Most deprived residential neighbourhood and oldest infrastructure



PROPOSED



Isle of Dogs: Business as Usual - Open Space Strategies

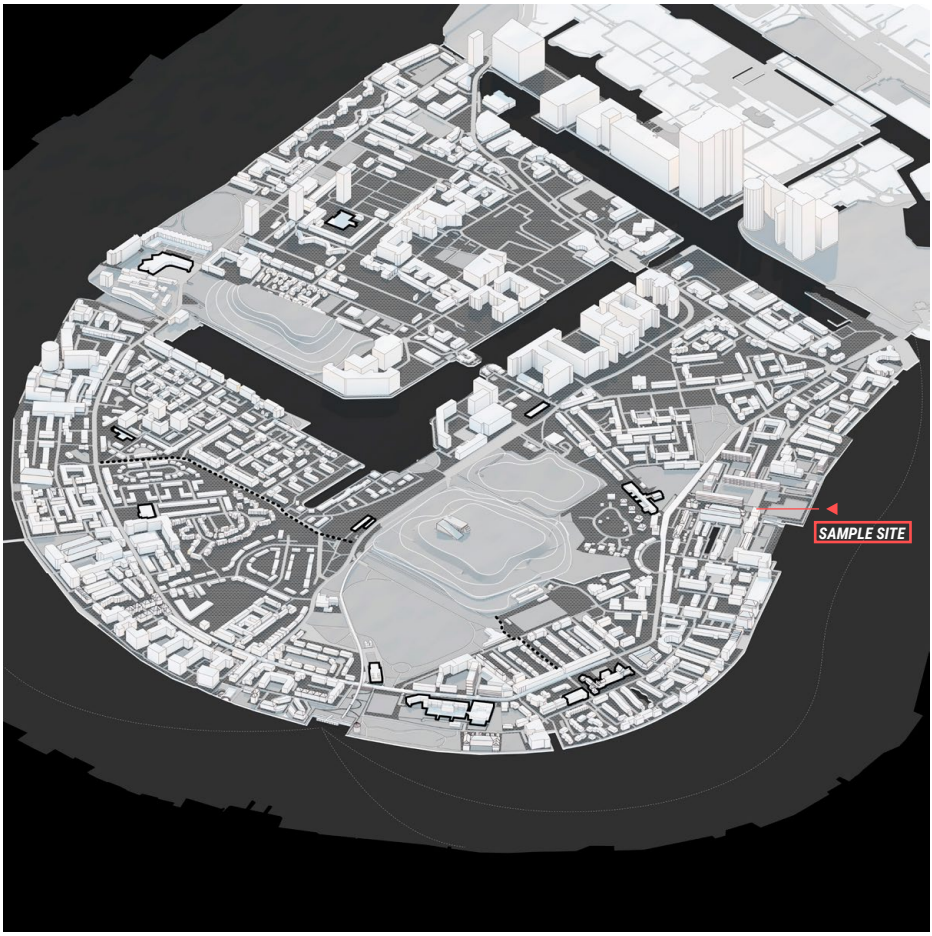
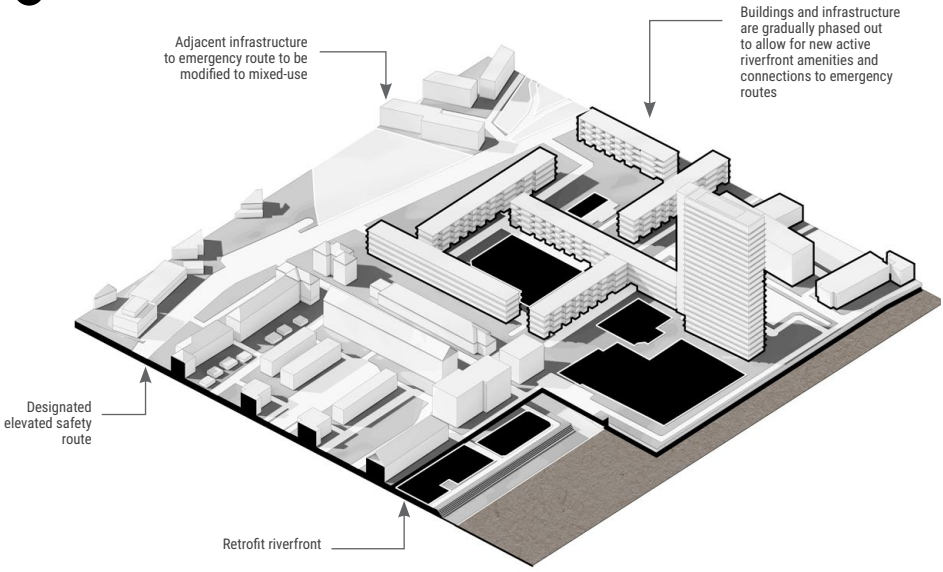


Figure 85 Proposed retrofitting of existing amenities for water retention

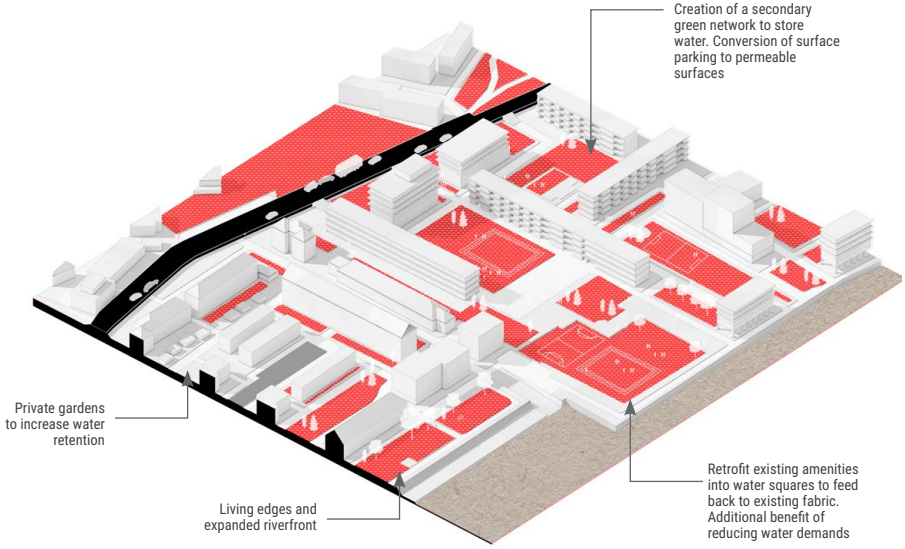
- Hard-scape conversion
  1,137,365m²
- 254,297m²
  Surface parking
- 211,936m²
  Domestic gardens

- The green/blue network could become a secondary network for the direction and storage of water
- Converting existing recreational facilities to water squares - water redirected to be stored in nearby facilities as backup systems
- Majority of hard infrastructure programmed to have more infiltration

EXISTING



PROPOSED



Isle of Dogs: Managed Retreat - Land Use

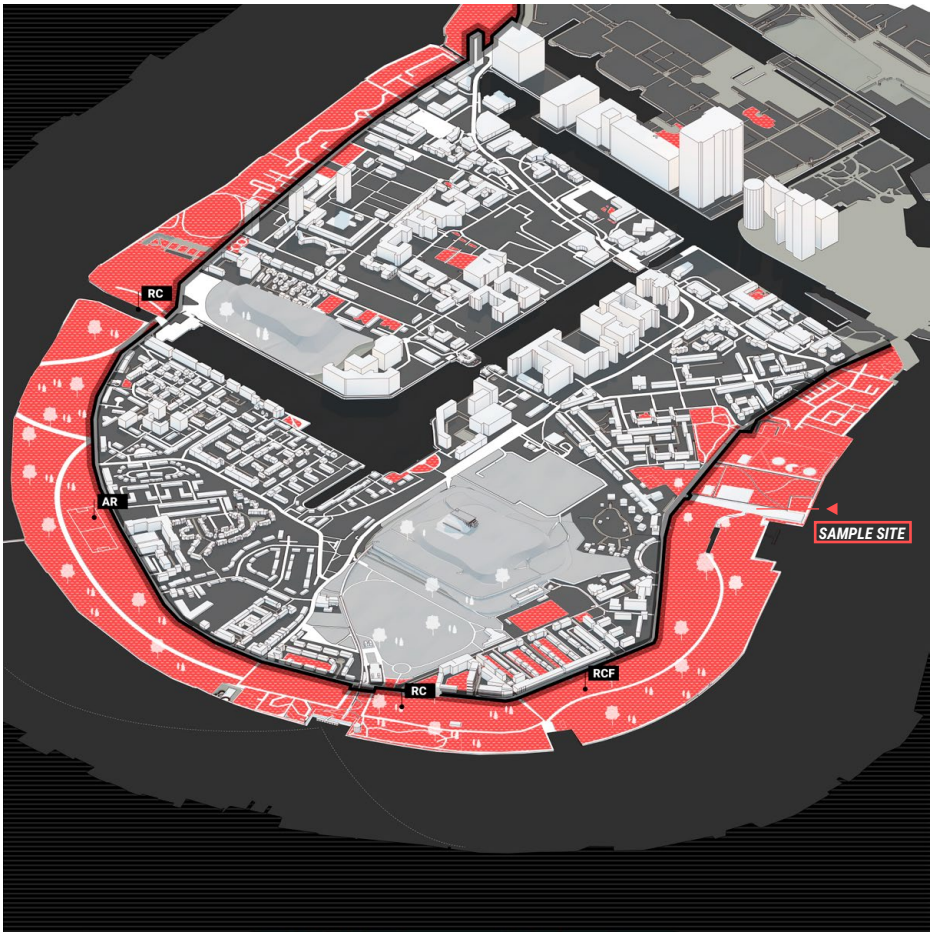


Figure 86 Proposed zoning and land uses for managed retreat

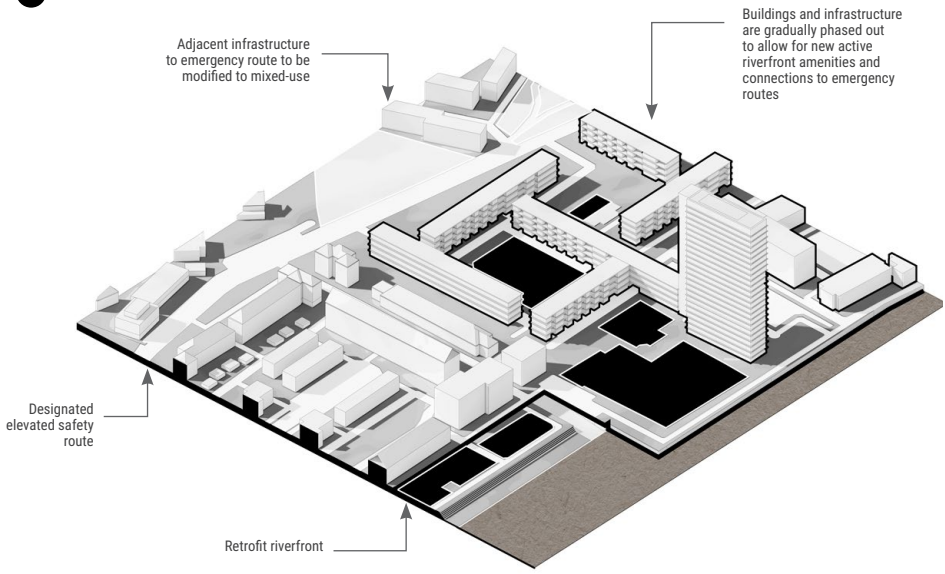
AR Active Riverfront

RC Riverfront Commercial

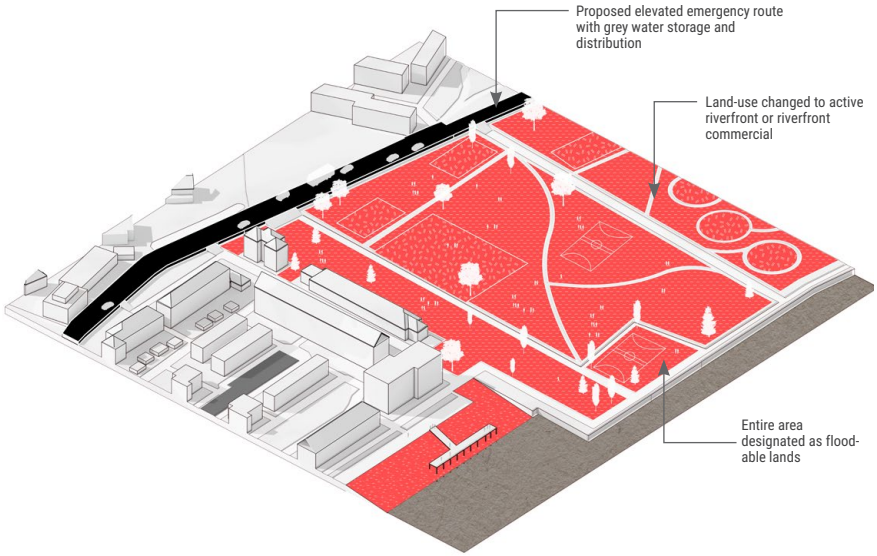
RCF Riverfront Facilities

The managed retreat scenario focuses on restricting development along the edges of the riverfront. With this in mind, the priority shifts to phasing out of old residential development to enable to the intrusion of nature and water. In conjunction with the development of emergency routes, the new open space amenities would tie into alleviating pressures on the existing urban development.

EXISTING



PROPOSED



Isle of Dogs: Managed Retreat - Open Space Strategies

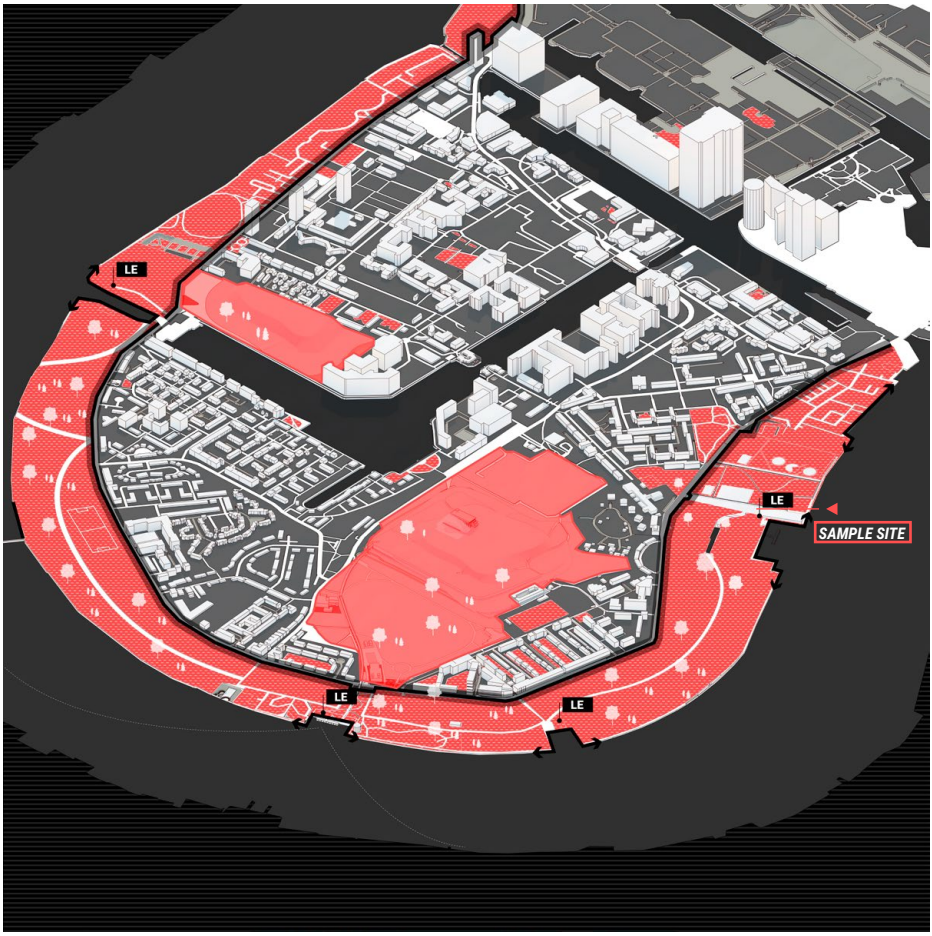


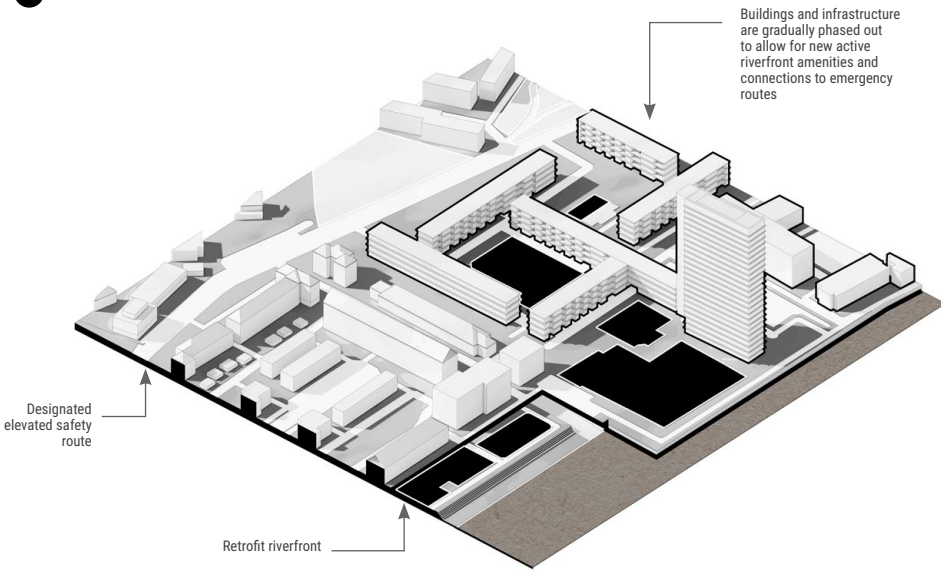
Figure 87 Proposed retrofitting of existing amenities for water retention

LE Living Edges

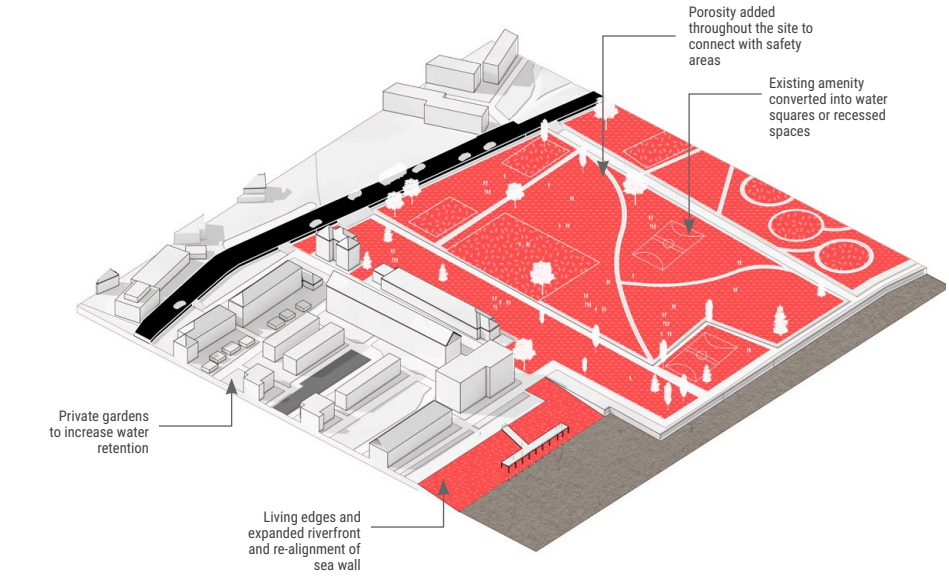
- Hard-scape conversion
  1,137,365m²
- 254,297m²
  Surface parking
- 211,936m²
  Domestic gardens

- Complete transformation and removal of infrastructure along river front
- Large expansive green space to connect with safety zones

EXISTING



PROPOSED



Zoom-In: Isle of Dogs, Sample of Proposed Interventions

RE-PURPOSED ELEVATED AQUEDUCT

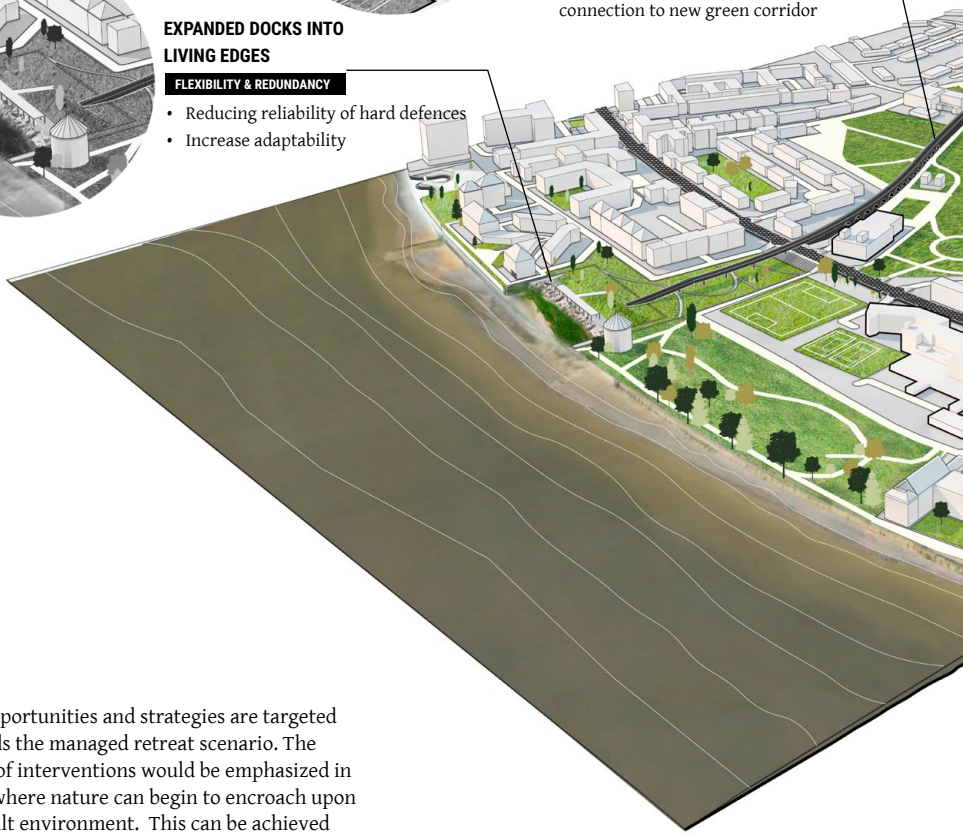
FLEXIBILITY & REDUNDANCY

- Secondary elevated route for pedestrians and cyclists to evacuate to a nearby shelter
- Disused rail aqueduct to establish a connection to new green corridor

EXPANDED DOCKS INTO LIVING EDGES

FLEXIBILITY & REDUNDANCY

- Reducing reliability of hard defences
- Increase adaptability

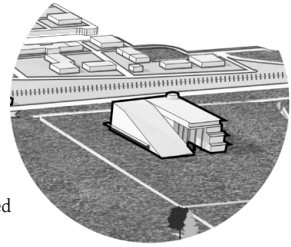


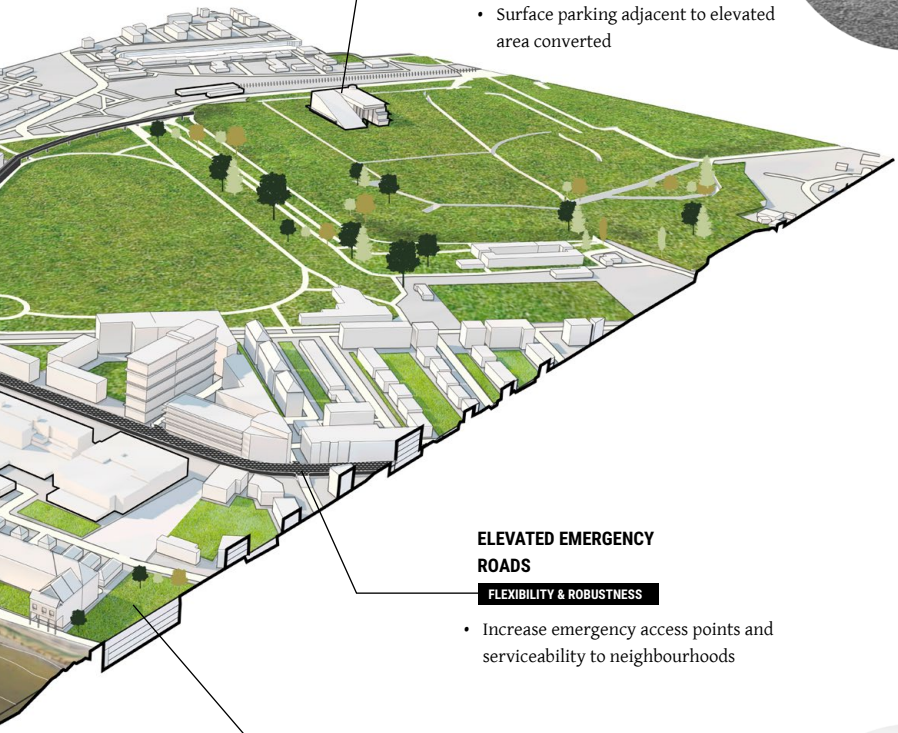
The opportunities and strategies are targeted towards the managed retreat scenario. The series of interventions would be emphasized in areas where nature can begin to encroach upon the built environment. This can be achieved through the nature of life-cycle planning once the functional lifespan of infrastructure is reaching its expiry. The process would begin within the time constraints of phasing out of infrastructure adjacent to the Thames Riverfront and furthermore in the defined priority resilience areas. Critical infrastructure within the priority resilience area will be gradually replaced by green infrastructure. In addition, any new development within the area will continue to be restricted.

DESIGNATED SAFE SHELTERS

FLEXIBILITY & ROBUSTNESS

- New shelters to have multi-functional purposes and equipped with decentralized energy & water collection systems
- Facilitate direct communication to emergency vehicles
- Surface parking adjacent to elevated area converted





ELEVATED EMERGENCY ROADS

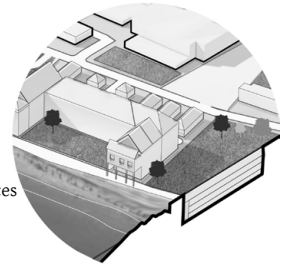
FLEXIBILITY & ROBUSTNESS

- Increase emergency access points and serviceability to neighbourhoods

CONVERSION OF SURFACE PARKING & GREY INFRASTRUCTURE

FLEXIBILITY & ROBUSTNESS

- Removal of surface parking and change into open/recreational spaces for additional water infiltration



Increasing Accessibility and Awareness

Elevating Open Spaces and Creating Safe Grounds

Back up Systems

Manipulating Land-Use and Urban Renewal

Dry-proofing/Wet-proofing Existing Infrastructure

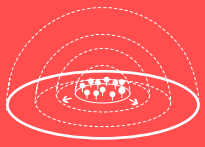
Private Gardens to Retain More Water

Linking Safety Grounds With Elevated Emergency Routes

Living Edges/ Enlargement of Natural Defences

Integrating Smart Grid Services

Burying Train Rails



Expanding Existing Park Space

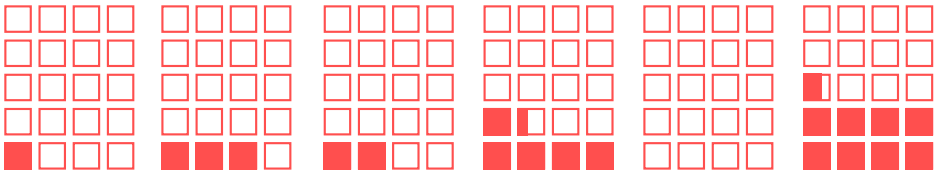
Relocating CI to Higher Grounds

▲
Interventions applicable in this policy unit

The diagram on the right breaks down the occupation of space within the boundary ▶

Zoom-In: Royal Docks

5%



Public Space
- 381,248m²
- 750,536m² Domestic gardens

Building Footprint
- 1,069,276m²
- 26,635m² Critical Infrastructure

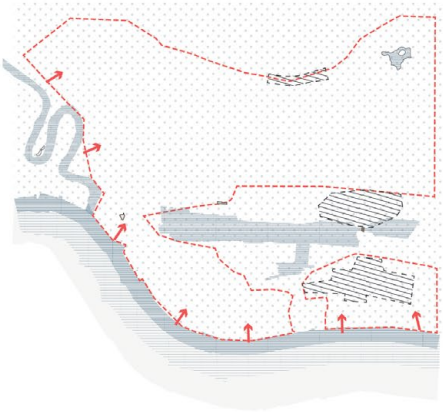
Road
- 732,918m²

Water
- 2,002,361m²

Surface Parking
- *combined with hardscapes

Hardscapes/Other
- 3,127,235m²

Royal Docks: Defining Priority Resilience Areas & Critical Infrastructure

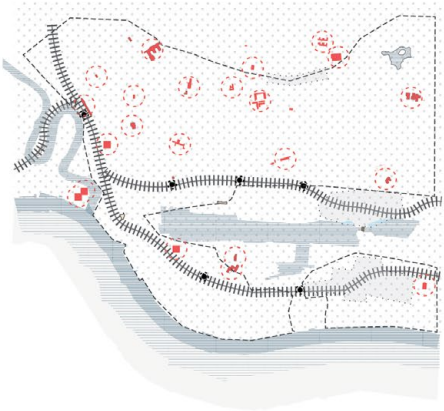


The Disrupted State

Residual risks from failed defences

Critical Drainage Areas

Priority Resilience Areas

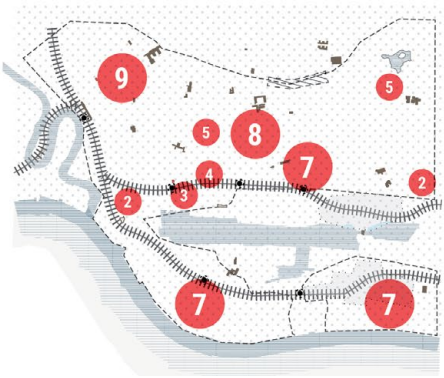


The Disrupted State: Place of Gatherings

Priority CI in affected area

Train Stations

Schools

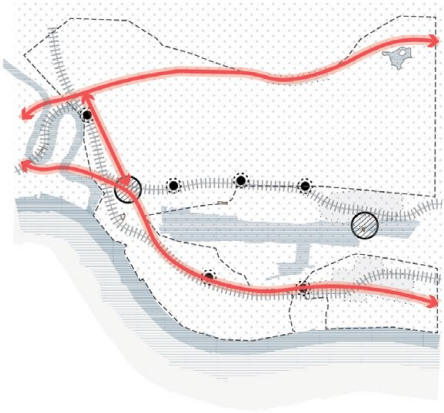


The Electrical Disrupted State

Affected electrical areas with >2m SLR

Electrical Substations

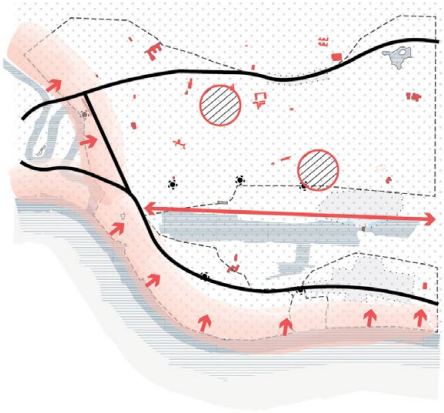
Royal Docks: General Strategic Interventions



Accessibility & Service

Proposed elevated areas and connections (automobile, pedestrians, water and cycling)

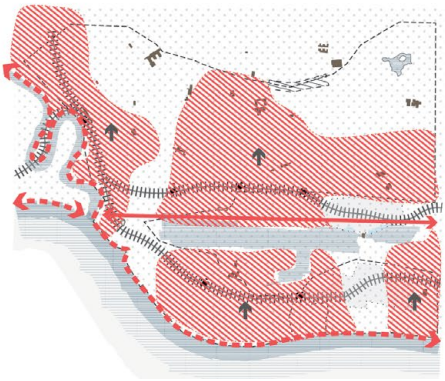
- Critical connection points
- Elevated roadway
- Elevated pedestrian/cyclist path
- Waterway (emergency relief)



Managed Retreat

Green buffer zone and green spine

- Removal of outer edge infrastructure
- Sacrificial edges or restricted development along corridors
- Primary elevated areas
- Relocation and allocation of growth outside of flood plain



Business as Usual

- Risk of islanding or separated from emergency relief
- Development pressure areas
- Increased Wall height

Royal Docks: Proposed Shelters and Emergency Routes

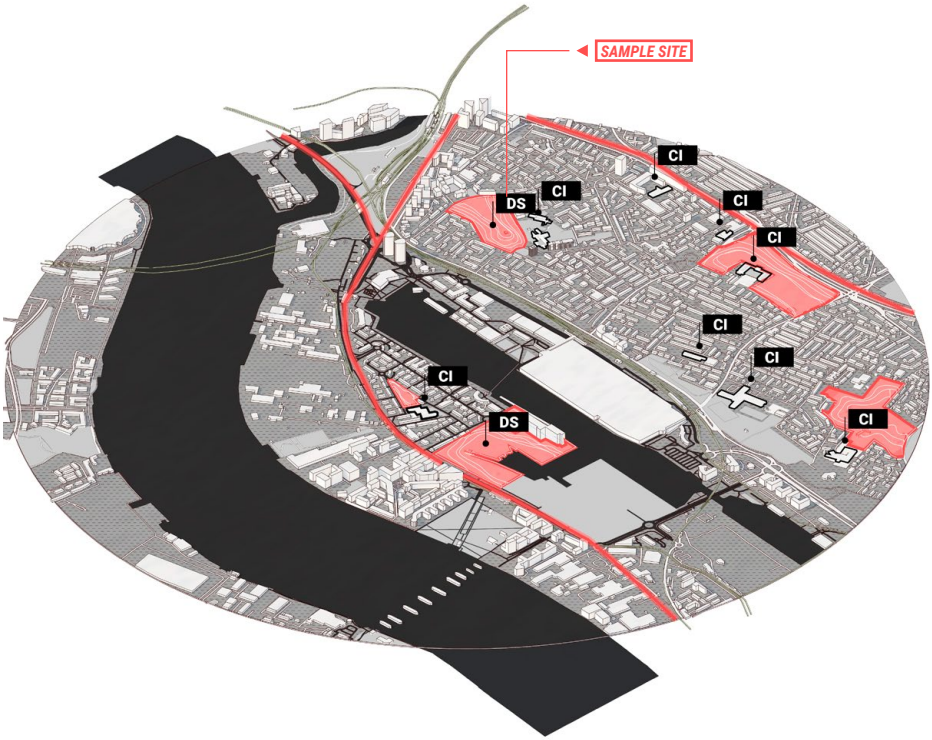


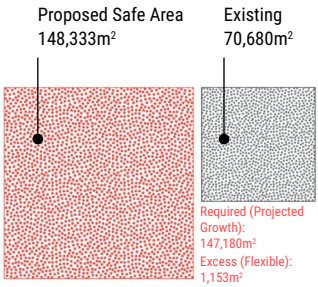
Figure 88 Proposed emergency routes, connections, and designated safe areas for Royal Docks (applied to existing context)

CI Critical Infrastructure

DS Designated Safe Shelter

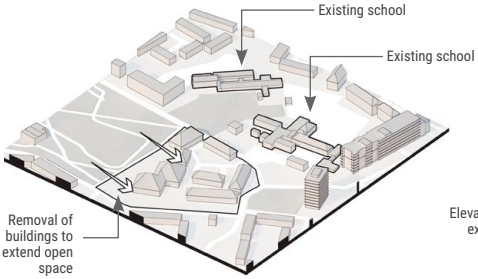
Elevated Emergency Routes

Designated Elevated Safe Grounds

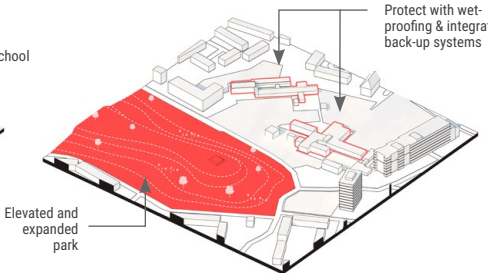


Royal Docks: Critical Infrastructure

EXISTING

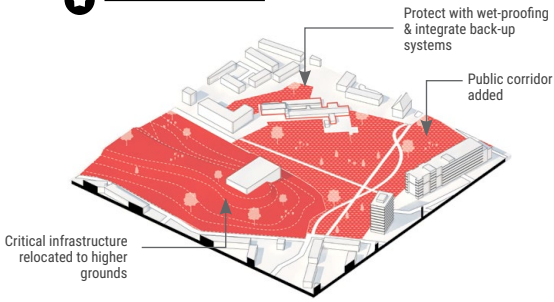


PROPOSED



There is an importance of phasing in monitoring systems with smart grids and decentralized energy systems to facilitate learning and response. In addition, new elevated safe areas provides a trigger of change within the community. Spaces could be re-arranged to provide more amenities and safety while offering new places for the community to gather.

PROPOSED



In the existing context, majority of the schools are tied with the only open public spaces in the area (northern) portion of the site. These facilities should be retrofitted to contain off-grid back up systems. Having the schools as designated safety locations adjacent to elevated safe grounds provides a landmark for communities.

Royal Docks: Land-use/Infrastructure Strategies

Working with the constraints of a highly intensified site, what if mono-functional sites were transformed into multi-functional?

Phasing in changes within the priority resilience area using life cycle planning could allow for:

- Alleviating some of the pressures of the east-west divide by creating more connections across the dock area
- Planned urban renewal could integrate stricter safety standards and embedding smart grids
- Enhanced riverfront environment, biodiversity and amenities
- Increased public awareness of emergency planning and response through visual cues and education
- Burying exposed train tracks to allow for more porosity from residential developments and reduction of risk on transportation
- Introduction of living edges and tidal parks to reduce reliability on raising the heights of the seawalls

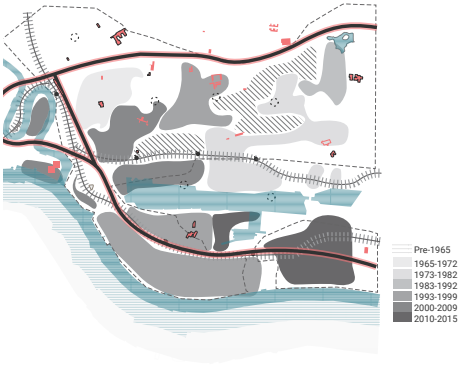


Figure 89 The characteristic of each residential neighbourhood is also clearly defined by the era they were constructed. The Royal Docks neighbourhoods consists of various eras developed in patches.

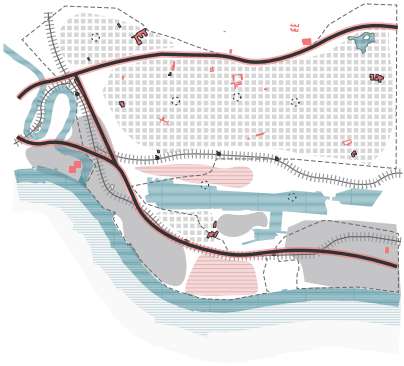


Figure 90 The Royal Docks policy unit is undergoing intensive urban renewal with the southern portion of the site defined by derelict industry. In contrast, the northern portion of the site is primarily residential.

Figure 91 Large derelict industrial areas adjacent to Thames Barrier Park, currently set for redevelopment

Figure 92 Dense residential development & storage facility

Figure 93 One of the few schools located in the southern portion of the site adjacent to a public park

All above images are from Google Earth, 2019

Figure 94 Urban renewal planned for industrial facilities

Figure 95 School located near proposed emergency route

Figure 96 Derelict industrial facilities and London City airport

Royal Docks: Business as Usual Strategies

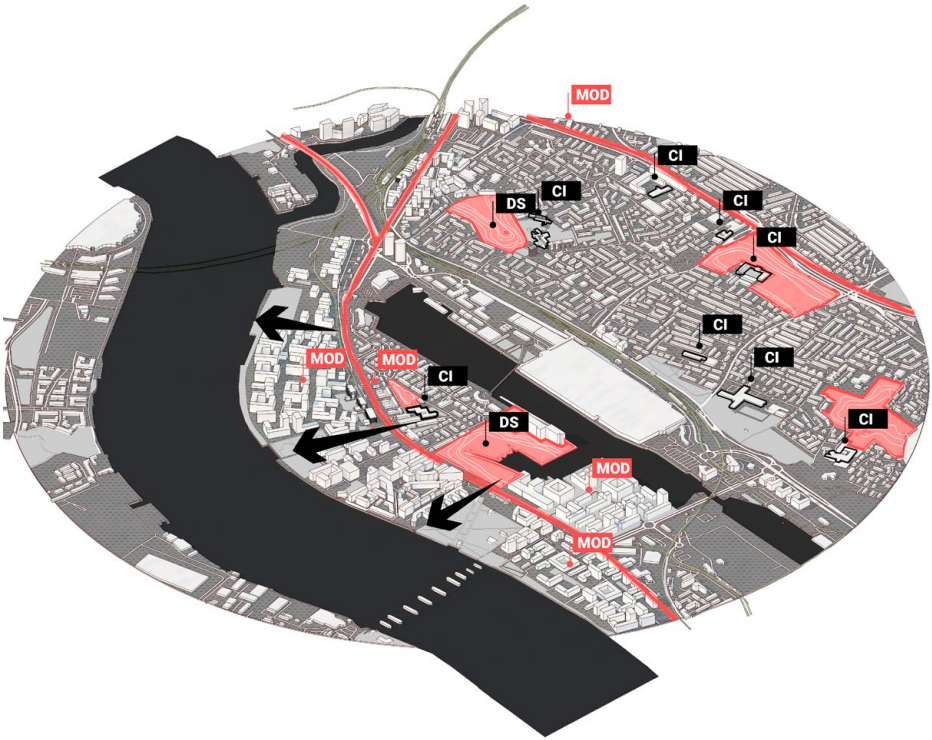


Figure 97 Business as usual scenario for the policy unit, Royal Docks.

MOD Modified Industrial/Surface Parking

CI Priority Critical Infrastructure (Schools)

DS Designated Safe Shelter - Permanent Public Access

Elevated Emergency Routes

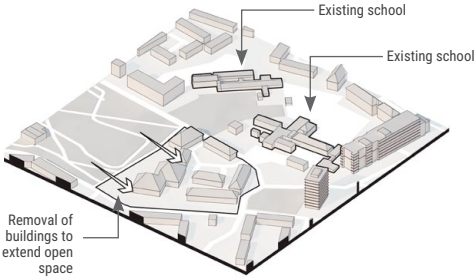
Designated Elevated Safe Grounds

Recommended permanent pedestrian access

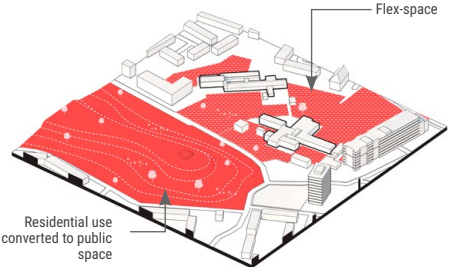
In contrast to the Isle of Dogs, the Royal Docks policy unit has several urban renewal projects underway. A portion of the developments along the corridor of the proposed evacuation routes contain planned mixed-use developments. However, there are residential units still occupy a large fraction of the site. The primary intentions of the new set of interventions is ensuring higher safety standards and designating permanent public pedestrian access.

Land Use Strategy Prototype

EXISTING

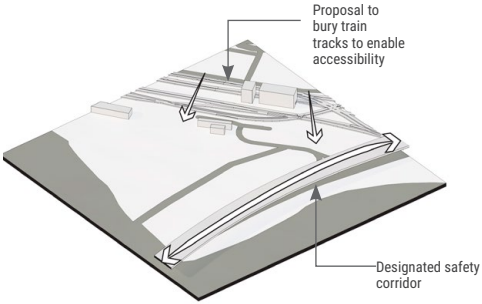


PROPOSED



Open Space Strategy Prototype

EXISTING



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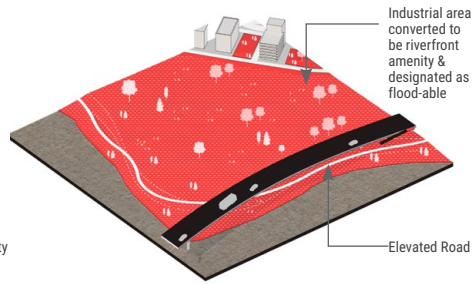

Royal Docks: Managed Retreat Strategies and Designations

Figure 98 Managed Retreat scenario for the policy unit, Royal Docks.

AR Active Riverfront

LE Living Edges

CI Critical Infrastructure

DS Designated Safe Shelter

Elevated Emergency Routes

Designated Elevated Safe Grounds

The managed retreat scenario shows opportunities to connect the existing parks located along the riverfront. This would also relieve the financial burden of maintaining and reinforcing the existing seawalls. With the upcoming plans of urban renewal, stricter regulations would need to be enforced to prevent future development along the riverfront. This would allow for more amenity space for the existing population and flexibility to deal with the deep uncertainty of flood risk.

Land Use Strategies Prototype

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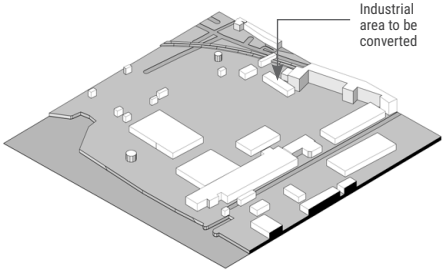

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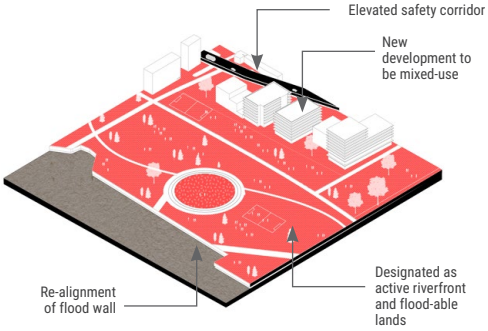

Open Space Strategies Prototype

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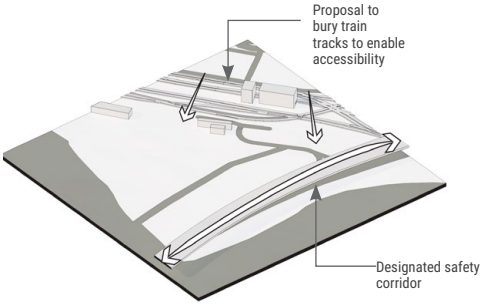

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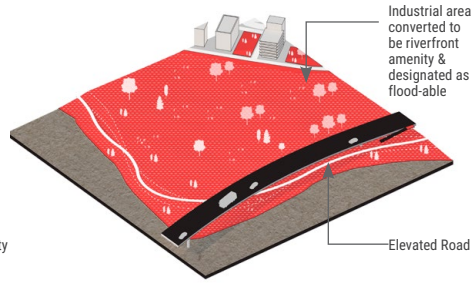


- Existing condition does not have a seawall
- Living edges created where pedestrians have access to the space to view changing water levels

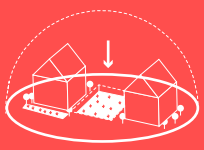
Increasing Accessibility and Awareness

Elevating Open Spaces and Creating Safe Grounds

Back up Systems for Existing CI

Back up Systems

Manipulation of Land-Use

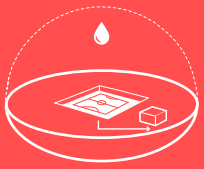


Private Gardens to Retain More Water

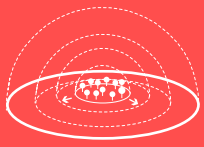
Linking Safety Grounds With Elevated Emergency Routes

Living Edges/ Enlargement of Natural Defences

Integrating Smart Grid Services



Retrofitting Outdoor Recreation to Water Squares



Expanding Park Network

▲
Interventions applicable in this policy unit

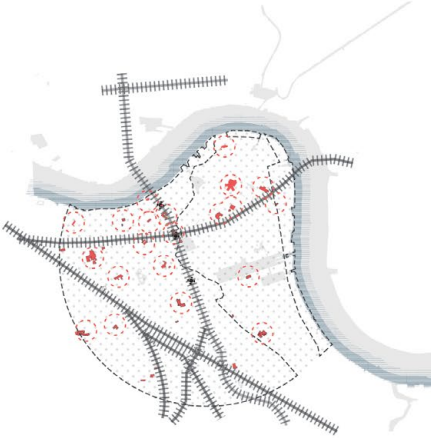
Zoom-In: Wandsworth to Deptford

Wandsworth: Defining Priority Resilience Areas & Critical Infrastructure

The Disrupted State

Residual risks from failed defences

Priority Resilience Areas

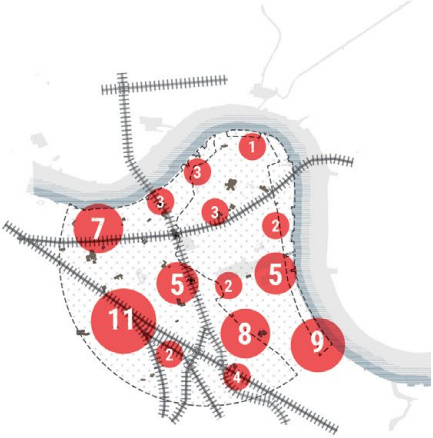


The Disrupted State: Place of Gatherings

Priority CI in affected area

Train Stations

Schools



The Electrical Disrupted State

Affected electrical areas with >2m SLR

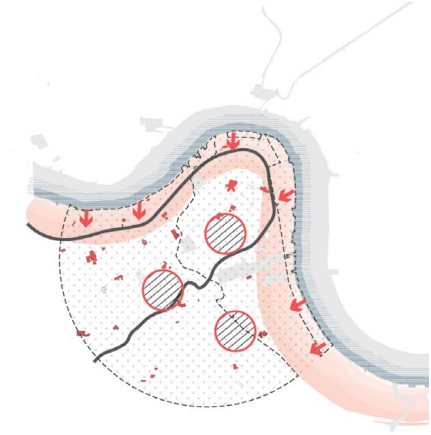
Electrical Substations

Wandsworth: General Strategic Interventions

Accessibility & Service

Proposed elevated areas and connections (automobile, pedestrians, water and cycling)

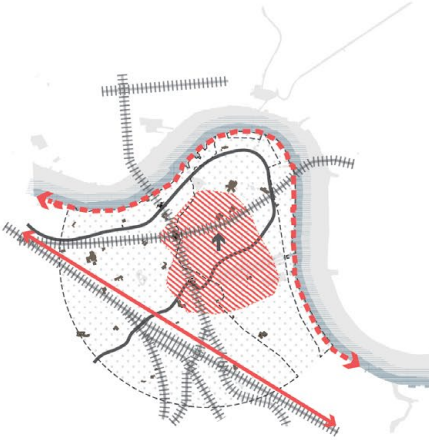
- Critical connection points
- Elevated roadway
- Elevated pedestrian/cyclist path
- Waterway (emergency relief)



Managed Retreat

Green buffer zone and green spine

- Removal of outer edge infrastructure
- Sacrificial edges or restricted development along corridors
- Primary elevated areas
- Relocation and allocation of growth outside of flood plain



Business as Usual

- Risk of islanding or separated from emergency relief
- Development pressure areas
- Increased Wall height

Wandsworth: Land-use/Infrastructure Strategies

Working with the constraints of a highly intensified site, what if mono-functional sites were transformed into multi-functional?

Phasing in changes to infrastructure within priority resilience area using life cycle based planning could allow for:

- Enhanced riverfront environment and amenities
- Increased public awareness of emergency planning and response
- Provide a more even distribution of available public spaces to the community

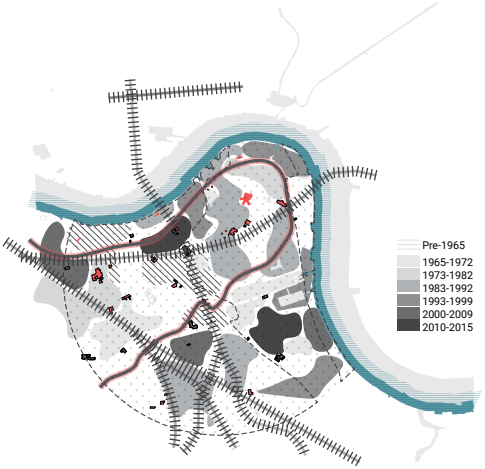


Figure 99 Similar to the other policy units, Wandsworth contains various "patches" of development. Understanding the building ages and life-cycles could assist in phasing in the proposed strategies.

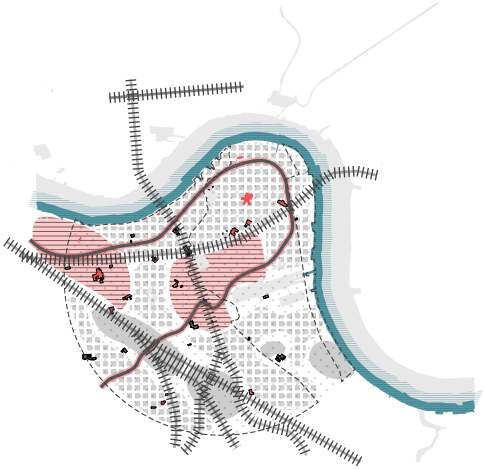


Figure 100 Wandsworth is defined by a large urban commercial areas, residential, large transportation hubs and industry.

Figure 101 Large mall with surface parking in between two large open spaces. This provides an opportunity to link the two spaces.

Figure 102 Large residential blocks with low quality riverfront access. Courtyards are used for surface parking

Figure 103 Majority of this residential neighbourhood has large swathes of hard grey infrastructure, lack of porous surfaces and are disconnected from the riverfront

All above images are from Google Earth, 2019

Figure 104 Mono-functional residential riverfront with seawall

Figure 105 Derelict industrial areas across the neighbourhood (adjacent to proposed evacuation corridor)

Figure 106 Docking area adjacent to proposed emergency corridor and large open space

7.6 Priority Safety Measures: Creating Hierarchy in the System
Conclusions From Scenario Studies

The mindset in utilizing evolutionary resilience is to not only achieve physical integrity in assets but to also maintain essential services and operating performance. The system should continue to grow, learn and adapt as time persists.

PRIMARY

Designating Safe Areas

- Prioritizing the creation of elevated safe grounds. These areas should be out of reach of high water levels in case of a flood event.
- Public spaces would also act as temporary shelters

Elevated Road Networks

- Focus on rerouting and assigning designated evacuation routes. This includes alternate routes and modalities to address any flood risk intensity.
- The network should connect designated safe zones

SECONDARY

Alterations to Land Use

- Enables the reconfiguration and composition of spaces to respond to risk management
- Enforces stricter regulations to existing developments to manage higher water capacities which will assist in managing the flow of water while directing flow of people
- As a result, the interventions allow for higher response times and accessibility

Existing Critical Infrastructure

- If there is continued pressures and demand on development, reinforcing the service continuity of the CI (medical facilities & schools designated as shelters) becomes priority
- Secondary stage would be retrofitting these facilities with backup systems
- Alternatively, critical infrastructure that are situated within the flood resilience priority areas should be re-allocated to outside of the floodplains. These areas will then be converted as part of the blue-green network

New Critical Infrastructure

- Dual purpose of creating additional public amenities that could trigger the chain reaction of decentralizing/semi-autonomous infrastructure (energy & water) and the creation of backup systems
- Self-sufficient energy, communication systems and water supply that could operate off-grid during disaster until additional emergency relief is provided
- An integrated monitoring system (part of DAP) would assist in developing an integrated feedback loop in continual improvements to the system
- Construction of smart grid as a safe-to-fail mechanism

Business as Usual

- New urban renewal developments to abide by stricter guidelines for ground floor uses and connection to river fronts
- Safety standards need to be held at a higher regard with a governing body held accountable for public awareness
- If regulations and safety parameters are ignored, the policy units will expose themselves to higher forms of cascading risks. The developments will also be exposed to higher forms of economic and environmental risks long-term.

Managed Retreat

- Challenges the norm of accepting residual risks at the background of development
- Phasing out existing developments are paired with life-cycle management to reduce financial burden. New incentives are born from providing new open space and recreation amenities.
- Living deprivation index improves for the policy units but financial risks may worsen due to the prevention of future developments along prime real estate

7.7 Proposed Addendum to Thames Estuary 2100 DAP

Addendum Summary
The addendum accommodates a time component rather than focusing on the execution of projects based on SLR. The current TE2100 provides a flexible framework in response to deep uncertainty but this creates a lack of standardized safety parameters across all policy units. With the addendum, safety parameters and infrastructure is accessed within each policy unit to see what can be modified in the existing urban fabric. In addition, it provides the minimum safety parameters for new urban development.

Response Awareness
The listed interventions only accommodate for spatial interventions but a key component in the response phase of risk management is to increase awareness. With less than 10% of the population that reside on the floodplain aware of risks, it is important to allocate responsibility to a designated governing body per policy unit. In addition, the interventions that provide accessibility to the riverfront should enable visual cues of changing water levels alongside educational facilities.

Phasing Projects Based on Life Cycle of Infrastructure
Refer to pg. 127, Fig. 70

General Constraints and Impediments
- Financial burdens and lack of funding
- Lack of awareness and public support
- De-centralized governance systems to impede on execution of plans
- Conflict of master plans and developments underway

Financial Risk Vs. Environmental Management Risk
List of Actions that could severely impact financial risks (ie. development costs)

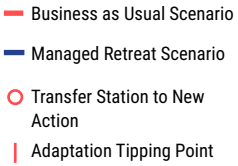
- C, F, G, M, P, Q, S

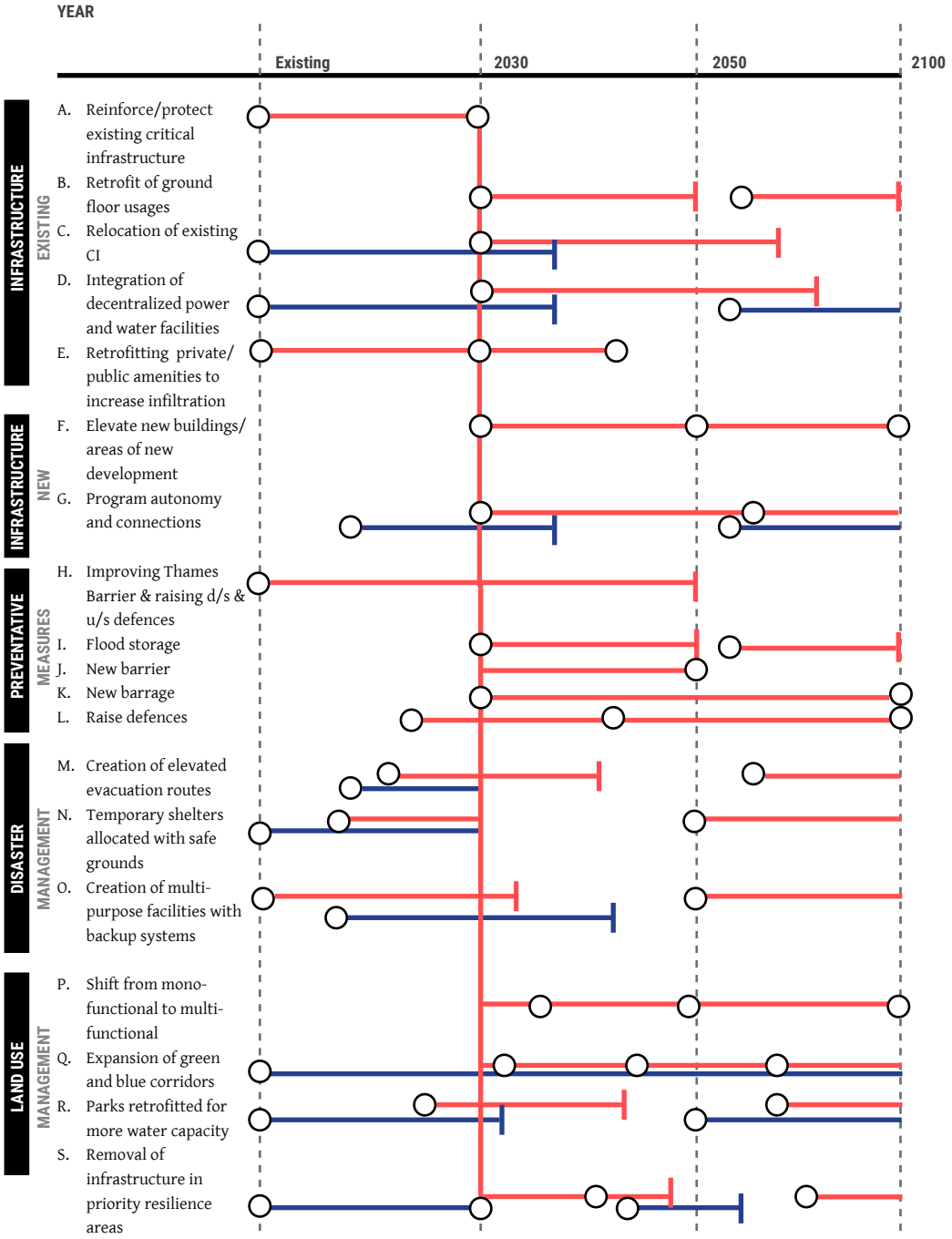
List of actions that could long term harm environmental management risks
- A, D, G, H, J, K, L, M

Ownership/Governance (Responsibilities & Conflicts)
- Department for Communities and Local Government - Planning and Policy Building Regulations
- Department for the Environment, Food and Local Affairs (DEFRA)
- Cabinet Office
- Environment Agency
- Local Flood Authorities
- District Councils
- Major Infrastructure Owners and Third Parties
- Local Residents

Co-benefits from Existing Systems
- Smart grid integration
- Thames Gateway Parklands Projects (Defra)
- Greater London Authority already executed studies on Decentralized Energy Capacities
- Communities gain a higher improved deprivation index on green space and amenities

Tipping Point
Each adaptation tipping point requires further monitoring of when it reaches capacity or threshold. Extending the tipping point is possible when the services are retrofitted to improve. Afterwards, the process begins again with the start of a new phase.




YEAR
Existing
2030
2050
2100
INFRASTRUCTURE
EXISTING
A. Reinforce/protect existing critical infrastructure
B. Retrofit of ground floor usages
C. Relocation of existing CI
D. Integration of decentralized power and water facilities
E. Retrofitting private/ public amenities to increase infiltration
INFRASTRUCTURE
NEW
F. Elevate new buildings/ areas of new development
G. Program autonomy and connections
PREVENTATIVE
MEASURES
H. Improving Thames Barrier & raising d/s & u/s defences
I. Flood storage
J. New barrier
K. New barrage
L. Raise defences
DISASTER
MANAGEMENT
M. Creation of elevated evacuation routes
N. Temporary shelters allocated with safe grounds
O. Creation of multi-purpose facilities with backup systems
LAND USE
MANAGEMENT
P. Shift from mono-functional to multi-functional
Q. Expansion of green and blue corridors
R. Parks retrofitted for more water capacity
S. Removal of infrastructure in priority resilience areas
Existing TE2100 Actions

Modified Scorecard

Interventions	Target effects	Relative Costs	Physical Impact	Visual Impact
Existing Infrastructure Actions				
Dry-proof or wet-proof critical infrastructure	Low	++	+	+
Retrofit ground floor usages	Medium	++	+	+
Relocation of existing critical infrastructure to higher grounds	High	+++	++	++
Integration of decentralized power, water and communication services	High	+++	+	+
Retrofitting private amenities for increased infiltration (gardens and courtyards)	Medium	+	++	+
Converting public amenities into water squares and increasing capacity	High	++	+++	+++
Excavating Existing Parks to increase infiltration	High	+++	+++	+++
Conversion of 'grey surfaces' to more porous material	Medium	++	++	++
New Infrastructure Actions				
Elevation of new buildings/new development	Medium	++	++	++
Program autonomy and connections to CI services	High	++++	++	+
Risk Management - Response Phase				
Creation of elevated evacuation routes	High	+++	++++	+++
Temporary shelters allocated with safe grounds	High	++	++	+
Creation of additional multi-purpose facilities with backup systems	High	++++	++	+
Link safety grounds with emergency elevated routes	High	+++	+++	++++
Land Use Management & Open Space				
Change mono-functional developments to multi-functional	Low	++++	++++	++
Expansion of blue green corridors	Medium	++	++++	++++
Breach existing sea wall to create living edges	Medium	+++	+++	++++
Floodplain enlargement - restructuring	High	++++	++++	++++
Removal of infrastructure in priority resilience areas	High	+++++	+++++	+++++
Floodable Parks	High	++++	++++	++++

Figure 107 Modified scorecard pathways to reflect proposed design interventions

Ch. To political env.	Ch. to social condition	Ch. To economic env.	Impediments/Constraints
Existing Infrastructure Actions			
+	+	+	Long-term phasing/funding
+	+++	++	Economic risk
++	+	+	Stakeholder ownership conflict
++++	+++	+++	Stakeholder ownership conflict
+	+++	++	Collective effort from community
+++	+++	+++	Negotiation between ownership/funding
++	+++	++	Costly, ownership, maintenance
+	+	++	Long-term project
New Infrastructure Actions			
+++	++	++	Policies to be modified
++++	++	++++	Requires large amounts of space and time
Risk Management - Response Phase			
++++	+++	+	Reliance of lifecycle
+++	++	+	Costs and ownership
+++	++++	+++	Funding
+++	+++	+++	Impediment of existing urban plans
Land Use Management & Open Space			
++	+++	++++	Funding and relocation of people
+	+++	++	Funding, long-term
+	++++	++++	Conflict of interests
++	+++	++++	Conflict of interests, funds
+++	+++++	+++++	Economic risk, large relocation of population
++	++++	++	Economic risk

**Note: existing TE2100 actions not included*

Ch. = change or change needed

env.= environment

+++++ extreme
++++ high
+++ medium
++ low
+ very low

Photo by author

EVALUATION & CONCLUSION

Network Analysis & Capacity

Second Evaluation: Design Proposal

Conclusion & Discussion

8.1 Second Evaluation of Design Proposal

Metrics

Using the same metrics established in the analysis chapter, the second evaluation is tested on the proposed new critical infrastructure network. This is to justify the proposed design interventions in improving the serviceability and accessibility to emergency services.

SUMMARY OF INDICATORS

TRAVEL TIME

Denotes travel time between an original and destination.

TIME FOR RECOVERY

Denotes the estimated time for recovery for disrupted roads after an event and after the project implementation.

PROVISION OF RELIEF

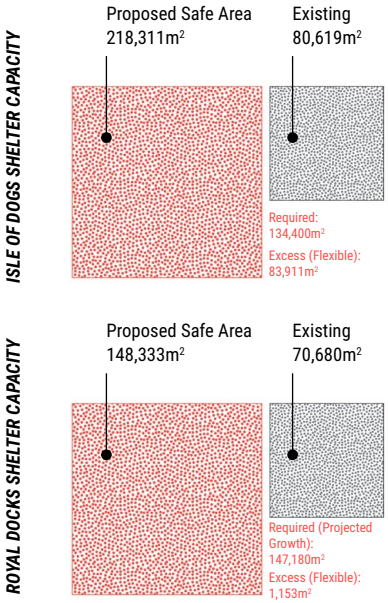
The affected population having accessibility to designated emergency shelters* (classified as medical facilities or schools) within certain time intervals under an ordinary state in comparison to a extreme event.

ACCESS TO LIFESAVING SERVICES

This relates to the accessibility and delivery of relief goods for isolated populations in a disrupted state.

Accessibility to Designated Safe Shelters

Through the re-evaluation of the system road network, the newly allocated safe zones and shelters force the system to recalibrate a new route. Utilizing the network analysis, the designated evacuation routes chosen in the design section have also proven to be the most efficient routes within the network (between designated safe shelters). Areas that were lacking within in the critical infrastructure network became supported by a secondary network established by the temporary shelters (open space). However, within the intervened policy units, more routes were added to the system to prevent a 'one-way' out situation which the network analysis does not account for. The fragmented nature of areas outside of the study area accounts for spaces lacking connections to shelters.



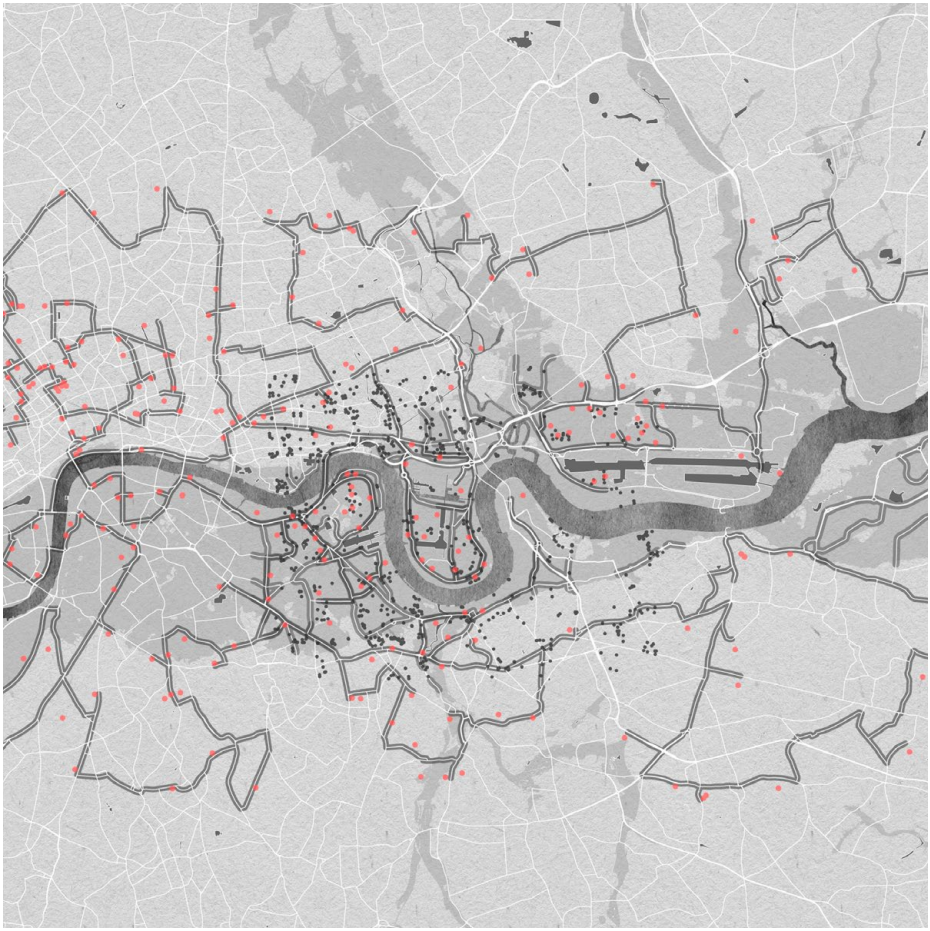


Figure 108 Provision of relief and access to lifesaving services map. This combines accessibility to temporary shelters (open parks) and designated facilities

Existing primary, secondary and tertiary roads
Primary emergency routes to shelters
Flood Zones
Proposed marked safe shelters
Entrances to designed safe zones

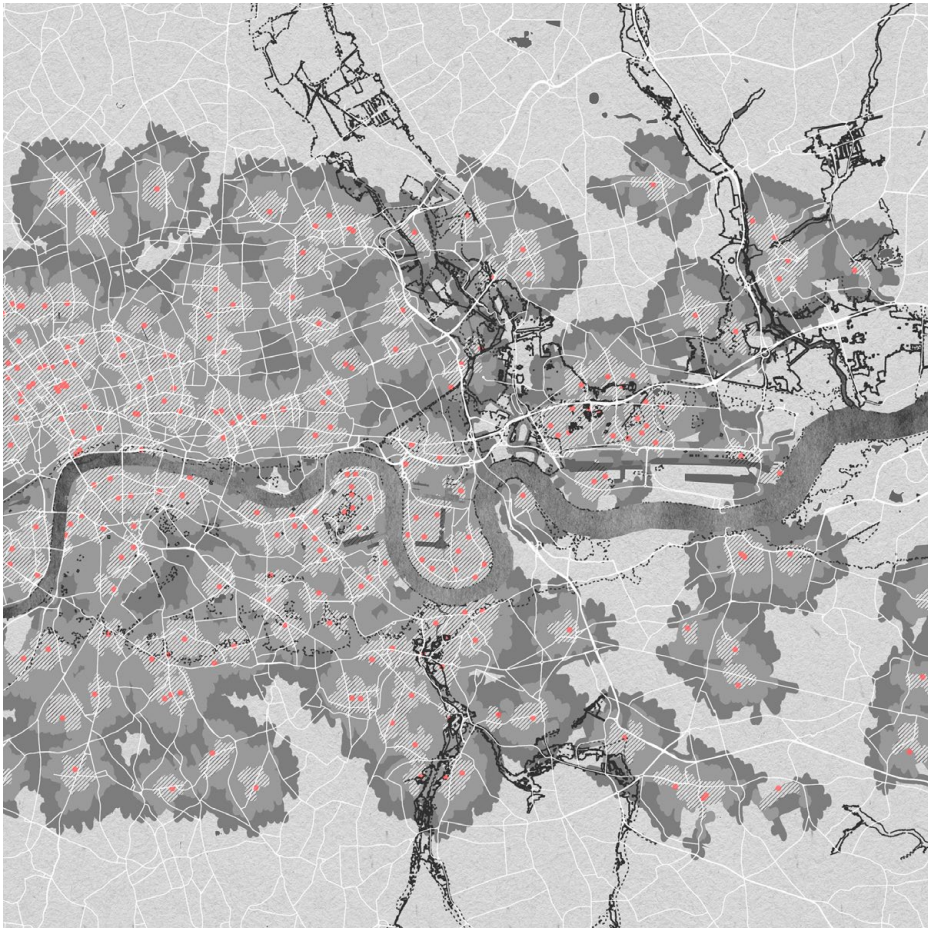


Figure 109 Serviceability map - travel time for pedestrians to access designated shelters

Existing primary, secondary and tertiary roads
Flood Zones
Proposed marked safe shelters

5 min access from a designated shelter
10 min access from a designated shelter
15 min access from a designated shelter

Serviceability to Designated Shelters (Pedestrians)

Pedestrians should be guaranteed access to a designated shelter within a maximum of 15 minute walking distance within the flood zone. Areas that are lacking accessibility have not been designed for within the policy units.

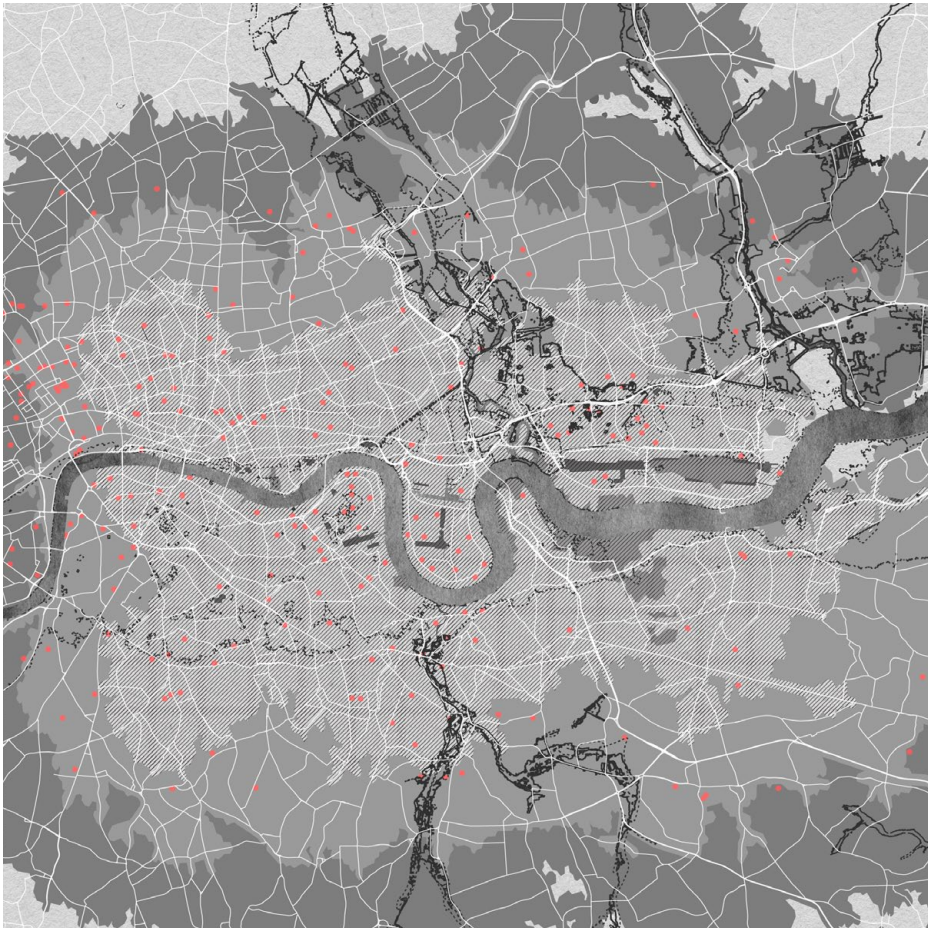


Figure 110 Serviceability map - travel time for automobiles to access designated shelters

Existing primary, secondary and tertiary roads
Flood Zone
Proposed marked safe shelters

5 min access from a designated shelter
10 min access from a designated shelter
15 min access from a designated shelter

Serviceability to Designated Shelters

Vehicles within 5,10, 15 minute intervals are guaranteed to have accessibility to designated emergency shelters even beyond the flood zone.

End-of-year Transitional Territories exhibition, photo by author

8.2 Conclusion & Discussion

At the start of the thesis, the scope was quite broad in attempting to design critical infrastructure systems to be more physically resilient in response to flood risks. Externalities and human-induced stresses to the system have posed a series of uncertainties for the future. Alongside these uncertainties, cities across the world are facing more frequent and intense precipitation patterns which are leaving critical infrastructure systems and interdependencies more exposed. However, investing in resilient infrastructure before a disaster does not typically occur, especially if the results are not immediately tangible. There is also the conflict of financing resilient infrastructure with traditional revenue and payback models as the benefits are only realized far in the future.

A large concern is that if there is no consideration of an extreme or radical way of how we plan and design cities, more risks can compound long-term. First, larger forms of risk will continue to perpetuate the system. Second, even though there may be guarantee that large population growth will bring in higher economic opportunities, the population will also continue to grow severely under prepared. Finally, the mindset of prioritizing new developments and continuation of developing large structural flood mitigation infrastructure is insufficient and unsustainable way to develop.

The thesis emphasizes in the creation of a spatial contingency plan through early response and recovery as a means of effectively increasing safety parameters instead of relying purely on mitigation approaches. The following are several proposed conditions and propositions in embedding resilience principles in critical infrastructure networks:

1. Iterations are necessary for the translation of risk management at multiple scales and allowance for flexibility.
2. Integrating early response and recovery can produce mutual benefits and new synergies in spatial developments.
3. Contingency plans are a by-product of hybrid infrastructure systems that can be multi-functional
4. By placing environmental risks at the highest priority, economic risks will decline over time.
5. There are large uncertainties in the future and thus, the system needs a new resilience parameter, namely the capacity to learn in order to grow and adapt to changing conditions.
6. It is economically unfeasible to ensure the complete protection and immunity of critical infrastructure systems. Instead there should be a focus to either limit failure or have conditions for the system to safely fail.

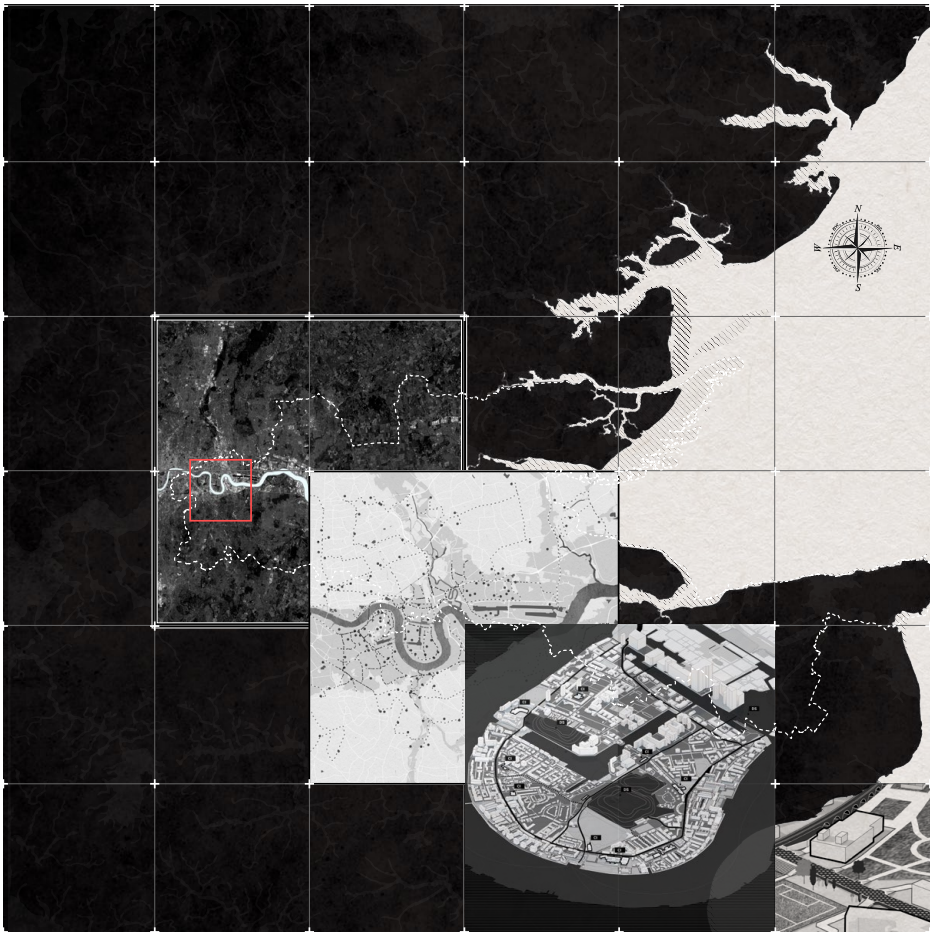


Figure 111 The risk taxonomy and mediating between scales. Drawn by Author and adapted from *Collision Map* by Chandra, W. (2012). AA School of Architecture Projects Review 2012 - Diploma 9 - Wynn Chandra. Retrieved June 15, 2019, from http://pr2012.aaschool.ac.uk/students/wynn-chandra

Aspect 1: The Risk Taxonomy and Mediating Between Scales

The frequency and magnitude of climate related events have caused direct and indirect damage to people and critical infrastructural services. Knowing the spatial extent of flood risk intensities and probability of when they can occur can assist decision-makers to make incremental short and long-term decisions. However, due to the complexity of translating flood risk management into space, it is vital to make a risk assessment framework that can translate across multiple scales.

The primary conclusion made from the research-by-design process was the importance of *iterations* The *cyclical process* of testing, analyzing and refining the design should be conducted through different scales and disciplines. Iterations also allow for flexibility to adapt and change to new conditions.

Recommendation:
First and foremost, an iterative process should be implemented in the planning and design process so that the program should continue to perform better over time. The method should enable the periodic refinement of plans in order to adapt to new changes, satisfy allocated safety parameters and increase the livability of an area.

Figure 112 Reshuffling of system thinking and networks: an overhaul of regulations. Drawn by Author and adapted from *Strait of Hormuz Grand Chessboard* by Ghosn, R., & Jazairy, E. H. (2018). Geostories: another architecture for the environment. Actar. Retrieved from https://depaul.on.worldcat.org/oclc/1017884991

Should there be a requirement in the future where building infrastructure, networks, land-use frameworks need to constantly change? Or is the existing system too broken?

Aspect 2: The Future of Planned Developments: Limiting Failure and Safe-to-Fail Systems

Designing resilient infrastructure systems is crucial in increasing the performance of urban systems. However, it is important to note that it would be technologically and financially impossible to ensure that all critical infrastructure would be immune to all external pressures and risks (Boomen et al., 2017).

Another major question raised is: when designing for existing or new urban developments, should there be a priority to benefit the entire system or just areas that are more economically beneficial to society? Urban development should not exclusively look at just morphological coherence (Boomen et al., 2017) in an attempt to fill empty voids within the urban fabric or to juggle real estate values. There is a larger demand to critique and improve the performance of a city. To conclude, a shift in focus on physical and social performance is needed especially in the fields of energy management, water management, sociocultural connectivity, biodiversity, economic vitality, and health and safety.

Recommendation:
There needs to be an alteration in priorities to increase resilience in either *limiting failure* or to have a set of guidelines that need to be met for the *system to safely fail*. The conditions needed would be:

- Defining and containing failure through the implementation of decentralized networks (provision of shelters, water, energy, sanitation, and communication)
- To have a mandate in restructure the system to include a hybrid structure. This would include a system that has the benefits of centralization and decentralization. To be resilient, the redundant infrastructure would offer back up facilities and would limit the extent of failure. But when additional assistance is needed, the centralized facilities could aid deprived areas.

The second set of changes to facilitate a contingency plan is:

- Flexible land-use policies and regulations. These would need to be modified in every proposed iteration. The intent would be to anticipate challenges and expected dangers rather than responding to the damages after an event.
- Spatial restructuring typically gravitates towards the concentration of built up areas and transit nodes. Alternatively, there is a potential in transforming areas adjacent to primary safe corridors. Synergetic benefits would include more amenities, public spaces and increase in quality of life while reducing risks.

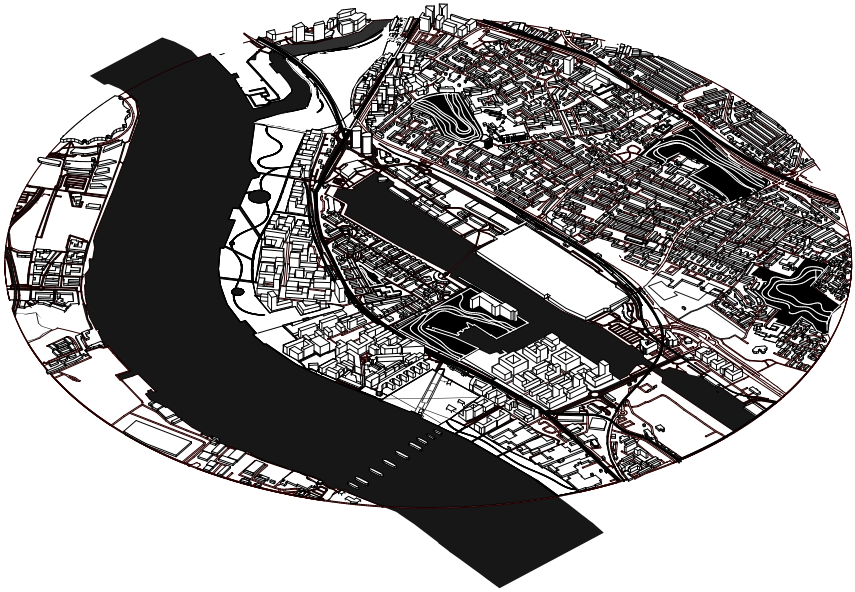


Figure 113 Emergency backbone services. Drawn by Author.

Are decentralized and back-up systems
the future solution?

Aspect 3: Emergency Backbone Services and The Spatial Contingency Plan

After a state of an emergency, the remaining functional and operable critical infrastructure is the starting point of expanding any new forms of development. If backbone emergency services are designed to remain, this can also offer and unravel new forms of opportunities. Thinking along the lines of speculative futures, new developments would already have spatial contingency plans embedded in the system and smaller modules could be tested to limit future failures.

Recommendation:
The emphasis of *integrating early response and recovery in the urban fabric* is at utmost priority. However, the conditions needed for this in an existing development is:

- Using the window of opportunity in lifecycle-based management to change land-use. This could be used as a method of executing and enhancing safety parameters in each neighbourhood.
- The ability to add, build on, interchange or reshuffle purposes and functionalities
- Navigating the rights over property and the interference between public and private ownership.
- The knowledge, access and awareness of resources should also be made explicit to the public.

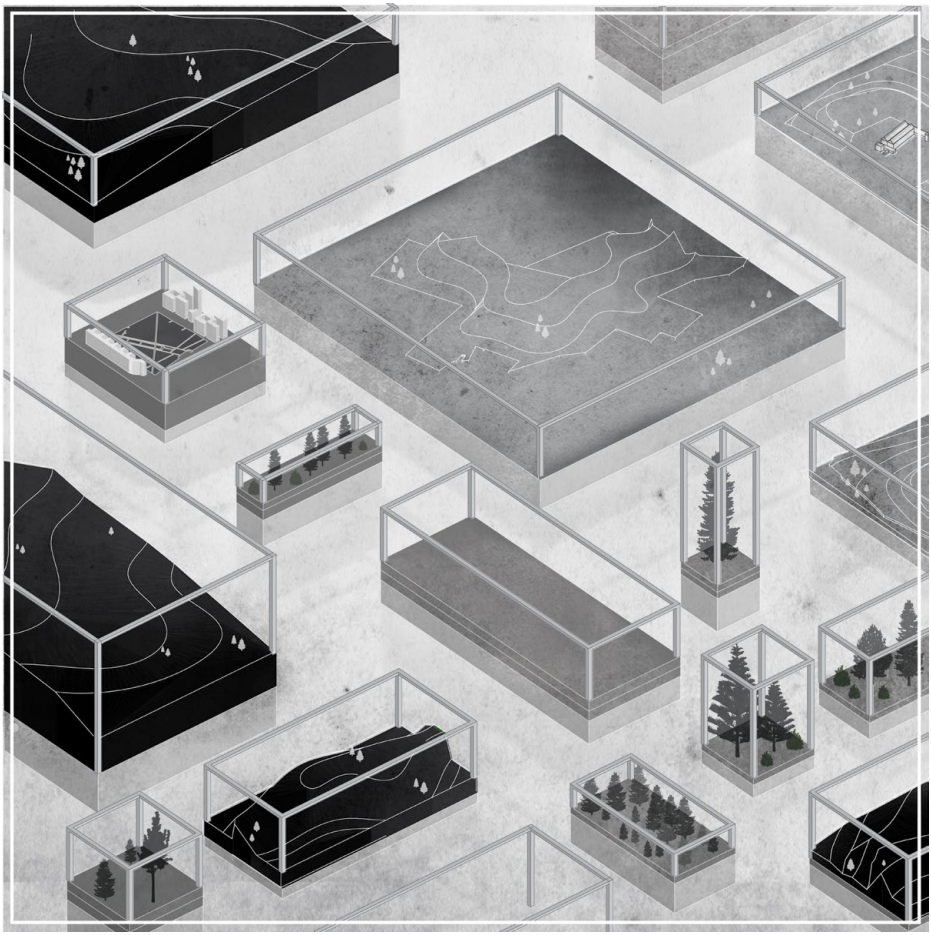


Figure 114 Is there a limit to how much you can stress the system? Do cities have a chronic problem? Drawn by Author and adapted from Turan, N., Yee, A., M. U. (2015). Museum of Lost Volumes by NEMESTUDIO (2015) – SOCKS. Retrieved June 15, 2019, from http://socks-studio.com/2015/10/17/museum-of-lost-volumes-by-nemestudio-2015/

Why are we so fixated in
compartmentalizing land-uses?

Aspect 4: Designing Exclusively for Environmental Risks: Limiting Stresses to the Urban System

Looking at current urban development trends, highly urbanized cities are constantly trying to keep things in a pristine state. Many spatial interventions that deal with risk mitigation and management strives to prevent the disturbance of the existing urban fabric in a negative manner. By taking small incremental steps, is this just being conservative in the field of design and is there a danger in thinking along these lines?

The situation will continue to decline if private companies continue to invest and densify on areas that are prone to be at risk. Furthermore, externalities will become increasingly more difficult to forecast and predict. Nonetheless, the system will continue to suffer from chronic problems and will start to showcase signs of compounding risks. The myriad of issues will not just be from increasing exposure to flood risks but can also expect higher expenditures for maintenance, urban heat island effect, increased water demands and higher risks to failing interdependencies. It will become economically more challenging to integrate flexibility into the system if the rate of intensification continues onto the flood plain. The future will continue to look bleak as environments would be radically degraded and any form of natural resilience would deteriorate in response to human greed.

Recommendation:
First, *environmental risks should be placed at the highest priority* rather than focusing purely on economic risks. As an output, by placing environmental risk as a priority, long-term economic risks will also decline. This can only be achieved with the preparation to reduce the amount of social and economic damage for any disaster scenario. A series of conditions need to be met such as:

- Inclusion of a more ecologically responsive strategies. For example, the thesis proposes to facilitate and strengthen green network connections amongst scattered open spaces to mediate broken connections. The output of the strategy would increase the time and safety parameter for accessibility and emergency refuge.
- Extending the 'tipping point' by providing more capacities in the system.
- Setting aside physical spaces to accommodate for future changes.
- An integrated model that is comprehensive in identifying all impacted systems from externalities (environmental, economic, cultural and social).
- Governments would need to facilitate coordination between planning, design, water management, risk management and natural resources.

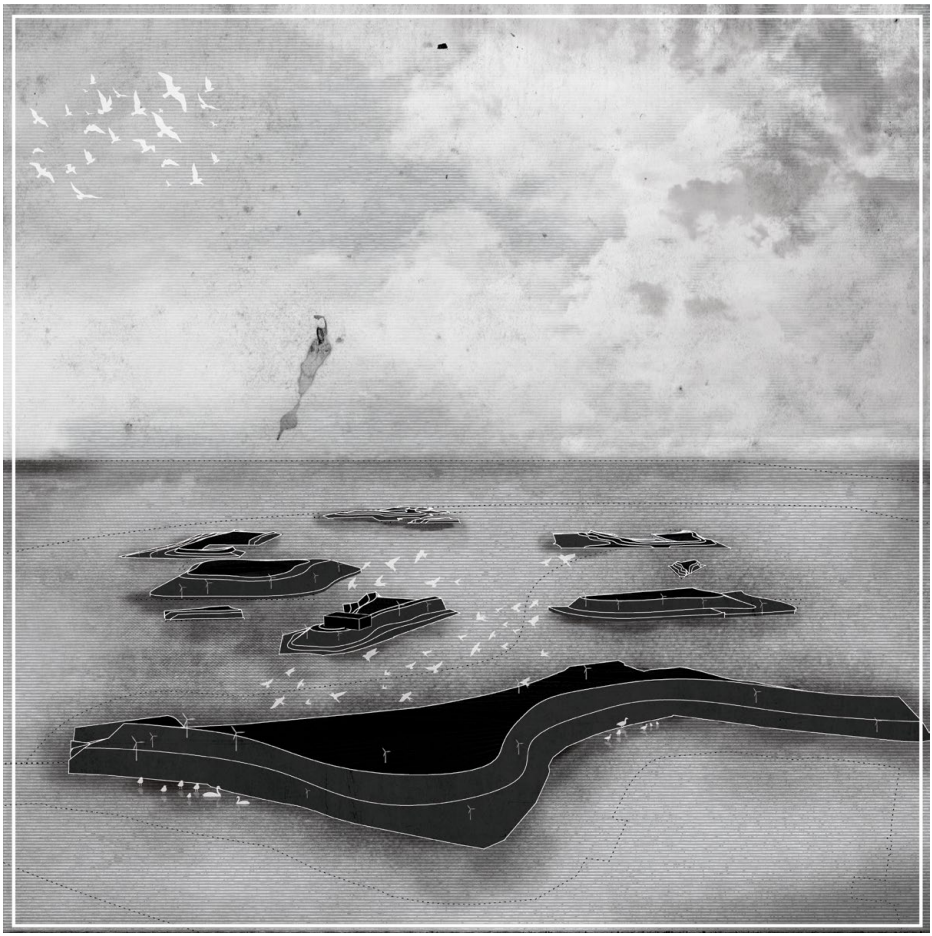


Figure 115 Self-sufficient islands: are we retreating from the land or water? Drawn by Author and adapted from *There Once Was an Island* by Ghosn, R., & Jazairy, E. H. (2018). Geostories: another architecture for the environment. Actar. Retrieved from https://depaul.on.worldcat.org/oclc/1017884991

What are the minimum requirements needed to have a functional, livable and safe society?

Are we only benefitting the individual? Society as a whole? Or neither?

Aspect 5: States of Isolation

One of the main questions in mind is that as a society, do we eventually combat extreme events with extreme measures? In the research-by-design phase, safety was placed at the highest priority. This marks an emphasis on producing a ***contingency plan with a set of hybrid and dual functionalities in infrastructure systems*** and open space. The intent of this was to limit the extent of damage, cascading risks and still provide essential services to impacted populations.

The forced islanding effect to a certain extent isolates failure. However, as part of the contingency plan, networks and routes should connect to alleviate other impacted areas if necessary.

Recommendation:

- Elevating safe areas and road networks to include alternative routes and modalities to address flood risk intensities
- Network should always connect to designated safe zones to manage the flow of people
- Provision of relief should include self-sufficient supplies of energy, communication and water systems that could operate off-grid
- Re-configuration of spaces to manage higher water capacities to direct the flow of water

Aspect 6: Capacity to Learn as a New Parameter

The recommendation of a new indicator for resilience should be investing in systems that could *embed learning* into critical infrastructure systems. Inherently, resilient infrastructure is more related to spatial components. In addition, many of these physical systems are designed with a fixed capacity, peak loads and thresholds. But what if systems could be designed so that these limits could be adjusted and distributed?

A series of questions remain, such as can systems be developed so that new lessons learned be transferred to other components? Can a monitoring framework be constructed to allow systems to learn through different changes and risks?

By not having a mindset of building back better, urban development would revert back to what society is comfortable with. This can be seen in many recent events in communities around the world where developments continue to fall back into old habits and constructing what was previously known. The intention of the project is also to prevent short-term and reactive thinking when a disaster strikes but for it to be readily prepared by integrating it into the urban fabric. In order for systems to be dynamic and adaptable, it is essential to be able to access and identify key detriments in the existing system in order to build back better.

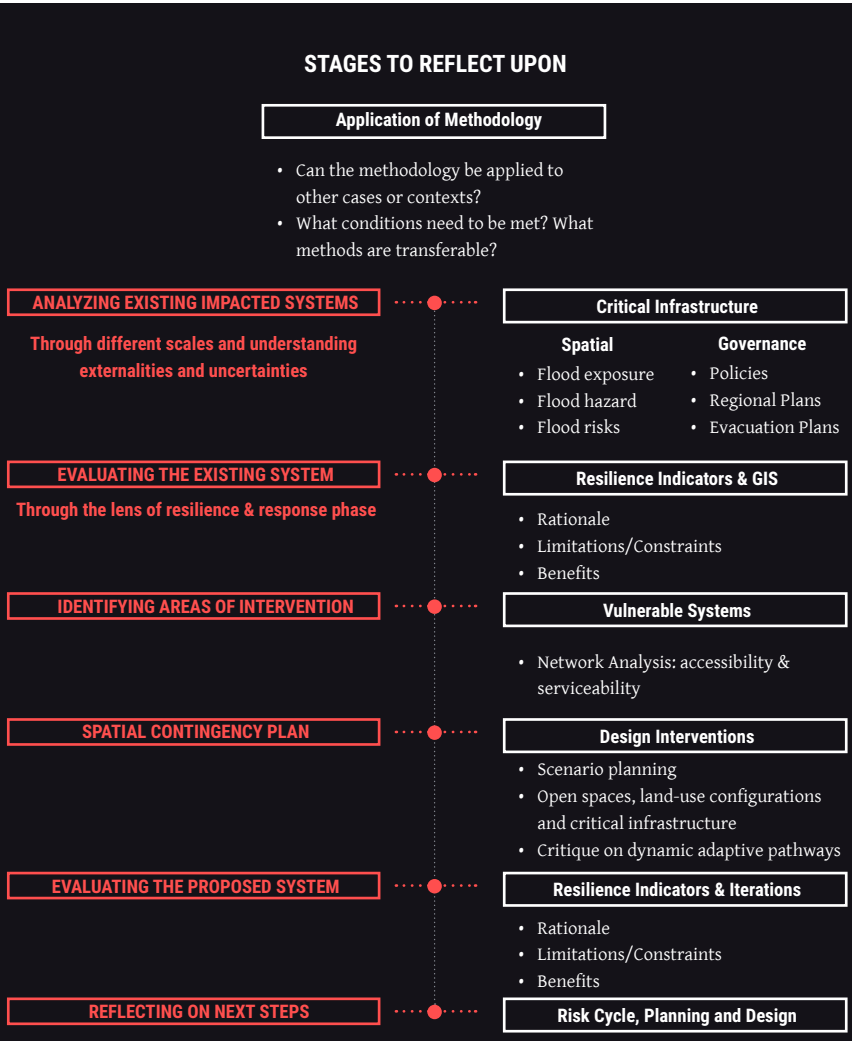
Photo by author

RELEVANCE & REFLECTION

9.1 Reflection

Introduction

The main intent of this chapter is to reflect upon the methods used within the thesis while outlining constraints, limitations, and how the process could be improved. The chapter concludes with a discussion on the ethical considerations and societal and scientific relevance.



Can the methodology be applied to other cases or contexts?

Based on the motivation of the thesis, the future intent was to test the transferability of the methods and lessons learned to a case study back in Canada. Over the years, there has been significant climatic issues and geohazards Canada has faced from coast to coast. If the process had to be replicated to another context, a series of steps that need to be fulfilled.

1. ***Analysis of Exogenous factors (drivers of change):*** uncertainties and trends in climate change

2. ***Spatial Analysis:***
   - Flood hazards: probability and extent of damages
   - Flood exposure
   - Flood vulnerability: populations and infrastructure exposed

3. ***Collection of data:***
   - Site specific data related to hydrology, climatology, geology, local history on flooding, landscape ecology
   - Inventory of critical infrastructure systems exposed to flood risk
   - Land-use, spatial morphology and building age of selected areas
   - Traffic model
   - Census tracts

4. ***Contexts would need to have similar attributes in:***
   - Governance: willing to invest in areas that are of high value (economic, political and social)
   - Political awareness and investments in flood risk management
   - Strong set of involved stakeholders
   - Available resources to accumulate and share data
   - Critical infrastructure protection programs
   - Economic state to develop, plan and execute large scale interventions
   - Strong urban planning regulations

The transferability of the project requires having available resources to model and identify weak vulnerable points in the system. The methods and recommendations proposed in the thesis are restricted to developed nations such as those in the EU, United States, Canada or Australia is due to these governing bodies already having regional critical infrastructure programs. In addition, these nations have access to various resources that would enable them to model and inventory physical vulnerable systems. The pitfall on using spatial analysis through GIS is placing investments over a long period of time in developing a database. While working on the Thames Estuary, the amount of open source data was abundant from the Environment Agency. Due to flood risk being a high priority in the UK and the Thames Estuary, a significant number of previous investments and models have been made privately and publicly available. In contrast to other areas around the world, this may prove difficult as the available amount of resources (from a top down perspective) is not available or is not placed at a high priority.

Other considerations would include debating about how much of the developed set of strategies and policies can be implemented to other countries based on regulations, governance, economic conditions and cultural norms. In addition, there may be limitations on the upscaling and applicability of some of the solutions. These may be restrictive to only addressing specific local contexts.

Process and Methodology: The Choice of Using Resilience Indicators

The process of selecting resilience indicators was to have variables to quantify and compare changes to urban systems. Currently, there is no existing framework set in place within the UK or for the Thames Estuary to evaluate how resilient critical infrastructure is to externalities. To limit the number of indicators, each variable had to correspond with the response cycle which translates to transportation infrastructure systems and emergency relief.

From analyzing travel times to access to services, this would impact the evaluation of the current and future system. In addition, it became a requirement in the design to consider isolation components from:

- The provision of electricity: backup generators, self-sufficient energy supply
- Provision of clean water
- Temporary refuge
- Safe access and egress to safe areas
- Sacrificing developed land

There is a constant feedback loop in understanding and addressing the displacement of specific infrastructure (such as residential units). This would require other areas outside the floodplain to cope with the change in capacity. In addition, the design intent would also need to consider the immediate demographics that would be affected.

From here, a set of parameters were needed to be made in order to understand the extent of the scenarios.

- Priority of elements and what is crucial to be maintained/require extra protection
- Number and placement of connections, services and of shelters
- Program of urban life and direction of development
- The states of isolation and how it is relieved

However, there are two key considerations and limitations in using resilience to evaluate the current and proposed system. First, the term resilience has been heavily debated upon. Resilience is seen to be more reactive and tries to restore the system to its previous state before any incident. Regarding this issue, this could eventually lead to short-sighted thinking and leading to the same perpetual risks and vulnerabilities in an existing system. Moreover, there is a gap in existing research on the spatial application of evolutionary resilience into existing and newly proposed critical infrastructure systems.

The second major limitation is the scope that the chosen resilience indicators can cover. In the process of trying to reduce risks, there was a clear intention finding weaknesses and gaps in the existing system. Using the indicators framed the context of the components of the system that needed to be improved. However, through the selective process of narrowing down the resilience indicators, there are several missed aspects. A future consideration on implementing this project in other contexts is that the indicators should be interchangeable and modifiable in other contexts.

Identifying Areas of Intervention
The process of identifying areas utilized the conclusions made from the methods in identifying the most vulnerable critical infrastructure systems exposed to flood risks. The process of designing and using scales was vital in creating spatial iterations of the project. Working between multiple scales also provided a comprehensive overview of how the system functions, is governed and risks in the system. This process is also essential in the iterative process of analyzing and designing a contingency plan. However, there are a series of limitations and trade-offs per scale which is listed in Figure 116.

Urban Analytics: Network Analysis and GIS
The project heavily relied on GIS as a primary platform and tool to visualize and synthesize spatial conclusions. With the defined resilience indicators, an accessibility and serviceability network analysis were performed to determine distances and availability of refuge. The intent would to build a system to compare the performance of the existing and proposed interventions.

Constraints and Evaluations

- There is a lack of comparative economic values for the interventions
- Weighing the direct benefits of the interventions would need to be further explored. Other models that would assist in developing a more robust process are:
  - Pedestrian and vehicle accessibility flows with a weighted factor:
  - Involving different demographics
  - Understanding the detours that may occur
  - Thresholds and speeds that the system can accommodate
  - Traffic analysis and the capacity that the system can take in an event of an emergency.
- Modeling catchment areas
  - Understanding the infiltration and water flows in the system
- Weighing the added benefits to the system that could impact social vulnerabilities

Scale	Limitations	Trade-offs
Territorial: UK	• Proposing site specific interventions are extremely difficult due to having limited detail of each context • Replications of the same design in each area would disregard the fluctuations in physical and social vulnerabilities • Level of risk impacts areas unevenly	• There is limited detail of the exact conditions of each location, but general conclusions can be put forth. For example, concentrations of vulnerabilities could be determined. A standard minimum resilience guideline for critical infrastructure could be made. This would enable smaller scales to interpret and execute a set of policies and regulations in a more flexible manner while raising safety standards.
Regional: Thames Estuary	• General outline given through a broad TE2100 framework	• Takes into consideration a regional network of affected cities and neighbourhoods. Physical and social vulnerabilities can be distinguished from the defined flood zones. However, the execution and responsibility of flood mitigation is reliant on the smaller scales.
Urban: City of London	• There is a certain level of detail made in strategizing the placement of designated elevated roads, priority safe shelters and connection to open spaces	• This scale enables the user to visualize a wider set of connections proposed from the smallest scale but exact interventions are not ideal to be made at this scale.
Neighbourhoods: Isle of Dogs, Wandsworth to Deptford and Royal Docks	• Ideal locations were informed by larger scales • Location specific strategies were limited by the series of resilience metrics developed to evaluate the system • Limited to small-scale interventions	• Decisions can be made at the local scale, but the scale cannot provide an overview of the grander scheme of things or a holistic perspective • The design, planning and implementation is site specific, and any intervention needs to be modified to the existing context. Interventions at this scale would feed back into the larger scales in order to evaluate changes to the system.

Figure 116 Matrix outlining the limitations and trade-offs in each scale

Developing the Spatial Contingency Plan: Scenario Planning and Lessons Learned

Scenario planning was used as a leverage to see how different interventions could meet a series of goals and objectives set for the response framework. Due to the uncertainties of the future, the scenarios offered a different way of thinking, ways of manipulating spaces and assemblages while working within the mindset to increase safety parameters. Three main elements were considered in each design iteration which includes: how critical infrastructure systems would be modified, changes in land-use and open space strategies. Through this process, the importance of iterative design thinking became apparent.

While investigating the impacts of a large-scale managed retreat, there was a question of how to execute and the practicalities of managed retreat. It is typically treated as a long-term option and is only considered effective when the costs of flood risk management exceed the value of the property that it protects. Often at times, this is seen in cases with low-density areas. Typically, this also involves a buy-out programme that relies on the full participation from the community which can also be politically sensitive. It is noted in some documents that in highly urbanized areas, this option would not be viable unless it was part of a post-disaster rebuilding strategy. However, this strategy allows for the proactive change in land use to open space, recreation of nature to avoid future developments in flood risk areas. However, if a contingency plan is not embedded in the urban fabric or is not considered, there will be a higher risk for future urban developments. The interdependencies within the existing system will continue to grow and there will be higher chances of cascading risks from not only future possible floods but other climate related issues.

Altering Interventions Based on Scenarios and Local Contexts

In outlining the opportunity areas within the designated focus units, there was a necessity in changing the initial 'catalogue' of spatial actions based on location. Modifications in the design and size requirements were restricted on the available land use. Opportunity areas that could be modified were identified in a systematic manner with the focus starting at priority resilience areas (most impacted by residual risks from a breach). Intervening in existing and highly developed urbanized areas posed as a challenge. Two proposals were conducted in the thesis where one envisioned a more radical and expensive perspective. In the managed retreat scenario, the main intention was to remove large swaths of infrastructure to create larger capacity of water and green zones to reduce risks. The second option is to connect fragmented spaces and to use these to direct water flow and capacity. Once these networks were identified, interventions could be made on how to strengthen these areas. This would also align with improving areas of deprivation and were lacking public amenities. New developments should have synergetic benefits that would not only improve the response phase but to also improve the urban landscape. In addition, there could be possibilities where incentives can be given from the government if private gardens or spaces can provide further infiltration or provide means of support.

Strategic and Spatial Interventions: Adjustments to the Utilized Interventions and Deliverables

In the research-by-design phase of the project, it was evident that the initial catalogue of strategies was insufficient to represent the full intent of the project. Several of the proposed interventions required another set of analysis. This included an investigation of what was readily available in the existing urban fabric and within the defined priority resilience areas. The implementation of the strategies differed per context even with the parameter of selecting designated safety areas for permanent public access. For example, the neighborhoods within the Isle of Dogs had an extreme disadvantage for finding room to expand public spaces. Due to the highly developed and dense neighbourhood structure, the interventions relied on life cycle-based planning and the period of retrofitting as the window of opportunity to expand. In contrast, the other two policy units already had shelters adjacent to large open parks alongside designated safety corridors.

Design Intentions: Using Public Spaces as Temporary Emergency Relief

The challenge of having the intent of working in built-up areas is that there are a series of societal, spatial, economic conflicts due to the lack of available space. In addition, there could be a struggle in financing or valuing the trade-offs in investments and interventions could foster disagreements with local residents. The proposed interventions could also result in a series of conflicts due to the multiple stakeholders affected. Each set of stakeholders have their own agenda within a set time frame, so it would be vital to find potential synergies and mutual benefits.

Benefits and Consequences of Recommendations

The idea of increasing and elevating public spaces was under the assumption that it would be beneficial towards nearby communities. In addition, it would improve the deprivation index of communities by increasing accessibility to open spaces. In a practical standpoint, the actual process and execution of the smaller scale projects would require public consultations.

As the thesis strove to find synergetic benefits while trying to meet the objectives of integrating an earlier response and recovery framework. One example of this is done through design iterations of reintegrating water storage and re-organizing the water system to be more visible and cohesive. Rather than concealing the process of the water system, this could enable a stronger relationship between carrying capacity of water, land use and risk management.

Additional Limitations in Proposed Spatial Interventions

An important element to consider when designing for vulnerability-focused adaptation is when an 'islanding effect' occurs. This would severely impact and limit the performance of systems related but not limited to: power, heat, sewers, and electrical infrastructure recovery capacity. Due to the limited scope of the thesis, it would be difficult to quantify the exact performance of these systems during and after a flood. The design will take into consideration on how temporary failure of power systems or reduced accessibility would occur in certain locations, but the cascading effects of the flooding would not be measured. At most, the project tries to explore the best methods to minimize large scale cascading effects that would reduce the recovery time if an extreme scenario would occur.

While developing spatial strategies, the thesis will also not be able to comprehensively describe all the hydrological, ecological systems or traffic conditions that would be impacted when configurations of land use or portions of flood walls are removed. This would be difficult to model in addition to quantifying residual risks that would impact the system.

During the process of analyzing infrastructure vulnerabilities, social vulnerabilities have also been analyzed as it is a key component in an integrative approach to risk mitigation. Due to the scope of the project, the underlying factors and conditions that perpetuate vulnerabilities cannot be fully addressed or solved. There are too many variables to account for to program the design to solve or address the core issues of why and how these areas are vulnerable. However, the scope of the design should also account for, assist and reduce flood risks on vulnerable populations. This is to be accounted for in the analysis using the deprivation index and SOVI to also address these areas.

Is Dynamic Adaptive Pathways (DAP) an effective means to evaluate, address deep uncertainty and create future plans?

Dynamic adaptive pathways is an example of a model that can plan or anticipate for future deep uncertainties. There should be multiple and diverse set of options that clearly outline the roles of stakeholders alongside constraints, impediments and benefits. However, in the research component of analyzing the TE2100 and Thames Gateway Project, it was important to be critical on the existing frameworks and policies that are currently hailed upon as successful. For example, the Thames Barrier is classified as one of the best-known movable storm surge barrier systems set to protect large urbanized areas from high tides similar to the Maeslantkering in Rotterdam. Interdependencies between higher level of flood protection and local level flood protection systems create complex governance arrangements which may lead to conflicting expectations and interest among several layers of authority. In addition, as storm surge barriers are known to generate a sense of security leading to a reduction of flood awareness and precaution and consequently to increased accumulation of assets in the protected hinterland. This has resulted in the paradoxical situation in which flood losses continue to increase even when more investments in flood protection are made. Evident in the Thames Estuary, further investments in storm surge barriers may create an irreversible situation that reduces flexibility and adaptability of local level systems. The TE2100 plan continues to propose proactive spatial planning to keep flood risk in the greater London area low, but the city continues to expand into floodplains.

Another concern is that there is a general critique of the DAP concept is it remains very conceptual and the application and execution of the adaptive planning can be challenging. For the success of the implementation of the project, there are many presumptions made. One of the key aspects is that decision-makers have the power and agency to make decisions and influence the system to be driven towards the most optimal pathway. This would also require a political and social consensus towards this decision.

Based on several case studies and reports, local adaptation strategies have encountered various difficulties in where the goals of adaptation have not been clearly defined. In addition, the level of resilience that the local government wants to achieve is also ill defined. Also, for the project, how does one define when something has reached an adequate level of resilience for an uncertain future?

As per the design, it needs to be recognized that not all critical infrastructure systems can be protected but parts of the system can be strategically maintained. One can speculate on how to design energy infrastructure so that these systems can be designed to be flexible. However, the modeling and testing of if the actual speculation could work would be too complicated. The other dilemma is the question of whether the design proposal compromises other cycles of risk management.

How to integrate the contingency plan and response phase into dynamic adaptive planning?

One of the main methods that was not fully executed was creating a DAP plan. However, after the creation of the spatial strategies and re-evaluating the existing TE2100 plan, it became evident that an addendum would be needed to address the uncertainty component and the practicalities in the execution of the project. Currently, there is no existing DAP modeled to address contingencies. In addition, with DAP, a series of dynamic policies would need to be created in order for the system to be fully functional. The time component would also need to be considered in the new addendum and understanding the conflicts of interest between environmental or economical risks. Also, due to the limited time constraint, the governance structure in which stakeholders would be involved in the execution of the project was not fully explored.

To satisfy the creation of dynamic and adaptive strategies, the thesis also proposes a model that would integrate iterations throughout the design and planning process which would enable the system to perform better with future uncertainties. The capacity to learn, re-assemblages of spaces would be able to unfold different if externalities continue to change. In addition, future conditions are unpredictable and there may be changes in the needs and demands of society or a change in political powers and interests. By having a contingency plan and iterative processes, this can accommodate for flexibility in the system.

The series of proposals in the thesis that allows built in flexibility and a certain extent of contingencies would be:

- Elevation changes to critical infrastructure systems (safety corridors, shelters and open spaces)
- Expansion of green and blue networks
- Decentralizing and redundancy in back-up systems
- Land-use modifications
- Ground plane modifications

Limiting the Scope to Critical Infrastructure Systems and Flood Risk Management

At the start of the thesis, the ambition was to look at how to make all critical infrastructure systems resilient to flood risks. However, it was recognized at a very early stage that researching and intervening in every component defined as critical infrastructure would be extremely difficult due to the limited time-frame of the thesis. To narrow the scope, it was important to determine which critical infrastructure systems should be placed as a priority. The rationale was based on understanding the risk cycle and choosing to further investigate the response phase. Due to the Thames Estuary having strong mitigation policies and spatial flood defences, it became more apparent to investigate if a spatial contingency plan exists. Recognizing a gap within policies, governance, planning and design of the urban structure regarding the state of 'plan b', the focus was directed towards the response phase. Within this phase, the critical infrastructure systems impacted were transportation systems, emergency services and shelters. All attention was then directed on how to improve the safety parameters of the system based on maintaining these services.

Another major point to highlight was the design interventions were restricted to adapting to flood risks. It is important to note that areas do not experience only one form of risk. In fact, there are multiple risks and uncertainties in every area of the world. Therefore, the design intent is not meant to accommodate or combat all forms of risk and is restricted to floods. However, the safety parameters and flexibility in the proposed interventions could alleviate other risks in the system. For example, London is experiencing higher water demands, droughts and urban heat island effect. But through the creation of multi-purpose spaces that allow for water infiltration and storage, and off-grid services, these could help in alleviating pressures in the existing system.

Reflecting on the Emphasis Placed on Systematic Thinking

During the time-frame of the thesis, there was a conscious effort in developing a systematic process from the initial stages of the analysis to the conclusion. Gathering an understanding of the overall scope of the project was a personal choice in amassing knowledge of the existing systems and theories that were defined within the scope. This included having a strong comprehension of existing risk management performed at all scales, governance, and policies and practices.

Referring to the road map made in the methodology chapter, each step was rationalized in order to move forward throughout different phases of the project. This was seen from determining the areas for interventions to the tools to used. However, this also put a huge time constraint on developing design strategies. Notably, when designing spaces, there was a lot more hesitation in intervening with the existing system due to the concern of negatively impacting areas or understanding the practicality of implementing the plans. By holding back or shooting down designs due to the mindset of practicalities, limits the process of iterating different designs. Instead, it would have been more beneficial to be more radical and take lessons learned through manipulating spaces. From there, aspects of the design could have been pushed further to really emphasize the need to change urban environments from how they are currently designed. Thus, the quality of spaces developed were not fully explored as well as the full extent of relationships and impacts made from the interventions.

The Future of Planned Developments: How Can Design Inform Governance and Planning?

Design should be used as a platform to challenge the existing norm and deliver a series of options that should advise current governance practices, policies and planning. One model of advancing this change is using GIS and Big Data to visualize flood risks, exposures and vulnerabilities which can further inform other disciplines. Due to rising complexities and dynamism of cities, research and design could be used as a method to streamline a better understanding of socio-economic data, land use, infrastructure networks and other correlations needed to inform long-term plans. Rather than relying on the static nature of urban plans, design speculates plausible futures and potential synergies that could benefit society, increase livability, and satisfy political and economic agendas. However, the field of design requires multidisciplinary collaboration, perseverance and exploratory approaches from all disciplines.

Can synergies within the risk cycle be used as the starting point for new development?

The primary intent of the risk cycle is to control, avoid or transfer risks. Figure 117 outlines the relationships found within the risk cycle and when there are synergies, these could be the new window of opportunities.

Practicalities in Implementing the Project

It is important to comprehend when and how the windows of opportunity are used to integrate resiliency into the system. Life cycle-based planning can be used as a factor in creating allowances to retrofit existing infrastructure, ground floor usages and land use. However, with the proposals made from the thesis, current governmental planning and design practices need to consider:

- A comprehensive overview of water, environment, social and critical infrastructure systems is required in the planning and design processes
- A need to integrate a more long-term trans-scalar design method to avoid the existing ad-hoc decision-making processes
- A proposal on determining which critical infrastructure should be maintained along with changing the model of spatial planning through series of iterations
- Negotiating between private and public stakeholders in land-use transitions
- Developing a range of adaptive capacities in the system

	Mitigation	Preparedness	Response	Recovery
Mitigation		***Synergy:*** • Public education, awareness and training	***Synergy:*** • Assessment to strengthen and improve infrastructure/services	***Synergy:*** • Spatial planning • Long-term planning • Retrofitting to alter spaces • Future reconstruction areas
Preparedness	***Conflict:*** Investments in prevention vs. capacity to respond to an event		***Synergy:*** • Time component • Short-term emergency management • Early warning systems	***Synergy:*** • Faster recovery with population having a stronger awareness to emergency relief, housing and services
Response	***Conflict:*** Mitigation tries to prevent risks to maintain all services. Whereas response maintains only essential services	***Conflict:*** Readiness and training vs. incident stabilization and mass care		***Synergy:*** • Faster recovery rate if response is efficient at organization (mass care) and maintains essential services
Recovery	***Conflict:*** Investments in protecting economies vs. economic recovery and restoration	***Conflict:*** Short-term vs. long-term objective	***Conflict:*** • Time conflicts and infrastructure priorities • Recovery focuses more on reducing economic risks and restoration	

Figure 117 Table outlining synergies and conflicts within the risk cycle

9.2 Ethical Considerations

When addressing vulnerabilities in the system, making the metric of who is considered ‘at risk’ needs to be determined. In addition, as a series of resiliency factors and strategies may be identified further in the project, it may become difficult to prioritize what should be protected, improved and redundant in the system (Coetzee, Van Niekerk, & Raju, 2016). In addition, even though resilience was a notion to combat and recover from the impacts of disasters, how does one determine what is the 'status quo' or the best state of functionality for a society? Finally, the design intentions and strategies may be biased for specific user groups. By programming these ‘flexible spaces’ or attempting to picture scenarios with islanding, this may this may cause more isolation and issues if not configured appropriately. There is also a concern of which buildings or communities would need to be removed in order to protect larger costs of infrastructure or lives.

9.3 Societal Relevance

The frequency and intensity of major extreme weather events such as storm surge, sea-level rise, and droughts have resulted in many regions left with critical systems and interdependencies exposed. It is crucial to critically think and plan how the state of extremity could also disrupt flows of services, people, goods and way of life. Disasters can inherently reduce a community’s resilience with the disruption of the operation of infrastructure ie. Electric power, transportation, water and are often referred to lifelines. As the dependency on these critical lifeline systems are increasing as well as these systems distributed over large geographic regions, they are often exposed to a broad amount of hazards. If there is a sudden impact on one of these networks or services, a large portion of society can become crippled. Malfunctions in the system at multiple locations can impede on the response and recovery of a community. Planning for resilience and recovery in these systems would prevent further disruptions and displacements of people or the compromise of social and economic losses. In the scope of the UK, failure and disruptions of services from floods have drastically affected electricity supplies, failure of bridges and disruption of communication networks. These adverse effects of extreme weather events and significant impacts are significant to regions of the world.

Establishing a study on critical infrastructure system performance can help better understand society needs during response and recovery. The main aim is also to help decision-makers in handling with deep uncertainty in making long-term decisions for urban planning. The emphasis is also to support short-term actions while being able to modify, extend or alter plans to the changing environment or future. This would also assist in identifying gaps between the desired and anticipated performance of key infrastructure and set priorities.

9.4 Scientific Relevance

The project aims to have a critical perspective on the role of critical infrastructure systems that can withstand extremities, and in particular flood risks. Having an assessment of critical lifeline system performance and understanding societal needs during a disaster is a prevalent issue in present society. Gradual shifts in long-term trends and extreme weather events due to rises in average temperatures have also reduced the capacity and efficiency of certain infrastructure (Dawson et al., 2018). This would also increase in the frequency of disruptions. With this in mind, it is also relevant to consider the lifespan and design of critical systems. Referring to the UK, the National Infrastructure Plan allocates £300 billion of planned investment across all sectors by 2021 with large capital costs of 30-200 years. There are limited flexibility to the infrastructure once it is constructed. It is essential to put emphasis on new and existing infrastructure that can adapt to the context of flood risk.

The assessments in the thesis includes:

- Detailed analysis and consideration of vulnerable populations and critical systems exposed to flood risk
- Technical and functional lifespan for infrastructure such as transportation systems, water systems and shelters.
- Recommendations to towards future critical infrastructure development and a spatial contingency plan. Also, to increase capacity and alternatives as an effective response and recovery from climate disruption.

In most cases, the repercussions of a system failing includes prolonged recovery times, large investments on reconstruction efforts, managing housing and blackouts. It is vital to continue to build upon the technical knowledge that would reinforce to dynamic and adaptive strategies. This would then inform and create a better understanding behind the complexity and subject matter of risk management and planning for uncertainties.

9.5 Streamlining the Thesis Process

Lens of Critical Infrastructure Systems

Step 1

ANALYZING EXISTING IMPACTED SYSTEMS

Through different scales and understanding exogenous drivers of change (climate change) and uncertainties.

Spatial

- Flood exposure
- Flood hazard
- Flood risks

Governance

- Policies
- Regional Plans
- Evacuation Plans

Step 4

SPATIAL CONTINGENCY PLAN

Design interventions are constructed to manipulate arrangements of spaces to integrate flexibility and adaptability into the system. Resilient network properties (redundancy, flexibility and robustness)are further developed.

Scenario Planning

- Business as Usual
- Managed Retreat

Spatial Modifications

- Critical Infrastructure Systems
- Open Space
- Land-use

Types of Interventions

- Redundancy
- Elevation Changes
- Decentralizing Systems
- Manipulating land-use
- Expanding networks
- Horizontal expansion
- Green/blue networks
- Relocation and retrofitting infrastructure

Step 2

EVALUATING THE EXISTING SYSTEM

Using resilience indicators corresponding with the response phase in the risk cycle.

Network Analysis (GIS) & Performance Metrics

- Travel time
- Time for recovery
- Provision of relief
- Access to lifesaving services

Step 3

IDENTIFYING AREAS OF INTERVENTION

Combining the information gathered in the previous stages, the synthesis determined the most vulnerable systems.

Qualities of Chosen Locations

- Densest concentration of CI exposed to flood risk
- Insufficient accessible and alternative emergency road networks and shelters
- Inadequate numbers and areas of safe refuge
- Risk of trapped volumes of water

Step 5

EVALUATING THE PROPOSED SYSTEM

Using resilience indicators corresponding with the response phase in the risk cycle.

Network Analysis (GIS) & Performance Metrics

- Travel time
- Time for recovery
- Provision of relief
- Access to lifesaving services

Increased Safety Parameters

- Manage flow of people
- Manage flow and direction of water

Step 6

REFLECTION & REPEAT PROCESS

Propositions and lessons learned made from thesis

Aspects

- Iterations are necessary for the translation of risk management at multiple scales and allowance for flexibility and adaptability
- Integrating early response and recovery can create new synergies and mutual benefits
- Contingency plans are a by-product of hybrid and dual functional infrastructure systems
- By placing environmental risks at the highest priority, economic risks will decline over time
- Required resilience parameter: capacity to learn
- Focus on limiting failure or set conditions for the system to safely fail

9.6 Streamlining the Design Process: Setting up the Contingency Plan

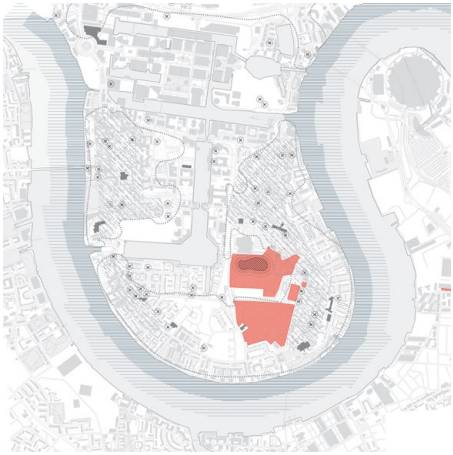
Step 1

DESIGNATING SAFE AREAS

Critical infrastructure: schools, medical facilities and hospitals

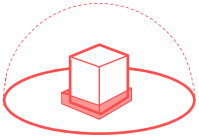
**note process replicated across three sites*

&



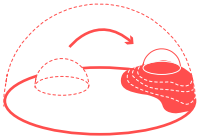
Temporary safe areas: open spaces to accommodate larger populations

Option 01: Reinforcement



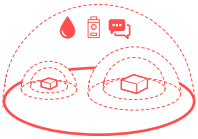
Dry-proofing or wet proofing

Option 02: Relocation



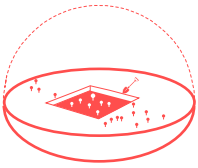
Transferring to higher grounds

Option 03: Redundancy



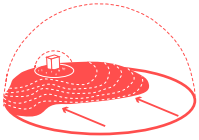
Adding spare capacity + back-up systems

Option 01: Excavating



Excavating green space to increase water capacity

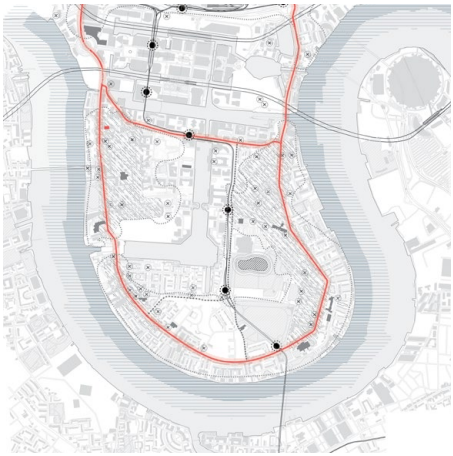
Option 02: Elevating



Elevating open spaces to create safe grounds + new facility with back up systems

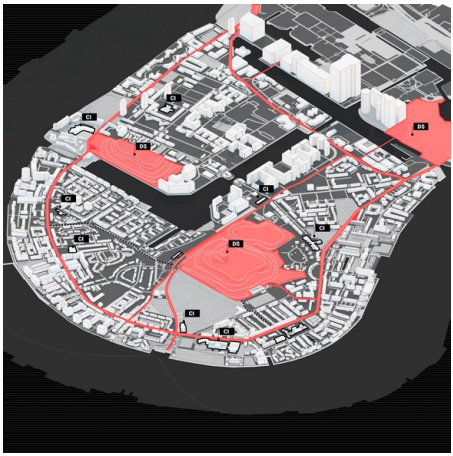
Step 2

ELEVATING ROAD NETWORKS



Critical infrastructure: major roads connecting to the network of shelters

Translation into masterplan

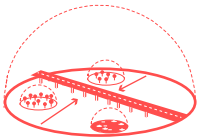


Proposed emergency routes, connections and designated safe areas for Isle of Dogs

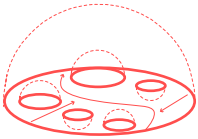
CI Priority Critical Infrastructure (Schools)

DS Designated Safe Grounds - Permanent Public Access

Option 01: Creating links to shelters

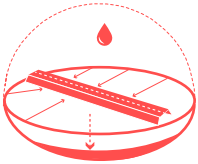


Option 02: Expanding the road network



Manipulating connections

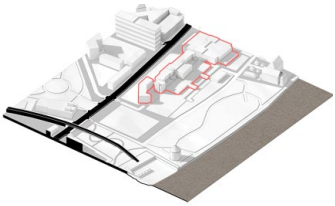
Option 03: Retrofitting roads



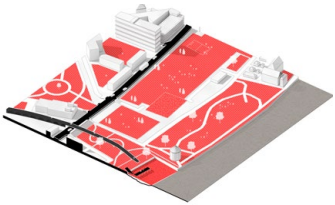
Roads to have increased porosity to store/direct water

Translating to smaller scale

Option 01: Reinforcement

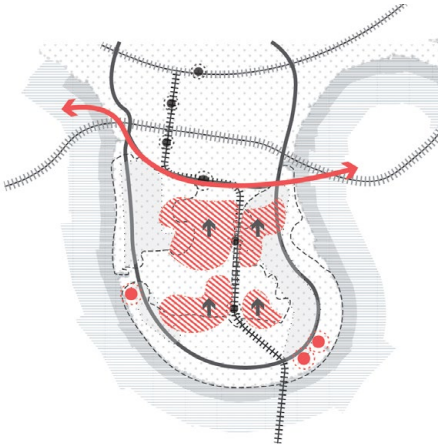


Option 02: Removal and relocation of CI



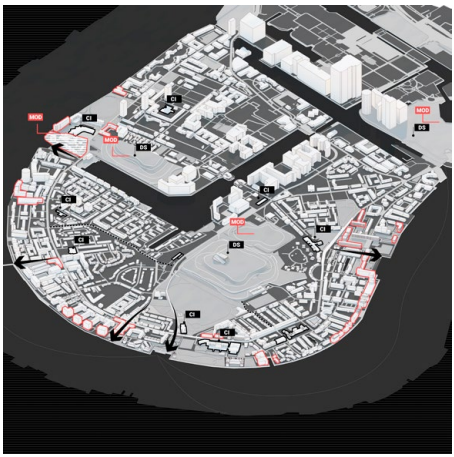
Re-located critical infrastructure enables expansion of open spaces and semi-autonomous systems

Scenario 01: Business as Usual



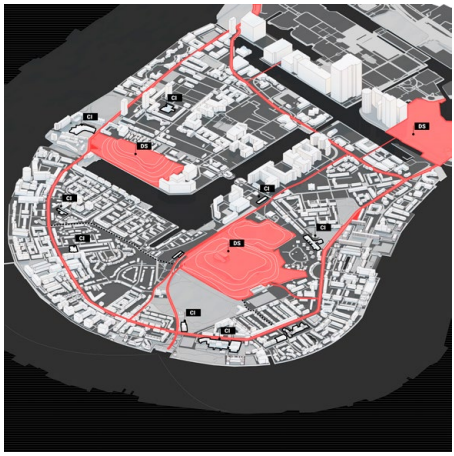
Continued intensification and pressures on the floodplain

Option 01: Modifications in Land-Use



Translation into master plan

Option 02: Modifications in Open Spaces

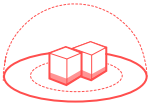


Translation into master plan

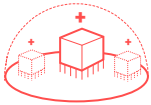
IDEATIONS

PROTOTYPE

Option 1A: Change ground floor amenities



Option 2A: New developments

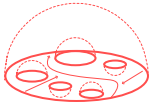


Porous or elevated

Option 3A: Retrofit

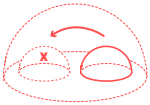
Integrate smart grid systems

Option 4A: New connections



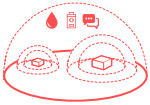
Manipulate spaces for increased accessibility

Option 5A: Remove & replace



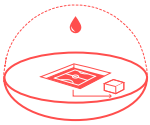
Replace with less vulnerable usages ie. retail/recreation

Option 6A: Decentralize



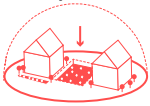
Integrate back-up systems

Option 1B: Retrofit



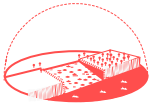
Convert amenities to increase water capacity

Option 2B: Private Spaces



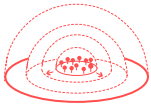
Collective vegetative depressions

Option 3B: Breach



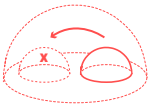
Create living edges, tidal parks or enlargement of natural defences

Option 4B: Expand



Expand park size and amenities

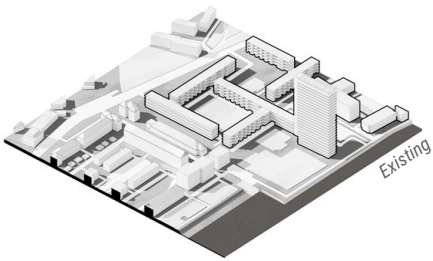
Option 5B: Remove

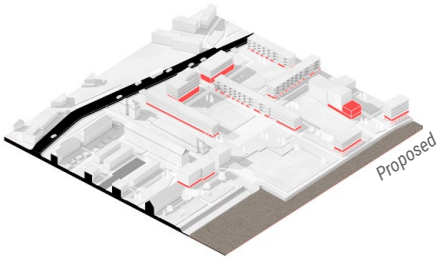


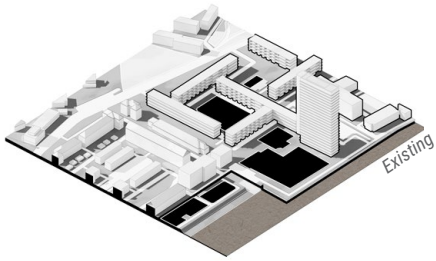
Remove infrastructure and relocate density

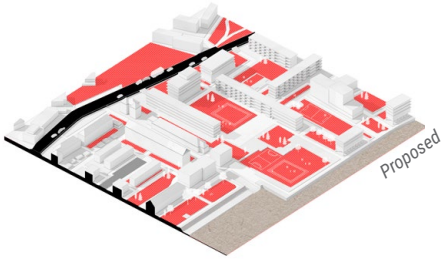
Option 6B: Expand Networks

Expand green networks and accessibility









REFINE & INFORM

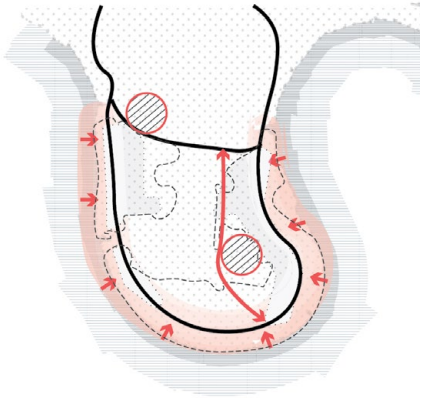
EVALUATE

Feasibility, Desirability, Viability

TEST

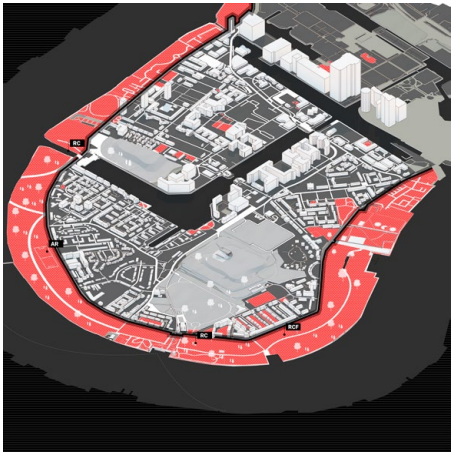
Combining strategies in site specific contexts to create new assemblages

Scenario 02: Managed Retreat



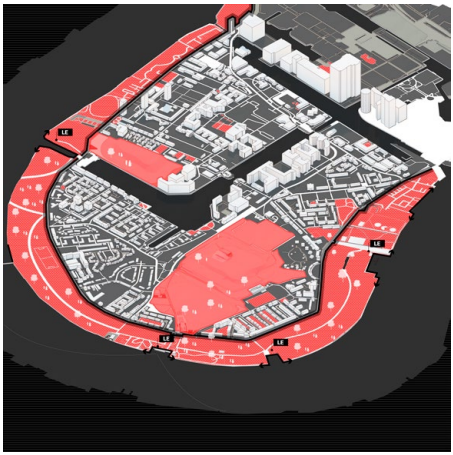
Intrusion of water and nature while receding the land and infrastructure

Option 01: Modifications in Land-Use



Translation into master plan

Option 02: Modifications in Open Spaces



Translation into master plan

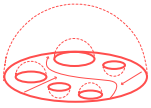
IDEATIONS

PROTOTYPE

Option 1A: Retrofit

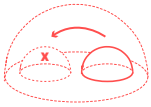
Integrate smart grid systems

Option 2A: New connections



Manipulate spaces for increased accessibility

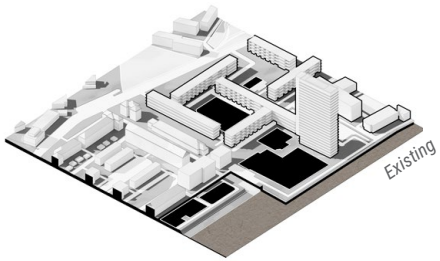
Option 3A: Remove & replace

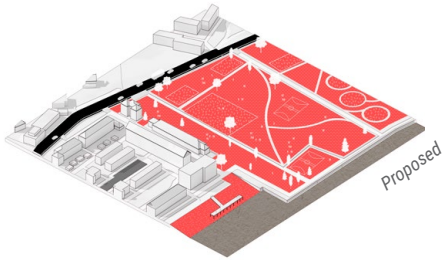


Remove infrastructure and replace with riverfront amenities and green space

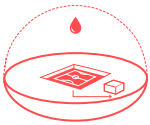
Option 4A: Decentralize

Integrate back-up systems





Option 1B: Retrofit

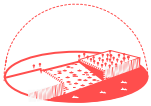


Convert amenities to increase water capacity

Option 2B: Private Spaces

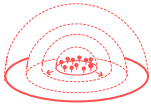
Increase in collective vegetative depressions and gardens

Option 3B: Breach



Create living edges, tidal parks or enlargement of natural defences

Option 4B: Expand

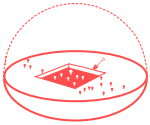


Expand park size and amenities

Option 5B: Expand Networks

Expand green networks and accessibility

Option 6B: Excavate



Increase water capacity

REFINE & INFORM

EVALUATE

Feasibility, Desirability, Viability

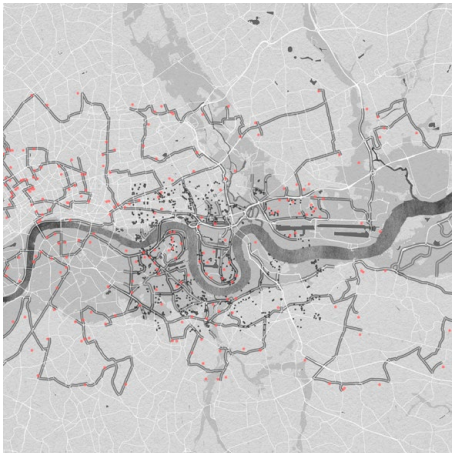
TEST

Combining strategies in site specific contexts to create new assemblages

Step 4

BUILDING THE NETWORK

Plan informs the creation of safety corridors (provision of relief & accessibility)

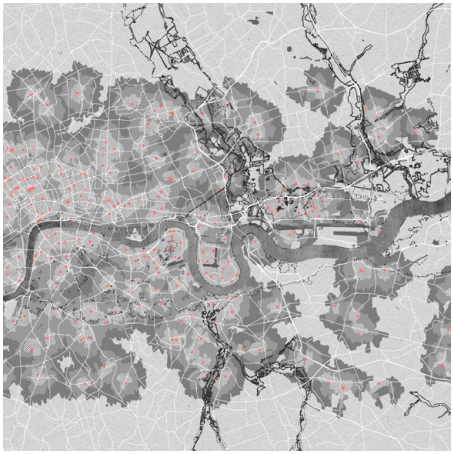


Accounts for designated safety shelters, emergency routes and entrances to designated safe zones

Step 5

EVALUATING THE NETWORK

Serviceability of modalities (travel time)



Shelter serviceability & emergency relief for pedestrians within fixed time frames

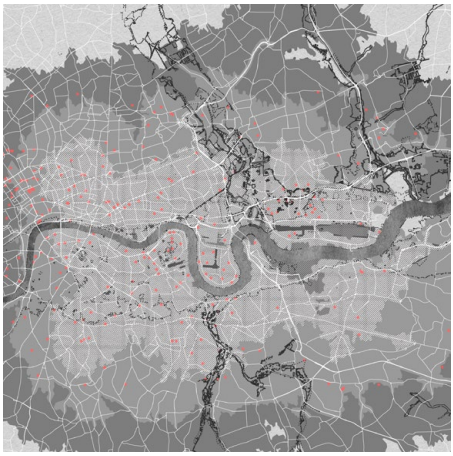
Step 8

RETURN TO START

Step 6

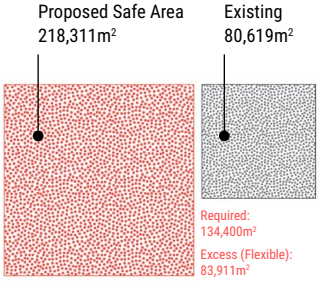
EVALUATING THE CAPACITY

Can the designed safe areas accommodate the projected population?

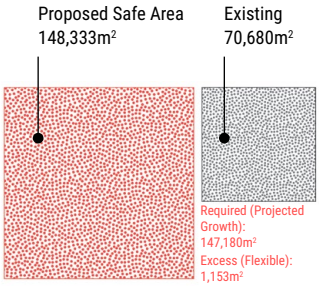


Shelter serviceability & emergency relief for automobiles within fixed time frames

ISLE OF DOGS SHELTER CAPACITY



ROYAL DOCKS SHELTER CAPACITY



Step 6

REFINE & INFORM

If conditions are not met, repeat steps through the scales

Step 7

REFLECT & REPEAT

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APPENDIX

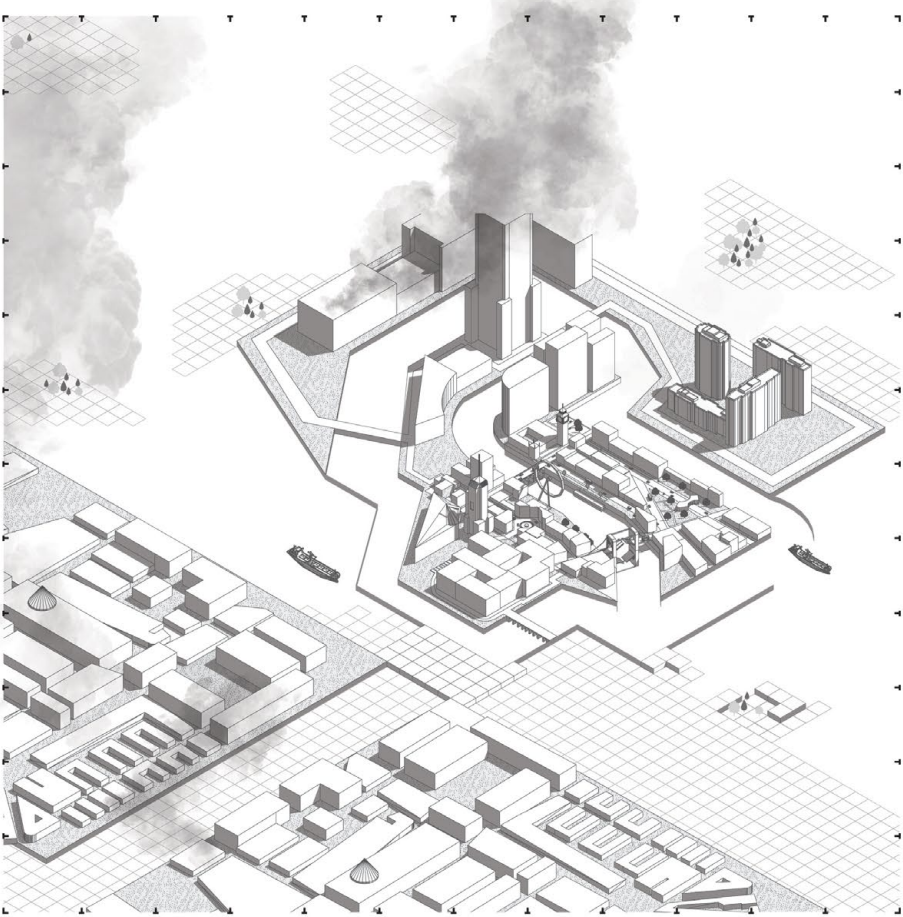


Figure 118 Transitional Territories Symposium Graphic - Re-negotiation of Space (Image by Author)

	Flood risk vulnerability classification
Essential Infrastructure	• Essential transport infrastructure (including mass evacuation routes) which has to cross the area at risk. • Essential utility infrastructure which has to be located in a flood risk area for operational reasons, including electricity generating power stations and grid and primary substations; and water treatment works that need to remain operational in times of flood.
Highly vulnerable	• Police and ambulance stations; fire stations and command centres; telecommunications installations required to be operational during flooding. • Emergency dispersal points. • Basement dwellings. • Caravans, mobile homes and park homes intended for permanent residential use.
More vulnerable	• Hospitals • Residential institutions such as residential care homes, children's homes, social services homes, prisons and hostels. • Buildings used for dwelling houses, student halls of residence, drinking establishments, nightclubs and hotels. • Non–residential uses for health services, nurseries and educational establishments. • Landfill* and sites used for waste management facilities for hazardous waste.
Less vulnerable	• Buildings used for shops; financial, professional and other services; restaurants, cafes and hot food takeaways; offices; general industry, storage and distribution; non-residential institutions not included in the 'more vulnerable' class; and assembly and leisure. • Land and buildings used for agriculture and forestry. • Minerals working and processing (except for sand and gravel working). • Sewage treatment works, if adequate measures to control pollution and manage sewage during flooding events are in place.

Defined by the TE2100 Plan

Calculations for Each Neighbourhood

District/Neighbourhood		
	Isle of Dogs	
	Method of Data Extraction	**Numbers**
(2016) Population	*census tract*	49,600
Forecasted Population	*policy document*	30,600+ new homes
		110,000 new jobs
	estimated added pop.	40000
Total Area	*archicad model (m2)*	3551472.81
Public Open Space	*archicad model (m2)*	284997.97
	Only the designated**	80,619.18
	Additional Required safe area needed	60000
Domestic Gardens	curb-building footprint x 24%	211936.2432
Avg space for garden	*GLA statistics*	24%
Area of Building Footprint	*GIS summary*	859207.97
Road	(total area-openspace-water-curb)	673007.21
Water	*archicad model (m2)*	342597.7
Curb	*archicad model (m2)*	1996572.79
	archicad model (m2)- building footprint	1137364.82
Surface Parking/Construction	*archicad model (m2)*	254297.14
CI within extreme scenario	*archicad model (m2)*	21024.1
Future scenario req. shelter	forecasted pop x 1.5 (m2)	60000
Shelter Space Currently Available	*park available / 1.5 (m2)*	53746.11933
Req. Capacity per person	1.5	
Affected Buildings between River		
Total Area (public space, road, water, curb)		3551472.81

District/Neighbourhood			
	Royal Docks		
	Method of Data Extraction	Numbers	Percentage Breakdown
(2016) Population	census tract	47,120	
Forecasted Population	policy document	47,120	
	new jobs generated	35,000	
	estimated added pop.	74,400	
Total Area	archicad model (m2)	7313220.29	
Public Open Space	archicad model (m2)	381428.29	5%
	Only the designated**	0.00	0%
	Additional Required safe area needed		
Domestic Gardens	curb-building footprint x 24%	750536.4384	10%
Avg space for garden	GLA statistics	24%	
Area of Building Footprint	GIS summary	1069276.91	15%
Road	(total area-openspace-water-curb)	732918.49	10%
Water	archicad model (m2)	2002361.44	27%
Curb	archicad model (m2)	4196512.07	
	archicad model (m2)- building footprint	3127235.16	43%
Surface Parking/Construction	archicad model (m2)	0	0%
CI within extreme scenario	archicad model (m2)	26635.75	
Future scenario req. shelter	forecasted pop x 1.5 (m2)	636900	
Shelter Space Currently Available	park available / 1.5 (m2)	0	
Req. Capacity per person	1.5		
Total Area (public space, road, water, curb)		7313220.29	

Designated Park	148,333
Req. Capacity per person	1.5

Population	47,120
Existing m2 needed:	70680

Population growth (estimate)	98,120
Total m2 needed:	147180

Flexible Space	1,153

Additional Policy Unit - Thamesmead

Among the policy units, Thamesmead also contains an extensive major road network and rail links. Similar to the previous policy unit, it is also within a low-lying area and is typically below 2-3m below high water during spring tides. In an extreme event, breaching of defences could be over topped by over 5m.

Major CI at risk:

- 21 schools
- 100+ electricity substations

The Thamesmead area is defined by:

- Major urban residential areas
- Belvedere Employment area
- The area is made from a large area of reclaimed land and is identified to be low lying and relatively flat.

This area is defined to be more susceptible to tidal flood risk. The probability of tidal flooding is roughly 0.1% per annum but the depths can range up to 5m. As for fluvial risks, it has a higher risk of 1% per annum compared to Wandsworth and from fluvial flooding it is less than 1% per annum. The current existing flood management system heavily relies on the Thames Barrier and the Marsh Dykes drainage system. Although the current drainage system 'works' there are still capacity and drainage issues due to the sheer size and flatness of the area.

The ground level in this area ranges from 0 to 1m AOD, but there are high grounds near the defences in Thamesmead.

Recommendations:
With more opportunities in future and larger redevelopment opportunities, floodplain management and defences can be incorporated in the landscape. This would also include thinking of a realignment of defences and more resilient development. Open spaces should be improved and enhanced for further tidal flood storage. The enlargement of drainage channels would also be required. While inactive for flood storage, these areas could also provide additional habitats and recreational opportunities. This is increasing in importance as new developments also raise run-offs and chances of surface flooding.
In alignment with future developments, flood awareness needs to be increased. New and existing developments need to be reinforced so that people and CI have alternative means in case of an emergency.

CONSTRAINTS

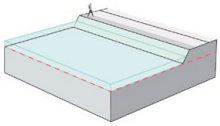
- Development pressures from improved transport links and areas of redevelopment
- At the same time, Erith Marshes continue to have pressures to be built upon, having larger losses to habitats and biodiversity
- Drainage systems were created in the 1960s and priority needs to be made on Erith marshes drainage systems within the next 10-30 years

OPPORTUNITIES

- There are raised landfill areas on the north west portion of the unit. The land is currently set in place for a new London river crossing.
- Capacity for drainage system is low
- Part of Thames Gateway regeneration area
- Erith Marshes are to be redeveloped and can integrate floodplain management and defences to enhance riverfront environment/habitats

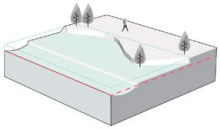
Reference Catalogue of Various Principles and Strategies

CATALOGUE

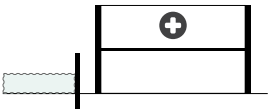


Elevated Road Networks
The road network would focus on rerouting and assigning designated evacuation routes; this entails that alternate modes and routes are possible in any flood risk intensity. The network should connect designated elevated areas for temporary shelters (open spaces) and permanent shelters (hospitals and schools).

Flood Shelters:
Elevated flood shelters should be constructed above the highest expected flood levels. They should be easily accessible and should be able to accommodate all people in the vicinity.

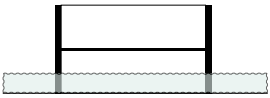


Safe Grounds - Public Spaces (Temporary):
Safe grounds are (isolated) parts of ground that are out of reach of high water levels in case of a flood event. These safe grounds can be naturally formed at random locations in flood risk plains or artificially shaped at specific places in the public space. These can also assist with infiltration capacity and reduce surface run-off.



Elevated Quay/Flood Wall at Shelters/Vital CI
A flood wall can be constructed to protect individual vital buildings/facilities against flooding. They can be either permanent or demountable. Sometimes gates are built in a flood wall to create space for roads. These gates are only closed during flood events.

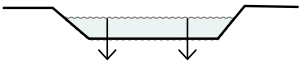
Backup Systems:
Require some existing healthcare facilities or designated shelters to install external electrical hookups for temporary generators and boilers; recommend as best practice for other buildings, including hookups for heating and cooling. An alternative is also relocating all energy systems to a higher level in the building.



Wet proofing
The interior of buildings or infrastructure in flood sensitive areas can be made waterproof. Instead of using water sensitive materials like wood or plaster-like building blocks more robust materials like concrete, steel and glass are used. If the building is flooded, damage is minimal. After a flood normal operation can restart much faster.

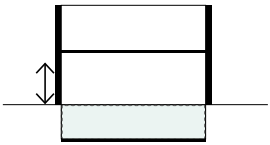
Relocation of CI
Some public utilities or vital infrastructure could be located in vulnerable flood prone locations. Relocation to higher ground is an option to minimize flood risk. The vacant areas left behind would be converted into recreation or open spaces.

Controlled islanding (electricity)
Forced partial system preservation and system recovery. This also accounts for partitioning power grids and to be separated into self-sufficient sub-networks.

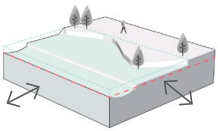


Rainwater Storage with Infrastructure
Large tanks underneath buildings/roads/bike paths can be used to store rainwater stored captured from the rooftops or along the sides of the building. Gutters and pipelines channel the water to the tank. Rainwater storage is able to store runoff during heavy rainfall and provides water in periods of droughts. This solution is to be applied to the road infrastructure and shelters.

Floodplain Excavation or Enlargement
The Thames Estuary floodplain could be enlarged by either lowering the level or increasing the width on portions of the floodplain. This would increase discharge capacity and provide upstream retention, along with decreasing the risk of flooding.



Flexible Infrastructure:
In new residential buildings, the ground level could have larger floor to ceiling space to allow for future conversion of first floor usages. This can be used to accommodate future elevations of flood defences or boulevard.



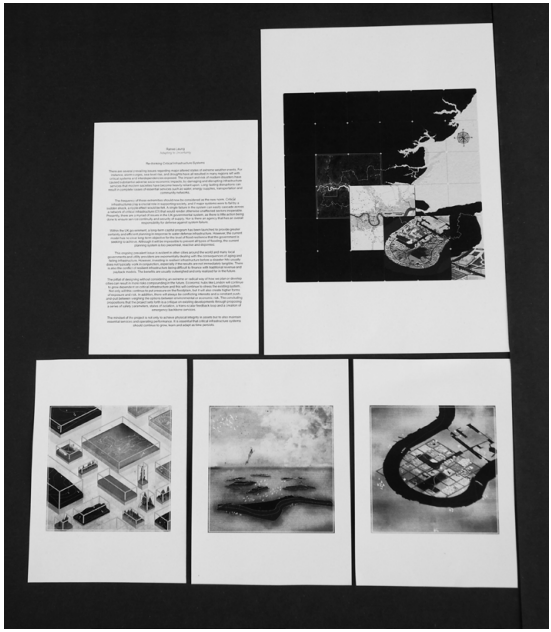
Creating Artificial (or expanding) Wetlands
Expanding or creating new wetlands will function as water retention areas, wastewater treatment, sediment traps and etc. Wetlands can be implemented with or without additions. Treatments would need to be added to deal with over topping of sewage systems.

The following are a collection of photos taken in London by the author


BIG EASY


LINER BUS SERVICES
DEPART HERE
EVERY 20 MINS

END-OF-YEAR
EXHIBITION



Transitional Territories Studio
North Sea: Landscapes of
Coexistence

Delft University of Technology
Graduation Thesis

Ranee Leung
2018-2019