# Adapting to Uncertainty: Re-thinking Critical Infrastructural Systems

There are several 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 impacts by damaging and disrupting infrastructure services that modern societies have become heavily reliant upon. Long-lasting disruptions can result in considerable losses of essential services such as water, energy supplies, transportation and community networks.

The frequency of these extremities should now be considered as the new norm. Critical infrastructures play a crucial role in supporting society, and if major systems were to fail by a sudden shock, a ripple effect would be felt. A single failure in the system can easily cascade across a network of critical infrastructure (CI) 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 defense against system failure. Within the UK government, a long-term capital program has been launched 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 disjointed. Thus, this translates to the main 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?

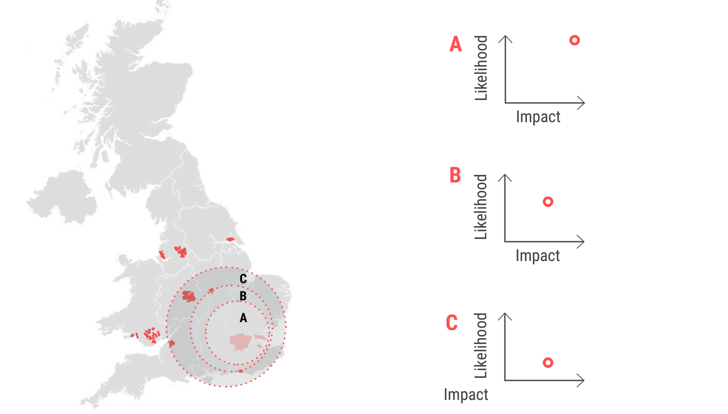
The thesis aims to address several key elements:

- To develop a methodology and framework to understand how to assess and develop resilient critical infrastructure and services.
- Translating a spatial contingency plan while improving safety and living standards.
- To develop a set of propositions based on research-by-design with insight on upscaling or replicability of the project.

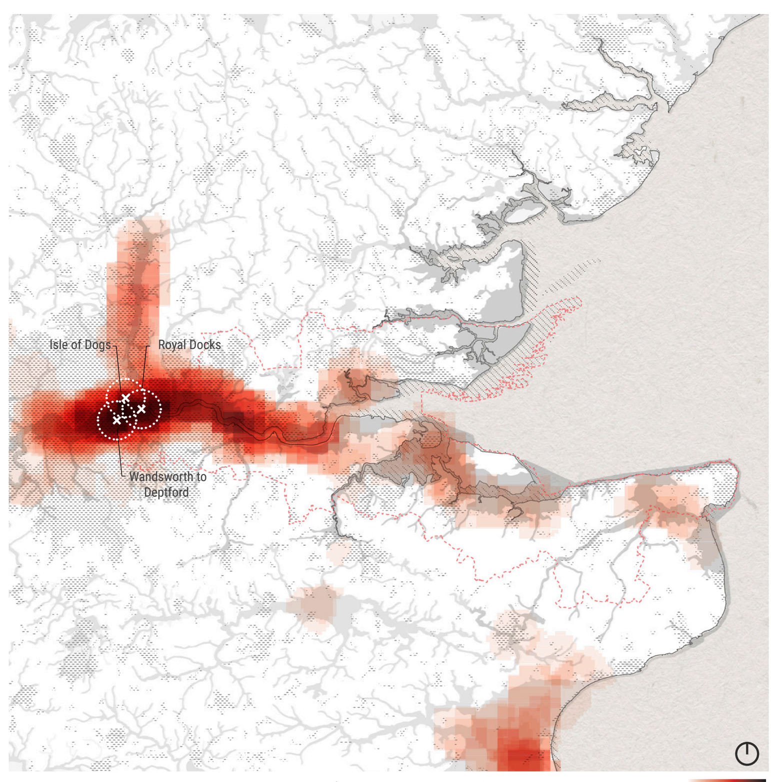
The design interventions have the intent to increase safety parameters while improving livability, to strengthen and alternative means of accessing designated safety areas, establish safety grounds with backup systems and encourage a faster response and recovery time. However, the pitfall of designing without considering an extreme option of how we plan or develop cities can result in more risks compounding in the future. Economic hubs like London will continue to grow dependent on critical infrastructure and this will continue to stress the existing system. This will remain to put pressure on the floodplain, but it will also create higher forms of exposure and risk. The concluding propositions that the project sets forth is a critique on existing developments through proposing a series of safety parameters, states of isolation, a trans-scalar feedback loop and the creation of emergency backbone services. The mindset of the project is not only to achieve physical integrity in assets but to also maintain essential services and operating performance. It is essential that critical infrastructure systems should continue to grow, learn and adapt as time persists.

Keywords:

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


Map of the densest accumulation of CI in the UK with a flood risk matrix. Areas with likelihood of surface water flooding and potential impacts (Adapted from Environment Agency, 2017)

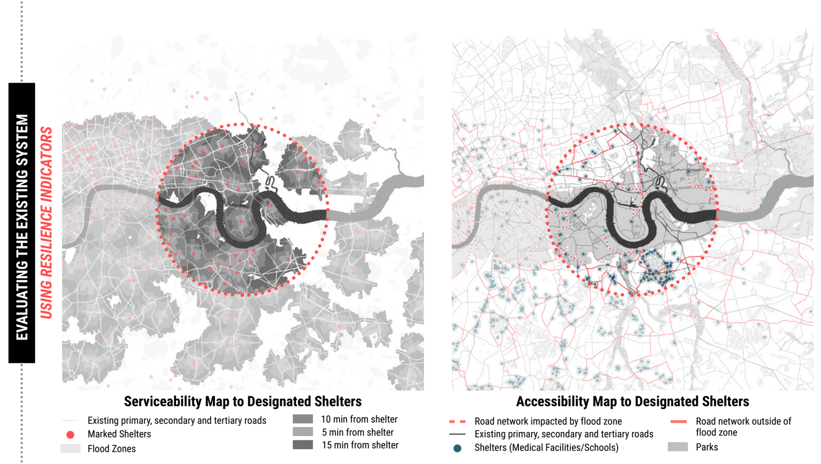


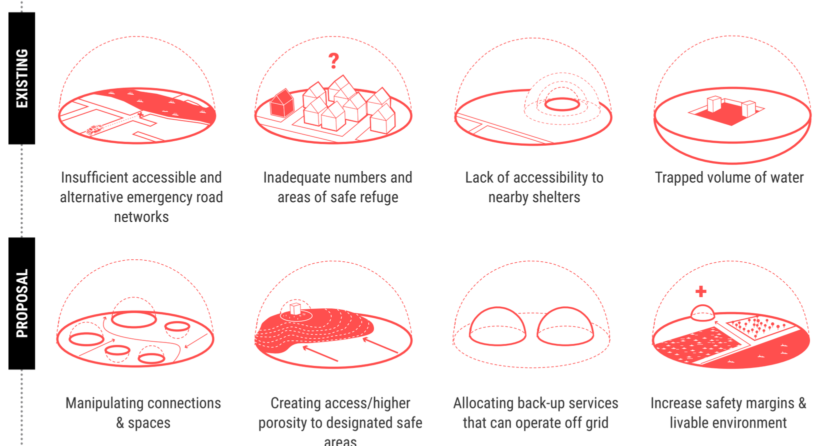

**Locating the Most Vulnerable Areas: Critical Infrastructure Density Map Relative to Flood Risk Intensities**

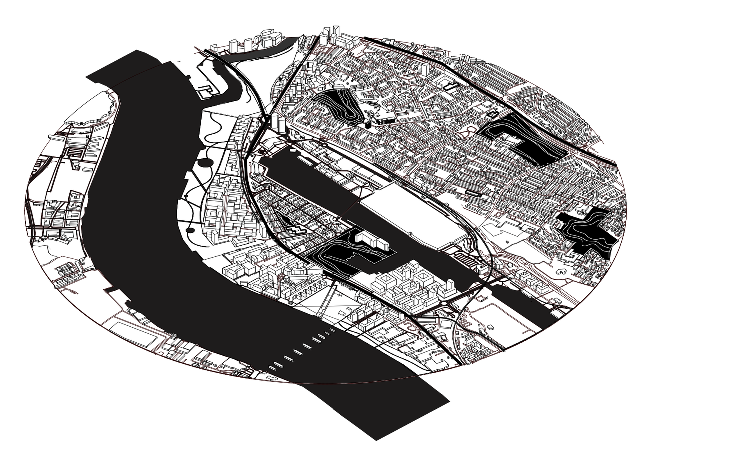
All defined critical infrastructure systems were spatially intersected with flood zone 2 & 3. Next, sq.km buffer areas were created to perform a point and line density spatial analysis. Three neighbourhoods were chosen with the highest concentration of critical infrastructure exposed to different flood intensities.

**NETWORK ANALYSIS & PERFORMANCE METRICS**

*Travel time, time for recovery, provision of relief and access to lifesaving services*



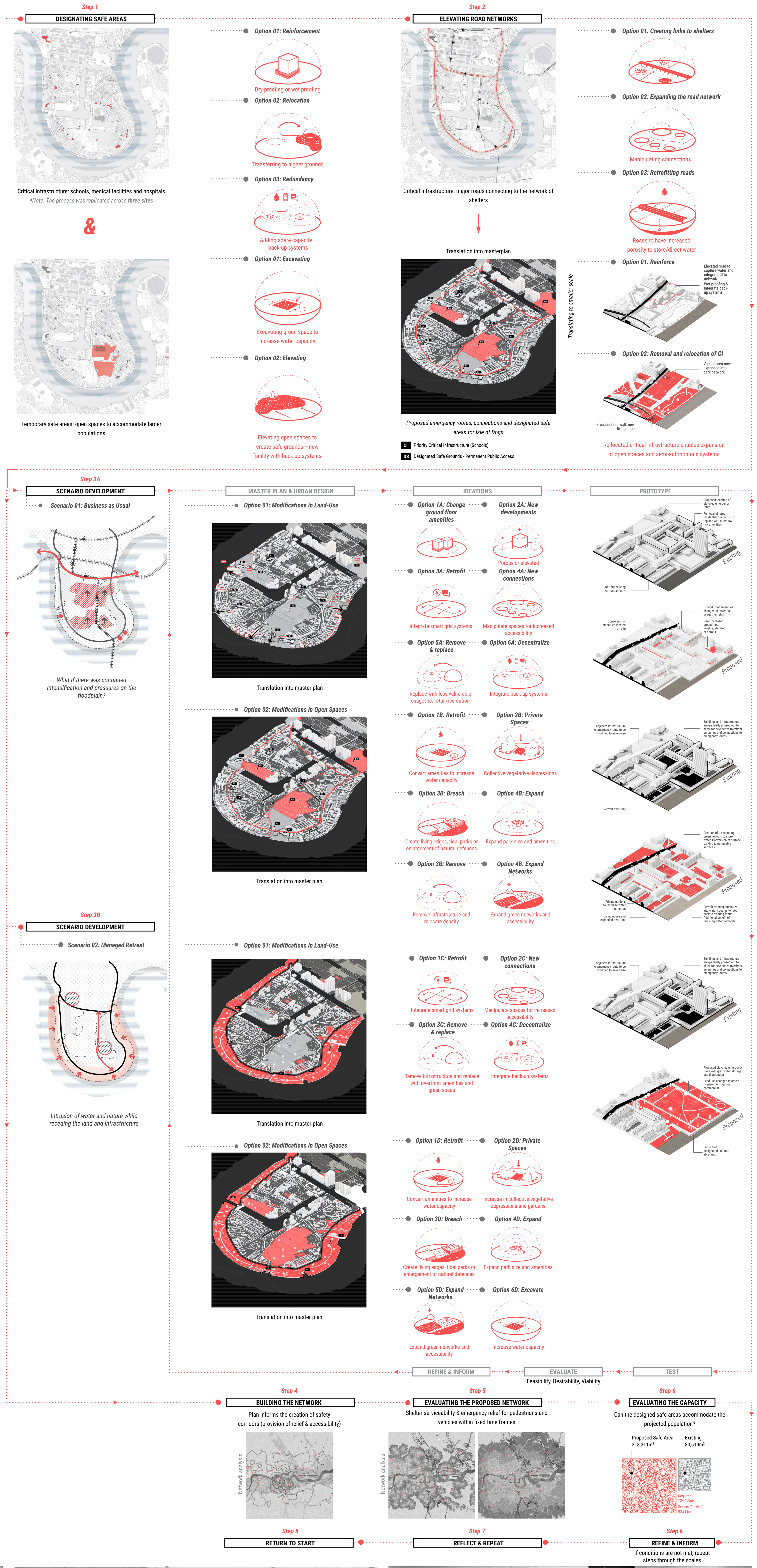



**Aspect 1: Emergency Backbone Services and The Spatial Contingency Plan**

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, the integration of early response and recovery in new developments should be a priority. Spatial contingency plans would embedded in the system and smaller modules could be tested to limit future failures.


## Streamlining the Design Process: Setting up the Contingency Plan



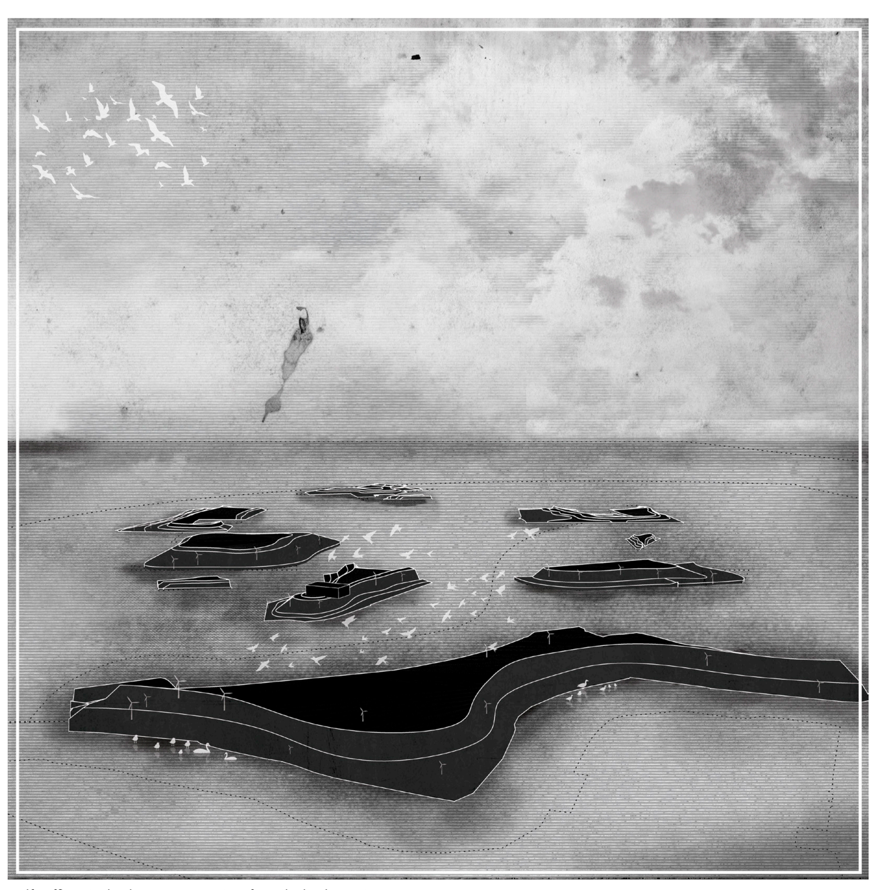


**Aspect 2: The Risk Taxonomy and Mediating Between Scales**

The frequency and magnitude of climate related events have caused direct and indirect damage to people and critical infrastructural services. 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** in 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.

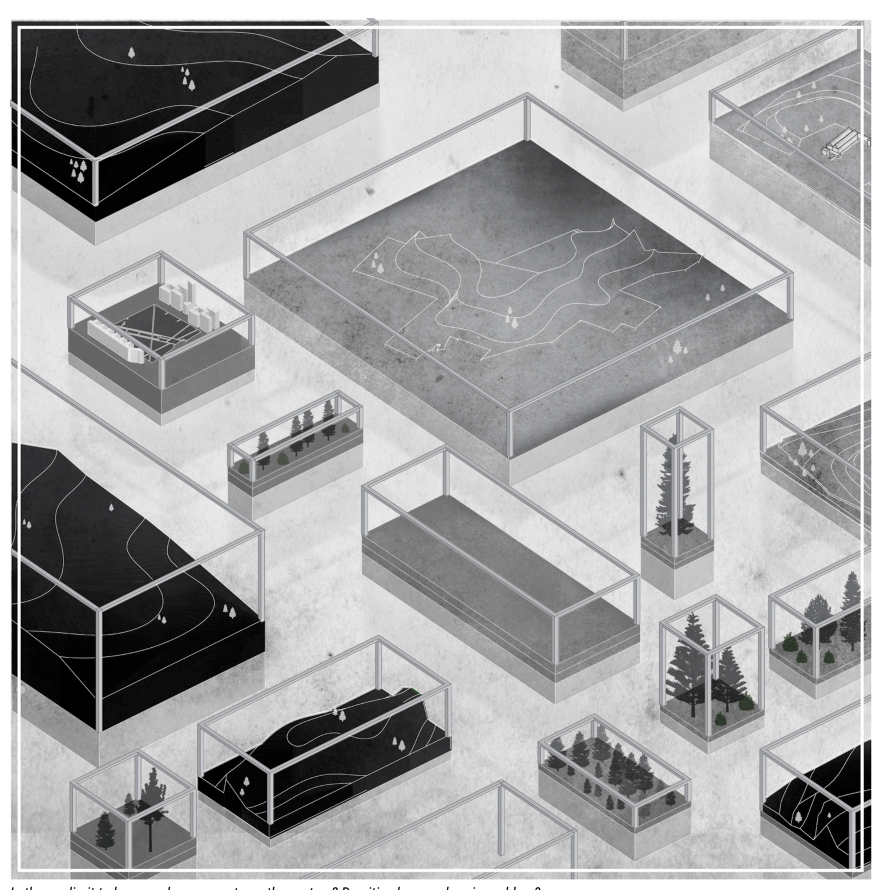


*Self-sufficient islands: are we retreating from the land or water?*

**Aspect 3: 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 ***spatial contingency plan with a set of hybrid and dual functionalities in infrastructure systems***. 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

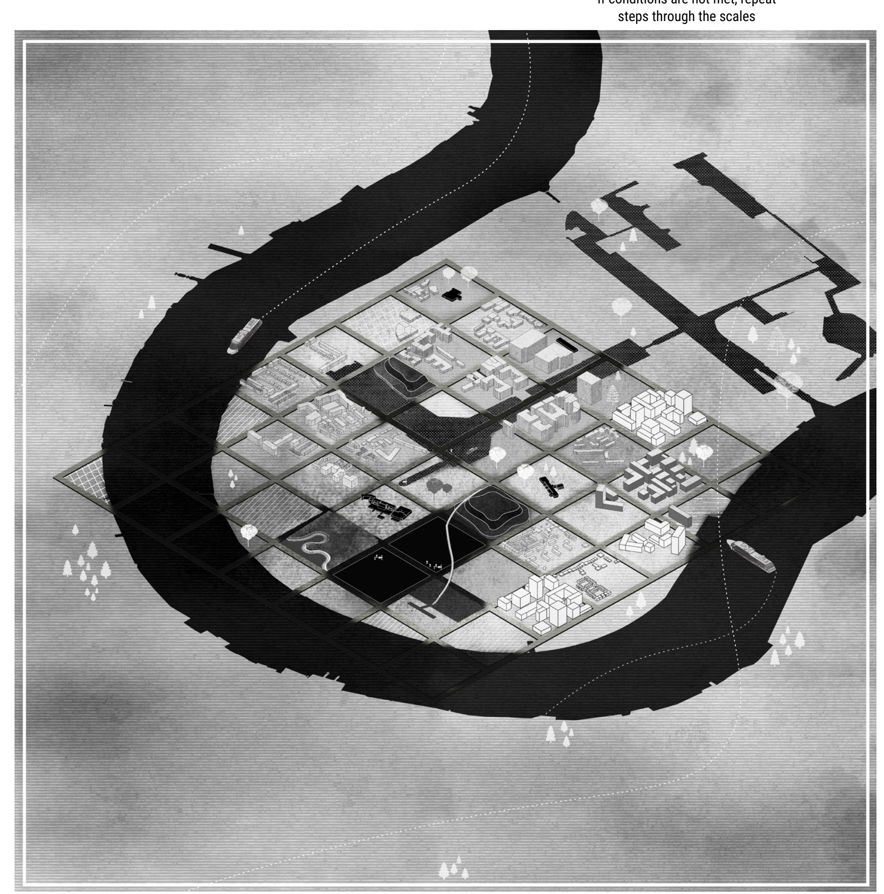


*Is there a limit to how much you can stress the system? Do cities have a chronic problem?*

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

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. But 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. Nonetheless, the system will continue to suffer from chronic problems and will start to showcase signs of compounding risks.

***Recommendation:***
By *placing environmental risk as the highest 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
- Facilitate and strengthen green network connections
- Extending the 'tipping point' by providing more capacities in the system
- Setting aside physical spaces to accommodate for future changes



*Reshuffling of system thinking and networks: an overhaul of regulations*

**Aspect 5: The Future of Planned Developments: Limiting Failure and Safe-to-Fail Systems + Aspect 6: Capacity to Learn as a New Parameter**

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). Spatial restructuring typically gravitates towards the concentration of built up areas and transit nodes. Through flexible land-use policies and regulations, 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.

***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*.
- Defining and containing failure through the implementation of decentralized networks
- Restructure the system to include a hybrid system that has the benefits of centralization and decentralization.
- Redundant infrastructure would offer back up facilities and would limit the extent of failure
- Anticipate challenges and expected dangers rather than responding to the damages after an event.

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