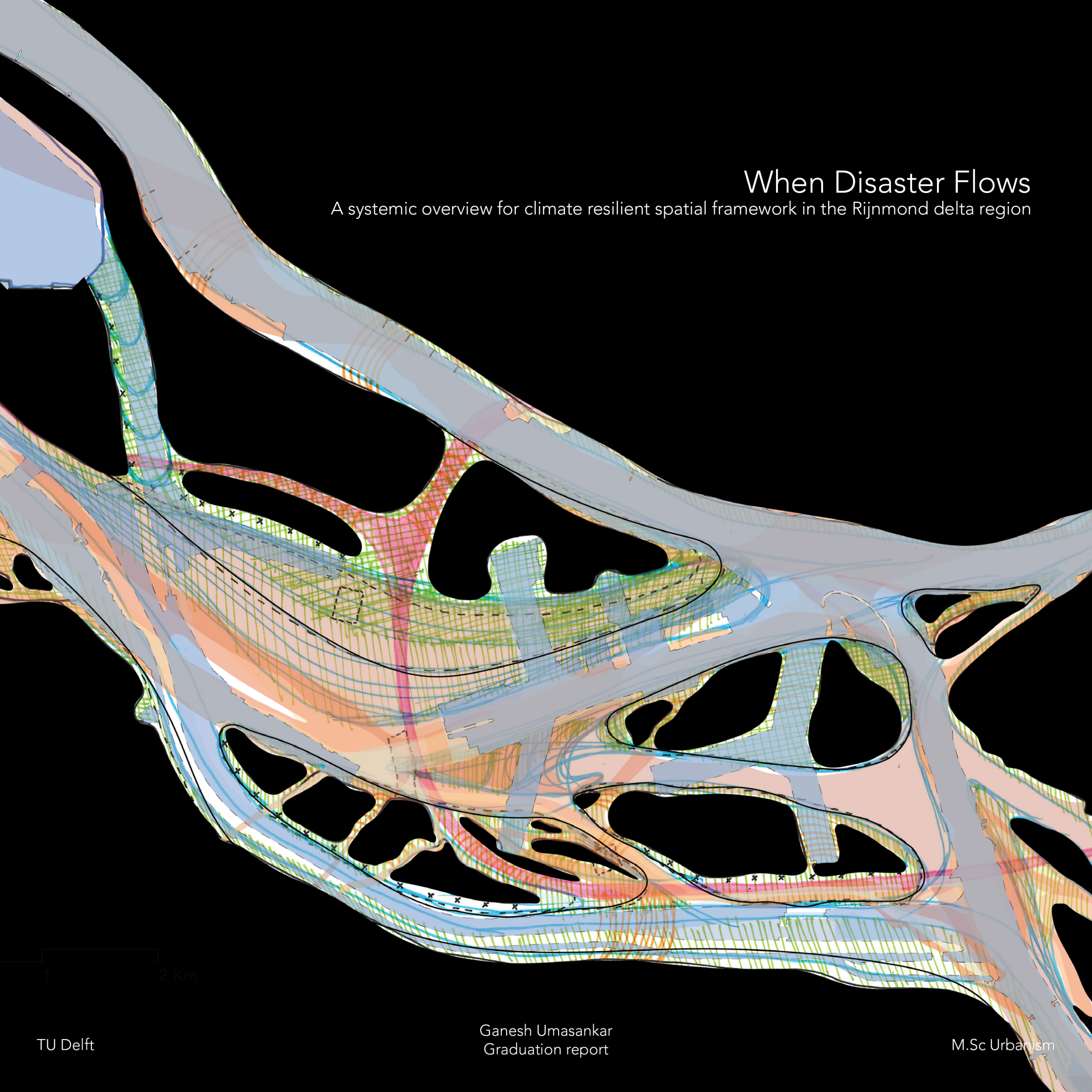
When Disaster Flows

A systemic overview for climate resilient spatial framework in the Rijnmond delta region



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Graduation report

TU Delft

M.Sc Urbanism

Master Thesis report

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TU Delft BK Bouwkunde Department of Architectural Engineering +Technology

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Abstract

When Disaster Flows examines how centuries of engineering the Rhine - Meuse delta have shaped the Rijnmond region an area that has long been central to the Netherlands' economic vitality and cultural identity. Despite its scale, with a river basin extending over 185,260 km² across Northwestern Europe (Copernicus, 2011), the delta's natural dynamics have been progressively constrained in favor of human safety, port expansion, and industrial development. This heavy reliance on engineered defenses has overshadowed the ecological functions that once sustained the landscape and moderated flood risks.

This research seeks to rediscover and reintegrate the delta's natural logic as a fundamental strategy for addressing intensifying climate impacts and growing uncertainty. Through a systems-thinking approach, the study analyses the Rijnmond region using methods such as the DPSIR framework and Adaptive Pathway Planning. These tools enable a comprehensive understanding of environmental pressures, socio-spatial vulnerabilities, and long-term adaptation trajectories, ultimately proposing a renewed delta regime that aligns natural processes with future resilience.

Key words: Climate proof, Tidal cities, Living with water, Spatial planning, Rhine archipelago, Systems thinking, Disaster resilience, Adaptive pathway planning, Spatial framework

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1 Introduction

1.1 Personal motivation
1.2 Climate change

1.1 Personal motivation

Years of living in India and now in the Netherlands have given me a unique perspective as an urbanist, allowing me to interpret both causes and consequences of urban events through a spatial lens. This shift from a developing country to a developed one revealed how societies invest in and value space differently

In the Netherlands, there is a strong emphasis on maintaining a resilient urban fabric, prioritizing climate adaptation, biodiversity preservation, and sustainable economic growth. In contrast, cities in developing nations often contend with rapid urbanization, resource limitations, and reactive planning. This contrast deepened my appreciation for spatial planning and its influence on human and ecological well-being.

Yet, I've observed a common shortcoming in both contexts: our tendency to underestimate the power of nature. Climate risks often escalate into disasters not just because of their inherent force, but due to our failure to anticipate their non-linear and cascading effects.

Two events that particularly shaped this realization are the 2015 floods in Chennai, my hometown, and the 2021 floods in Germany's Ahr Valley. While vastly different in context and infrastructure, both disasters were driven by similar root causes unchecked urban expansion, insufficient preparedness, and underestimation of climate threats. These events remind us that no country, regardless of its development status, is immune to climate extremes.

As an Urbanist, these experiences fuel my commitment to designing adaptive, anticipatory, and inclusive urban systems, ones that recognize the evolving power of nature and the need for spatial resilience at every scale.



Fig 1.1: 2015 Chennai floods
Source: Deccan chronicle

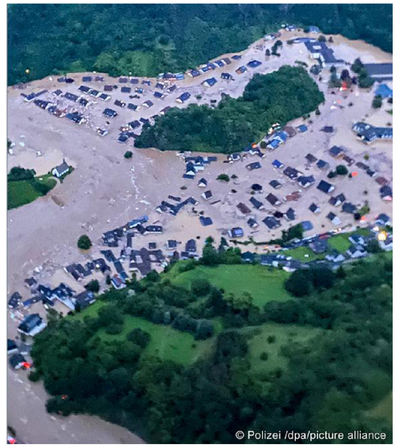


Fig 1.2: 2021 Ahr valley flood
Source:Polizei/dpa

Case 01:

The **criticality** of the Chennai floods in 2015, which resulted in **fatal consequences**, was significantly exacerbated by **underlying human factors and unregulated urban development**, identified as the **primary root causes**. While triggered by heavy rainfall from the Northeast monsoon, enhanced by El-Nino effects and sequential depressions, the scale of the disaster was magnified by **rapid and erroneous urbanisation**.

Key contributing factors included the **encroachment of riverbanks and marshy lands** and the **filling up of lakes and water reservoirs**, severely diminishing the city's natural capacity to absorb excess water. This was compounded by the replacement of natural land cover with impervious surfaces, leading to increased surface runoff6, inadequate capacity and connectivity of storm water drainage systems, and the clogging of drains by solid waste and construction debris.

Furthermore, development projects were situated below flood levels and within flood-prone areas like river plains and low-lying regions, directly increasing vulnerability to inundation. These factors led to a severe flood event, causing 422 deaths in Tamil Nadu and numerous fatalities in neighboring states and the Union Territory. The floods displaced over 1.8 million people, damaged more than 100,000 structures, and resulted in significant financial losses for millions of families and businesses. Essential infrastructure was severely disrupted, with power supplies suspended, hospitals ceasing operations, and transport networks closed.

Thus, the 2015 Chennai floods serve as a case highlighting how meteorological triggers, when combined with **systemic developmental failures** and **disregard for natural hydrological systems**, can escalate into a **major urban catastrophe**.

Case 02:

The 2021 Ahr valley flood was a critically severe event, primarily defined by an **exceptionally high number of fatalities** for Germany, totaling 190 deaths, with 134 occurring within the Ahr valley. This death toll exceeded the cumulative number of inland flood fatalities recorded in Germany over the preceding four decades (1980–2020).

The root causes of this high criticality were **multifaceted**, stemming from the **extreme nature of the flash flood** itself, combined with a systemic failure in risk perception and communication. Hydrologically, the event was unprecedented in terms of rapid onset, high water levels, and high flow velocities. However, its deadliness was significantly amplified by the **underestimation of its severity** by both the populace and authorities, **leading to inadequate early warning and evacuation measures**.

Official hazard maps for extreme scenarios considerably underestimated the actual inundation extent, contributing to a false sense of security outside mapped zones, where 75% of fatalities occurred. Warnings issued often failed to convey the extreme danger, surprising many and resulting in delayed or absent evacuations for a significant portion of affected residents.

Furthermore, exposure in particularly dangerous locations like cellars and basement flats contributed to deaths, but a large number of fatalities also occurred unexpectedly on ground floors (37%) and even outdoors on streets (18%). **Vulnerability** was a key factor, with the elderly (aged 60 and over) comprising 78% of victims and individuals with mobility or cognitive impairments also being disproportionately affected (16%).

Thus, the high number of fatalities resulted from the convergence of an extreme natural hazard with critical failures in hazard mapping, warning systems, evacuation procedures, and a lack of public understanding regarding the specific dangers of flash floods and vulnerable populations.

Source: Chennai flood 2015. Report by National institute of disaster management

Source: Rhine, B. and Kreibich, H.: Causes of the exceptionally high number of fatalities in the Ahr valley, Germany, during the 2021 flood, Nat. Hazards Earth Syst. Sci., 25, 581–589, https://doi.org/10.5194/nhess-25-581-2025, 2025.

1.2 Climate change

Years of living in India and now in the Netherlands have given me a unique perspective as an urbanist, allowing me to interpret both causes and consequences of urban events through a spatial lens. This shift from a developing country to a developed one revealed how societies invest in and value space differently

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Fig 1.3: The extend to which current and future generations will live in a warmer and different world depends on choices made now and in the short term
Source: IPCC, AR6 Synthesis Report

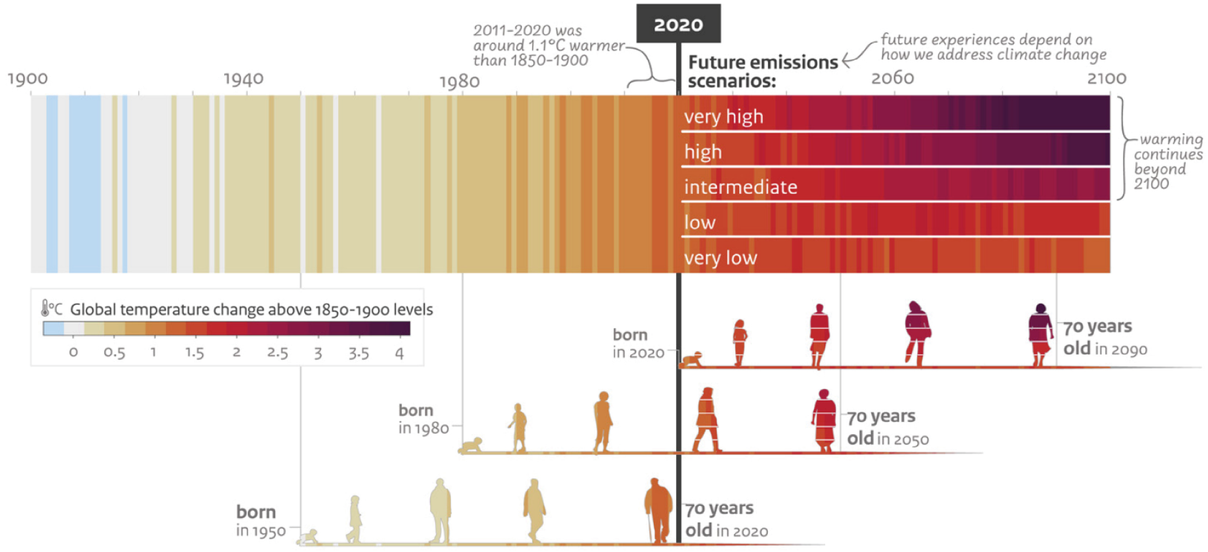
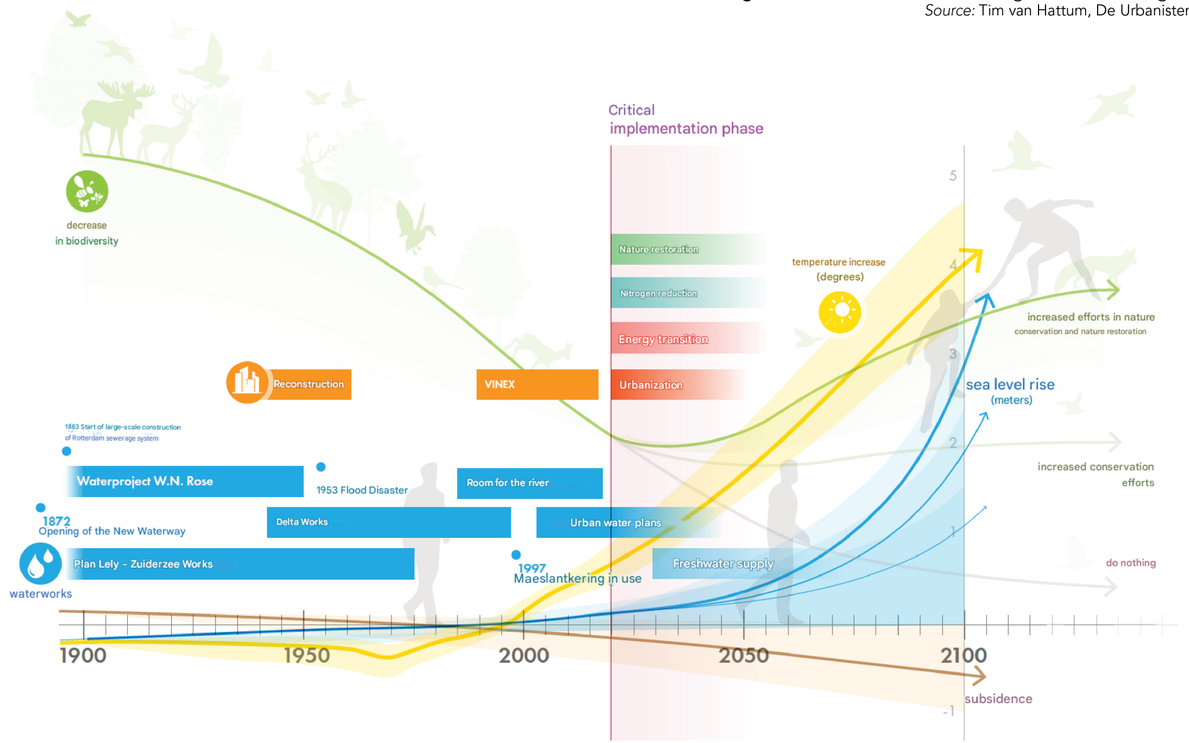


Fig 1.4: Timeline of climate challenge faced in the region
Source: Tim van Hattum, De Urbanisten



Return period of climate risks being reduced and the region would haven't been recovered from previous climate threat.

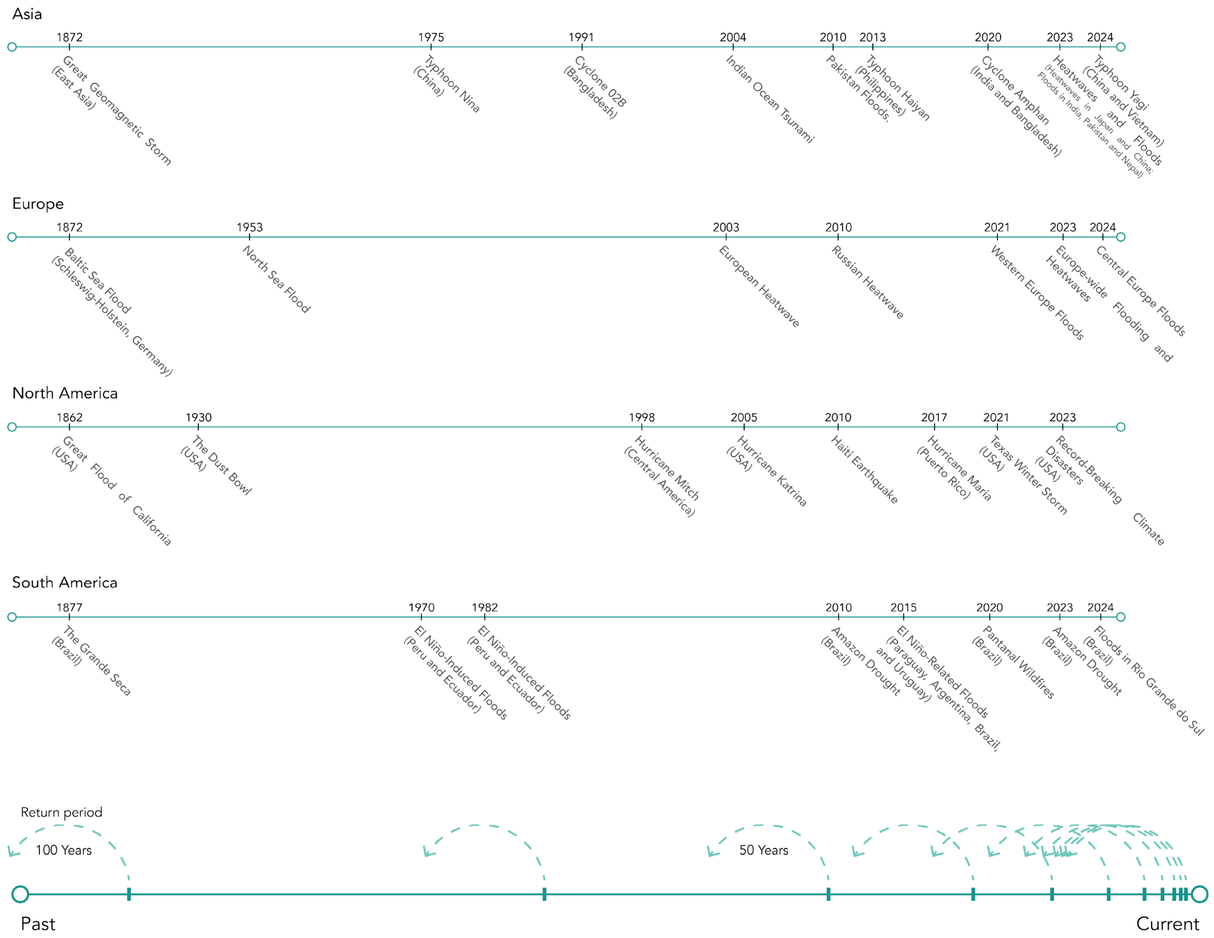


Fig 1.5: Timeline showing major climate events from different continents and their return period
Source: author

2 Criticality (in) Focus

This chapter examines the range of water-related threats faced by the Netherlands and the ways in which climate risks are categorized and addressed within existing frameworks. It establishes a foundational understanding of the key elements that contribute to climate threats and their implications for water systems.

2.1 Water threats in The Netherlands
2.2 Complex risks
2.3 Climate vulnerability and Spatial variation

2.1 Water threats in The Netherlands

Climate change significantly affects the Dutch delta landscapes, including the Rhine-Meuse Delta, which is particularly **vulnerable** due to its **densely populated and largely low-lying nature**. These impacts are complex and are expected to increase in the future, posing major water challenges. The effects of climate change on the Dutch delta landscapes include:

Increasing Water Levels

- **Sea level rise** increases pressure on **dikes and the coast**, necessitating measures to guarantee long-term safety and reserving sufficient space for future water safety interventions. Approximately rising 1.5 millimeters per year between 1940-1959 to about 2.9 millimeters per year between 2000-2019 (van Gaalen et al., 2024). It also affects sand nourishments, storm surge barriers, and the discharge of water from rivers, lakes, and canals. There is uncertainty about the speed of sea level rise after 2050, which requires careful preparation through knowledge programmes.
- **Higher river discharges** can occur in winter, increasing challenges for water safety and making the main water system vulnerable to flooding. Ensuring the safe drainage of water, sediment, and ice remains necessary with these increased discharges.
- **Water logging due to heavy rainfall** will increasingly be experienced, posing significant climate threats and leading to problems like fish deaths in streams and substantial damage from water nuisance if no measures are taken.

Water Scarcity and Quality Issues

- **Freshwater shortages** and **drought** are increasing due to climate change. The Netherlands has experienced four extremely dry summers in the last five years, with 2022 being one of the driest and warmest globally (MIWM*, 2024a). This can lead to economic damage and water quality problems. Lower river discharges in summer impact freshwater and drinking water supply, as well as shipping.
- **Salinisation** is a growing concern, exacerbated by drought and certain physical interventions, and impacts freshwater availability.
- **Groundwater issues** arise as climate change, alongside other developments, puts the soil and water system under pressure, leading to problems such as drought, salinisation, and soil subsidence. This impacts groundwater levels, affecting nature and agricultural productivity. Climate change can influence groundwater bodies via hydrology, physico-chemistry (salination, eutrophication), or biology.
- **Water quality problems** are also linked to climate change, including issues arising from heavy rainfall, drought, and increased temperatures.

Impacts on Ecosystems and Biodiversity

- Climate change affects the **diversity of life forms**, including plants and animals, by impacting their habitat and introducing negative influences like pollution and desiccation. **Loss of biodiversity and ecosystem services** are significant due to temperature increases, extreme drought, wetness, sea level rise, and salinisation (van Gaalen et al., 2024).
- It affects the **ecological functioning of the Wadden Sea**, potentially changing its morphology, influencing the composition of species, and leading to more fluctuating salt levels.
- Increased temperatures, changes in nutrient supply, and fluctuating salt levels can affect nature.
- Prolonged drought and the advance of invasive species can have **unpredictable consequences for the ecosystem of Dutch rivers.**
- The condition of water bodies themselves can also affect climate change, as surface water (especially cloudy, algae-dominated water) contributes to **greenhouse gas emissions.**
- This effects amplifies existing pressures such as acidification, fertilisation, and fragmentation (van Gaalen et al., 2024).

Challenges for Infrastructure and Human Activities

- **Outdated infrastructure** like bridges and locks need maintenance and replacement, with climate impacts being a key consideration for their resilience (van Gaalen et al., 2024).
- Climate change impacts the **performance and functioning of road and waterway networks**, leading to issues like shipping disruption during low water or movable bridges getting stuck.
- It affects sectors like **agriculture**, which faces problems like drought, and requires investments in solutions such as water retention and adjustments in land use (van Gaalen et al., 2024).
- **Urban areas** are vulnerable to water nuisance, heat, drought, and flooding, impacting safety, health, the economy, and biodiversity.
- **Rising water temperatures** can put pressure on the availability of cooling water for industry and energy sectors.

*(*MIWM=Ministry of Infrastructure and Water Management)*

2.2 Complex risks

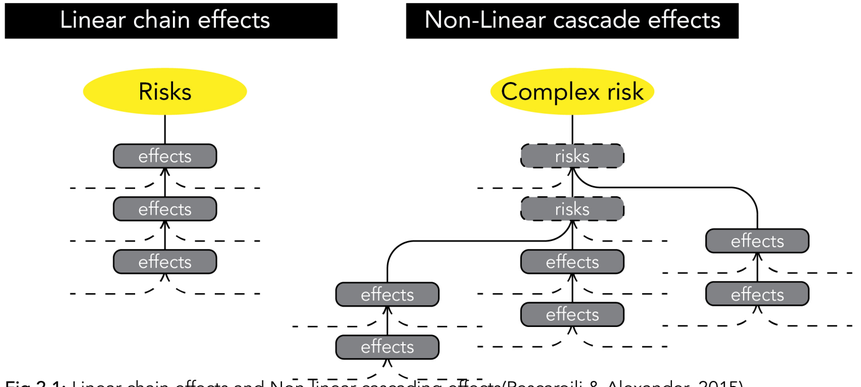


Fig 2.1: Linear chain effects and Non-linear cascading effects(Pescaroili & Alexander, 2015)
Source: author

Complex risks

Risks due to potential direct and indirect impacts (chain, cascade, network, cross-border and system impacts, for example in logistics chains) Risks from combinations of gradual developments and/or different weather extremes with variability in time and space that occur simultaneously, successively or repeatedly. For example, a storm that is accompanied by both strong winds and heavy precipitation in combination with sea level rise (Hillier et al. 2020).

Risks can also arise from combinations of factors, of which climate change is one, for example the potential impact on a nature reserve of a heat wave and extreme drought in combination with eutrophication and desiccation due to water level management or groundwater extraction.

Analysis methods for complex climate risks are still in full development(Leonard et al. 2014; Simpson et al. 2021; UNDRR 2022).

Chain and cascade effects

A climate-related hazard can have direct and indirect impacts that have a knock-on effect in a system (ISO 14091). Chain effects describe a linear, cumulative impact. Cascade effects describe a non-linear chain, where effects are cross-sectoral and can reinforce each other or create a new risk (Pescaroli & Alexander 2015). For example, large-scale flooding in Central Europe in 2002 caused casualties and direct damage to buildings and vital and vulnerable infrastructure, resulting in power outages and a leak in a chemical plant. This subsequently resulted in a threat to the drinking water supply.

Black swans / Tipping point

Risks with uncertain and/or irreversible potential impacts

Risks due to creeping developments, where a critical threshold can be exceeded with irreversible or very difficult to reverse impact, leading to undesirable situations.

Black swans are unthinkable risks with a major impact. Based on Taleb (2007), a black swan is described as: 'an unpredictable event that is beyond normal expectations and has an extreme impact'. Characteristically, black swans are very rare, have an extreme impact and cannot be noticed or predicted, while in retrospect they could have been explained and expected.

According to this definition, a specific black swan can **only occur once**, after which it is considered. Since black swans are unimaginable and unpredictable in the existing perception, a risk analysis based on impact and probability is not possible.

Climate threat (hazard)

Climate threat "A potential source of harm". In IPCC AR5 "The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision,ecosystems and environmental resources. The term 'hazard' refers to climate-related physical events or trends or their physical impacts" (IPCC 2014). A climate threat is therefore the possible occurrence of a physical, climate- or weather-related phenomenon with the potential to cause damage. A climate threat is characterized by the intensity, geographical distribution and duration of a climate phenomenon, and the probability that the phenomenon will occur. A climate threat that actually occurs is called a climate event.

Adaptive capacity

Adaptive capacity is defined in IPCC "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences".

Adaptation capacity is the ability of systems, institutions, people or organisms to adapt to potential harm, exploit opportunities or respond to impacts. Adaptation is the process of adjusting to actual or potential climate impacts.

Adaptation capacity is a complex concept with many aspects. In the example of heat stress in the elderly, adaptive capacity is the extent to which these elderly people are able to protect themselves reactively, independently or with support, against heat, and whether preventive measures have been taken for this. Adaptive capacity concerns awareness of and attention to the risk in the relevant policy areas, and the presence of plans for adaptation, flexibility and the turnover rate and/or lifespan of investments in the system that must be adapted by technical, organizational, administrative, financial and political factors.

Vulnerability

'The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt' (IPCC, 2014). Vulnerability means the tendency of a system to be negatively affected by a climate threat. Vulnerability concerns internal properties of the affected system itself. Vulnerability is a function of the sensitivity to a climate threat and the adaptation capacity to cope with this threat in advance (preventive adaptation) or its consequences (reactive adaptation). Vulnerability = f (Sensitivity, Adaptive capacity).

Factors that influence vulnerability include socio-economic and spatial developments, and administrative organisation (IPCC 2014). A climate risk is therefore not only determined by climate change (climate attribution), but also by other factors that influence exposure and vulnerability. For example, population growth in risky locations and other factors that make affected systems more sensitive to climate threats, such as population composition and resilience of specific groups.

2.3 Climate vulnerability and spatial variation

Vulnerable areas are discussed within the larger context of climate risks and adaptation in the Netherlands. Vulnerability to climate change is not uniform across the country, and certain areas are inherently more susceptible to climate threats due to their location and characteristics (Franken et al., 2023).

Vulnerability as a component of Climate risk.

Climate risk can be defined as a combination of climate threat, exposure, and vulnerability (Franken et al., 2023). Vulnerability itself is further broken down into **sensitivity** and **adaptive capacity**. Vulnerability concerns the internal properties of the affected system, such as a particular area or policy sector, that make it susceptible to negative effects from a climate threat (Franken et al., 2023).

Spatial Variation and Vulnerable areas.

The concept of vulnerable areas is explicitly linked to **spatial variation** (Franken et al., 2023). The Dutch climate risk analysis 2022-2026 focuses primarily on a national scale but will apply spatial variation to risks where relevant. This is important because climate threats, socio-economic circumstances, exposure, sensitivity, adaptation capacity, adaptation policy, and probability can all differ spatially.

Potentially vulnerable due to spatial characteristics include:

- **Low-lying parts** of the Netherlands, particularly close to the coast and in floodplains.
- **Low-lying polders**, mentioned as an example where water nuisance easily occurs.
- **Urban and rural areas**, which can have different vulnerabilities.
- **High and low Netherlands**, reflecting geographical differences in elevation.
- **Physical geographic regions** and areas related to primary and regional water safety (Franken et al., 2023).

Specific regions known for certain vulnerabilities, such as the river area, the Green Heart, and Friesland where foundation damage due to drought is frequently reported (Franken et al., 2023).

Factors Influencing Vulnerability in Specific Areas

- **Geographic and spatial position**: Being in a low-lying area or near the coast or floodplains increases exposure to certain threats like flooding or sea level rise (Franken et al., 2023).

- **Socio-economic and spatial developments**: These developments can change the exposure and sensitivity of society to climate change (Franken et al., 2023). For example, high population density, a lot of construction, and invested capital in low-lying areas can be unfavorable for exposure and vulnerability.

- **Sensitivity:** Certain areas or systems within them may be inherently more sensitive. An example is the sensitivity of buildings to flooding (Franken et al., 2023). The built environment is influenced by spatial planning and can influence sensitivity and exposure to climate impacts (Franken et al., 2023).

- **Adaptation Capacity:** The ability to cope with climate threats also varies spatially (Franken et al., 2023). **Socio-economic** and **spatial circumstances** can limit adaptation capacity (Franken et al., 2023). For instance, vulnerable neighbourhoods with less socio-economic capacity may struggle to finance adaptations like better insulation or adapting homes to flooding, drought, and heat (Franken et al., 2023).

2.3 Climate vulnerability and spatial variation

Spatial variation

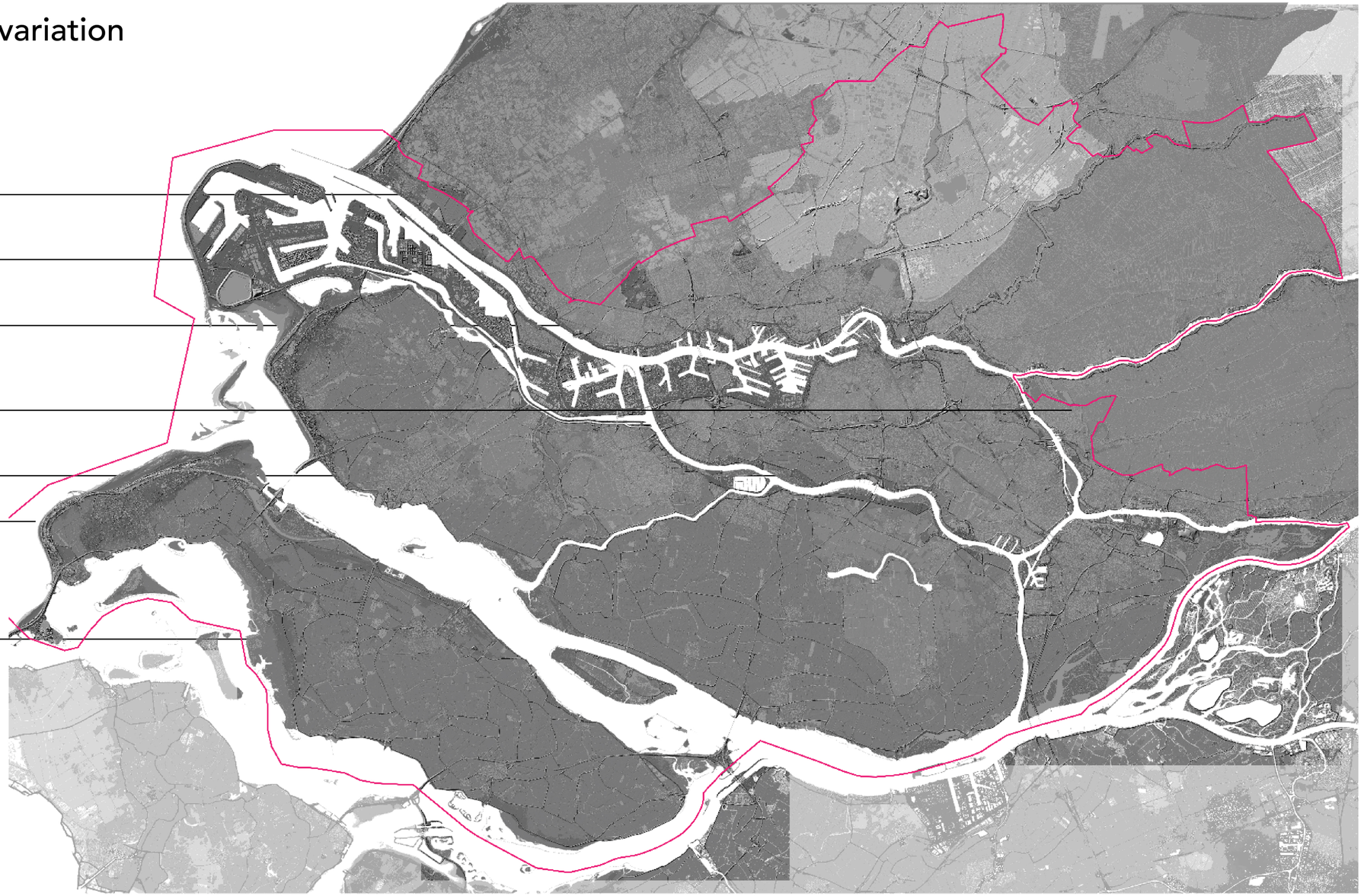


Fig 2.2: Spatial variation of the Rijnmond region
Source: author
Dataset: AHN

3
Criticality (in) Theory

This chapter analyses historical water-related crises and classifies water-based disasters from a systems perspective into three categories: excess case, water scarcity- exhaustion case, and water quality degradation- exemption case. Through a synthesis of relevant literature and policy documents, this chapter formulates the central problem statement of the project.

3.1 Climate scenarios in The Netherlands
3.2 Literature findings
3.3 Excess scenario
3.4 Policies
3.5 Responsibilities
3.6 Problem statement

3.1 Climate scenarios in The Netherlands

Records from the past decade clearly shows that the intensity of extreme water events and its impacts have increases leading to high economic loss in the region alongside increasing the sensitivity of the region

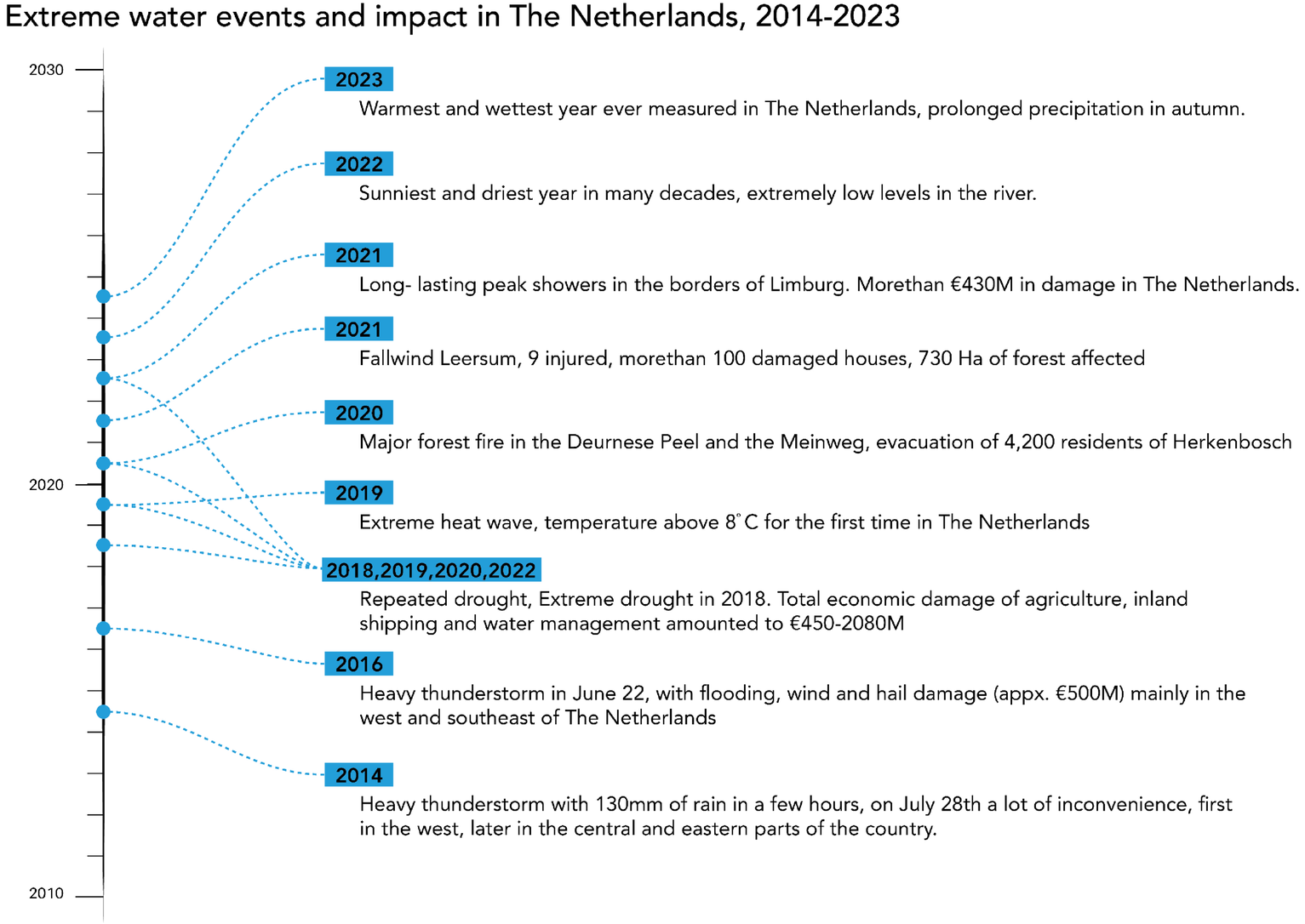


Fig 3.1: Extreme weather events and impact in the Netherlands
Source: KNMI

Source: KNMI; Eden et al 2018; Copernicus 2023; Otten et al. 2000

3.1.1 Excess case

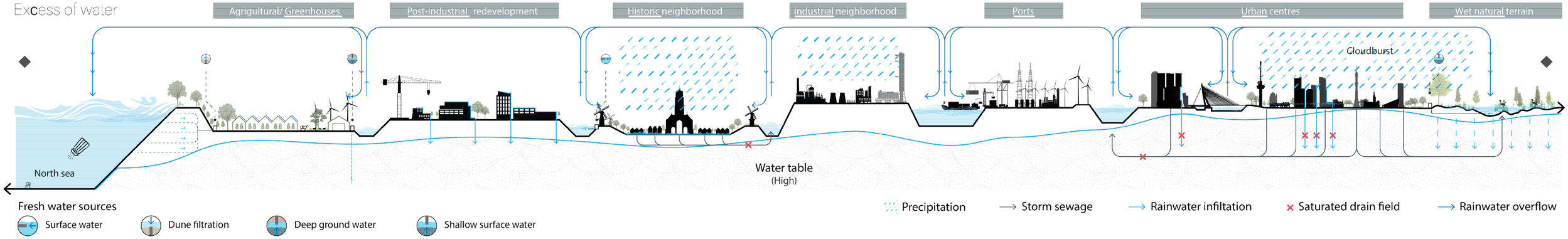


Fig 3.2: Excess case of water in a systemic section
Source: author

Excess case impacts

- Water safety
- Disrupts emergency services due to water logging in roads.
- Seepage of water into subsoil structures
- Storm water drainage into main water system
- Erosion of riparian zones and flood plains.

Physical effects include

- Water stagnation in cities and streets.
- Saturated drain fields
- High ground water levels
- Salination due to sea level raise
- Locking storm barriers which disrupts ship movement.
- Saturated wetlands

3.1.2 Exhaustion case

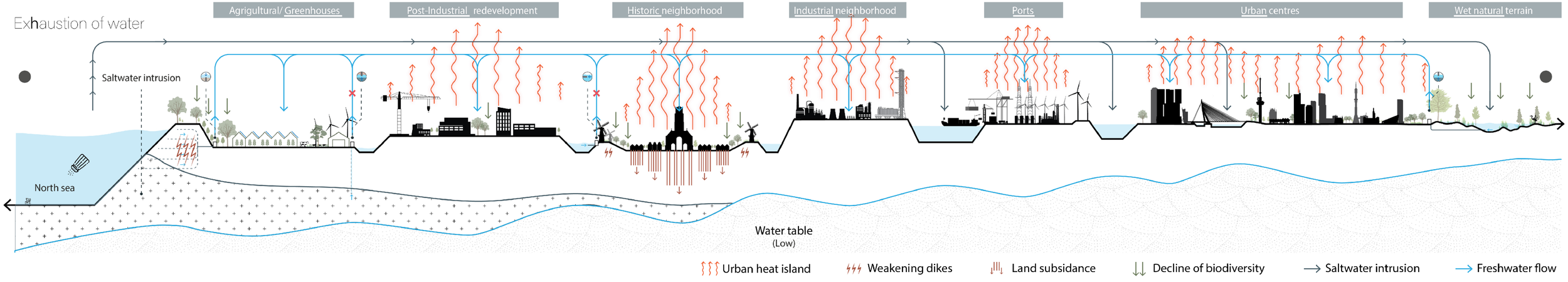


Fig 3.3: Exhaustion case of water in a systemic section
Source: author

Exhaustion case impacts

- Water quality
- Limiting drinking water, sources for extraction and concentrations of harmful substances.
- Salination
- Recreation
- Fish mortality, Closing fish passage
- Shipping, Longer waiting times at locks and less heavy loading.

Physical effects include

- Higher water temperature
- Salinisation of soil surface and water surface
- Low water levels
- Less soil moisture
- Low ground water levels
- Soil subsidence due to oxidation of peat and settlements and subsidence of clay

Natural damage (sometimes irreversible)

- Mortality and deterioration of flora and fauna
- Increasing risk of wildfire
- Drying streams due to low ground water levels

Infrastructure

- Cracks and subsidence of dikes, barriers and buildings.
- Pile rot due to low ground water levels
- Damage to green heritage

Agriculture and Industry

- Lower crop yields
- Irrigation bans on both surface and ground water
- Loss of production due to less intake for cooling water.

3.1.3 Exemption case

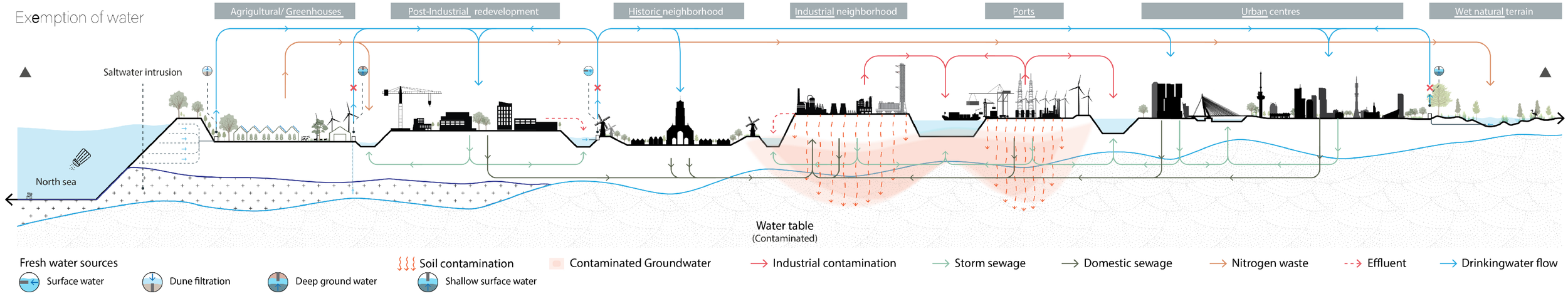


Fig 3.4: Exemption case of water in a systemic section
Source: author

Water quality

Drinking water companies, agriculture, fisheries, industry, nature and recreation need clean and healthy ground and surface water, both fresh and salt. **Ecological water quality** and **Chemical water quality** are equally essential for the region.

Weather and climate impact

- Salination causes salty surface water and salty ground water, this affects agriculture and disrupts fresh groundwater resources.
- Drought
- Waste water overflow by downpours

Industry

- Discharge of waste materials
- Water withdrawals
- Discharge of hot water

Agriculture

- Pesticides
- Nitrogen and phosphate from manure
- Extraction of surface and ground water for irrigation

Sewage treatment plant

- Remaining nitrogen and phosphate
- Water material such as drug residues

96%

Conclusion.

The superposition of intrinsic vulnerabilities for the complete urban extent in the Netherlands indicates that about **96% of the Dutch urban area** is susceptible to one or more climate hazards, with approximately **10% susceptible** (van Gaalen et al., 2024) to all four studied hazards which includes **heat stress, drought, water nuisance and flooding**.

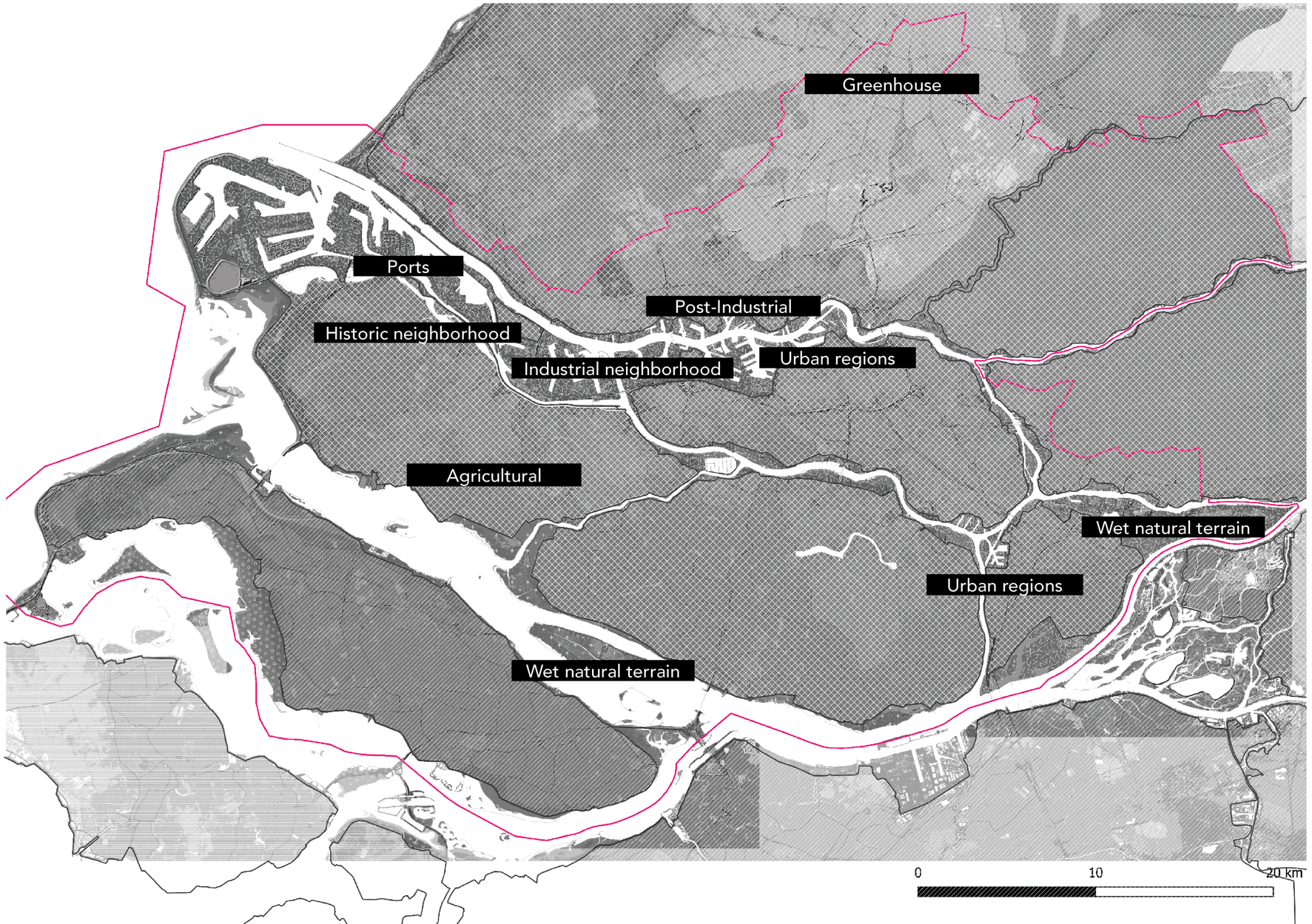


Fig 3.5: Characters of Rijnmond region
Source: author
Dataset: Klimaateffectatlas, AHN

3.2.1 Literature findings

Conceptual framework for the Dutch climate risk analysis 2022 – 2026

- The conceptual framework developed by the PBL (Netherlands Environmental Assessment Agency) is primarily structured for conducting the National Climate Risk Analysis (NCRA) 2022–2026, which aims to support the revision of the National Climate Adaptation Strategy (NAS) and Delta Decisions by providing insight into current and future climate risks (PBL 2024).
- The structured input for the revision of the National Climate Adaptation Strategy (NAS) and Delta Decisions in 2026, aiming to achieve a 'climate-proof and water-robust Netherlands in 2050' (PBL 2024) establishes a rigorous methodology, differing significantly from the previous 2014/2015 analysis, primarily by serving as a baseline measurement for structural risk analysis that is transparent, systematic, and repeatable, aligning with international standards such as ISO 14091.
- This analysis method assesses climate risk by examining four key elements: climate threats, exposure, sensitivity, and adaptive capacity. It identifies six categories of climate-related threats: increasing heat, rising precipitation, growing drought, other forms of extreme weather, rising sea levels, and ocean acidification. These threats include both long-term shifts in average climate conditions and changes in extreme events.
- Exposure, sensitivity, and adaptive capacity are influenced by existing adaptation policies as well as ongoing social and spatial developments. For the present-day assessment, the method evaluates the effects of all adaptation measures implemented up to 2022. For future risk assessments (for the years 2050, 2100, and 2150), the method considers not only what has already been implemented, but also the full set of current adaptation policies that were officially adopted, regulated, and funded by 2022.
- To explore future risks, the method applies two scenarios that combine climate change with social development trends: one scenario assumes a moderate increase in risk, and the other assumes a strong increase. Both scenarios are considered risk-enhancing because continued climate change is expected to worsen impacts over time. Without additional adaptation measures, these changes are projected to heighten overall climate risks.
- Finally, the methodology brings together all these elements to generate an assessment of both the probability and impact of each climate risk. It also acknowledges that cascading effects may intensify impacts or create new types of risks either within the same policy domain or across different sectors.

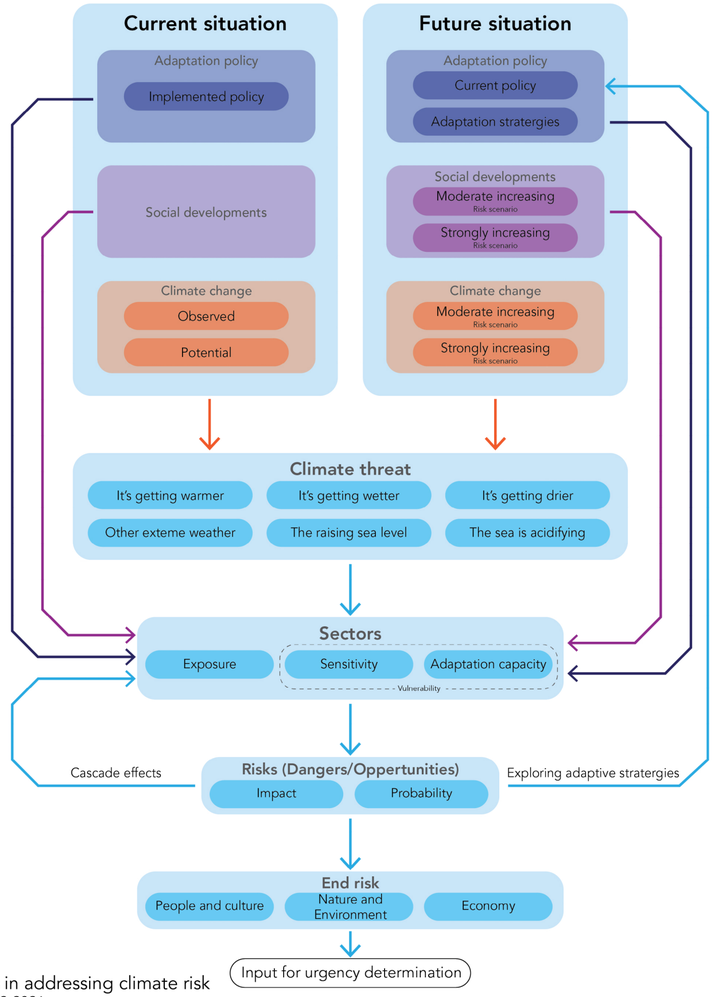


Fig 3.6: Conceptual frameworks in addressing climate risk
Source: Dutch climate risk analysis 2022-2026

- Mind map on principles widely mentioned in the documents The Netherlands in 2030 and 2050: two reference scenario on future exploration and prosperity and living environment (2015), Delta program 2024, NOVEX development perspective for port of Rotterdam (2023), PBL's The 2021 SSP Scenario of the image 3.2 model, National climate risk assessment 2022- 2026(2023), Climate risk in the Netherlands (2024) is drawn with key overarching principles to address climate change. These key principles include understanding urban system, categorizing vulnerability and impacts, strategies and implementations and assessment and tools. To understand, analyse, monitor and react to the developing climate risk.



Fig 3.7: Literature synthesis wheel for climate risks
Source: author

3.2.2 Literature synthesis

Challenges and Limitations of National climate risk assessment 2022-2026.

- While spatial variation is considered, the analysis faces limitations. The first climate risk analysis did not have a common methodology or collaboration between knowledge institutes during the sectoral studies, although it did use a common framework.

- The 2022-2026 analysis aims for a structured method and common conceptual frameworks and definitions. However, due to budget limitations, certain important sectors or risks for the Netherlands due to climate change abroad have not been included in detail in the current report (PBL 2024). The overseas areas of the Netherlands are also not yet included due to a lack of resources. There is also a need for more knowledge about how climate threats impact a specific sector and how a risk leads to an impact in concrete terms, including who bears the consequences. Knowledge about the dryness of buildings and the number of vulnerable objects is lacking.

- In summary, the climate vulnerability varies spatially across the Netherlands, driven by geography, socio-economic factors, existing infrastructure, and the adaptive capacity within those areas. The national climate risk analysis aims to account for this spatial differentiation and identify specific vulnerable locations or regions to inform adaptation policy.

- In the larger context of climate risks and adaptation, areas like the Rijnmond/Delta region are central to adaptation policy, particularly the Delta Programme, which focuses on water safety, freshwater supply, and spatial planning in specific areas, including the coast and large waters. Socio-economic and spatial developments, such as high population density, construction, and invested capital in low-lying parts of the Netherlands like the Rijnmond/Delta region, can exacerbate exposure and vulnerability to these water-related risks. The analysis of climate risks includes considering how exposure and vulnerability are developing, including in conjunction with other social or spatial developments. Low-lying, densely populated coastal areas in Europe, which description fits Rijnmond, are generally seen as particularly vulnerable to multiple climate risks.

Analysis of Vulnerable Areas in the Risk Assessment

The climate risk analysis 2022-2026 intends to include spatial variation where relevant. Knowledge institutes involved in the analysis are asked to explicitly describe the exposure, sensitivity, and adaptation capacity for examined climate risks, indicating how they are developing, including in conjunction with other social or spatial developments. Mapping out missing knowledge about exposure and vulnerability can reveal where uncertainties lie. Spatially differentiated climate data and maps are also used.

For some risks, spatial differentiation is highly relevant. This can involve creating '**exposure maps**' and overview maps that combine risky areas for a specific climate threat with the location of vital and vulnerable functions.

Specific Examples of Vulnerability in Areas

- **Buildings** are exposed when located in areas prone to water nuisance (Franken et al., 2023). Their vulnerability to flooding depends on sensitivity (e.g., how easily water flows in) and adaptation capacity. Older buildings or those in certain neighbourhoods may be less insulated, affecting their vulnerability to heat stress. Foundation damage due to drought is particularly reported in certain regions with soft soils or in the river area.

- **Nature in areas** can be vulnerable to heat, drought, and flooding, with risks for rare habitats and species. The resilience of nature in a specific area can be increased by reducing other pressures (Franken et al., 2023).

- **Roads and infrastructure** in lower-lying areas are vulnerable to flooding from heavy precipitation, leading to temporary inaccessibility.

3.3 Excess scenario

Extreme precipitation and flooding

- In the Netherlands, increased average rainfall and extreme rainfall events will lead to more water nuisance from pluvial flooding and high groundwater levels. Accumulated local pluvial flooding events can result in substantial aggregate damages, often underestimated.
- Increasing water depths due to climate change could lead to more damages for provinces like Zuid-Holland and Flevoland, the Northern coastal zone, and west of the IJssel lake.
- Industrial and commercial areas are more prone to coastal, fluvial, and pluvial flooding damage than residential areas due to higher direct and indirect damage potential. Infrastructure damages are a significant contributor to overall flood damages.
- Heavier summer storms due to climate change mean more pluvial flooding because sewage systems are not designed for such intensity.
- Extreme storms can cause increased damage to critical infrastructure such as oil rigs, high-voltage transmission lines, roads, bridges, and vehicles.
- The economic costs of extreme weather, storms, and floods are very high and are increasing. There is also an increased probability of surface water pollution from sewerage overflow after heavy rain.
- Flooding from extreme events is identified as a top risk for cities.
- Flooding can cause loss of life, homes, infrastructure damage, and negative economic impacts. It can also disrupt access to essential resources like food and energy.
- Physical dangers include drowning and injuries.
- Biological and chemical dangers arise from the spread of waterborne and vector borne diseases, and exposure to hazardous chemicals like heavy metals. Contaminated drinking water sources increase the risk of infection and disease.
- Flooding in dense urban areas can damage surrounding ecosystems due to the overflow of sewage systems carrying pollution into waterways.
- Regarding casualties, the potential number is largest in areas threatened by river floods with high water depths. More casualties are expected for larger coastal dike rings due to increasing water depths and flood extents. The 2021 Ahr valley flood, an unprecedented flash flood, resulted in 190 fatalities in Germany, largely due to extreme severity, underestimation of risk, and inadequate warning/evacuation; 75% of fatalities occurred outside mapped hazard zones. Particularly dangerous places were campsites, cellars, and basement flats, but many fatalities also occurred on the ground floor and outside in the street.
- In Rijnmond delta region, climate change scenarios cause concern as the frequency of extreme flood events shifts into more regular events, meaning moderate damages become more common.

3.4.1 Policies

Policies and Governing Authorities Implementing Interventions.

Various national policies and programmes, alongside the responsibilities of different governmental layers, guide and implement climate adaptation efforts in the Rhine-Meuse Delta and the Netherlands.

National Water Programme (Nationaal Water Programma 2022–2027)

- Describes the main lines of national water policy and its implementation, addressing major water challenges like climate change, flooding protection, robust freshwater supply, and water quality (MIWM*, 2022a) (MIWM*, 2022b).
- Climate adaptation is a new theme in this NWP, with policy and implementation further developed since the last planning period.
- The NWP connects with the National Environmental Vision (NOVI) and aligns with frameworks from the Water Act and Water Decree (RIVM).
- It contains weighing principles for water policy and management.

Delta Programme (Deltaprogramma)

- The Delta Programme is central to addressing the four major threats of climate change: **water nuisance, heat, drought, and flooding** (MIWM*, 2022a).
- It is supported by the Delta Act, which provides the legal framework for the Delta Programme, the Delta Commissioner, and the Delta Fund for multi-year financing of measures (MIWM*, 2022b).

A. Delta Plan for Spatial Adaptation

Aims for the Netherlands to be climate-proof and water-robust by 2050. Agreements for implementation are made based on stress tests and risk dialogues (MIWM*, 2022a).

B. Delta Programme Freshwater

Focuses on ensuring sufficient freshwater, even in dry periods, through joint realisation of measures (MIWM*, 2022a). It has strong overlaps with spatial adaptation to climate change (MIWM*, 2022a).

C. Integrated River Management Programme

Focuses on managing and developing the river area, including addressing the effects of climate change like greater extremes in river discharges and rising water temperatures (MIWM*, 2022b).

National Climate Adaptation Strategy.

- Adopted by the Dutch government in 2017. It outlines steps to adapt to climate change consequences.
- It provides additional impetus for integrating climate adaptation into policy across various sectors like agriculture, nature, infrastructure, health, and the built environment (MIWM*, 2022a).

Flood Risk Management Plan (Hoogwaterbeschermingspro-gramma):

- This plan incorporates climate change consequences, such as higher temperatures leading to sea level rise and higher peak discharges in rivers, to control flood risks in the long term (MIWM*, 2022b).
- It includes measures to maintain or improve discharge and storage capacity of regional waters (MIWM*, 2022b).

*(*MIWM=Ministry of Infrastructure and Water Management)*

3.4.2 Existing strategies

Implementation of the Delta Programme

This national programme involves municipalities, water boards, provinces, and the central government working together to make the Netherlands **water-robust and climate-proof** (NDP, 2023). The Delta Programme includes themes directly relevant to the Rijnmond region, such as **water safety** (specifically concerning flooding from the main water system, which includes the coast and large waters like those in the delta) (NDP, 2023), freshwater supply, and spatial planning to limit the consequences of flooding in urban and rural areas.

Structural and Substantial Investments in Primary Water Defences

There has been a tradition in the Netherlands of dealing with and adapting to water, which has led to investments in dikes and water-retaining structures to prevent floods (NDP, 2023). These **primary barriers** protect against water from the North Sea and major rivers. **The High Water Protection Programme (HWBP)** is in place to reinforce water defences that do not meet the legal standards. While substantial investments have reduced the overall probability of flooding from the main water system, a significant portion of these primary barriers, especially along major rivers and in the Zeeland delta (relevant to Rijnmond), do not currently meet the standard and require urgent improvement to reach the 2050 standards (NDP, 2023).

Operation of Large Flood Barriers

Specific to the Rijnmond delta region, large barriers are operated during high water events. The **Maeslantkering**, located in the Rhine-Meuse estuary, automatically closing for the first time during storm Pia, along with five other barriers (NDP, 2023). This is a concrete example of an action in effect to prevent flooding from the sea.

Implementation of Water Safety Standards

The Netherlands operates based on a system of standards for both the main water system and regional waters (NDP, 2023). New standards for water safety apply from 2017 and must be achieved by 2050. The ongoing assessment and reinforcement work under the HWBP are aimed at meeting these standards (NDP, 2023).

Layered Approach to Flood Risk Reduction

The approach to managing flood risk involves a layered strategy. This includes:

Prevention:
Measures to reduce the chance of flooding, such as structural defences (dikes) and making informed location choices for new construction (NDP, 2023).

Spatial Planning:
Measures to store/retain water, adapt infrastructure (NDP, 2023), and zone development away from flood-prone areas (NDP, 2023). For highly urbanised coastlines like Rijnmond, **dry-proofing buildings** is considered especially promising and cost-effective in existing urban areas (Ligtvoet et al., 2023).

Crisis Management:
Actions taken during or immediately after an event, such as warning systems, disaster plans, placing sandbags, and evacuation. Safety regions play a role in planning for climate incidents, including flooding (NDP, 2023).

Recovery:
Arranging for quick damage repair and return to normal life after a flood.

An underlying layer of water awareness among citizens and companies is also promoted (NDP, 2023)

Addressing Salinization

As the Rhine-Meuse estuary is susceptible to salinization, particularly at Hoek van Holland during low river discharges (Deltares, 2024), water management efforts are needed to manage this risk to freshwater availability.

*(*NDP=National Delta Program)*

3.4.2 Existing stratergies

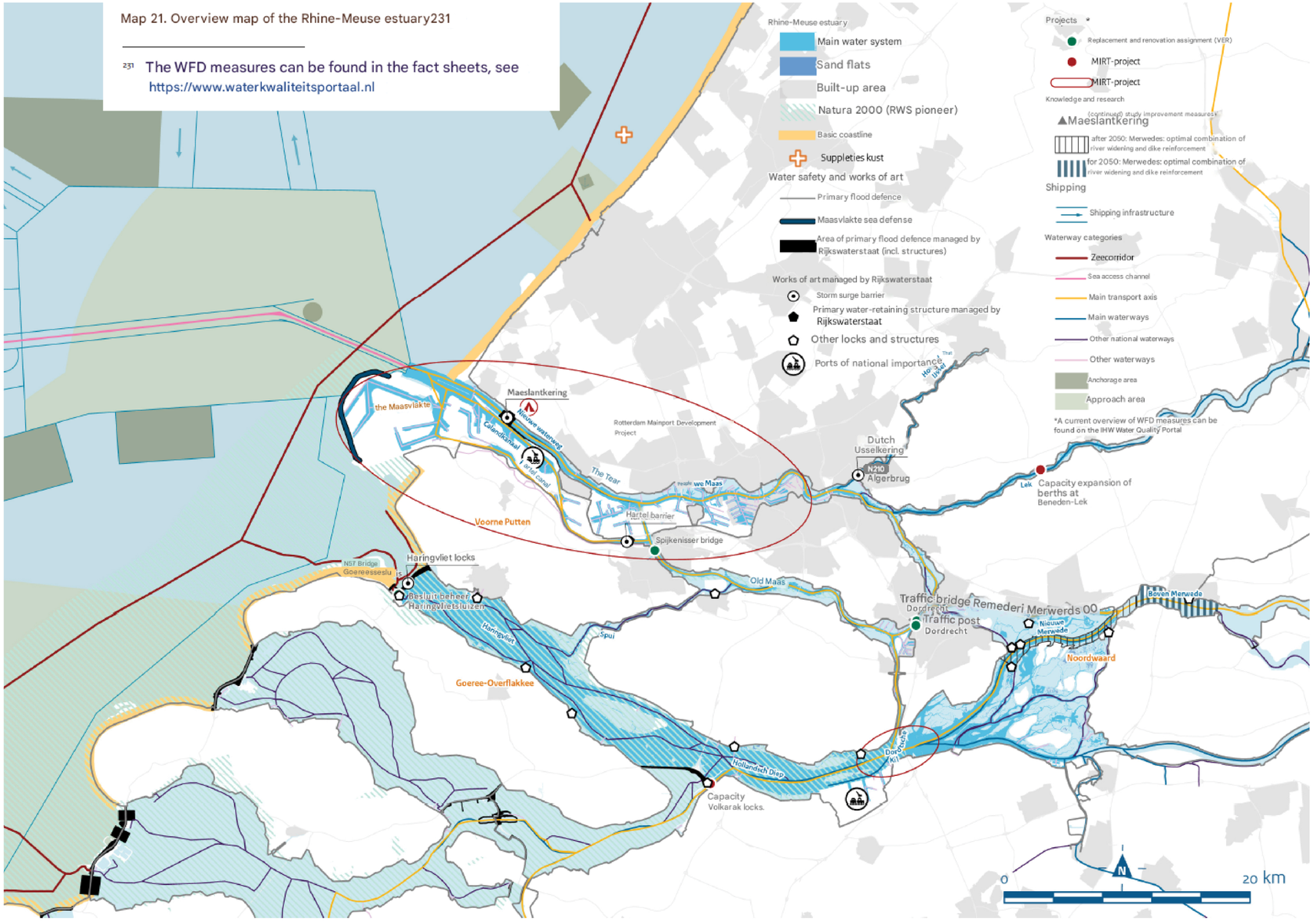


Fig 3.8: Overview map of the Rhine-Meuse estuary
Source: waterkwaliteitsportal.nl
Dataset: Klimaateffectatlas, AHN

3.4.3 Literature shortcomings

Shortcomings identified from policies addressing excess water scenario

Regarding Rising Sea Levels

Exacerbated by Subsidence:

The Netherlands, including low-lying coastal areas and deltas like South Holland, faces **subsidence that often exceeds the rate of sea level rise** (Ligtvoet et al., 2023). This subsidence is primarily caused by **groundwater abstraction for freshwater supply and critically exacerbates flood risk and salinisation of groundwater systems** (Ligtvoet et al., 2023)**.** The government recognises that while traditionally successful, there is a **limit to the current system** and it is becoming **more difficult to control the water**, with the sea level rising and increasing the chance of dike breaches in the long term (MIWM*, 2024a).

Impeded Natural Adaptation:

Deltas naturally adapt to sea level rise through sediment deposition from rivers. However, this process is now **hampered by reduced sediment supply** (due to factors like dams and sand mining) and **ongoing subsidence** (Ligtvoet et al., 2023). Current projects aiming to restore sediment deposition are minimal, covering only **0.1% of the global delta area** (Ligtvoet et al., 2023).

Approaching Critical Conditions:

The current rate of global sea level rise (3.6 mm/year) and projected increases may soon **exceed the 5-10 mm/year rate at which most deltas formed naturally**, potentially leading to c**ritical conditions for delta survival within the next 50 years** where natural adaptation methods **may no longer be sufficient** (Ligtvoet et al., 2023). The IPCC 2022 indicates **no signs of adequate response**s to these challenges, with deltas showing *highly alarming signs and all warning lights flashing red* (Ligtvoet et al., 2023).

Regarding Seepage/Stagnation due to Heavy Rainfall

Urban Vulnerability and Limited Storage:

Urban areas in the west of the country, which includes South Holland, are **particularly susceptible to acute flooding and water nuisance** from extreme precipitation due to **limited water storage capacity** (NDP, 2023)**.**

Reduced Soil Infiltration:

Prolonged drought leads to **dried-out soil, which has reduced infiltration capacity,** causing water to r**un off more quickly and increasing flooding** during heavy rainfall events (NDP, 2023).

Exceeded Drainage Capacity:

Extreme rainfall can **exceed the designed drainage capacity** of current sewerage systems, leading to problems such as **puddle formation**, and issues in tunnels and underground areas due to rising groundwater levels (NDP, 2023). The inadequacy of the system's design capacity is a common issue, alongside maintenance failures (NDP, 2023).

Aging Infrastructure:

Much of the sewerage infrastructure in residential areas, constructed in the second half of the previous century, is **approaching the end of its lifespan**, indicating a **major replacement task** is needed to address this vulnerability (MIWM*, 2024a).

Policy Implementation Delays:

Despite awareness, many adaptation measures for greater climate resilience **take time**, and choices need to be made now or in the short term to deal with increased climate risks, as measures with long lead times **threaten to not be realised** (NDP, 2023).

Regarding River Flooding:

Failure to Meet Dike Standards:

A significant portion of the water barriers along major rivers, including those in the Rhine-Meuse Delta, do not currently meet the established standards (NDP, 2023). A recent assessment (ILT 2023) shows that **62% of primary water barriers do not meet the legal standard** that must be achieved by 2050, and improvement is urgent for 26% of these, particularly in the river area. This means the **flood risk in adjacent areas is greater than intended in policy** (NDP, 2023)**.**

Erosion Due to Drainage Regime:

The current drainage regime of the Haringvliet sluices leads to **high water velocities and severe erosion** along river branches such as the Spui, Dordtse Kil, and Oude Maas, which in turn **undermines the stability of the dikes** (Paalvast & Van Der Velde, 2014)**.**

Increased Salinisation Risk:

Low river discharges, which are becoming more frequent, lead to **increased salinisation in the western Netherlands** (at the Rijnmond region) because less freshwater is available to push back seawater (MIWM*, 2024a).

Vulnerability of Riverine Cities:

Cities in the river area are particularly vulnerable to flooding (NDP, 2023).

Complex Interacting Risks:

There is a risk of **major flooding** when **enormous rainfall** causes the **regional water system to become overfull and saturated**, combined with **high water levels on the main water system**, at which point the region can no longer discharge water effectively (NDP, 2023).

Incomplete Risk Assessment:

Some important sectors, such as vital and vulnerable infrastructure (beyond drinking water and main transport networks), energy, ICT, and the recreational sector, are not fully elaborated in current climate risk reports due to a lack of capacity and budget, suggesting a **limited understanding of overall cascading impacts** (NDP, 2023)**.**

(NDP=National Delta Program)
*(*MIWM=Ministry of Infrastructure and Water Management)*

3.5 Responsibilities

Governing Authorities and Responsibilities:

The Government (Central):
Sets national policy, provides overarching guidance, allocates funds (e.g., via the Delta Fund), and ensures implementation of climate adaptation measures through action programmes. The Minister of Infrastructure and Water Management is the coordinating minister for climate adaptation.

Rijkswaterstaat:
Responsible for managing the main water system, the main waterway network, and state-managed water safety infrastructure like dikes and storm surge barriers. They conduct stress tests, risk dialogues, and implement measures for national vital functions (e.g., drinking water, energy supply) and their own networks.

Provinces:
Responsible for translating national policy into a regional policy framework and strategic goals. They also have tasks for part of groundwater management and designate regional flood defences.

Water Boards:
Key partners in water management, responsible for integrating climate adaptation into their policies, making their assets climate-proof, managing regional waters, and part of groundwater management.

Municipalities:
Responsible for integrating the climate adaptation challenge into their own policies and making their urban and regional water systems climate-proof.

Delta Commissioner:
Advises the government on the programming of measures within the Delta Programme.

KNMI (Royal Netherlands Meteorological Institute), Landelijk Informatiesysteem Water en Overstromingen (LIWO) :
Provides new climate scenarios and climate signals that show the urgency of climate change and water logging.

International Bodies:
International River Commissions (Rhine, Meuse, Scheldt, Ems) and the European Commission (Europese Richtlijn Overstromingsrisico) are involved in cross-border climate adaptation strategies and cooperation.

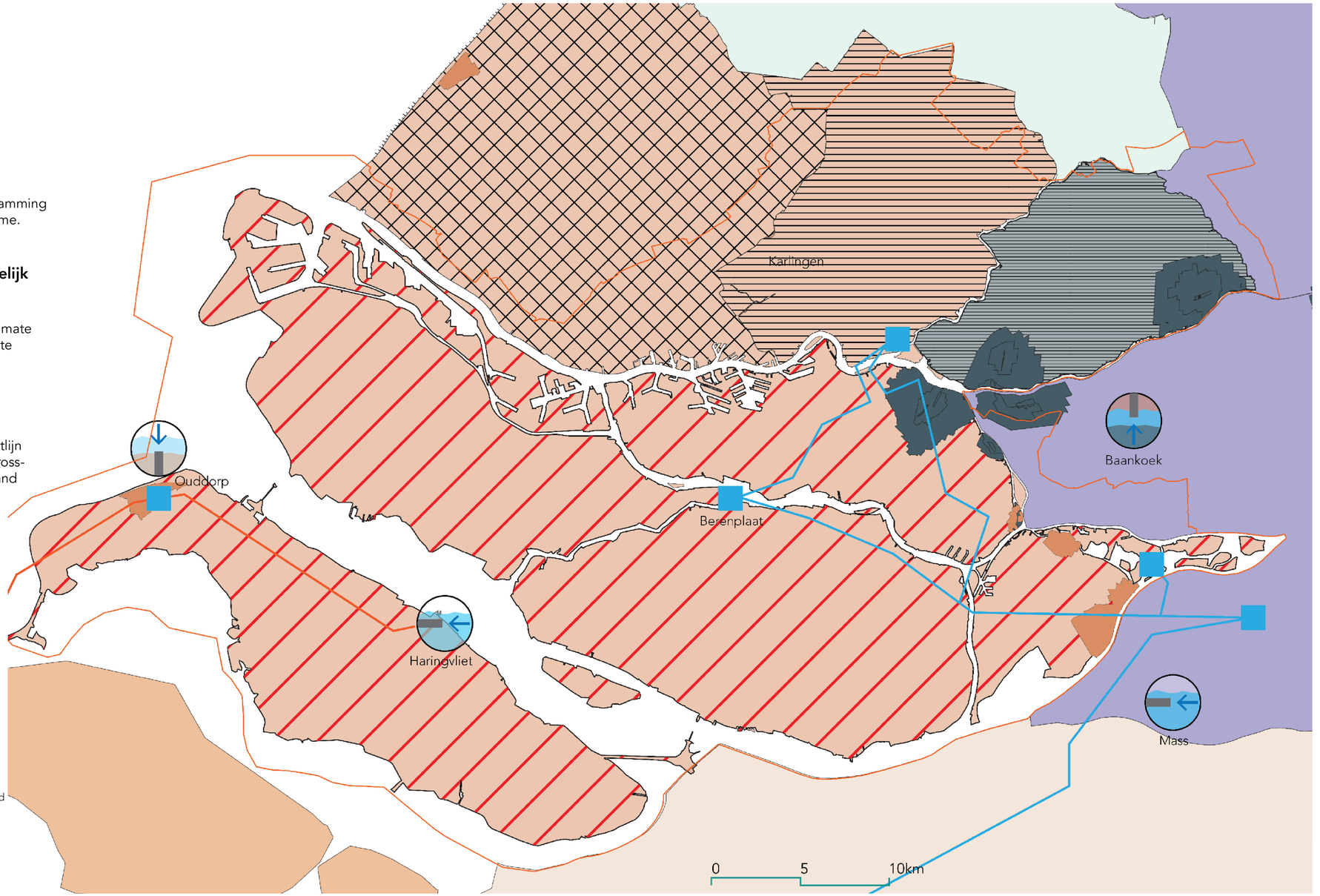


Fig 3.9: Map showing the boundaries of responsibilities of water region
Source: author
Dataset: PDOK

3.6 Problem statement

Problem statement

The rise of global warming has increased the frequency of extreme natural calamities in recent years across the globe. Record-breaking heat waves on land and in the ocean, drenching rains, severe floods, years-long droughts, extreme wildfires, and widespread flooding during hurricanes are all becoming more frequent and more intense. (NASA, 2021) Water is one element that plays a key role in all of these extremities, it influences Heat extremities, Wildfire, Drought, Tropical cyclones, Heavy precipitation, Floods, High-tide flooding and Marine Heatwaves. Natural hazards are deeply intertwined, and if managed separately, can feed off each other to drive more extreme damage. That's because the climate crisis acts as a **threat multiplier**. Drought may parch vegetation, increasing the amount of tinder available to spark wildfire, which incinerates a forested area, releasing CO2 and further increasing the climate crisis in a negative feedback loop. (Vernick D, 2024). The frequency of these extreme climate scenarios is increasing over the years; this brings the urgency to focus on climate resilience alongside disaster resilience. The disaster resilience would involve vulnerability framework and strategies to enhance its spatial condition of a region.

Contextualizing this problem in a geographical location such as The Netherlands were the Policies, strategies and vision plans were made under meticulous research, outlies and ground reality. By 2035, the goal was to enhance the urban quality of life and increase water resilience through green roofs, water retention squares, and even floating urbanization. (De Graaf, R. E., 2009). The Rijnmond region, along with the broader Netherlands, faces significant and complex water challenges that are expected to increase in the future, primarily due to climate change. Adapting to these changes is a crucial, cross-cutting task that affects many policy areas and sectors. The ambition is for the Netherlands to be **climate-proof and water-robust by 2050**. Critical Aspects of climate change in the delta region include increasing water levels from the ocean, increasing water levels from rivers (High River discharge), Water logging due to heavy rainfall, groundwater issues and freshwater shortages

Water safety, water quantity and water quality are prime elements to focus on in these contexts. Additionally, climate change intensifies these effects which we are not prepared for. Aging Infrastructure which are critical to the main water system and waterway network are over 50 years old and require replacement or they don't meet the operational requirement in the predicted future. A recent assessment (ILT 2023) shows that **62% of primary water barriers** do not meet the legal standard that must be achieved by 2050, and improvement is urgent for 26% of these, particularly in the river area. Even proactive countries like the Netherlands are **vulnerable to complex risks** and unexpected events (black swans). This makes it essential for regions such as the Rijnmond delta to adopt an integrated, place-specific approach that allows for a deeper understanding of these challenges and develop an effective strategy to address them.

Research aim

- The aim of this reseatch is to understand the system that is in place to address delta landscape against increasing climate risks through scales in Rijnmond region
- Analyse threshold capacity, coping capacity, recovery capacity and adaptive capacity of the region with current climate extremities and look for shortcoming in the system
- To propose a strategic framework that maximises and utilises delta landscape across scales
- To identify regions/ regions which have an effect on overlapping across timeline and look through extreme scenarios and design on spatial realm.

How can **systemic transition** in Rijnmond region, incorporate a **disaster resilience**, **future proof region** which **enhances livability** while addressing effects of **developing climate risks**, resulting in **excess water** in the region?

4 Methodology

This chapter outlines the methodological approach adopted for the graduation project. It presents the scientific rationale behind the selected methods and frameworks and explains how they collectively structure and guide the research process.

4.1 Introduction
4.2 Research framework
4.3 Conceptual framework
4.4 Methods
4.5 Research Timeline

4.1 Introduction

Problem field
Climate adaptation, Flooding protection, Delta landscape, Climate vulnerability

Key words
Climate proof, Tidal cities, Systemic transition, Living with water, Spatial planning, Rhine archipelago

Location
The Netherlands - Rijnmond region

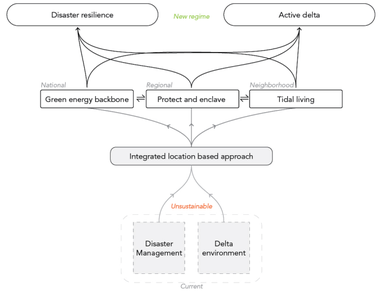
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Research Question
How can systemic transition in Rijnmond region, incorporate a disaster resilience, future proof region which enhances livability while addressing effects of developing climate risks, resulting in excess water in the region?

Research approach
Integrated location based approach

Conceptual framework

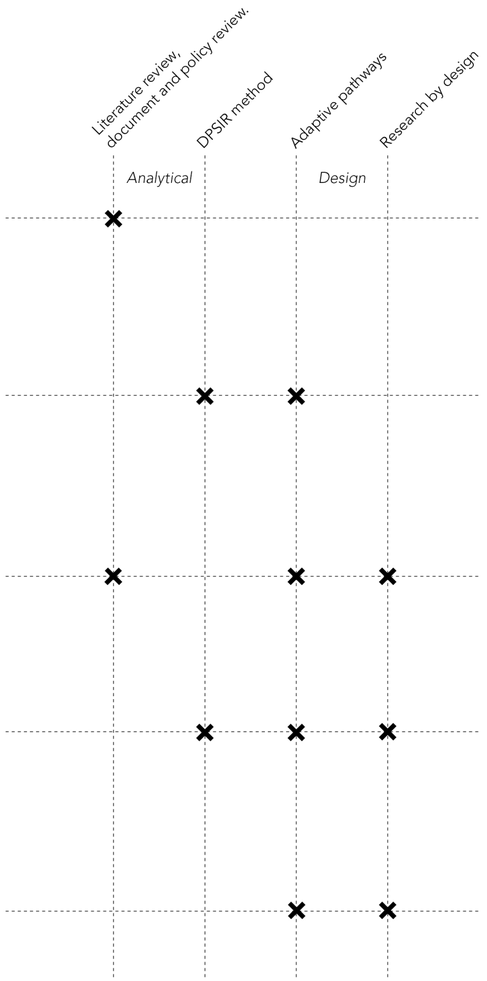


Methods
Literature review, Document and policy review, DPSIR method, Adaptive pathway planning , Research through design

Outcomes
Regional strategy, Non-conflicting pathway trends, New tidal regime, Tidal urban development

4.2 Research framework

Main research question		Sub research question	Methods	Expected outcomes
How can **systemic transition** in Rijnmond region, incorporate a **disaster resilience, future proof** region which **enhances livability** while addressing effects of **developing climate risks**, resulting in **excess water** in the region?	*SRQ. 01,05*	*SRQ.01:* Which existing systems are designed to protect the region from excess water, what are their limitations and lifespan?	Literature review, document and policy review	Understanding of the system and region through predicted scenarios and climate forecast, this helps formulates the analytical and design framework through addressing its flaws.
	SRQ. 03,04	*SRQ.02:* How does the climate risk pose a threat to the spatial environment and what are their critical pressure points?	DPSIR method, Adaptive pathways	Critical points of the region which has a huge impact on the system and the region
	SRQ. 02	*SRQ.03:* What are the innovations and future trends which will help us achieve disaster resilience and future proof region that can be incorporated into the current transition?	Literature review, document and policy review Adaptive pathways, Research by design	Understanding of current trends through policy and spacialise them
		SRQ.04: How are the pathways that enhances livability while ensuring water defense, enrich delta and align with sustainable energy transition configure?	DPSIR method, Adaptive pathways, Research by design	Adaptive pathways that help us achieve disaster resilience and future proof regions
		SRQ.05: How can these pathways transform the region and how can coexist?	Adaptive pathways, Research by design	Zoom-in(s) which show how Non- conflicting pathway trends end up on human scale



4.3 Conceptual framework

Project mainly revolves on addressing disaster in the delta region. This has been achieved by understanding the existing strategies which include **critical infrastructures** in the form of **hard defenses, dunes and wetlands** in some regions. While we strategies for climate change, the current delta is artificially engineered to cater humans (Urban needs and industries) backed by energy infrastructure which runs on non-renewable resources. The strategies for disaster management and how we treat delta are leading to an unsustainable path. In this project, using an integrated location-based approach, using different methods for different scales addressing the whole system helps us achieve a new regime which has **green energy backbone** on a national level, **protect and enclave** on regional level and **tidal living** on neighborhood level achieves **Disaster resilient and Active delta** in the Rijnmond region.

Active delta has attributes such as **open estuary, tidal buffers and green port** making Biodiverse at the same time economically viable for the region. **Climate buffers** and **Natural infrastructure** hold the region resilient to water-based disasters. Dunes, wetlands and swamps are critical natural infrastructures while marshes, riparian zones and flood plains acts as climate buffer in the delta region.

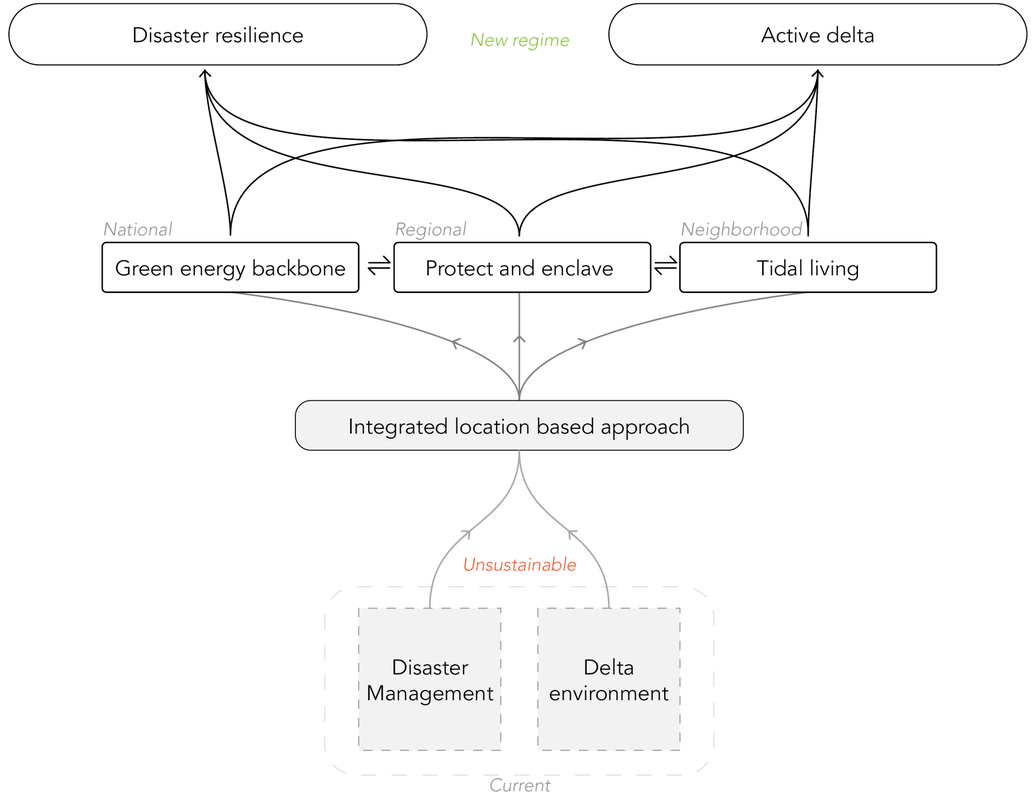


Fig 4.1: Conceptula framework
Source: author

4.5 Methods

Literature review, document and Policy review/analysis

- The literature review entails a critical examination of scholarly articles, books, official reports, and academic publications to build a theoretical and contextual foundation for the research. This process allows for a comprehensive understanding of existing knowledge, perspectives, and findings relevant to the topic. It plays a crucial role in shaping the research problem, identifying knowledge gaps, and guiding the direction of the study. Given the research's reliance on complex systems theories such as complex adaptive systems and assemblage theory to analyse cities and regions, the review is instrumental in establishing a robust conceptual framework.

Documents and policy review

- This method involves an in-depth analysis of key spatial planning documents and policy instruments at both regional and national levels. Various governmental bodies have produced strategic plans, climate risk assessments, environmental policies, and disaster management frameworks. These are evaluated critically to assess the trajectory of urban development, uncover institutional constraints, and identify potential inconsistencies, overlaps, or limitations within current policy approaches.

DPSIR method

- This approach is valuable for interpreting and visualizing the physical characteristics of a geographical region. It conceptualizes space as either continuous or discrete, but acknowledges that spatial reality is multifaceted, requiring complex modelling to capture its full range of dimensions.

- By understanding the Driver, Pressure, State, Impact and Response of a certain geological location under the lens of developing climate risks helps un narrow down to key regions and bottlenecks that have a bigger impact in the region.

- DPSIR method spatializes the problem statement and gives us a preliminary response to understand where the research could focus and multi-scalar mapping techniques help pin aspects of the project to be later intervened. This offers both vertical (sectoral or institutional) and horizontal (geographical or jurisdictional) perspectives of planning. Spatial mapping specifically aids in understanding how different phenomena interact across scales, revealing connections between Drivers, pressures, and Impacts.

- Ultimately, this method supports a deeper understanding of spatial planning and urban development in relation to climate adaptation, offering a multidisciplinary lens through which to read the landscape.

Adaptive pathways

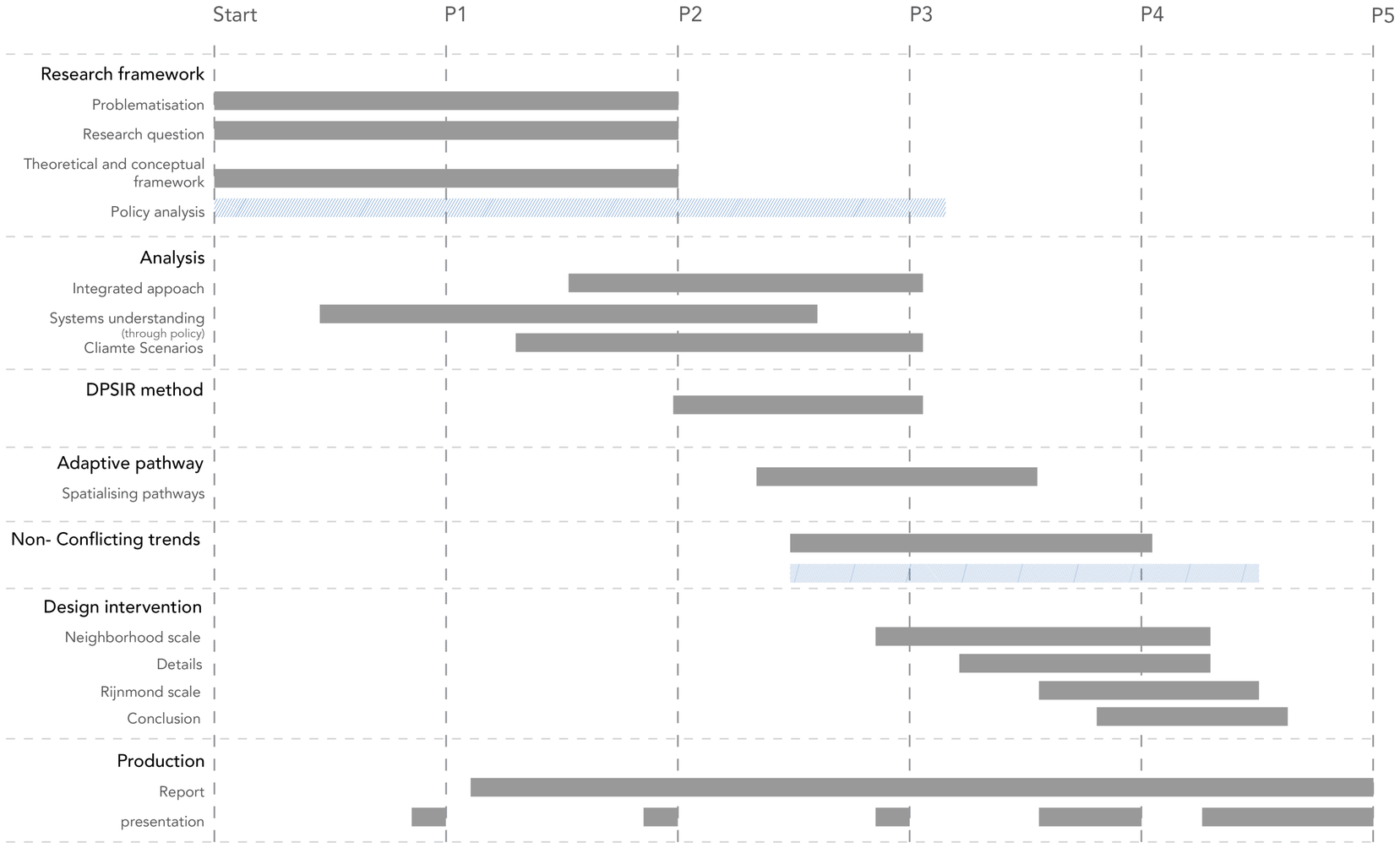
- Adaptive pathway planning method is used in situations dealing with climate change, they come with deep uncertainty and this method is predominantly useful for decisions or plans that "have a long-term (multidecadal) lifespan or long societal impact," that "experience ongoing progression of impacts," and those that "are surrounded by uncertainties and can have a large impact" or "have the potential for path-dependencies to emerge" (Haasnoot et al., 2024). By using this method decision making under deep uncertainty (DMUD) is achieved through pathway planning. Combining the current trends as variables for the pathway configuration and aligning the timeline with predicted climate trends, a pathway configuration is achieved.

- This pathway configuration could be focused on favoured pathways which achieve the project goals. Identifying limits to current and future adaptation strategies "can illuminate the need for transformative adaptation, if the system is sufficiently stressed against changing conditions (e.g. low-likelihood or longer time horizon)" (Haasnoot et al., 2020; van Alphen et al., 2022). The challenge then would be to either follow one preferred pathway and develop a spatial strategy for the region or to combine all the preferred pathways towards a non- conflicting pathway trend and develop the spatial strategy.

Research by/ through design

- Research through design applies design thinking as a tool to investigate the potential of a given context by formulating and testing solutions to identify challenges. This structured approach aids in uncovering the root causes of complex issues. It is a pragmatic, goal-driven method that emphasizes the feasibility and applicability of strategies. In this research, the approach is used to experiment with spatial patterns drawn from both theoretical and historic backing while exploration on spatial planning helps to achieve the design outcome for the region.

4.5 Research timeline



5 Analysis

This chapter examines the regional context through an analysis of historical development, infrastructure systems, networks, and policy frameworks. Geological conditions, climate projections, and the DPSIR method are employed to deepen contextual understanding and to further refine the research focus.

5.1 History
5.2 Spatial form
5.3 Critical infrastructure
5.4 Protected areas
5.5 Climate scenarios
5.6 DPSIR method
5.7 Method focus

5.1 History

The Rhine delta initially developed around the Maasmond as a predominantly river-dominated (fluvial) delta. Around 1000 AD, increased sand deposition from the North Sea gradually altered the delta's dynamics, shifting it toward a tide dominated system. This transition resulted in the formation of an estuarine environment influenced by both fluvial and tidal processes. The accumulation of marine sediments led to the development of extensive dune systems along the Dutch coast, extending as far as Hoek van Holland. These dune deposits played a decisive role in shaping the present-day coastline of the Netherlands (Zagwijn, 1991).

The resulting open estuary was characterized by rich estuarine landscapes and fertile lands, supporting diverse ecological systems and human settlement. However, from the late nineteenth century onward, increasing human intervention and large-scale hydrological engineering significantly transformed the delta. One of the most influential modifications was the straightening of the Nieuwe Maas, which reduced sediment deposition along the riverbanks. At the time, this change was not perceived as problematic, as the delta was primarily valued for trade and transport functions. Consequently, port infrastructure expanded along the waterways, extending toward the North Sea and reinforcing the delta's role as a logistical and economic hub.

Today, the Rhine delta is consid
one of the most heavily engineered de
the world. While extensive hydraulic w
and flood defense systems have succe
mitigated the risks associated with risi
levels, they have also led to the degra
and loss of ecosystems that were intrir
linked to the natural dynamics of the c
In context, dikes and coastal dunes for
backbone of flood protection against l
riverine and marine water levels, unde
the continued reliance on engineered
in managing the delta landscape.

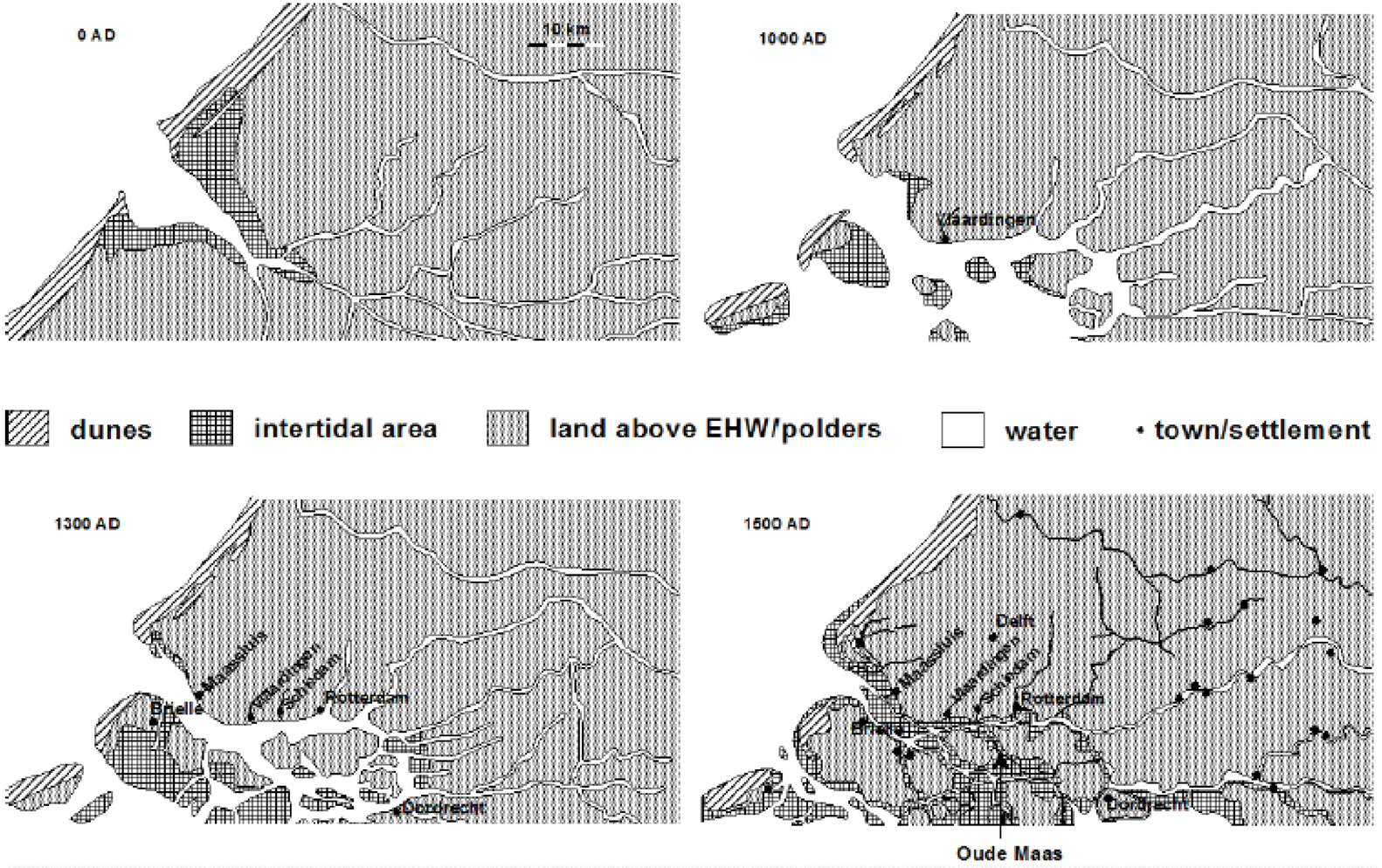


Fig 5.1: Geomorphological changes at the mean low water level in the Massmond
Source: Zagwijn, 1991

5.2 Spatial form

Rijnmond region

The Rijnmond (translation: Mouth of River Rhine), located near the confluence of the Rhine and Meuse rivers in the Netherlands. The Rijnmond region, encompassing the city of Rotterdam and its surrounding areas, exhibits several characteristics that foster urbanisation, economic activity, and ecological diversity.

Strategic Geographical Location

Situated at the mouth of the Rhine River, Rijnmond serves as a critical juncture between major European inland waterways and the North Sea. This advantageous position has historically facilitated trade and transportation, contributing to significant urban and economic development.

Powerful Economic Infrastructure

The presence of the Port of Rotterdam, one of the world's largest and busiest ports, anchors the region's economy. The port's extensive facilities and global connectivity attract diverse industries, including logistics, manufacturing, and services, thereby promoting urbanization and economic growth. (Heijman et al., 2017)

Comprehensive Transportation Network

An extensive network of roads, railways, and waterways enhances the region's accessibility and connectivity. This infrastructure supports efficient movement of goods and people, further stimulating economic activities and urban expansion. Commitment to Environmental Management Despite its industrial prominence, Rijnmond has implemented policies aimed at balancing economic development with ecological preservation. Initiatives to monitor and manage air quality, noise pollution, and green spaces contribute to maintaining ecological diversity and residents' quality of life. (Kruize et al., 2007)

Diverse Natural Habitats

The confluence of riverine, estuarine, and marine environments in Rijnmond creates a mosaic of habitats that support a wide range of flora and fauna. Efforts to protect and integrate these natural areas within urban settings enhances biodiversity and offer recreational opportunities for inhabitants.

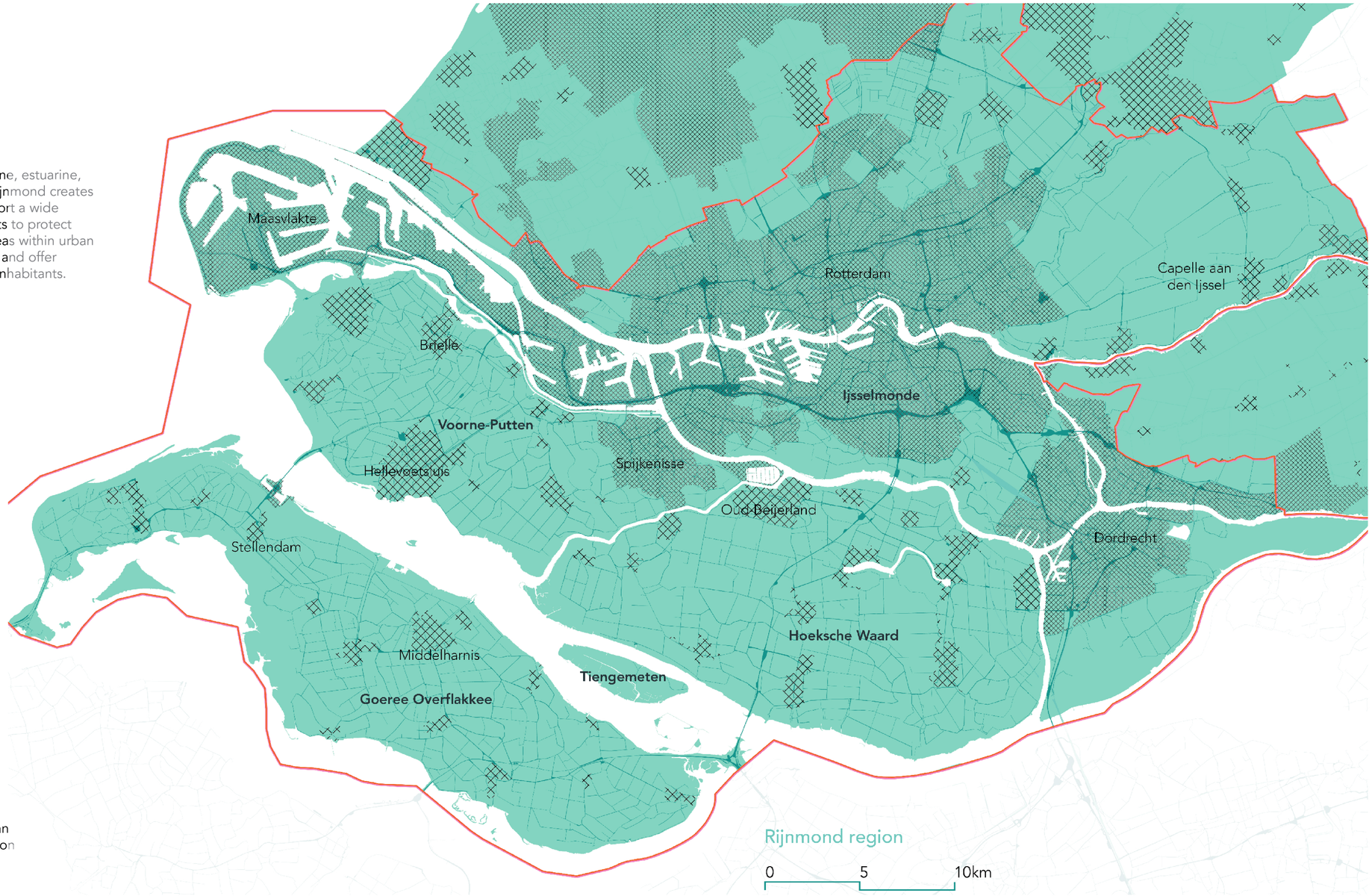


Fig 5.2: Map showing the urban regions of Rijnmond delta region
Source: author

5.3 Critical infrastructure

Primary Flood Protection and Storm Surge Barriers

The delta is protected by a complex system of primary water barriers, which include more than 1,500 kilometres of dikes, dams, and dunes designed to withstand high water from the North Sea and major rivers (Ministry of Infrastructure and Water Management, 2024a).

Storm Surge Barriers: The Maeslantkering and Hartelkering are the most important structures for the safety of the Rotterdam port area, acting as the final line of defence against sea-level surges.

Haringvliet Sluices: This part of the Delta Works controls the hydrology of the entire Rijnmond area. The sluices discharge river water at slack tide and close during flood tide to protect the southwest of the Netherlands from storm surges (van Gaalen et al., 2024).

Dike Systems: A significant portion of the primary barriers along the major rivers do not currently meet the required safety standards, making their reinforcement a critical ongoing task to prevent catastrophic flooding of the hinterland (van Gaalen et al., 2024).

Transport and Mobility Networks

Railway Infrastructure: The track, embankments, and electrical installations are vulnerable to track spalling (rails buckling due to heat), which can cause derailments or bring the network to a standstill (van Gaalen et al., 2024).

Main Waterway Network: The large navigable rivers (Rhine and Meuse) are essential for inland shipping. During extreme drought, reduced navigation depth leads to loading restrictions and significant economic losses for the logistics chain (van Gaalen et al., 2024).

Road Network: National roads utilize Very Open Asphalt Concrete (ZOAB) to improve drainage during heavy showers, yet sunken sections and tunnel entries remain at risk of flooding (van Gaalen et al., 2024).

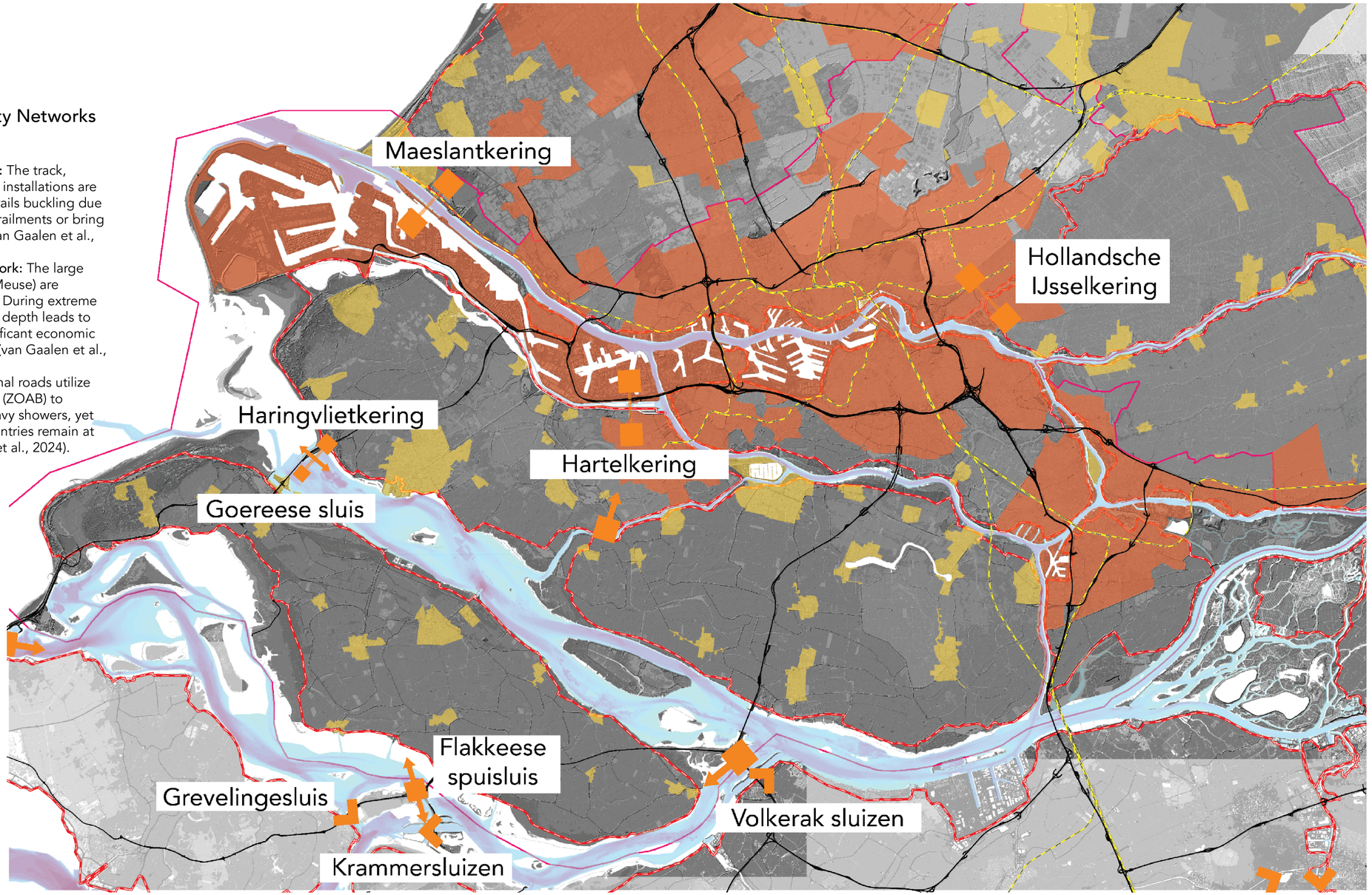


Fig 5.3: Map of critical infrastructure of Rijnmond delta region
Source: author
Dataset: PDOK

5.4 Protected areas

Ecological Resilience: Natura 2000 and NNN

Nature reserves in the Rijnmond area, such as the Voordelta and North Sea coastal zones, are essential for biodiversity but are under significant pressure (Franken et al., 2023).

Nature-Based Solutions (NBS): Healthy ecosystems act as a "sponge," providing natural water storage to mitigate flooding and a cooling effect to counter urban heat islands (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties & Ministerie van Infrastructuur en Waterstaat, 2023).

Climate Buffers: The Programmatic Approach to Large Waters (PAGW) focuses on creating ecologically healthy and future-proof systems in the South-Western Delta to ensure nature can "withstand a blow" (Ministry of Infrastructure and Water Management, 2024a).

Drinking Water Protection Areas

Protecting these zones is a vital process for national security, especially as Rijnmond faces increasing external salinisation.

Security of Supply: Approximately 60% of Dutch drinking water is extracted from groundwater. In dry periods, surface water becomes riskier due to higher concentrations of pollutants and salt intrusion at Hoek van Holland (van Gaalen et al., 2024).

Inner-City Heritage Areas

The Rijnmond delta contains significant built and archaeological heritage in cities like Rotterdam, Schiedam, and Vlaardingen that face unique climate threats.

The protected areas of the Rijnmond delta are crucial because they serve as the "Hull and Heart" of the region. They are not merely passive landscapes but active infrastructure: NNN and Natura 2000 areas function as a protective hull that absorbs environmental shocks; Drinking Water areas are the heart, ensuring basic survival; and Heritage and Geological zones provide the essential structural memory and skeletal stability of the delta (van Gaalen et al., 2024). Failure to protect these zones would trigger a cascade of failures, leading to irreversible cultural loss, structural collapse of the built environment, and the total exhaustion of the region's natural resilience.

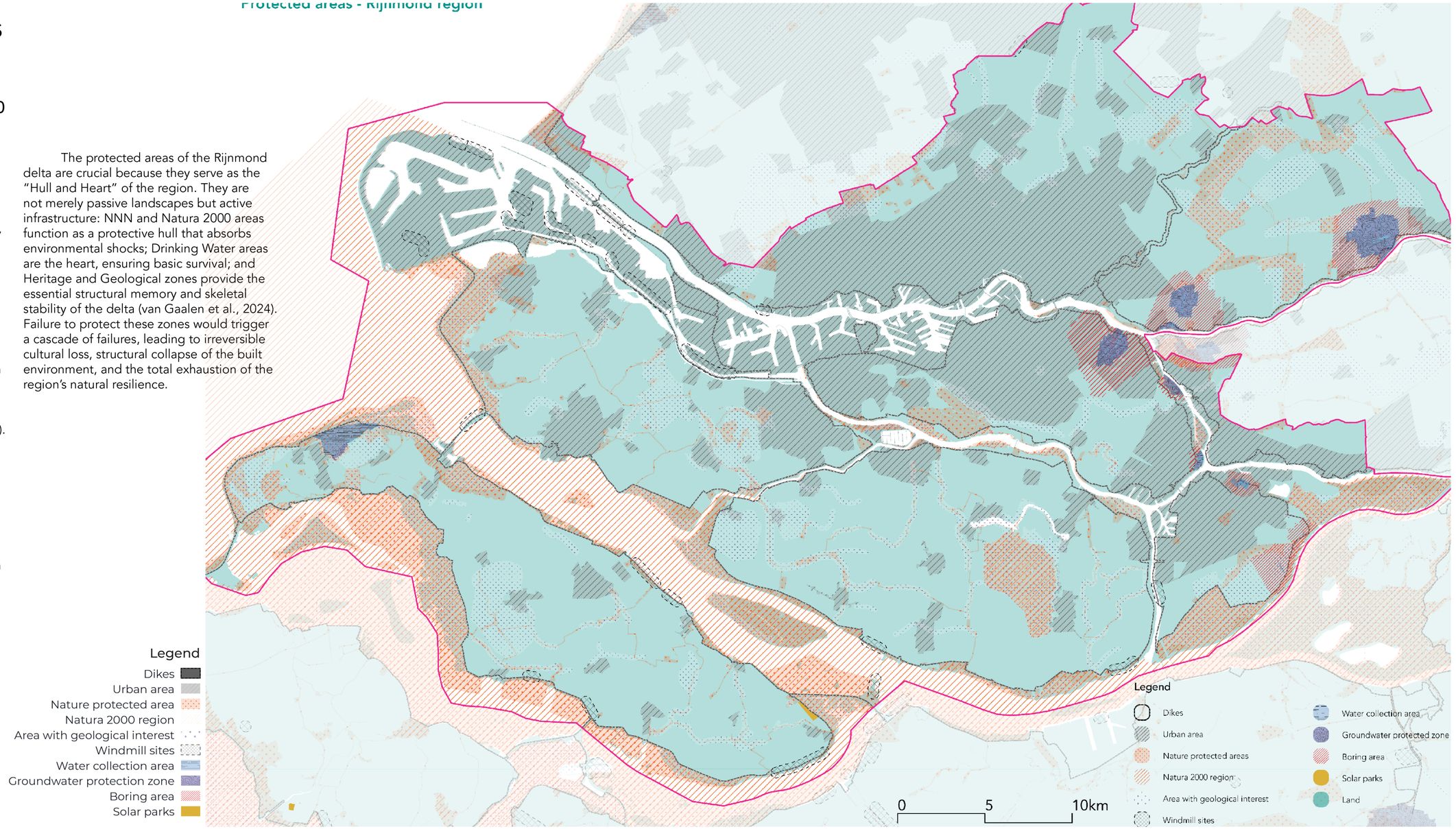


Fig 5.4: Map of protected areas of Rijnmond delta region
Source: author
Dataset: PDOK

5.5 Climate scenarios

Flooding from the Sea, Large Rivers, and Lakes

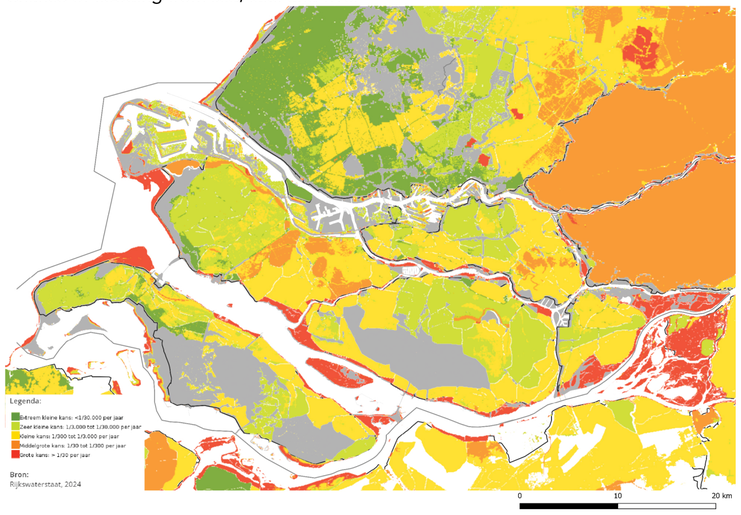
Scenario:

Flooding occurs when coastal defenses, rivers, or large lakes break or overflow (NDP 2024). The risk of flooding from the main water system (sea, large rivers, large lakes) has a very high potential impact, affecting hundreds of thousands of people and causing billions in economic damage (NDP, 2023).

Spatial Influence:

Approximately 50% of the Netherlands can be flooded by surface water (NDP, 2023). The Rijnmond/Delta region is part of the area exposed to these risks due to its location near the coast and major rivers like the Rhine and Meuse. While substantial investments in dikes and water-retaining structures have reduced the probability of flooding from the main water system, a significant portion of primary water barriers, especially in the river area, do not currently meet the legal standard, making the adjacent areas more vulnerable than intended by policy (NDP, 2023). The flood risk in the Rhine-Meuse estuary (within Rijnmond) is specifically mentioned as being determined by river discharge, wind (direction and speed), storm surge, and sea level rise (NDP, 2023).

Chance of flooding from sea, lake and river



Type of flooding

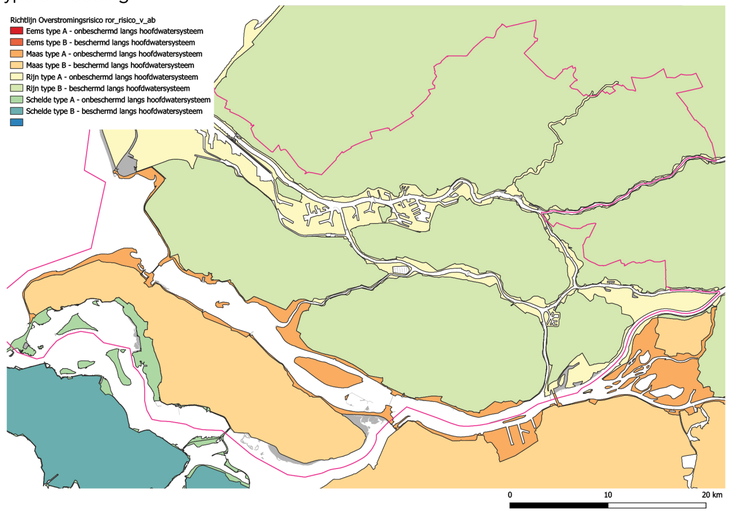
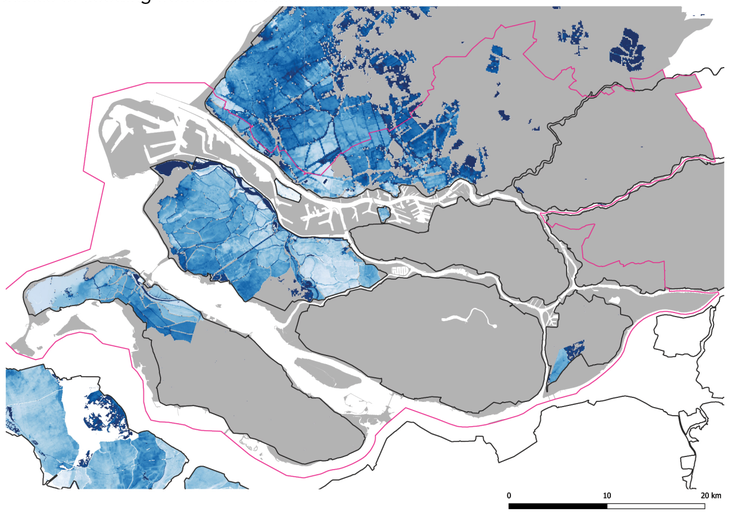


Fig 5.5:(top) Map of flooding prediction
Source: Rijswaterstraat

Fig 5.6:(bottom) Map showing the type of flooding in Rijnmond delta region
Source: KNMI

Climate scenario maps from Rijkswaterstaat and KNMI and PBL demotes how vulnerable the Rijnmond region is susceptible to fatal disasters once the existing systems fail to protect the region

Chance of flooding from coastal dike break



Chance of flooding from river dike break

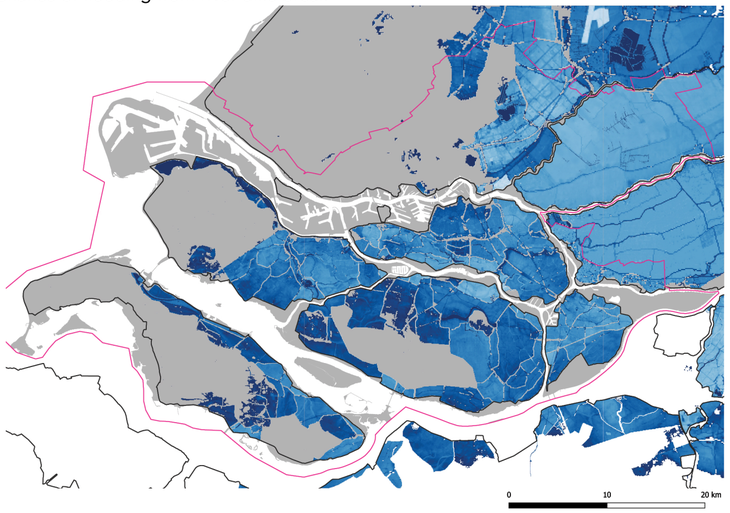


Fig 5.7:(top) Map showing change of flooding in case of coastal dike breachin Rijnmond delta region
Source: KNMI

Fig 5.8:(bottom) Map showing chances of flooding in case of river dike breach in Rijnmond delta region
Source: KNMI

5.6 DPSIR method

Driver, Pressure, State, Impact and Response

Driver:

Main drivers of the port of Rotterdam include industrial needs, growing cities, sinking neighborhoods and climate factors such as sea level rise, seasonal river flooding and increasing salination, posing a threat to underground freshwater reserve

State:

Rijnmond region as previously explained is formed and managed by human intervention. Each river branch and curve is factored by humans to cater to the efficient functioning of the region. The region is densely populated, heavily industrialised but also is protected thought some regulations to have balance between built-up and natural areas.

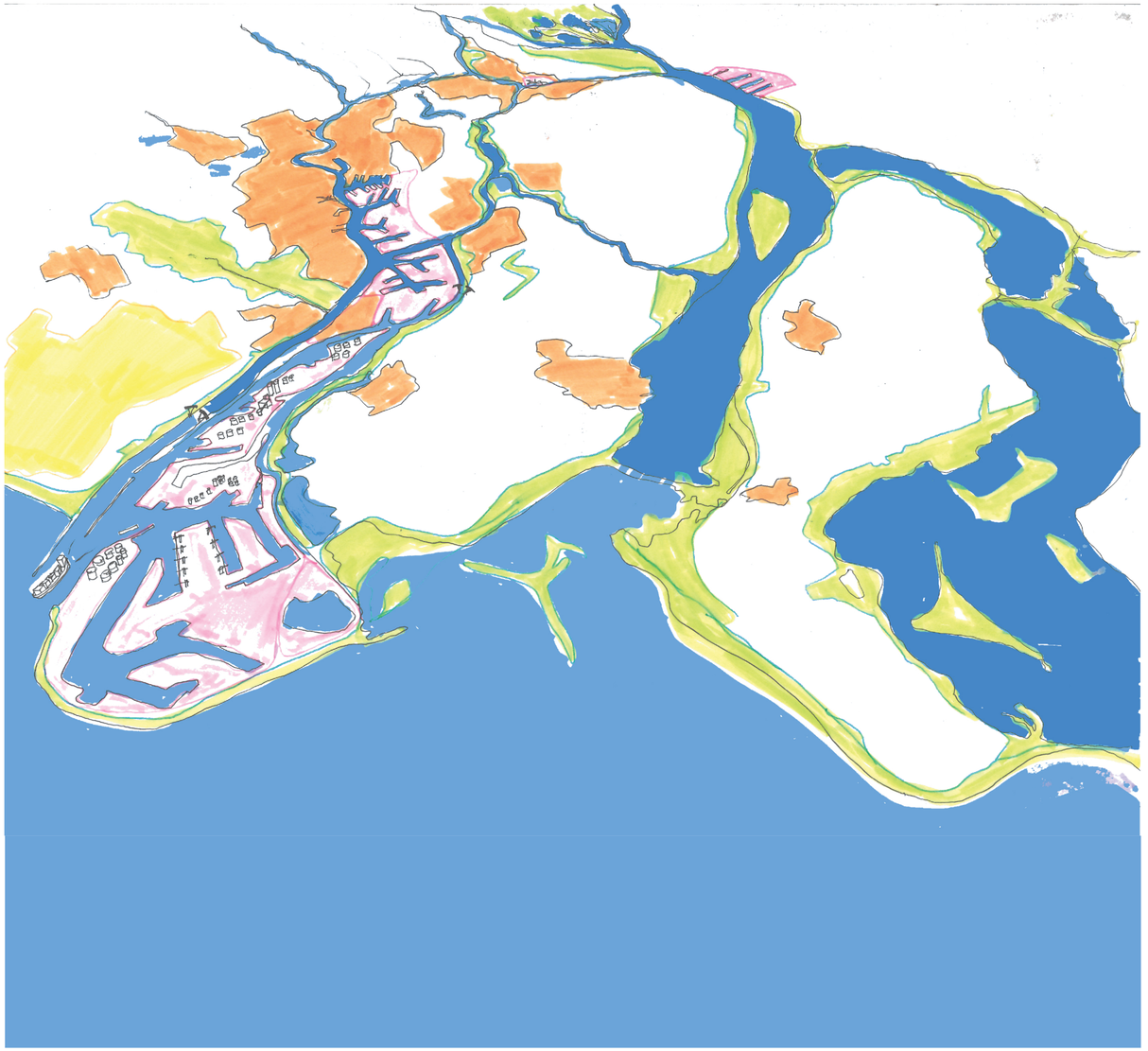


Fig 5.9: Perspective of Rijnmond delta region showing state of the region
Source: author

5.6 DPSIR method

Driver, Pressure, State, Impact and Response

Pressure:

Pressure from humans involves needing space for more urban and industrial zones. From nature in the form of raising sea level and dying delta/ river flow and sedimentation and biodiversity which is dependent on those ecosystems.

Impact:

Major impacts are seen in vulnerable areas, areas next to Dikes, outer dike regions, areas next to industries, freshwater bodies next to river and economic disruptions, heavily impacted due to fluctuating condition of the water levels

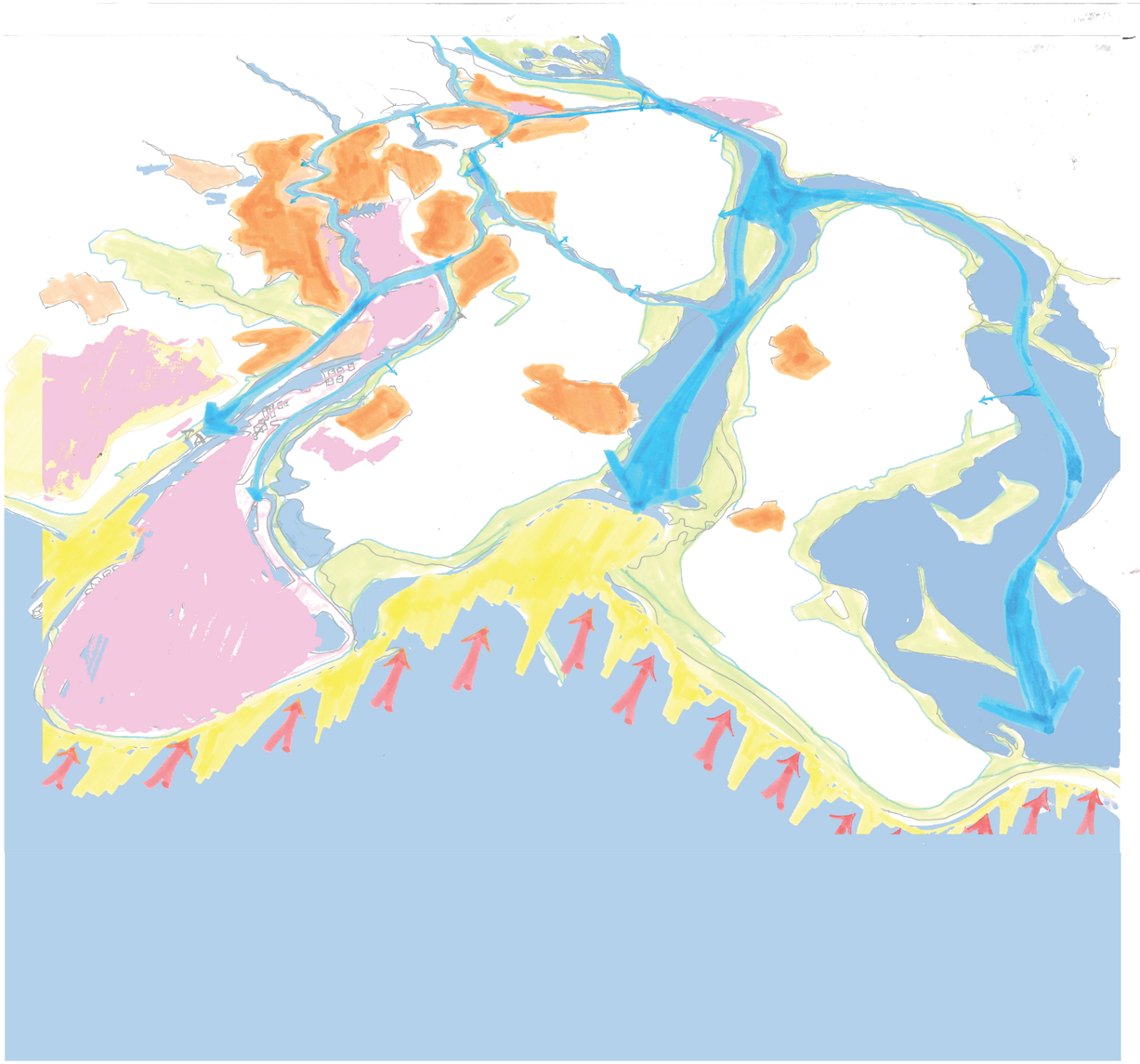


Fig 5.10: Perspective of Rijnmond delta region showing pressure and impact of the region
Source: author

5.6 DPSIR method

Driver, Pressure, State, Impact and Response

Critical points:

Critical points and bottlenecks include hard defenses engineered by humans, failing its design capacity and design life due to increasing climate change disasters. Few of such bottle necks are Maeslantkering, pumps in Haringvliet, Dikes in Krimpenerwaard region failing its minimum standard for water defense.

Infrastructure bottlenecks

- **Haringvliet and Hollandsch Diep** are specifically mentioned as areas for which adaptation paths are needed due to **sea level rise** and **changes in river discharges** after 2050 (MIWM*, 2022a). They are also vulnerable to salinisation, as salt water can reach these southern areas in exceptional circumstances like storms or during lower river discharges (MIWM*, 2022a).

- The **Nieuwe Waterweg**, including the **Nieuwe Maas**, Hollandsche IJssel, and the Lek, form the northern edge of the Rhine-Meuse estuary where salt water can penetrate and cause salinisation, especially during lower discharges or storms (MIWM*, 2022a).

- **Areas outside the dikes** in the Rhine-Meuse estuary are not legally protected against water and are therefore vulnerable to water damage (MIWM*, 2022a). Residents and users in these areas are responsible for their own risk mitigation (MIWM*, 2022a).

- The **Rijnmond-Drechtsteden area** and the **port of Rotterdam** include approximately 60,000 residents living in outside-dike areas, making them vulnerable to (threatened) **flooding** (MIWM*, 2022a).

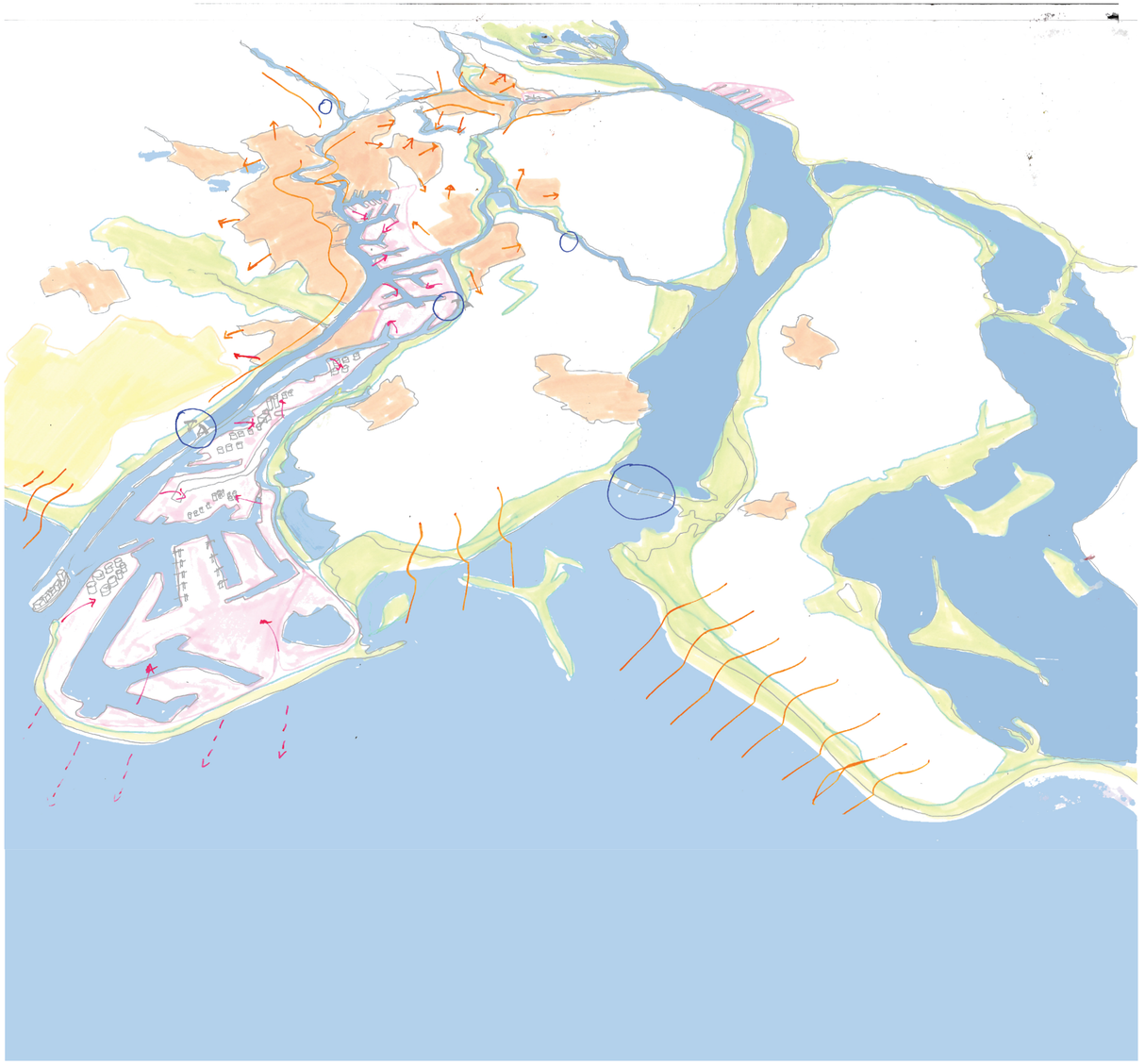


Fig 5.11: Perspective of Rijnmond delta region showing critical points and infrastructure bottle necks of the region
Source: author

5.7 Method focus

Maeslantkering - Outer dike region

Maeslantkering (Storm surge barrier):

From investing the spatial aspects of the region. Maeslantkering and outer dike region of Rotterdam is selected to focus. This is made to understand that the storm surge barrier is losing its optimal design life in 50 years and needs to be replaced. The further chapter understands the impacts and significance of the barrier and what the region has to offer

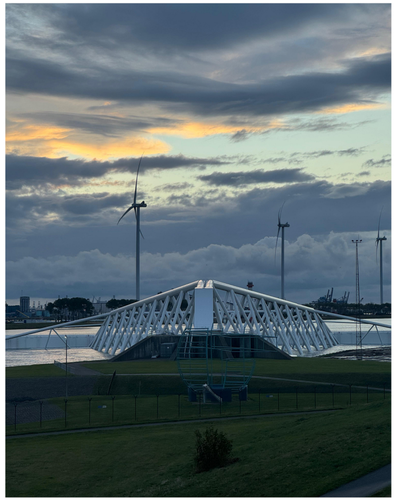


Fig 5.13: Maeslantkering arm
Source: author





Fig 5.12:(top) Annual closing of Maeslatkering
Source: author

Fig 5.14(bottom): Maselantkering near Maasdijk
Source: Michielverbeek

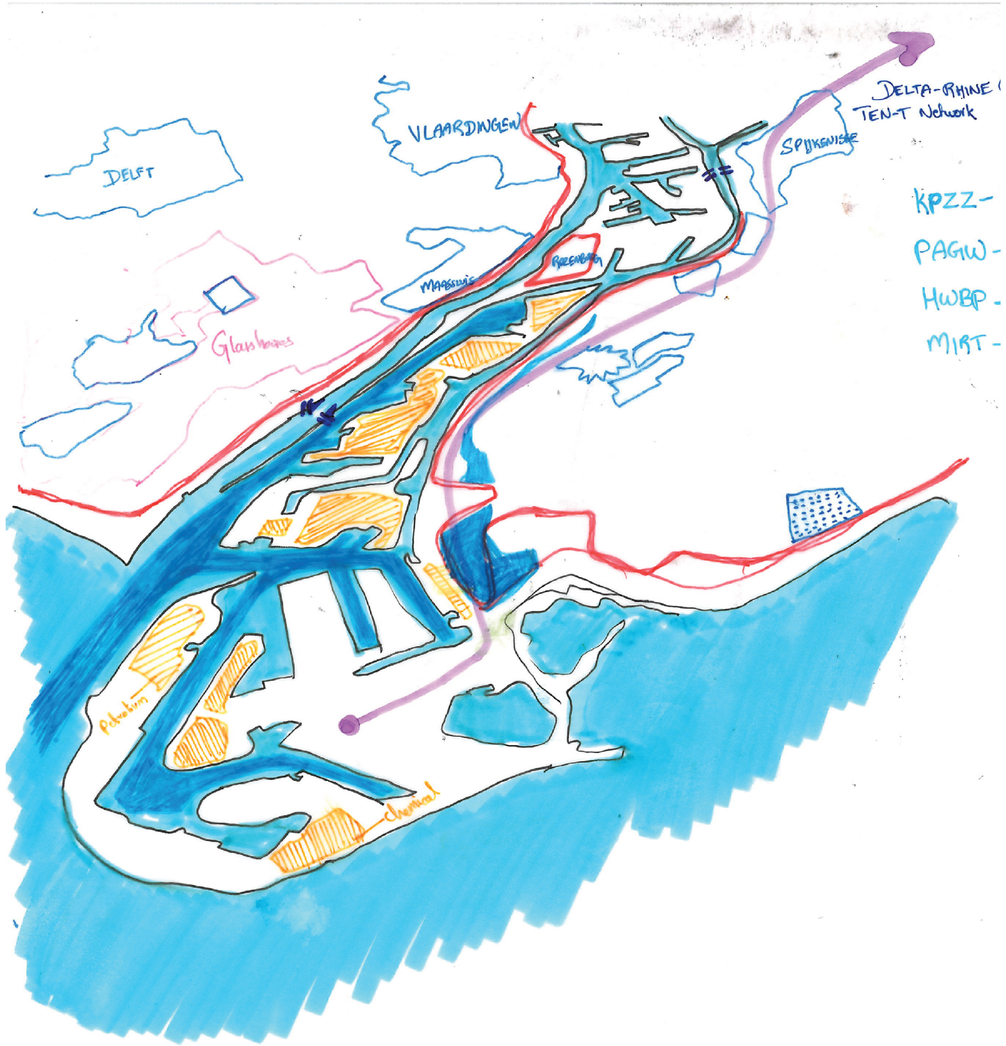


Fig 5.15: Port of Rotterdam
Source: author

06

Design for Resilience

Building on the findings of the previous chapters, this chapter applies the adaptive pathway planning approach to explore potential strategies for regional transformation. It evaluates how these pathways respond to climate uncertainty while addressing the overarching research question.

6.1 Focus region
6.2 Climate trends
6.3 Adaptive pathway planning

6.1 Focus region

Port of Rotterdam

Port of Rotterdam region has been selected to focus further bases on previous analysis. The port primarily focusses on processing and transporting crude oil. The strategic location of the port between the oil ridges in the North Sea and industries in Ruhr region of Germany and connected well through inland water and pipelines makes this region perfect to process and store crude oil. Alongside wet bulk, Port logistics and ship maintenance yards take up space in the port making it one of Europe's biggest port in the North Sea region.

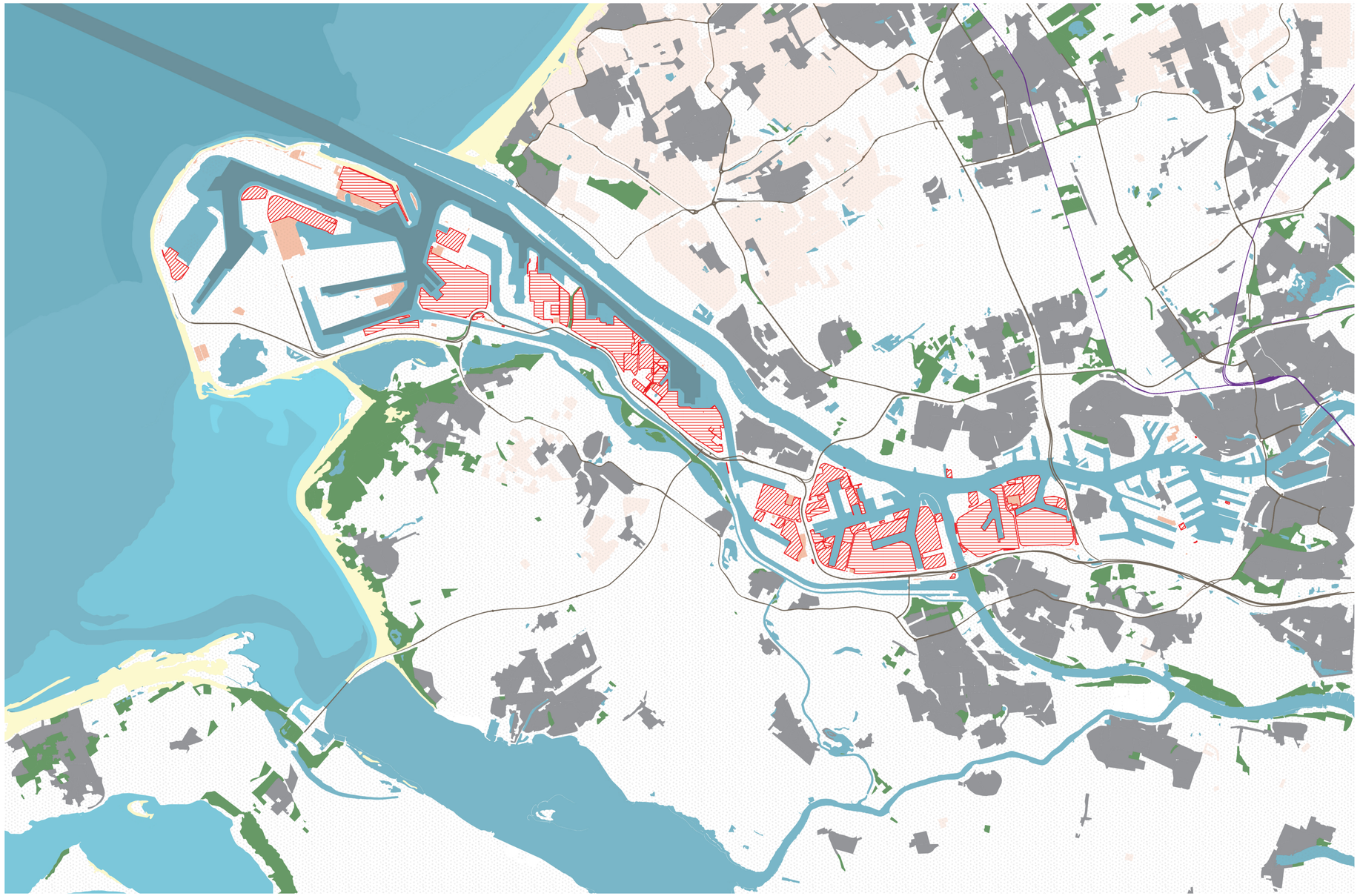


Fig 6.1: Map of port of Rotterdam and its surroundings
Source: author

6.1.1 Sociological layer

Port of Rotterdam

The Port of Rotterdam acts as the economic lungs of the Netherlands; by inhaling vast quantities of global energy and goods and exhaling them into the hinterland, it provides the “oxygen” of jobs and revenue that sustains the nation’s financial health (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties & Ministerie van Infrastructuur en Waterstaat, 2023).

If the port’s transition to a sustainable industrial complex fails, it would have national consequences, stating, “if it doesn’t work here, it will work nowhere” (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties & Ministerie van Infrastructuur en Waterstaat, 2023). The port’s economic utility is balanced against social challenges, such as the need to build 900,000 homes nationally, with nearly 94,000 of those planned for the Rotterdam region by 2030 to support the growing workforce (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties & Ministerie van Infrastructuur en Waterstaat, 2023).

Characters of different regions of port are mapped alongside planned development infrastructure and housing developed. Understanding the sociological layer gives us the flow, hindrances of materials and people. Data from CBS and Allecijfers is used to understand how the movement occurs throughout a day and how they could impact future development.

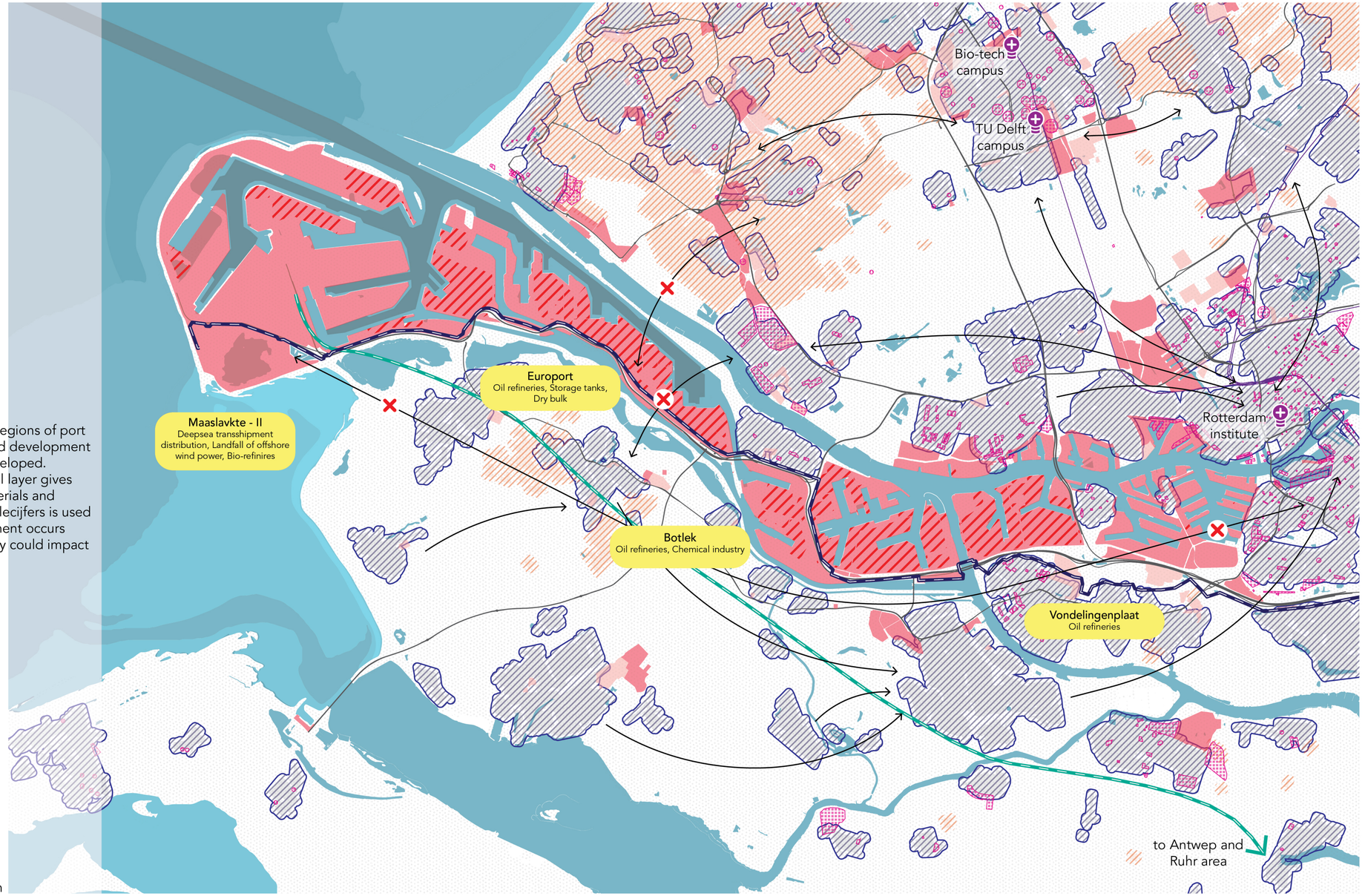


Fig 6.2: Map of sociological layer surrounding the port of Rotterdam
Source: author

6.1.2 Ecological layer

Port of Rotterdam

Ecology is integrated through strategic spatial planning that balances industrial transitions with the preservation and restoration of the delta's natural systems. Under the "Clean Port in the Delta" development direction, the port is envisioned as part of a robust and future-proof delta where nature and industry function sustainably together (Ministerie van Infrastructuur en Waterstaat, 2023). The "Clean Port in the Delta" perspective prioritises the planet above "profit," based on the principle that long-term climate and nature adaptation determines the port's future development potential. This includes:

Efforts focus on restoring foreshores around the Maasvlakte and developing a "wetland bypass" between the coast and the Oude Maas river to allow for natural dynamics (Ministerie van Infrastructuur en Waterstaat, 2023).

Tidal Nature: Projects like "Tidal Park XL" are designed to create accessible tidal nature along the river, enhancing both ecological quality and recreational value for the region.

Migration Hub: The port area acts as a crossroad for international migration flows, connecting the Rhine-Meuse river system with the sea for migratory birds and fish (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties & Ministerie van Infrastructuur en Waterstaat, 2023).

The region is heavily industrialized but at the same time heavily regulated to address natural conservation. Policies such as Natura2000 and Nature Network Netherlands play a role in regulating unwanted human interference in preserved areas. Heavy industry contour and 55db noise contour is mapped alongside to show the impact of heavy industries in the region.

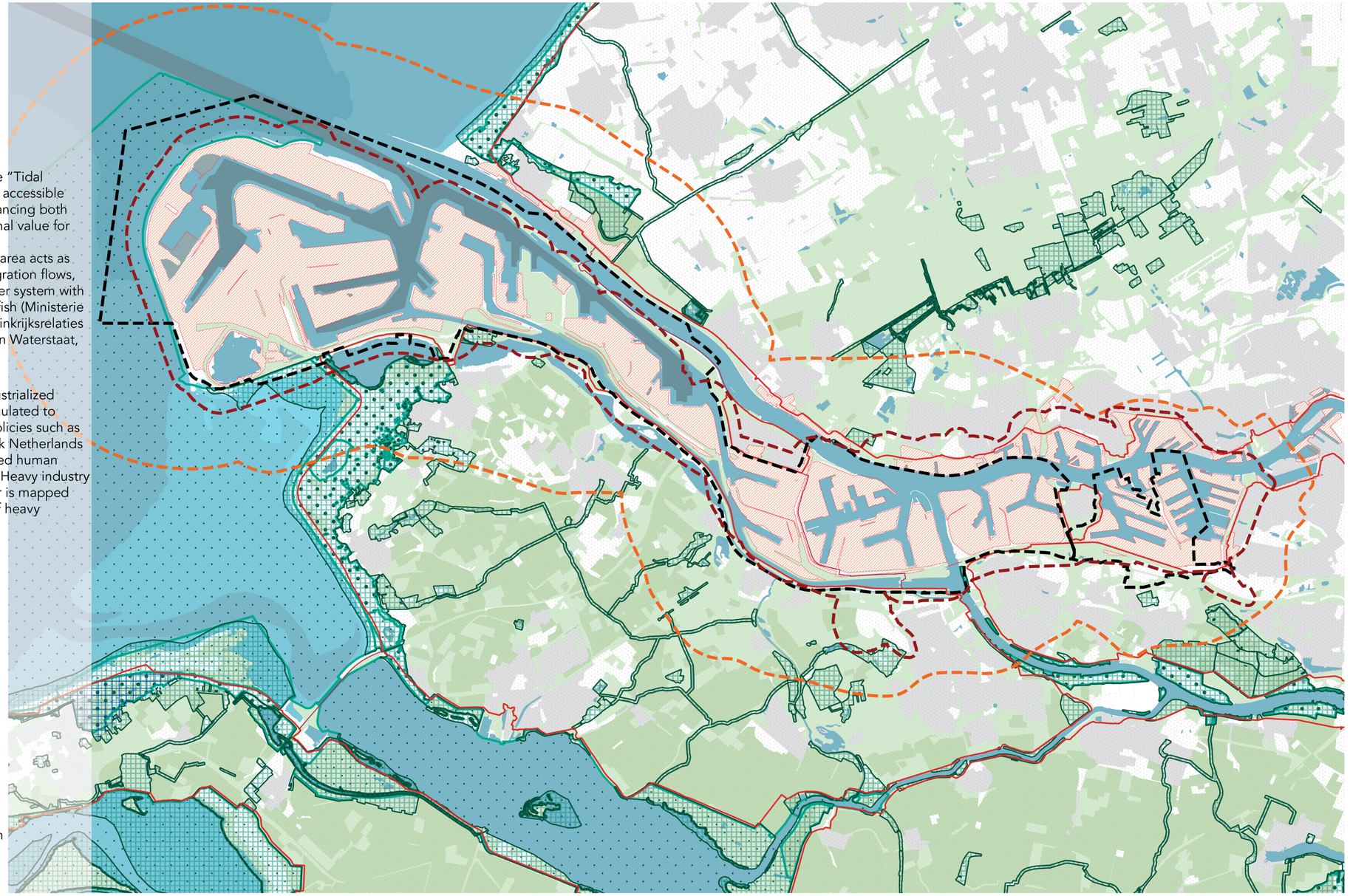


Fig 6.3: Map showing the ecological region surrounding port of Rotterdam
Source: author

6.2.1 Climate trends

Increasing sea level poses a threat to increasing population in the urban regions. UN's predicted population forecast shows by 2100 the population of Netherlands would be around 22.2M while sea level may rise +1.27m from existing levels. These numbers are alarming not just for safety in the region but in the entire nation.

The current water safety strategy, described as **"lockable-open,"** relies on the Maeslantkering and Hartelkering barriers (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties & Ministerie van Infrastructuur en Waterstaat, 2023). While this foundation is considered adequate until approximately 2070, this timeframe is not fixed and must be adjusted as new figures for climate change and sea level rise emerge. Because new large-scale infrastructure requires significant construction time, preparations for **post-2070 decision-making** will likely need to begin as early as 2040

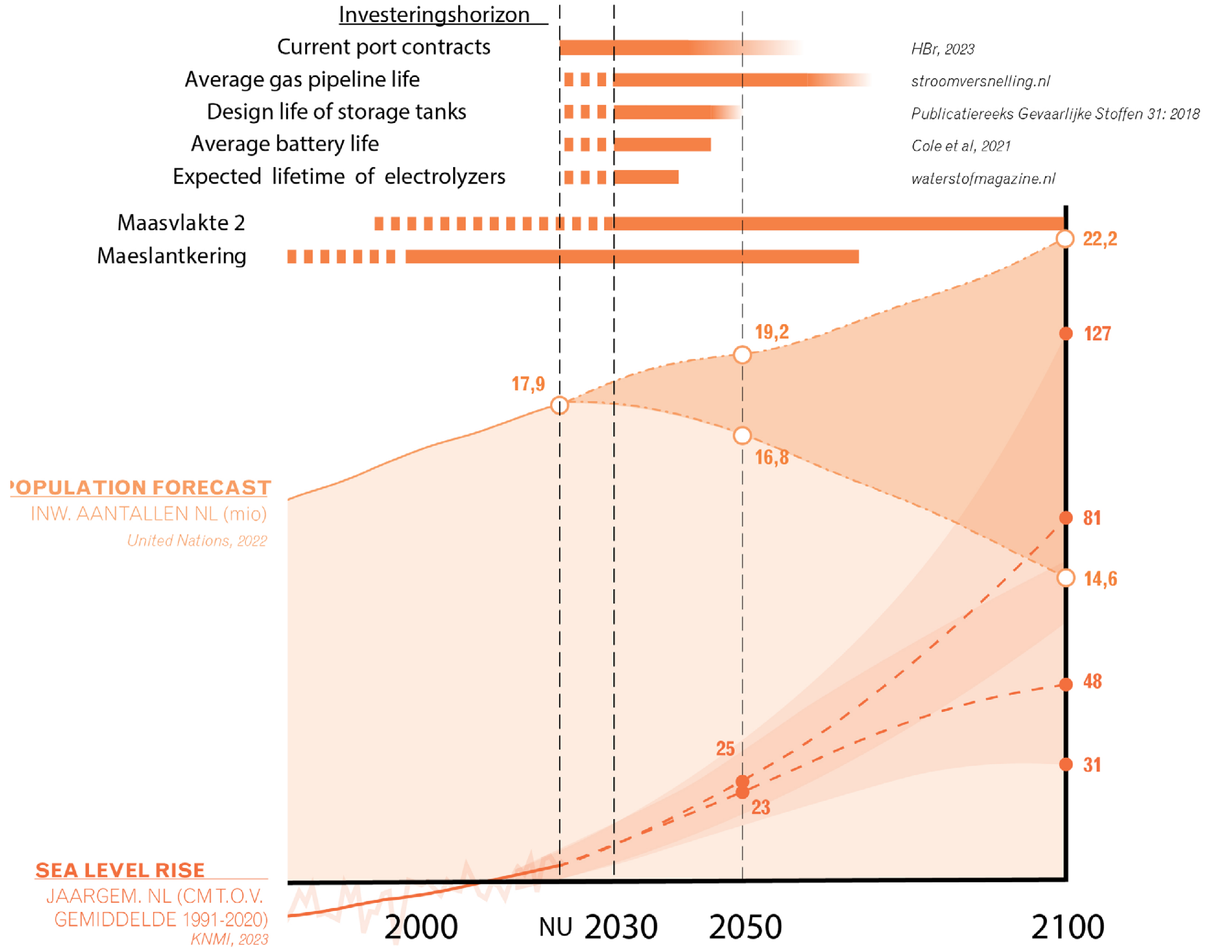
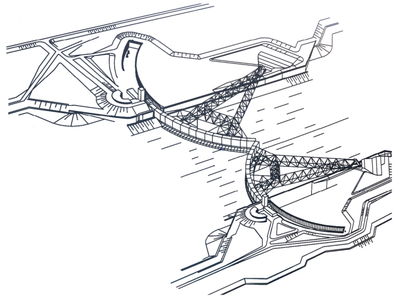


Fig 6.4: Climate trends and infrastructure lifespan
Source: NOVEX Rotterdam harbour development perspectives

6.2.2 Infrastructure



Maeslantkering

Storm surge barrier ~2075

Planned in 1990's completed in 1997, one of Delta work's biggest investments as seen in that day with a design life of 100 years changed dramatically when climate change was increasing and disaster predictions changed leading to have design life for next 50 years. As climate change increases, its design life decreases

Fig 6.5: Maeslantkering illustration
Source: illustration found on a tourist information board



Port contracts

Ground lease ~2050

Land contracts for crude bases industries need it be renovated as their lease period is coming to an end and with developing concerns on nature preservation and green energy, the increasing carbon tax might force traditional industries into green industries

Fig 6.6: Calandkanaal
Source: Thialf Heerema



Pipelines

Design life ~50 years

One of the effective ways to transport fluids over a long time. Pipelines play a vital role in transforming natural gas to inland ports. The port of Rotterdam is connected to moerdijk, Antwerp and chemelot, plans by Gasuine to invest in Delta Rhine corridor will be effective when Hydrogen industries are replacing non-renewables.

Fig 6.7: Storage tanks in Europort
Source: Eric Bakker



Storage tanks

Stainless steel storage tank ~ 40-60 years

Storage tanks take up a huge space in the region and have the capacity to store bulk goods. Once the cured industries lose their significance. Heavy industrial grade storage tanks need to be repurposed. Either recycled for new development or adaptive reuse of existing structures or repurposing storage tanks to store other forms of materials

Fig 6.8: Arieal view of harbour of Rotterdam
Source: Dkvtig,Own work, CC BY-SA 4.0



Li - Batteries

Average lifespan ~15 years

Electrification is backbone in green energy transition. Unfortunately, Li batteries don't not break the unsustainable flow chain but direct it towards another unsustainable linear material flow. With average of 10-15 years of usage, major maintenance and cooling is required to sustain the nation's energy grid through battery backup.

Fig 6.9: Li-Batteries
Source: Stockphoto



Flow batteries (Alternate energy storage)

In development (Salt based and Soild state batteries)

Recent innovations in the field of storing electricity, flow batteries (otherwise called salt batteries) and solid-state batteries are proven to be efficient. Still developing them into a large-scale infrastructure is on the way. These methods could help us store electricity in very efficient ways.

Fig 6.10: Flow batteries in a solar farm
Source: Stockphoto

6.3 Adaptive pathway configuration

Adaptive pathway planning

Adaptive pathways planning is a strategic approach designed to map the solution space over time, providing a structured framework for decision-making under deep uncertainty. This is particularly vital in the context of climate change, where uncertainties regarding future impacts, climate extremes, and tipping points make traditional static planning insufficient (Haasnoot et al., 2024).

Identifying limits to current and future adaptation strategies "can illuminate the need for transformative adaptation, if the system is sufficiently stressed against changing conditions (e.g. low-likelihood or longer time horizon)" (Haasnoot et al., 2020; van Alphen et al., 2022).

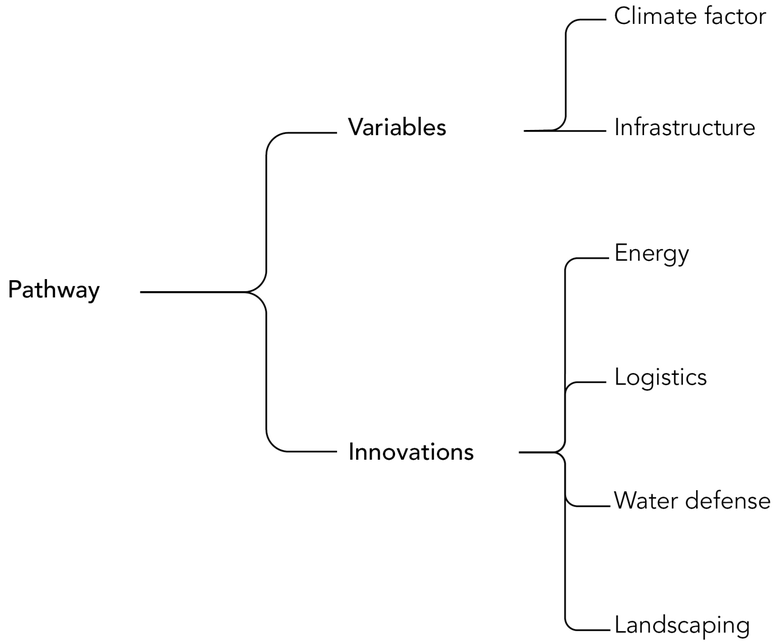
The roadmap-like visualisation of the solution space, often depicted as a "metro-map" helps decision-making to

• Link short-term actions to long-term goals.

•Overcome decision paralysis by showing that there are multiple robust choices available even in an uncertain future.

• Understand the "lifetime" of different decisions and the lead time required for future implementations (Haasnoot et al., 2024).

Imagine adaptive pathways planning as a **sophisticated GPS for a long-distance journey through** unknown territory. Rather than committing to a single fixed route that might be blocked by unforeseen weather or road closures, the GPS provides a map of all possible intersections. This research tend to reach a future that provides water safety, nature integration in the delta and sustainable energy transition.



Variables

Cliamte factor

Raising sea levels and need for delta in the region are the uncertain climate factors that play a huge role in long term planning

Infrastructure

Buildup area catering human needs deals with housing demand and need for space for Industries in harbor region.

Innovations

Energy

Industries mainly focus on energy production. They could be classified as crude oil based, hydrogen and biochemical based and solar/ wind/geothermal based. Among these. Hydrogen and biochemical bases industries are still in development and innovation while solar/ wind and geothermal tend to get optimized along the time.

Logistics

Logistics of energy and resources are mainly through road, rail and waterway but these modes tend to innovate but act the same. On the contrary, introducing pipelines networks, storage tanks, traditional batteries and innovation in storing electrical energy is addressed here.

Water defence

Primarily thought dikes and dunes water defense also includes the storm surge barrier, Maeslatkering. Replacements with better locks also provide resilience to increasing salination

Landscape

Dunes play a major role in defining the Dutch coast. Dune landscapes can be regulated and reinforced. Sand reserves from the North Sea could also be used to develop a secondary coast to the Dutch coast to fight rising sea levels. Opening up Haringvliet would change the delta dynamics and would reduce stress from river flooding in nieuwe Maas.

6.3.1 Adaptive pathway configuration

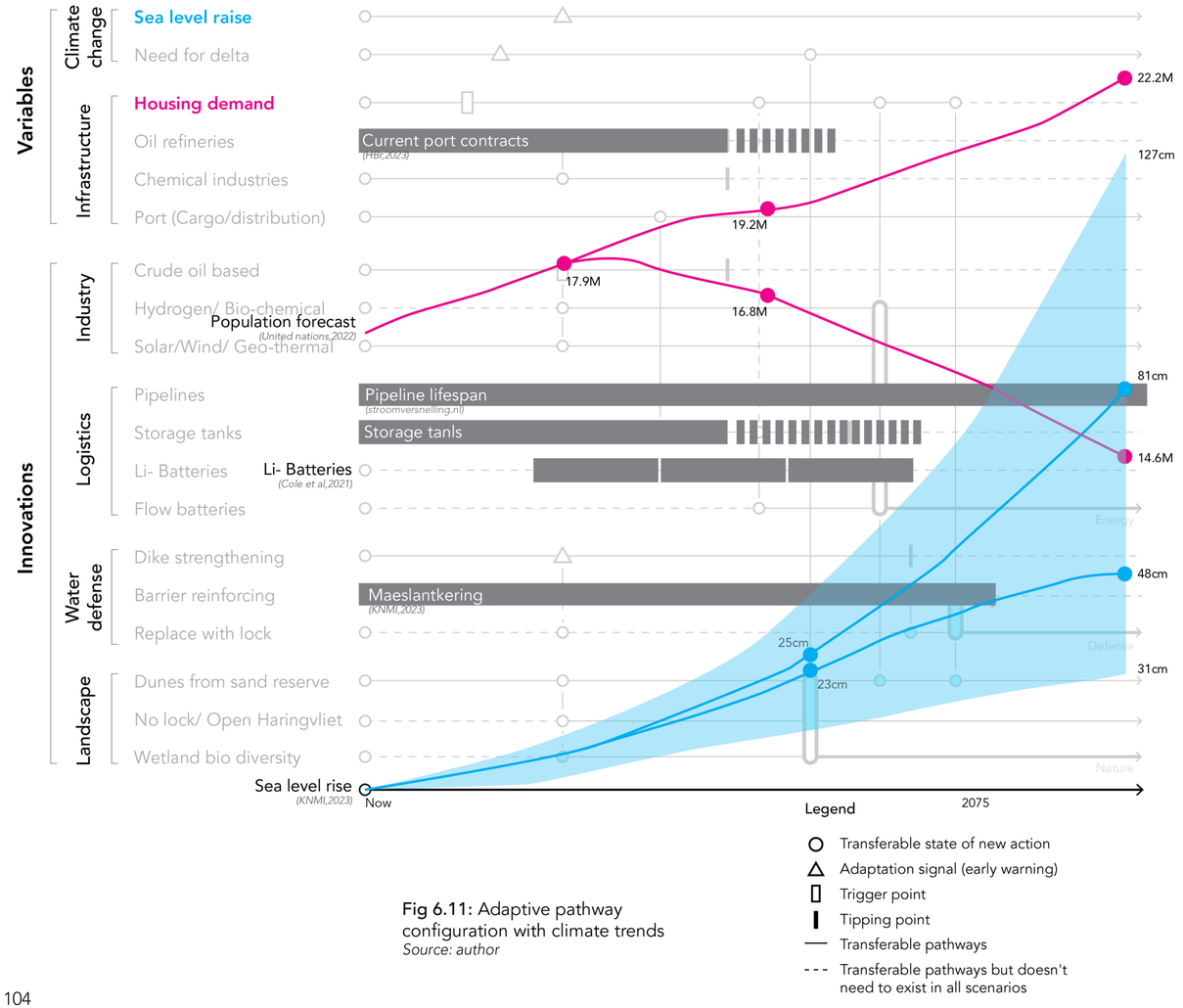


Fig 6.11: Adaptive pathway configuration with climate trends
Source: author

Pathways configuration

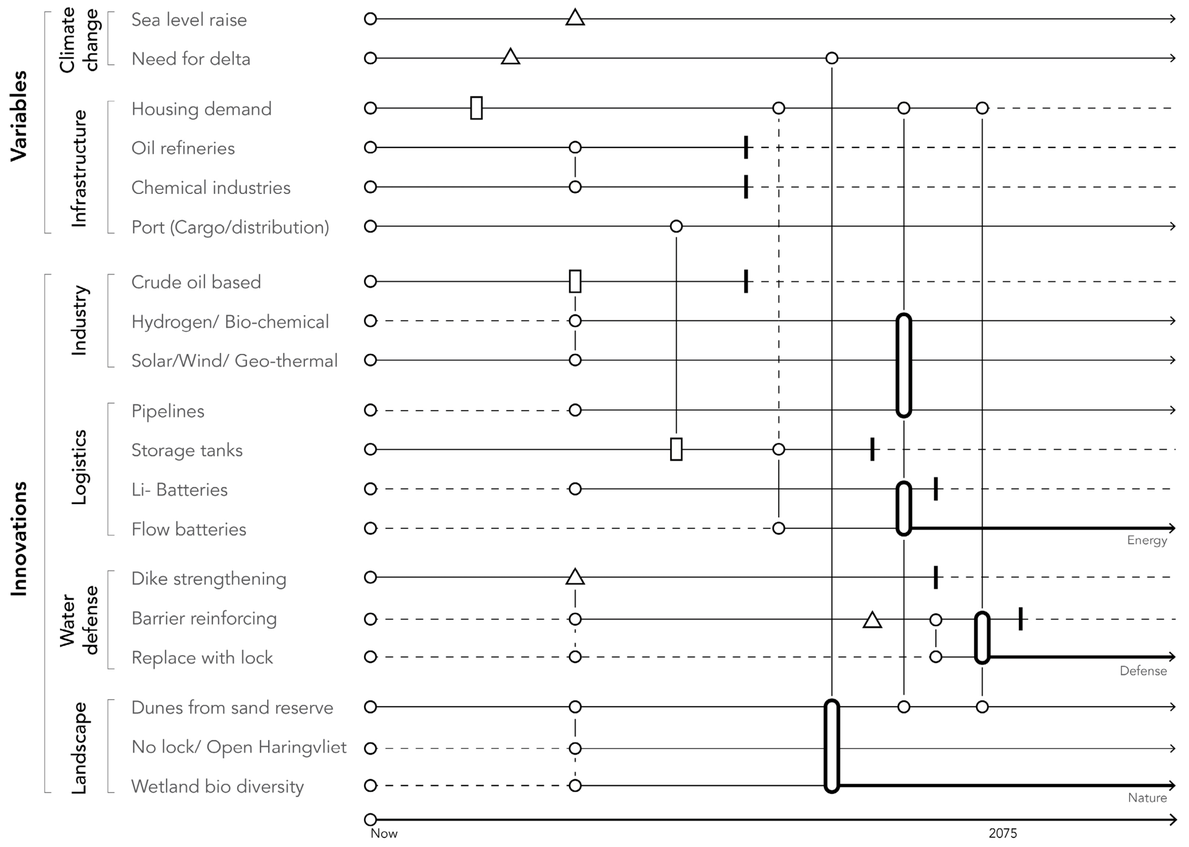


Fig 6.12: Adaptive pathway configuration
Source: author

6.3.2 Pathway trends

Water defence focus

This pathway focuses on using the sand reserve from North Sea and expanding the port to the sea. Replacing the storm barrier with a bigger lock and enclave port activities within the europort and maasvlakte. This gives much safety to inner dike regions which could be repurposed to residential neighborhoods

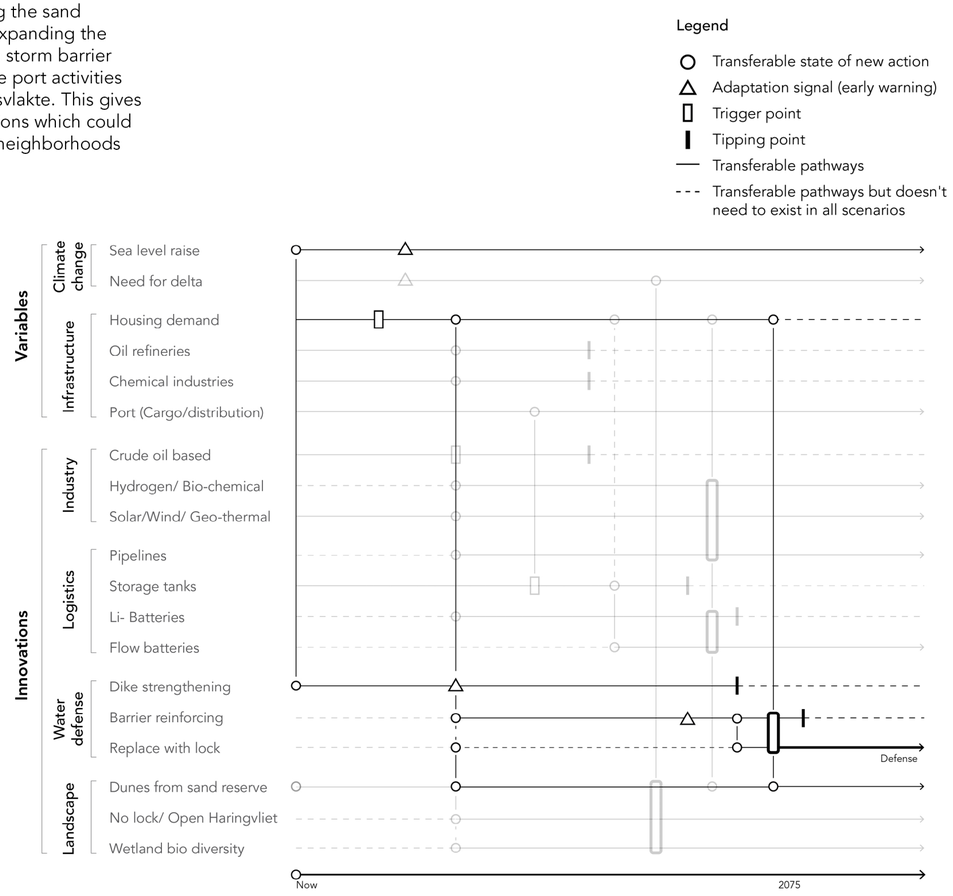


Fig 6.13: Adaptive pathway configuration leading to water defence future
Source: author

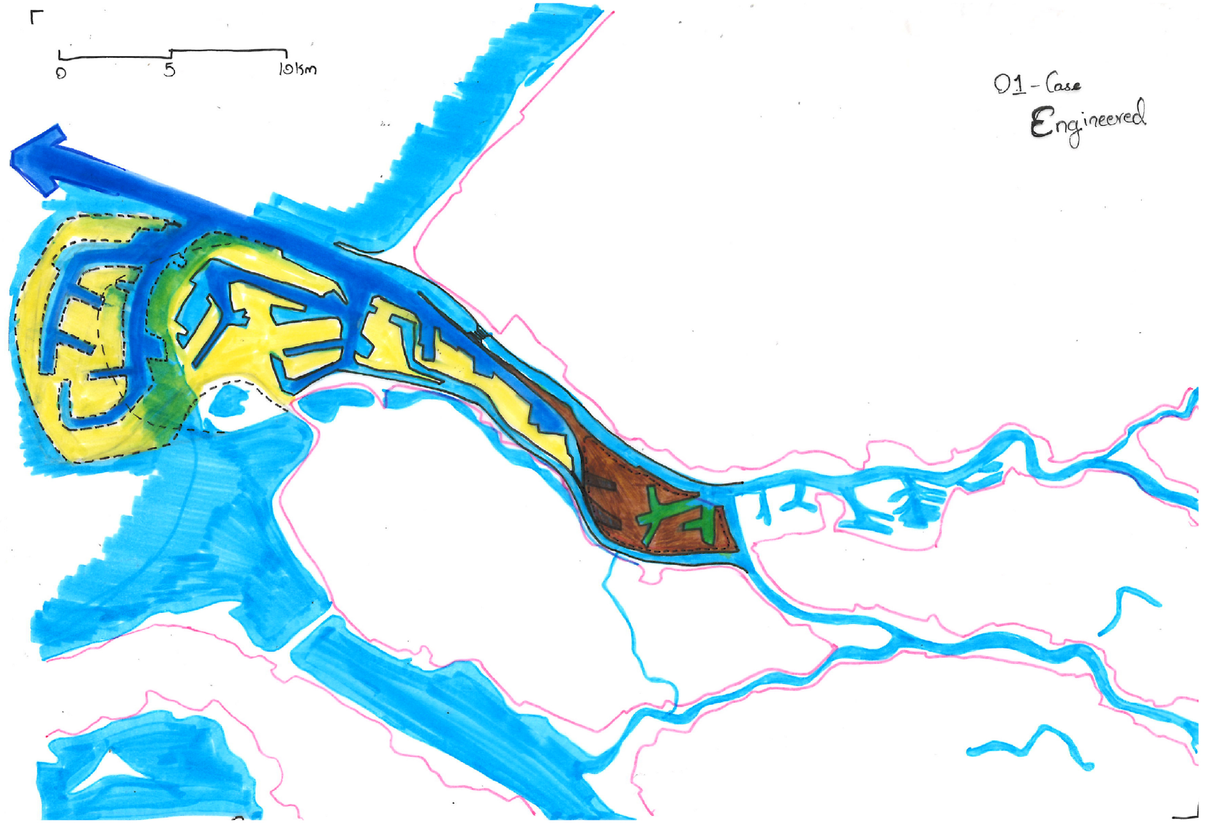


Fig 6.16: Map showing the spatial strategy for water defence focused pathway
Source: author

At the regional scale, current strategies primarily address rising water levels through the reinforcement of primary flood defense infrastructure, such as dikes, storm surge barriers, and locks. While these measures increase safety, they also have significant spatial implications. Reinforcing dikes often require adjacent infrastructure and urban functions to be relocated in order to create space for increased dike height and width.

Over time, this approach reduces the amount of usable urban land within protected areas, raising concerns about its long-term sustainability. Along the coast, sediment-based interventions such as extending the Maasvlakte through sand deposition shift port activities further seaward, creating opportunities to redevelop or repurpose existing industrial areas for urban functions, including housing.

6.3.2 Pathway trends

Landscape focus

Drastic yet viable ways to go forward can be achieved by removing the existing barriers. Breaking up the primary dike in Voorne islands into smaller dikes only protecting the built up while the polders and arable lands are given back to nature as floodplains and purification-swaps and freshwater buffers. This trend also allows opening up Haringvliet as Rhine's primary water deposit and depends on wetlands and marshes to tackle climate threats.

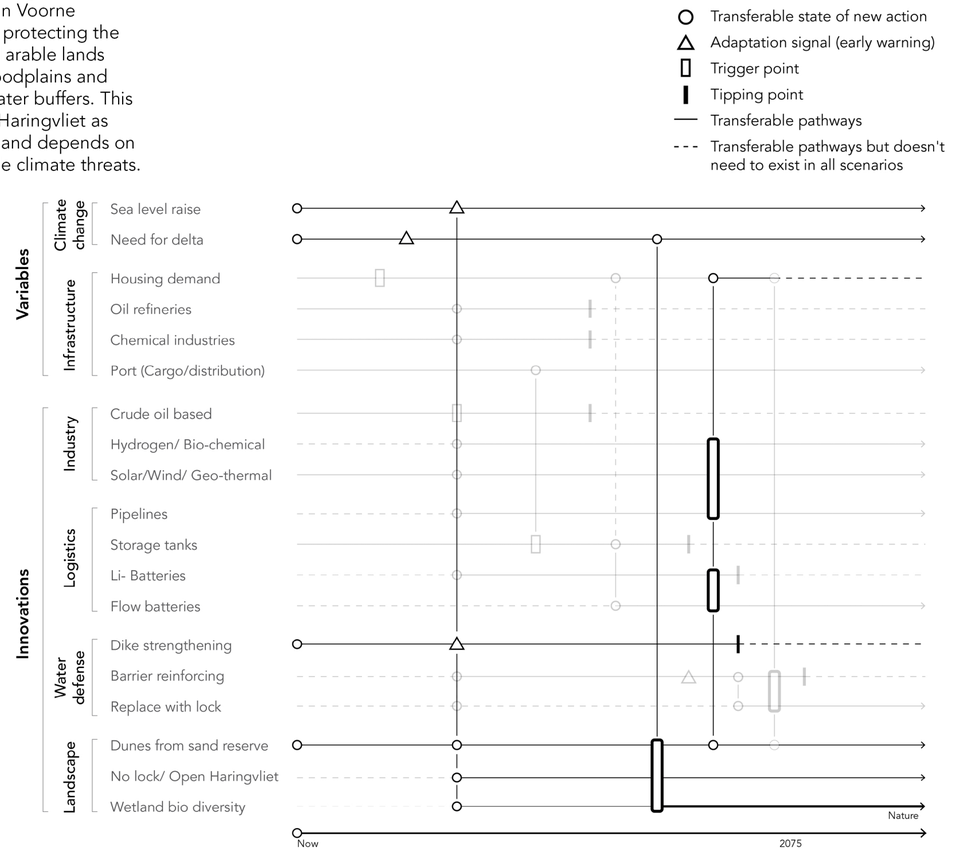
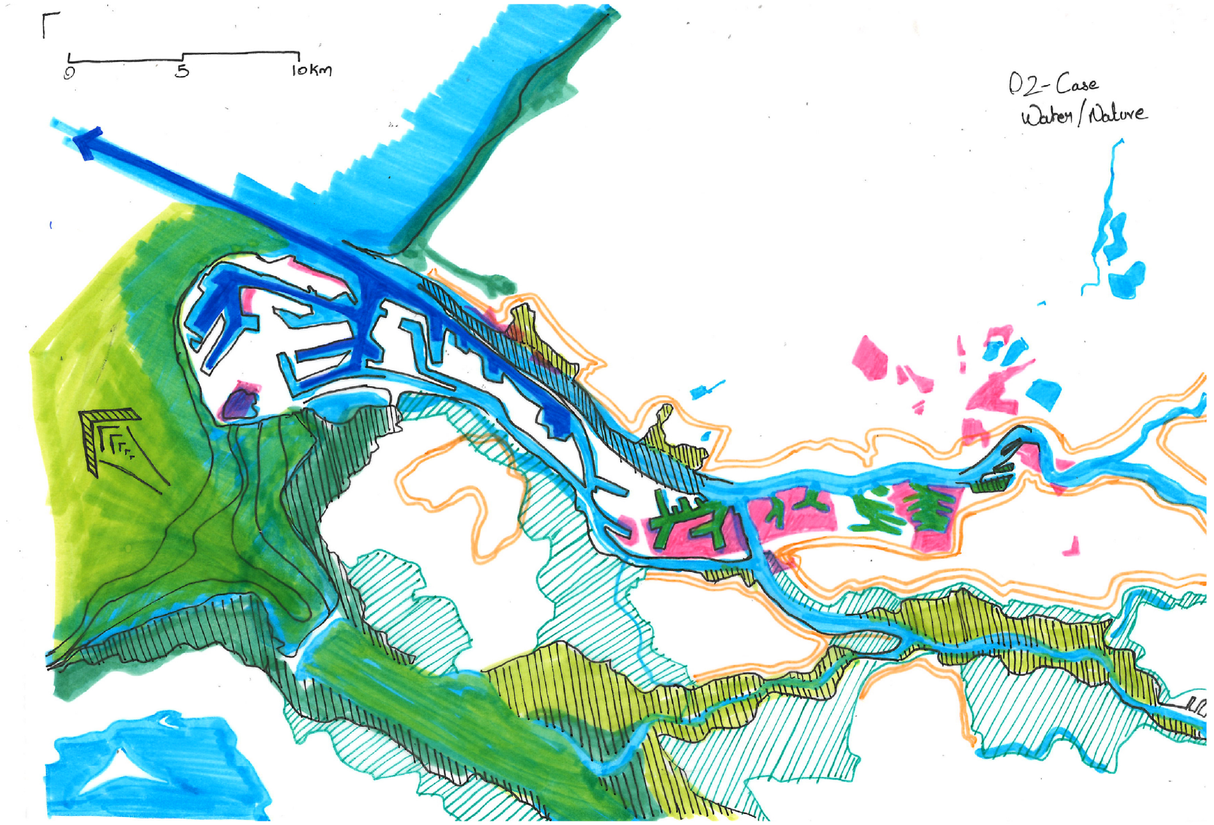


Fig 6.14: Adaptive pathway configuration leading to focusing nature
Source: author



A landscape-oriented future strategy begins by re-establishing the delta's natural dynamics. This approach advocates for gradual de-engineering of the delta by reducing reliance on hard hydraulic infrastructure and reintroducing natural processes. Key measures include opening the Haringvliet to restore estuarine conditions, reallocating selected polders to function as river floodplains, and reintroducing marshlands into the delta system. Together, these interventions aim to enhance ecological resilience while accommodating fluctuating water levels.

Fig 6.17: Map showing the spatial strategy for reintroducing nature into delta
Source: author

6.3.2 Pathway trends

Energy focus

With innovation and investments in making the industries less nuisance to the neighborhood. Greener alternatives in the form of hydrogen energy and wind farms offshore and electrification of energy grid. This pathway trend aims for maximum utilization and efficiency with less nuisance to nature. Using heat links to heat up urban areas during winter and pipelines to effectively transport hydrogen energy, this pathway trend influences national scale.

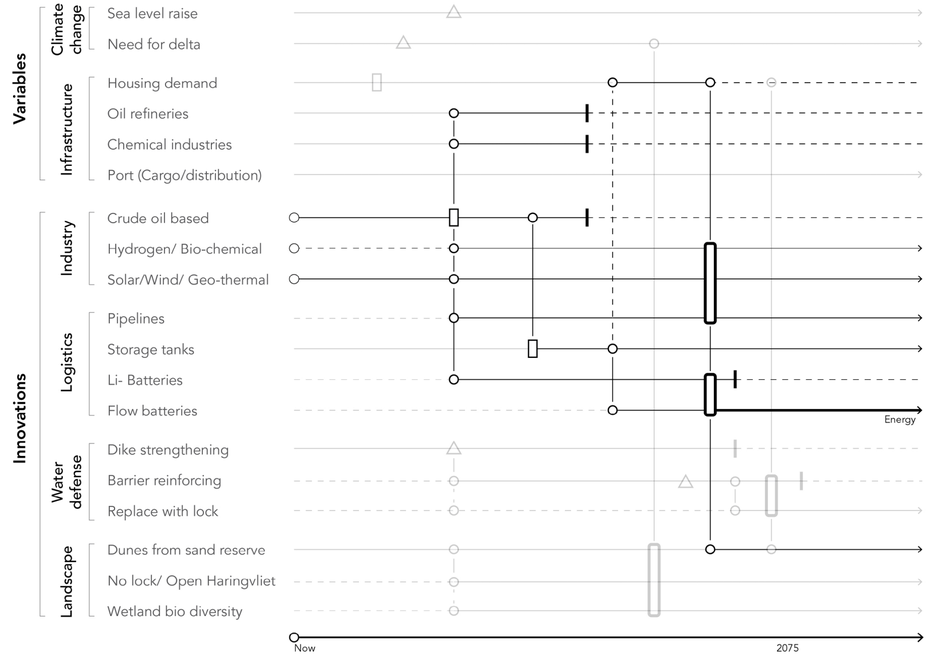
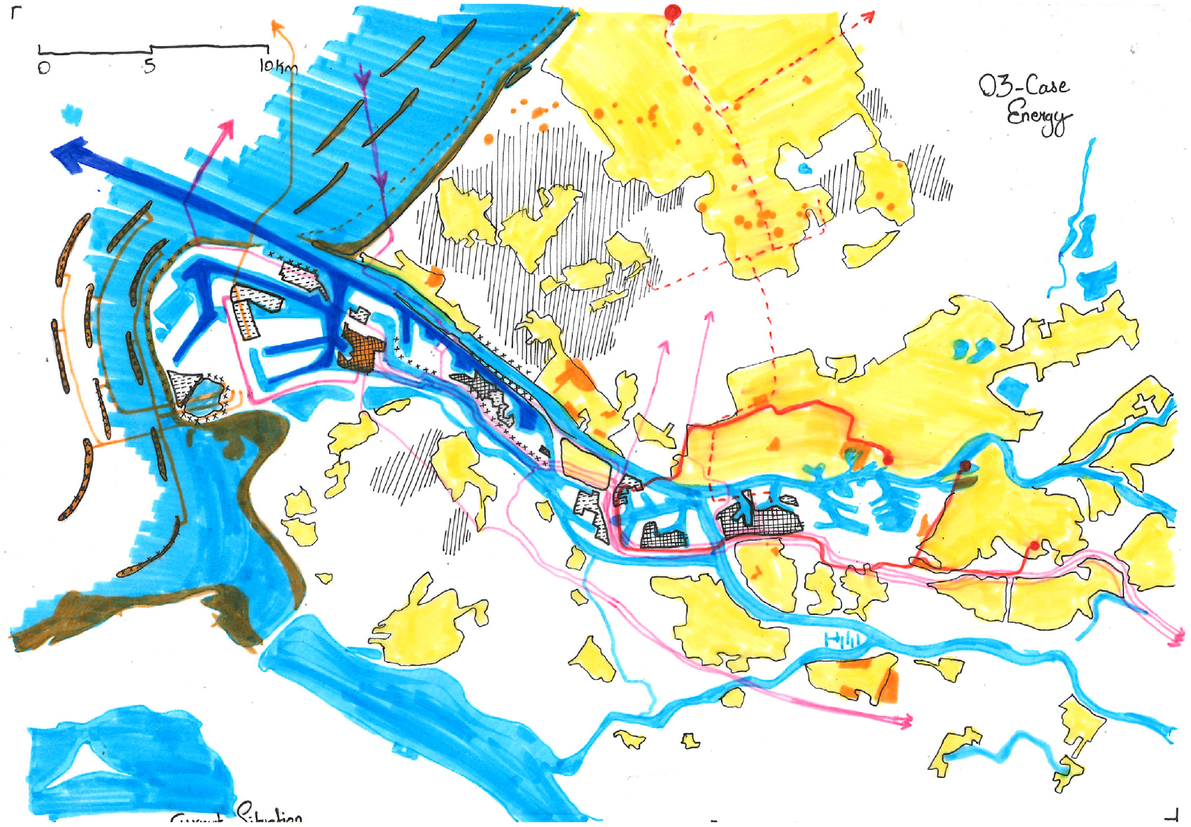


Fig 6.15: Adaptive pathway configuration leading to sustainable energy transition and generation
Source: author



The Port of Rotterdam can be understood as a large-scale energy landscape, where energy is produced, refined, and distributed. At present, this system is predominantly dependent on crude oil. A sustainable transition of port-related industries driven by renewable energy sources and the adoption of hydrogen as a primary industrial fuel has the potential to fundamentally transform this energy landscape.

Fig 6.18: Map showing the spatial strategy for sustainable energy transition and production focused pathway
Source: author

This transition builds on existing assets, including district heating networks that reuse industrial waste heat, the adaptation of pipeline infrastructure for alternative fuels, and continued investment in offshore wind energy. Collectively, these measures position the port as a key driver in the transition toward a low-carbon and climate-resilient regional economy.

6.3.3 Non-conflicting pathway trends

Impact near the coast

By integrating these pathways within a single strategic framework, potential conflicts between sectoral objectives such as flood protection, industrial transformation, and ecological restoration are mitigated. This integrated approach allows the region to progress toward long-term resilience while maintaining economic vitality and spatial quality. The convergence of energy, water, and landscape strategies demonstrates a coherent route toward achieving project goals, ensuring that future development is both adaptive to climate uncertainties and conducive to sustainable regional growth.

Pathways configuration

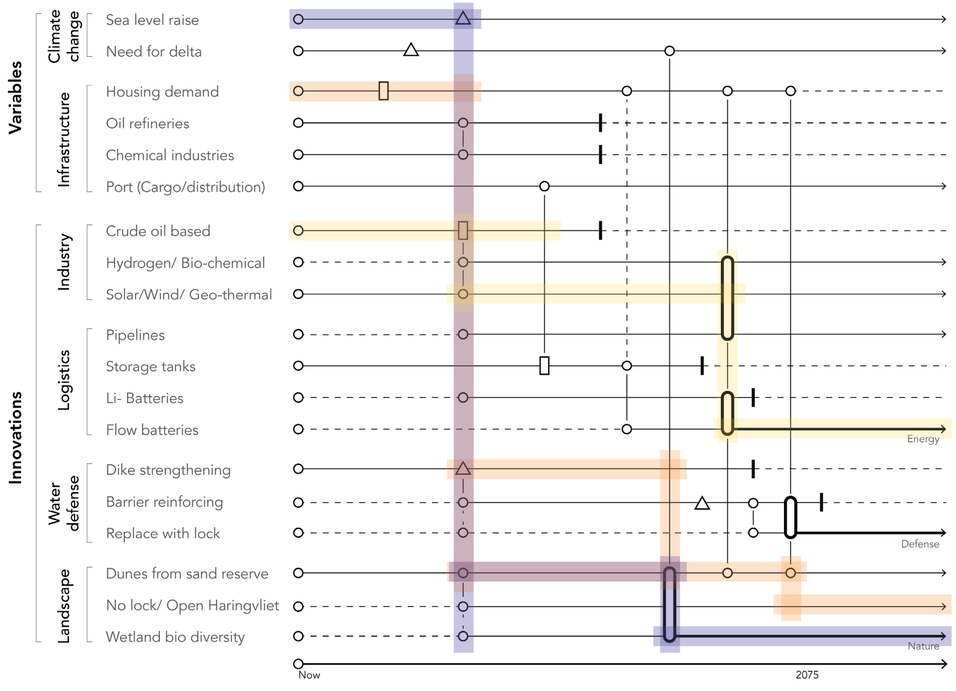


Fig 6.19: Non-conflicting pathways trends from adaptive pathway planning
Source: author

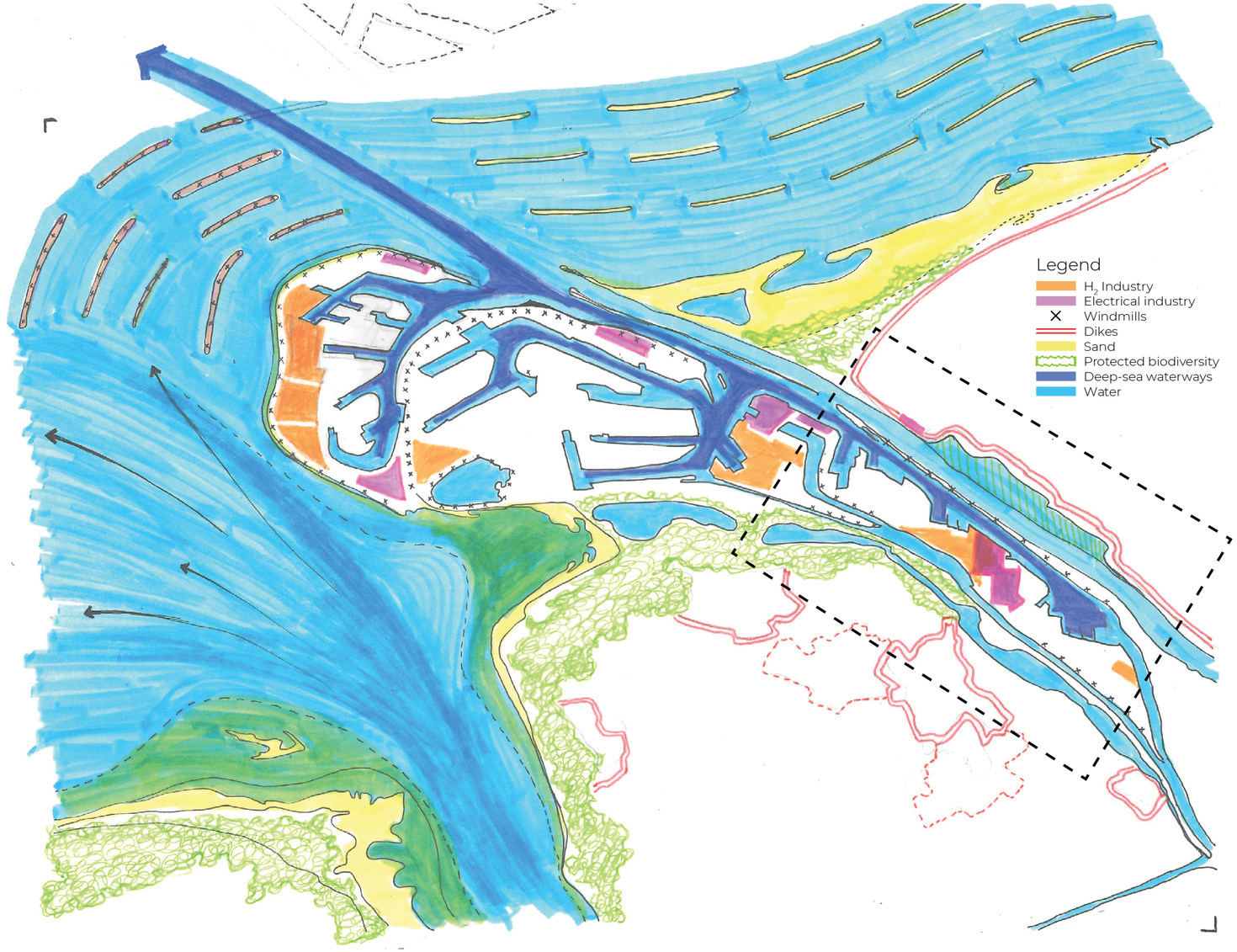


Fig 6.20:(right) Perspective of spatial strategy showing the coexistence of non-conflicting pathway trends
Source: author

6.3.3 Non-conflicting pathway trends

Imapct on port

Major transition in the port region in terms of developing hydrogen industries and repurposing storage tanks. Battery farms and innovation center to develop new efficient forms of energy storage. Having bio ducts within the port for the habitat connection between mainland of zuid holland and Voorne islands.

Transition and phasing on how they all come together for the new spatial realm.

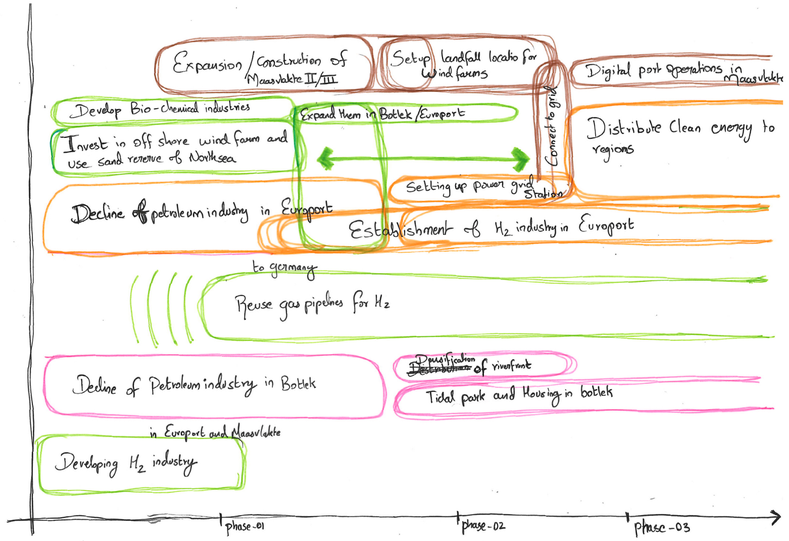


Fig 6.21(above): Draft phasing for sustainable energy transition in the Port of Rotterdam
Source: author

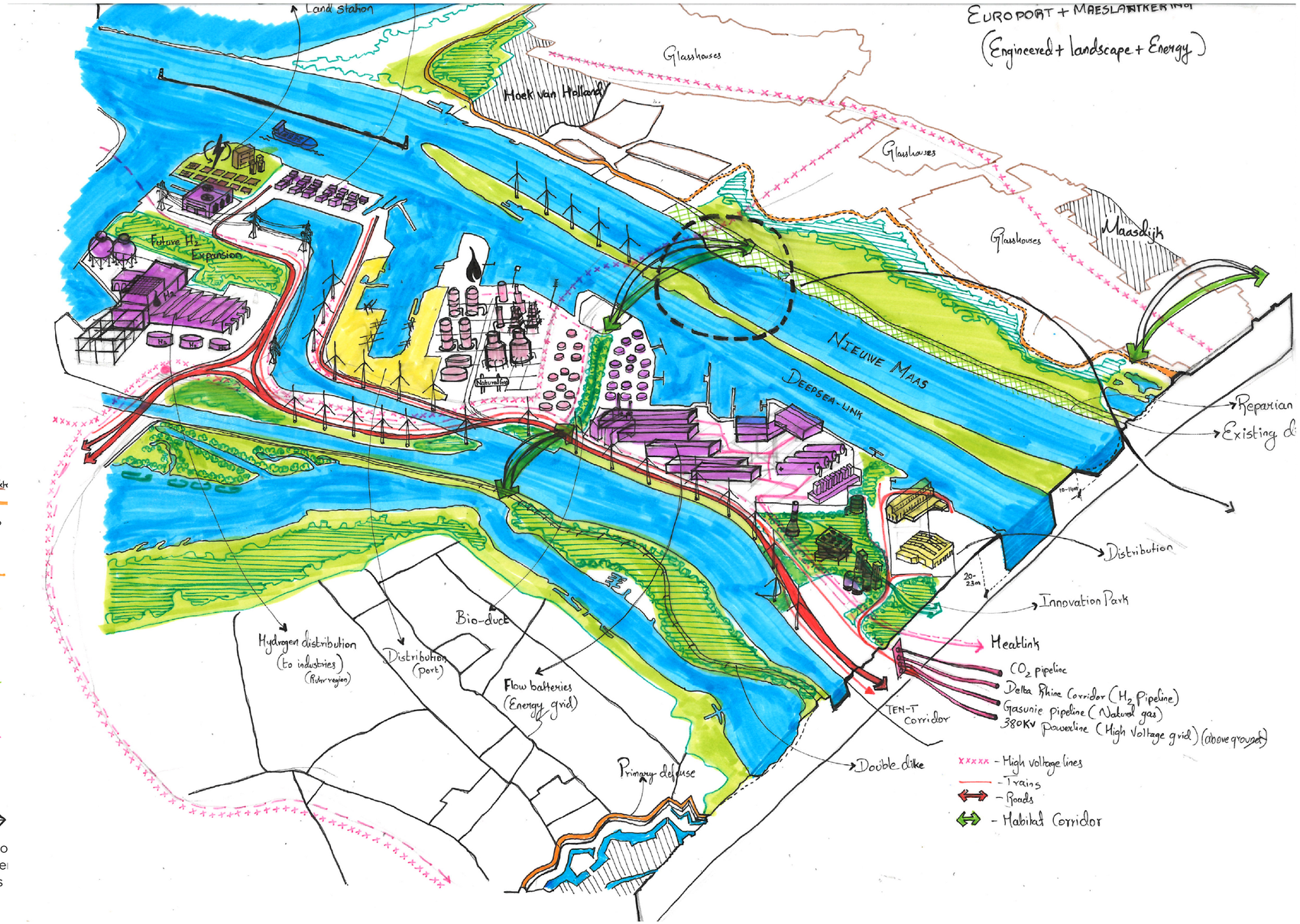


Fig 6.22(right): Draft perspective of the Europoo of Rotterdam going through the sustainable ene transition converting the crude based industries renewable industries
Source: author

07

Zoomed-In Resilience

This chapter presents research-by-design exploration, integrating historical analysis, present-day conditions, and future-oriented scenarios. While regional trends are addressed in the preceding chapter, this chapter shifts focus to urban-scale conditions, particularly within the inner dike region. Drawing on case studies and project precedents, it translates the proposed regime into a coherent and vibrant urban development framework.

7.1 Outer dike region
7.2 Existing condition
7.3 Browifield remediation
7.4 Historical analysis
7.5 Design exploration
7.6 Rhine archipelago
7.7 Phasing
7.7 New Rijnmond

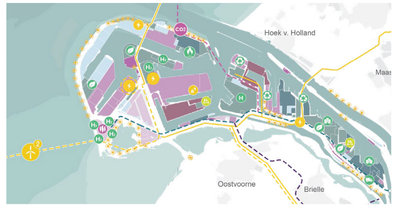
7.1 Outer dike regions

Development trends in the outer dike region

Recent trends and plans lead us to a conclusion is that port moving close to sea and developing maasvlakte 3 for port expansion is a trend that seeks more operationality in the future. International Biennale of Rotterdam's recent session on rijnmond 2100 discusses how Deltapolder: transforming ports into water rich urban environment could be made possible and what are the challenges ahead. The outer dike region adapts river city/ floating city concepts where dwellings are developed on water.



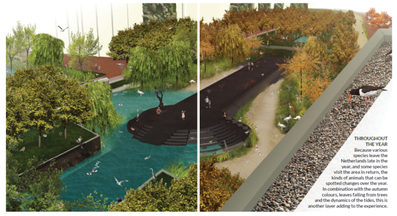
Rotterdam waterstad 2100
@De Urbanisten, Deltares (2023)



NOVEX Rotterdam harbor area development perspective
@Ministry (2023)



Neste Bio-fuel cluster
@Port of Rotterdam (2025)



Rotterdam as **Urban Tides-capes**
@Graduation thesis by Ivo Brands (2022)



Resilient rotterdam port
@Graduation thesis by Baokun Wei(2021)



Floating Area in the Maashaven
@Graduation thesis by Marisa Fang (2013)



Rijnhaven masterplan @Barcode architects



Two-stream country_Self-rising delta city
@Palmbout (2022)



Deltapolder
@IABR discussion session (2025)

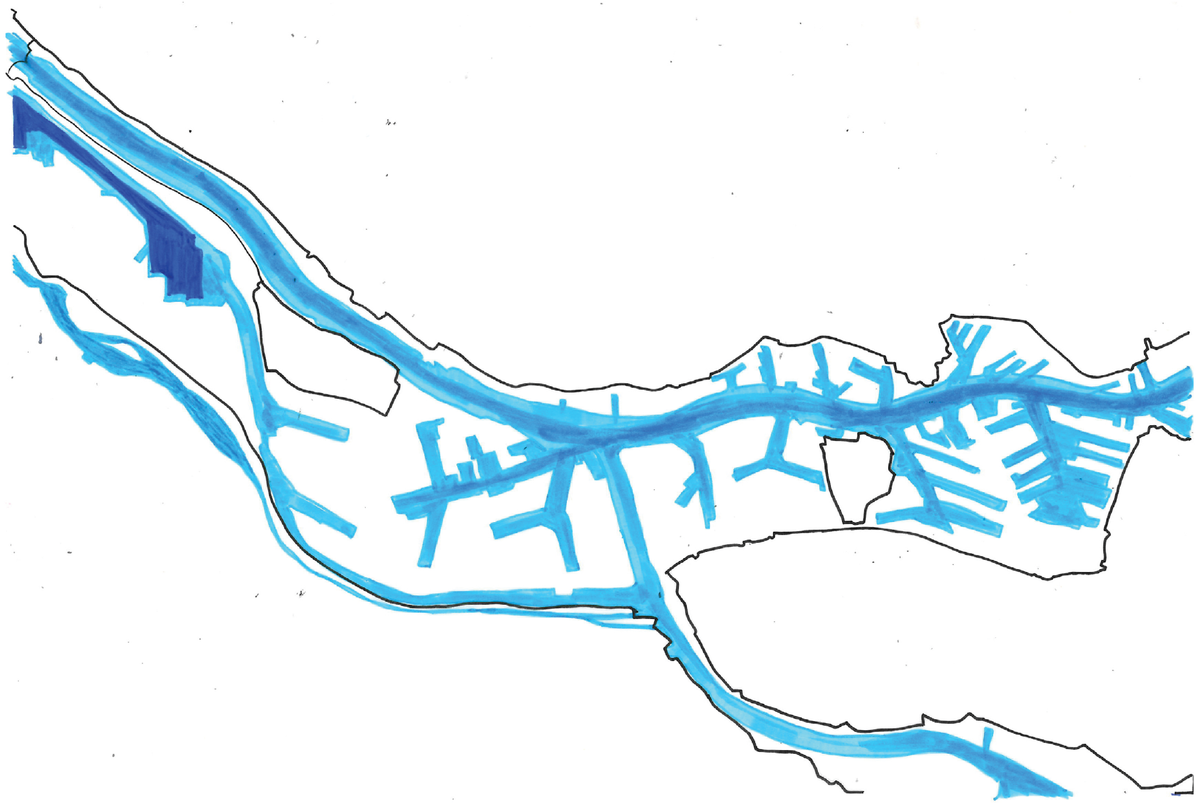


Fig 7.1: Outer dike region between the city and port of Rotterdam
Source: author

7.2.1 Existing conditions - Botlek

Botlek Island

Botlek is a key location in port of Rotterdam. It's a massive man-made industrial island developed by a vision called 'botlekplan'. It was part of a broader strategy of Rotterdam's "trek naar de kust" ("pull to the coast") expanding the port westward to secure space for heavy industry. Today, it's one of Europe's most important petrochemical and logistics hubs and today plays a vital national role in the Netherlands' industrial economy while transforming into a key site for the energy transition.

National Economic Importance

Botlek is one of the core industrial areas of the Netherlands, contributing heavily to National GDP, Export value, Petrochemical production and logistics, international pipeline (Rhine-Delta corridor) networks (Belgium and Germany)

Botlek's existing investments leads the island into a central for Dutch and EU decarbonized industry, Hydrogen transport and storage, Biofuel and biochemicals, Carbon capture networks, Circular chemical production (Port of Rotterdam, 2024).

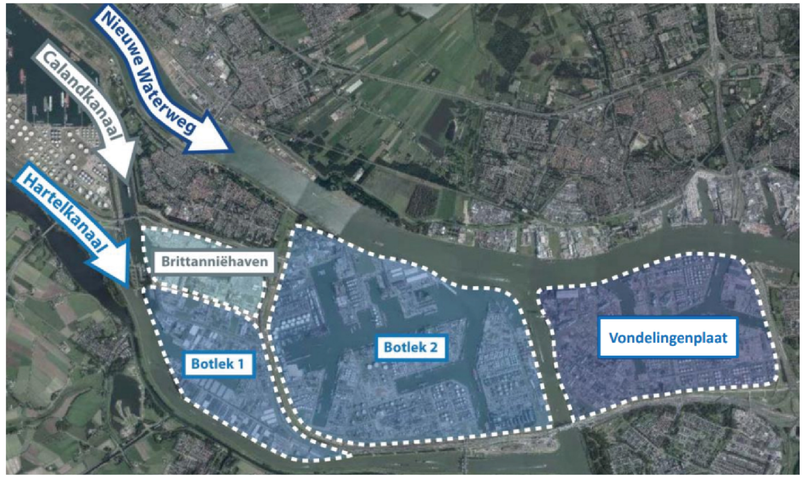


Fig 7.2: Sectors and channels feeding to Botlek
Source: port of Rotterdam



Fig 7.3: Industrial area of Botlek
Source: port of Rotterdam

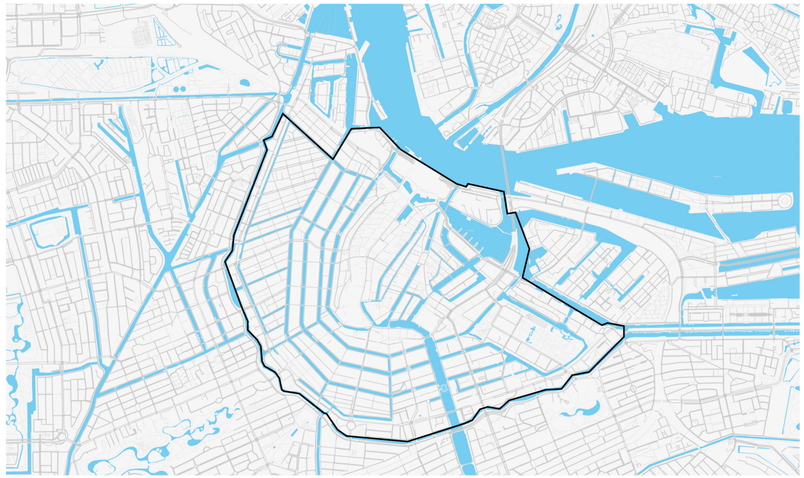
7.2.2 President analysis - Botlek

The Botlek plan (1950s)

Botlek is a Part of the Rotterdam Industrial Complex, one of the largest in the world. Its deep-water basins and connections support Rotterdam's competitiveness as a global port. Critical infrastructure in this region includes Tank terminals, Chemical production clusters, Ship repair and maritime services, Pipeline integration, It is also a major employment zone for the metropolitan region. The island currently is adjacent to Rosenberg neighborhood; this neighborhood is protected by a dike ring. The water around this island is heavily salinated due to less water flow thought the nieuwe Maas and increasing sea levels of North Sea.

This region is heavily densified for optimal performance of industrial functions. Size comparison next to Amsterdam intercity canal rings gives us a perspective of how big this region is and how valuable it would be to redevelop this region. Such a huge new development not just gives us a keystone for new ways of development perspectives but also takes toll out of developing housing crisis.





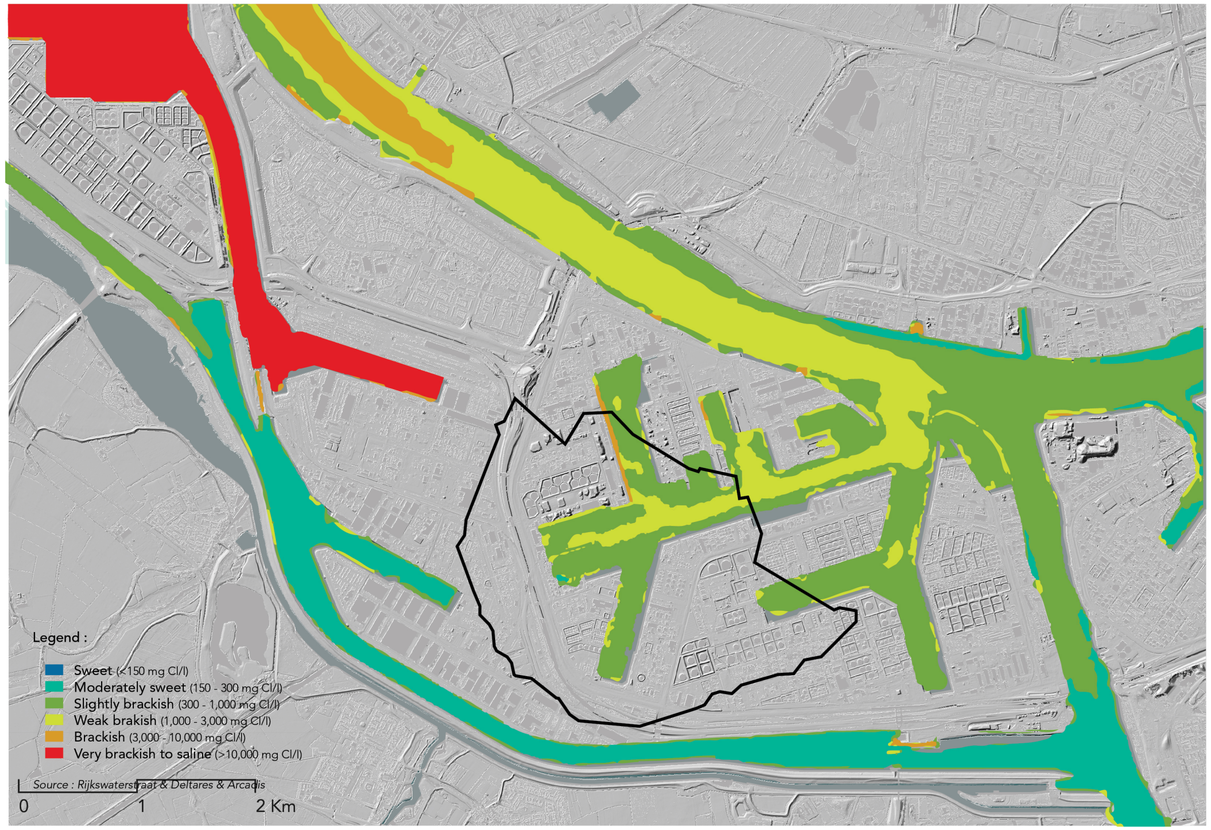


Fig 7.4(top): Botlek bridge
Source: Danny Cornelissen

Fig 7.5(bottom): Layout of canals in Amsterdam
Source: Google maps

Fig 7.7(right): Map showing the salinity level of water around Botlek and its area competition to historic centrum of Amsterdam
Source: author

7.2.2 President analysis - Botlek

Current state

Being Europe's one of the important petrochemical and logistic hub connected to the rest of north-east Europe through TEN-T corridors and pipelines, industrial optimization is the key strategy on place to development of this region. One of the biggest oil refineries. BP refinery exists in this region, since the island is isolated with residential neighborhood though water. High risk, flammable heavy industries are functioning here. Majority of port functions include import and distribution of wet bulk. Some dry bulk and rolling logistics.

Major function of this industrial landscape is to store, process and distribute crude oil and its biproducts. There are still functions and critical infrastructure in the region that this project tends to retain as the same. Road, pipelines and rail networks are critical for the port to function. They are retained in the new transformation, only that they are made into overpasses as they are going to cross major water bodies, marshes, wetlands, tidal zones and new landforms. They are buffered through active green to avoid noise and air pollution entering the new landforms. Other functions include areas with electric grid stabilisers and transformers help the ongoing energy transition. The neighbourhood of Rosenberg is retained while its outer edger is transformed from hard flood defence to active and soft flood defence. The transformation includes removing the dickering and adding/ developing marshes and floodplains above sea level. These marshes act as climate buffer for the residential neighbourhood.



Fig 7.8: Areal view of Botlek island
Source: Dkvtig, Own work, CC BY-SA 4.0

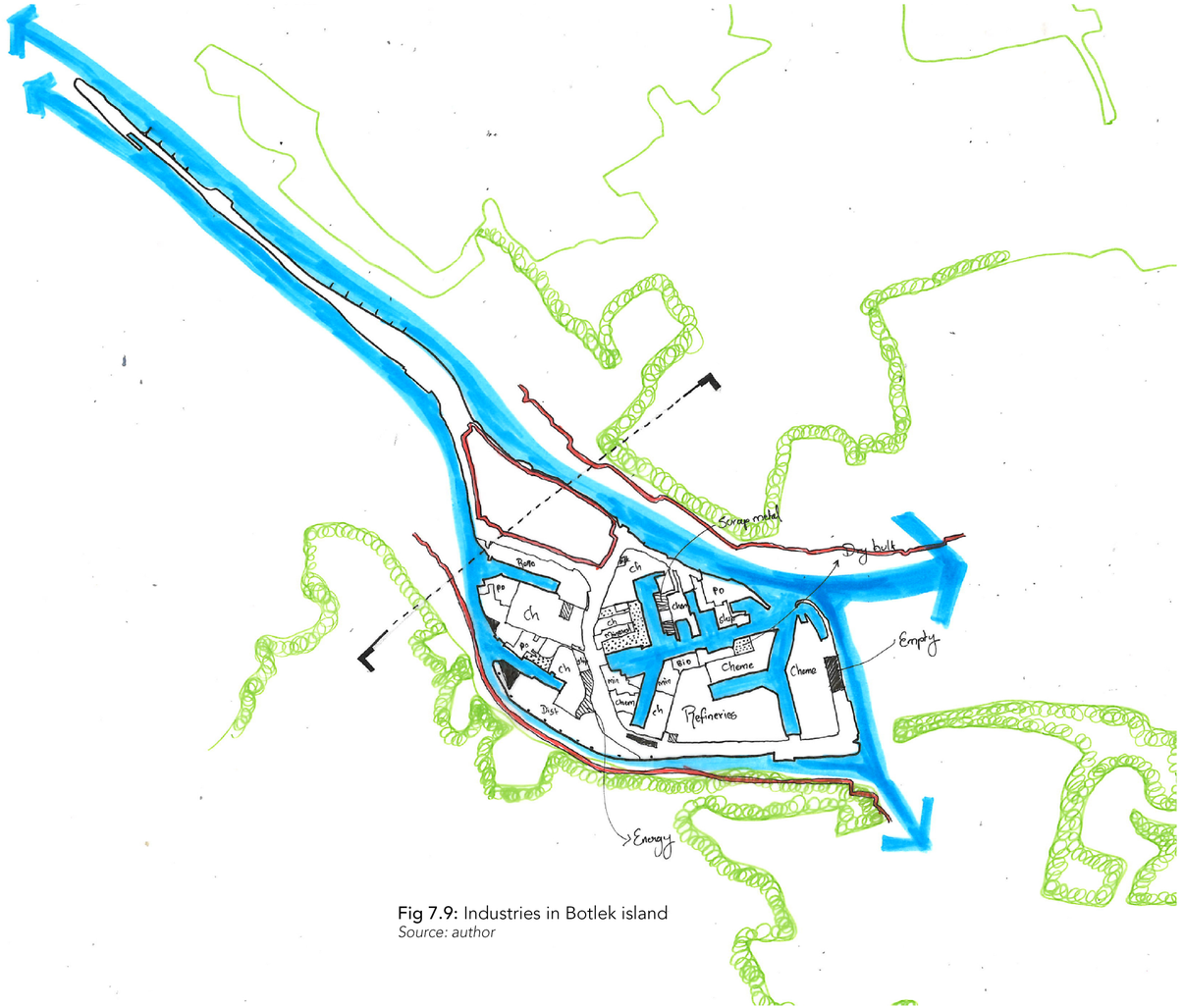


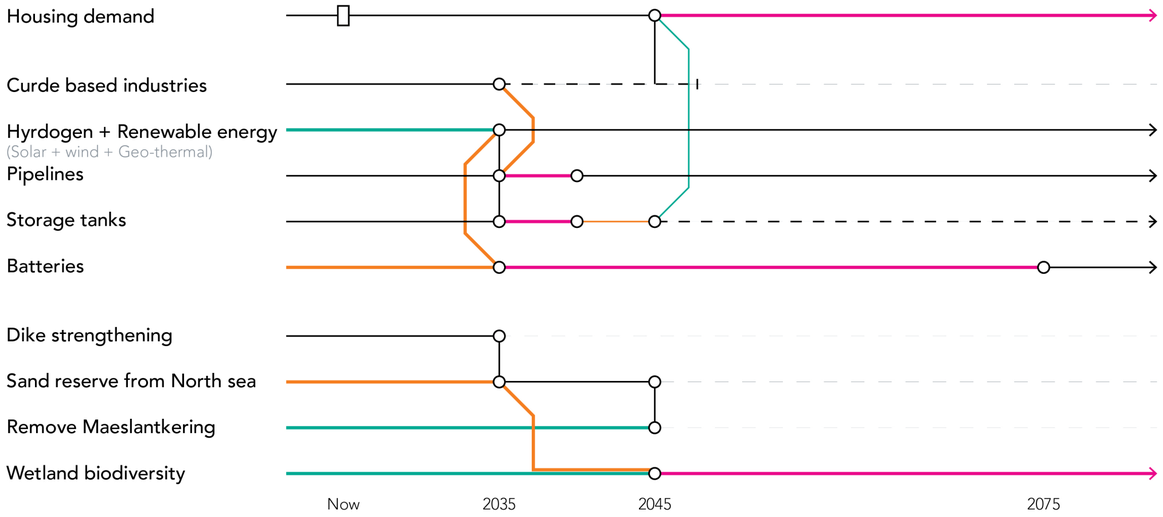
Fig 7.9: Industries in Botlek island
Source: author

7.3 Brownfield remediation - Botlek

Non- conflicting pathway trends

Non conflicting pathway trends, spatially focused on Botlek island simplifies the actions required to take the new regime. With industries moved to the west, space in the Botlek industrial island is utilised to begin the pilot project of this regional transformation. Like every other brownfield project.

A phased brownfield redevelopment strategy enables contaminated industrial landscapes to be safely reclaimed by sequencing risk assessment, remediation, and redevelopment while balancing environmental recovery, economic transition, and long-term spatial resilience.



Preperation (Risk Understanding & Enabling Conditions)

Make contamination visible, manageable, and governable, without disrupting essential operations prematurely.
Preparation phase is intended to
-Environmental baseline
-Legal clarity
-Spatial strategy
-Safe interim conditions

Transformation (Decontamination & Landscape Reprogramming)

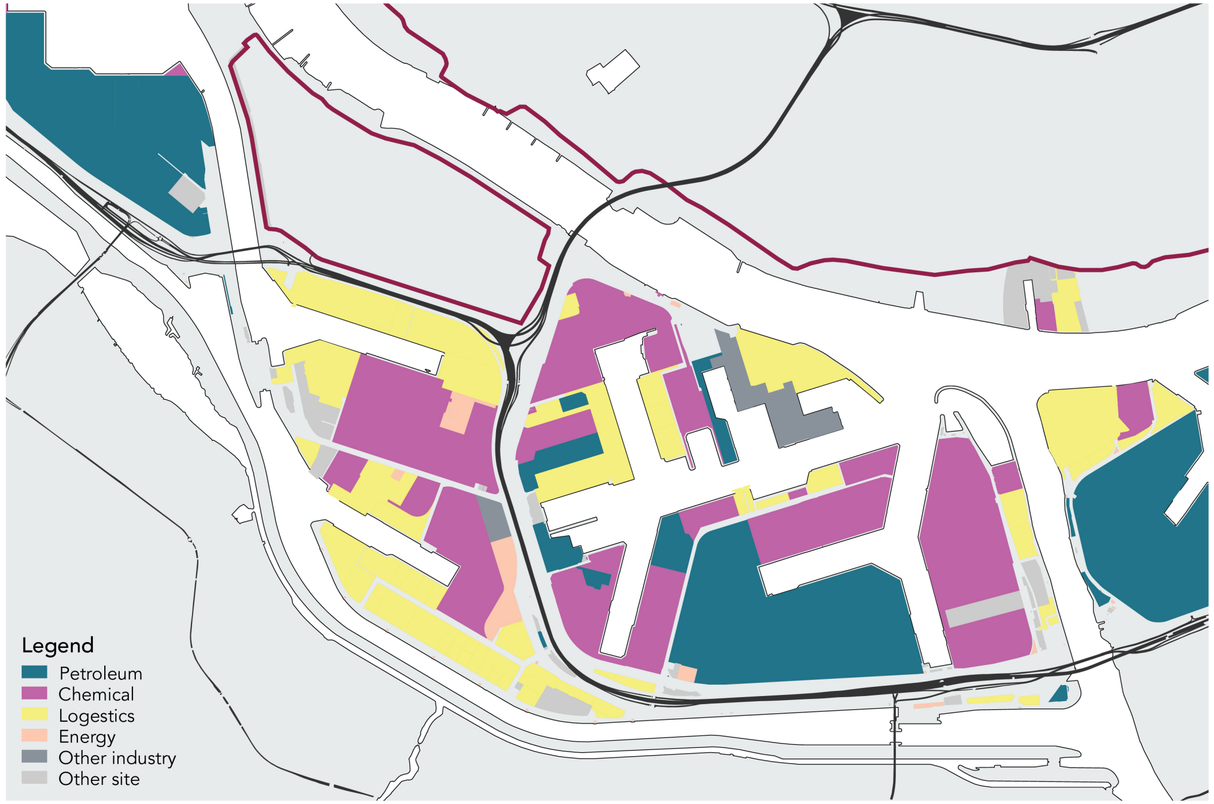
Gradually reclaim land by coupling remediation with spatial and ecological transformation.
Transformation phase intends to
-Reduced contamination levels
-Functional landscapes
-Adaptive infrastructure
-Increased land value

Process (Redevelopment & Long-Term Monitoring)

Make contamination visible, manageable, and governable, without disrupting essential operations prematurely.
Preparation phase is intended to
-Environmental baseline
-Legal clarity
-Spatial strategy
-Safe interim conditions

Existing industies

Fig 7.10: Map of industry classification on Botlek
Source: author



7.3 Brownfield remediation

Remediation of industrial area

In brownfield redevelopment, bioremediation, phytoextraction, and monitored natural attenuation (MNA) are time-dependent remediation strategies whose effectiveness is strongly linked to contaminant type, concentration, depth, and site conditions. Unlike engineered clean-up methods, these approaches trade speed for ecological integration and lower disruption, making their processing time and capacity critical factors in phasing and land-use decisions.

In brownfield management, bioremediation, phytoextraction, and monitored natural attenuation (MNA) differ sharply in how fast they act and how much contamination they can realistically treat.

Remediation process



Fig 7.11: Maps showing the phasing of brownfield remediation process
Source: author

Bio-remediation (engineered microbial degradation) (6-18 months)

Timing

Active bioremediation (biostimulation/ bioaugmentation) can reduce petroleum hydrocarbons by ~99% within weeks–months when conditions (oxygen, nutrients, temperature) are optimized 1015.
Field examples of optimized biochemical treatment achieved ~99.99% removal of petroleum hydrocarbons in 2 months (Fernández et al., 2023).

Biostimulation/bioaugmentation for groundwater uranium reduced concentrations by >90% in about 120 days, and bioaugmentation further shortened the timeframe by 1–2 months (Jakubauskait⊠ et al., 2023).

Capacity

Works best for biodegradable organic contaminants (petroleum hydrocarbons, many solvents, some pesticides); performance depends on electron acceptors, nutrients, and bioavailability (Fernández et al., 2023).

Phytoextration (plant uptake and harvest) (2-5 years)

Timing

For PFAS, 90% removal was estimated to require 6–466 crop cycles depending on compound and plant, implying many decades at realistic cropping intervals (Shahid et al., 2012).
Reviews conclude that phytoextraction must be reduced from “several decades” to <20–25 years to be operationally viable, which is rarely achieved under current practice (Shahid et al., 2012).

Capacity

Capacity depends on biomass production and contaminant concentration in harvestable tissues (bioaccumulation factor (Fernández et al., 2023).

More realistic role is soil polishing or gradual risk reduction at low–moderate contamination, often combined with productive land use (phytomanagement) (Shahid et al., 2012).

Monitored natural attenuation (20+ years)

Timing

MNA relies on existing biological, chemical, and physical processes; it is inherently slow.
Petroleum hydrocarbon plumes: modeled remediation times of ~1.3–10.6 years, with many wells achieving goals in 3–7 years (Jakubauskait⊠ et al., 2023).
Reviews emphasize MNA as a long-term remedy requiring sustained monitoring and acceptable risk during the long cleanup period (Fernández et al., 2023).

Capacity

Most effective where natural degradation and sorption are already significantly shrinking plumes; biodegradation is often the dominant mass-loss process for petroleum hydrocarbons (Jakubauskait⊠ et al., 2023).
MNA is considered low-intervention, low-cost, but capacity is strongly site-specific and may be insufficient to meet strict targets within acceptable timeframes (Jakubauskait⊠ et al., 2023).

7.3 Brownfield remediation

Botlek Island

This map shows the steel reinforcement along the waterfront which helps retain the form of the port, these reinforcements are well engineered to withstand heavy port activities.

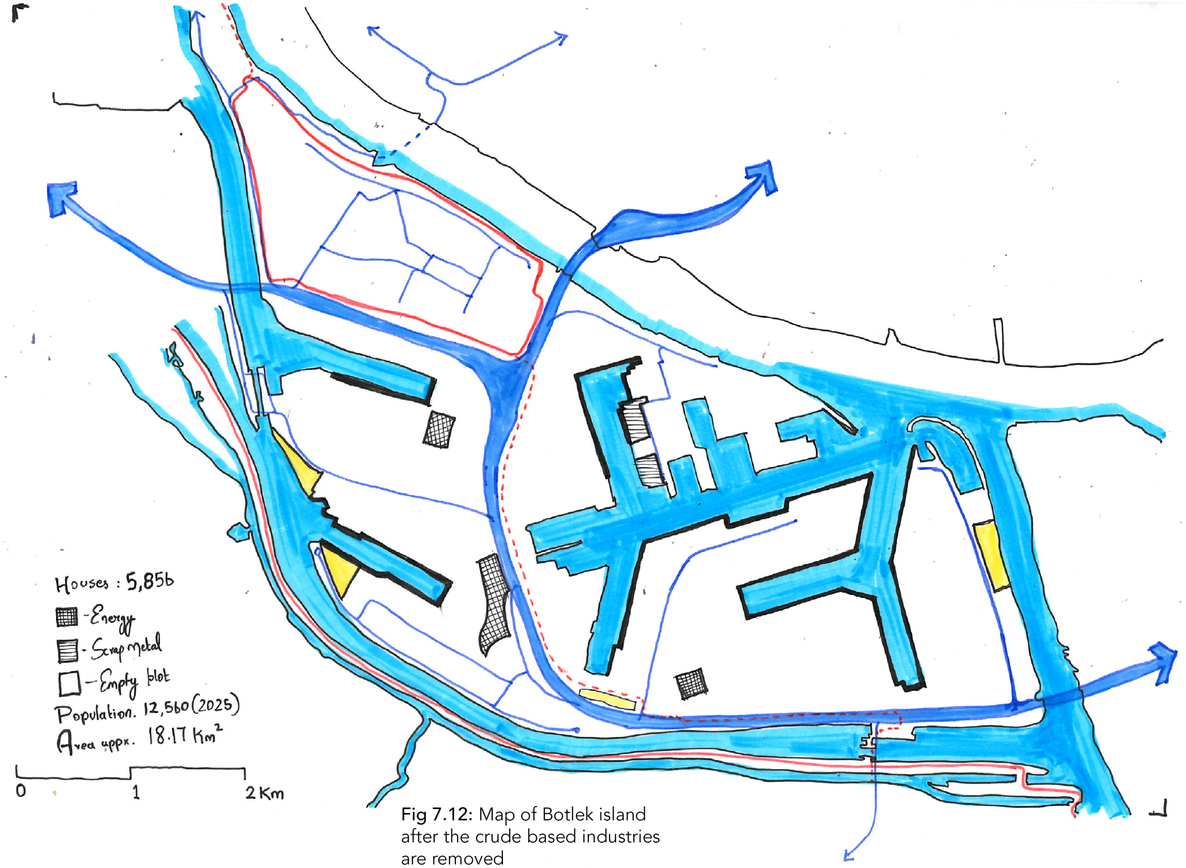


Fig 7.12: Map of Botlek island after the crude based industries are removed
Source: author

Re-naturalising the islands starts with removing this heavy reinforcement. This process is the first step to bring back the original character of the island. The natural formation would now bring back the tidal character. Creating groups of islands. These islands are furthered denoted as Botlek archipelago in further stages.

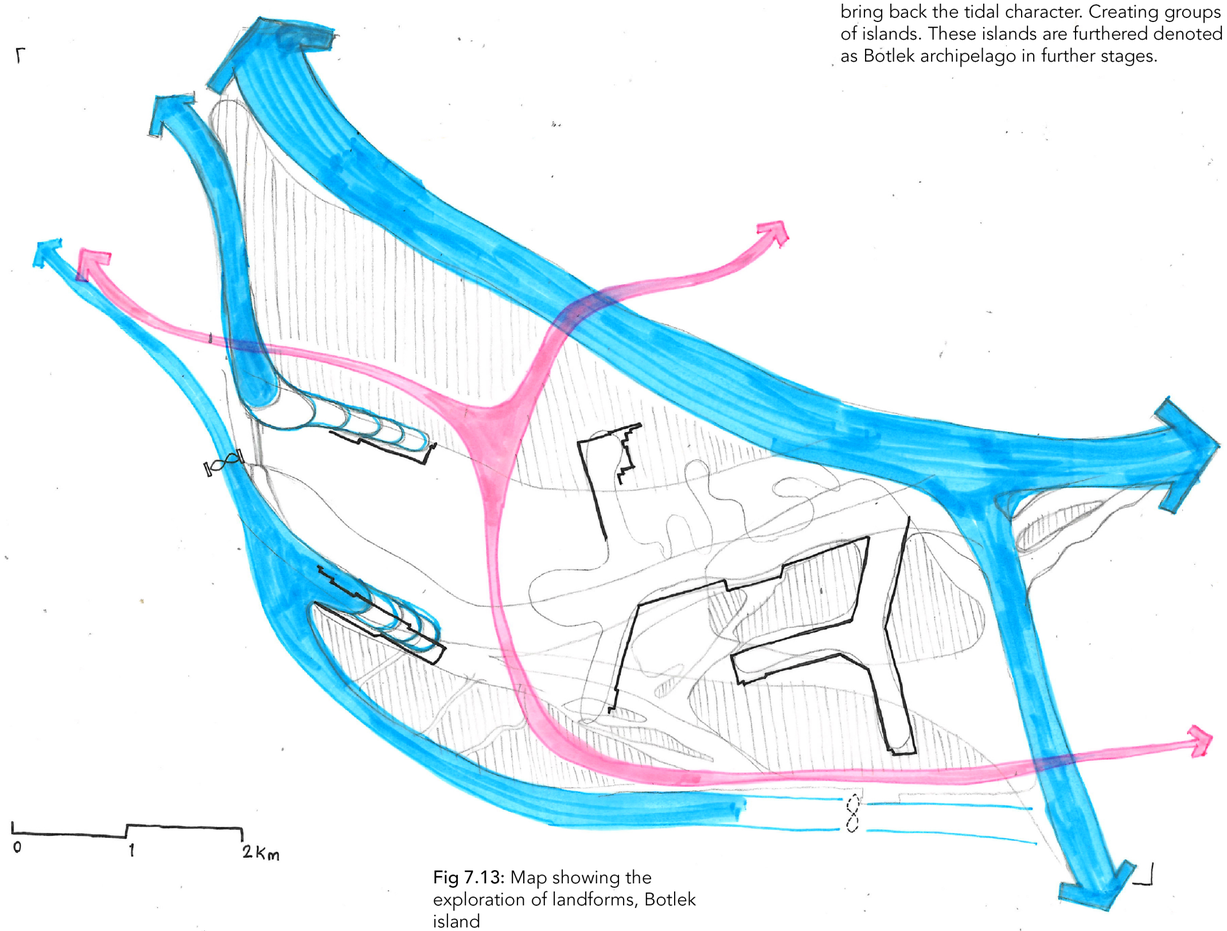


Fig 7.13: Map showing the exploration of landforms, Botlek island
Source: author

7.4 Historical analysis

Botlek Island

The name Botlek originally refers to a tidal channel of the nieuwe Maas. This estuarine landscape separated the Rosenberg islands and a wetland strip called welplaat. The area was originally marshy, tidal and inhabited, mainly used by fishermen community. In the late 1850's and early 1900, Rotterdam region begins major hydraulic works and building dikes, resulting in straightening the river and reduced sediment flows/deposit. This resulted in the botlek region losing its tidal character. Once the river system was engineered Rosenberg Island was inhabited by small group of villages with agricultural land. As the tidal character decline and Rotterdam had ambitions expansion plans for its port. Botlek island became the primary key location for port's future expansion.

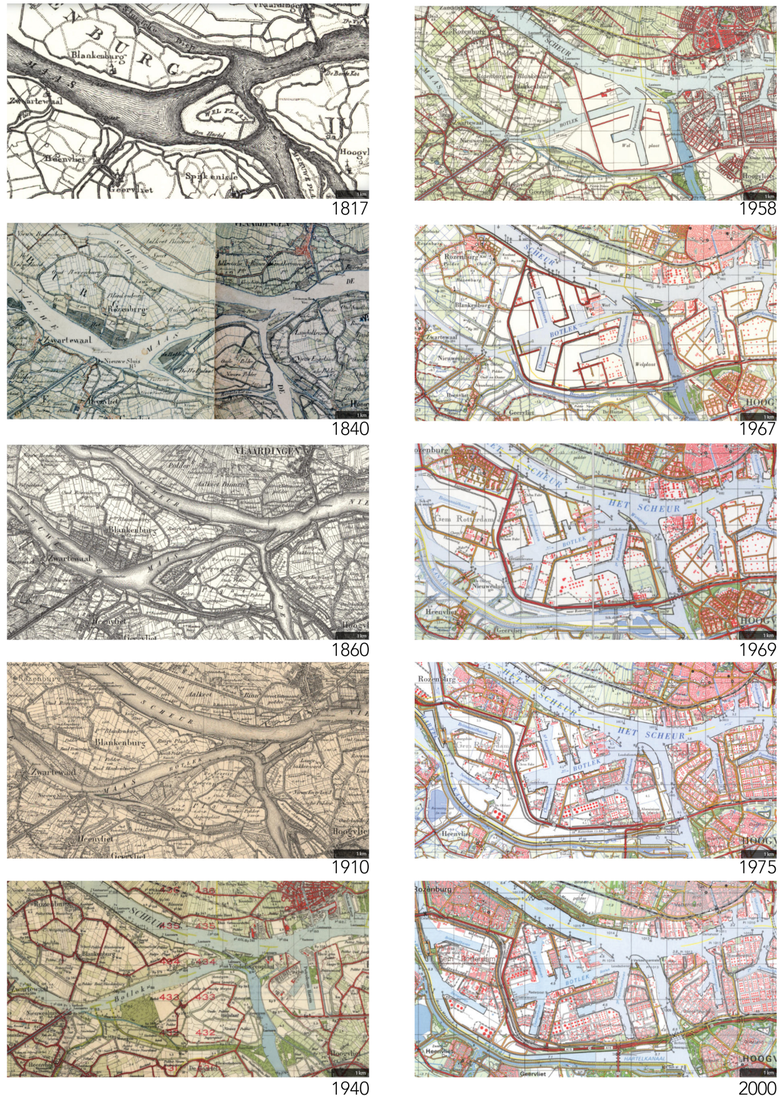


Fig 7.14: Historical maps of Botlek
Source: Topotijdreis

The historical analysis of water flow helps us identify landforms which is has both physical, geomorphological and ecologically sound land for nature centric development. This region also helps water to flow vertical and not horizontal (vertical water movement rain> infiltration > ground water) this region has no alluvial deposits as the landscape acted as a hydrological barrier during historic times.

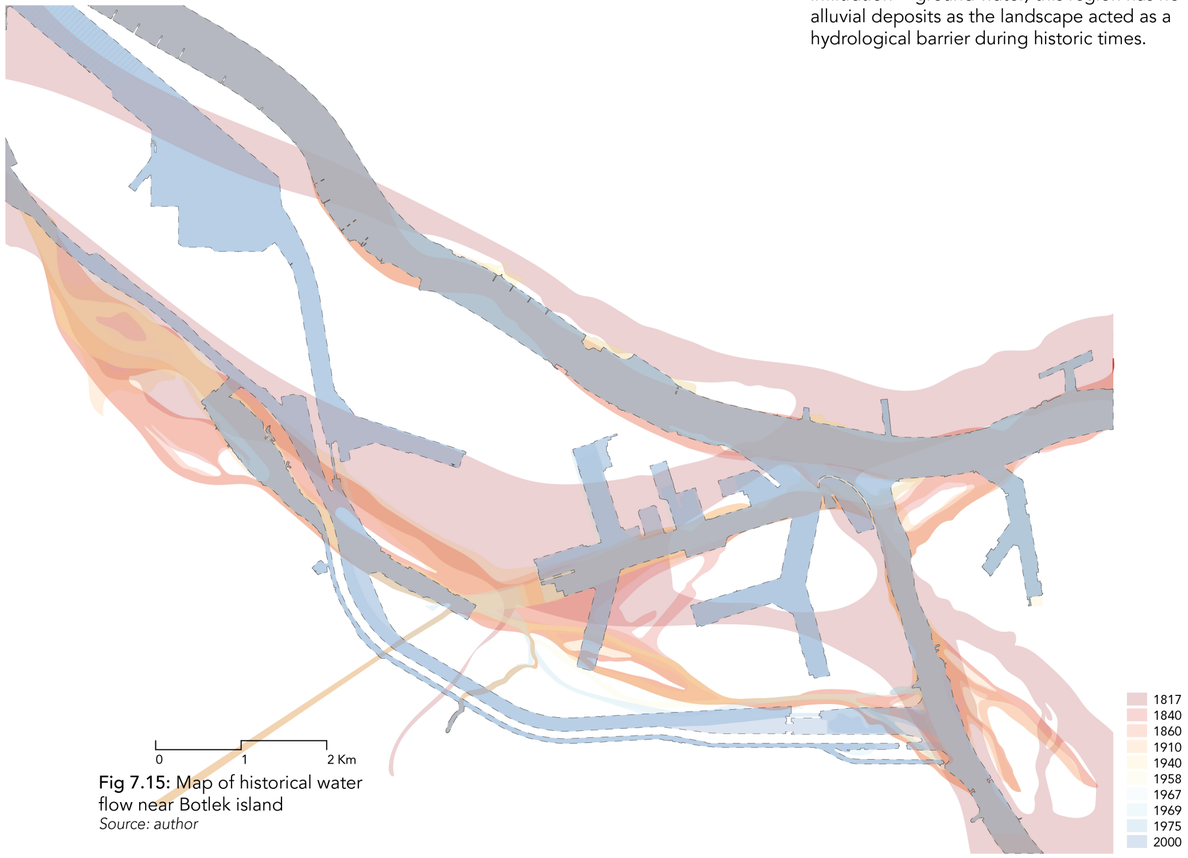
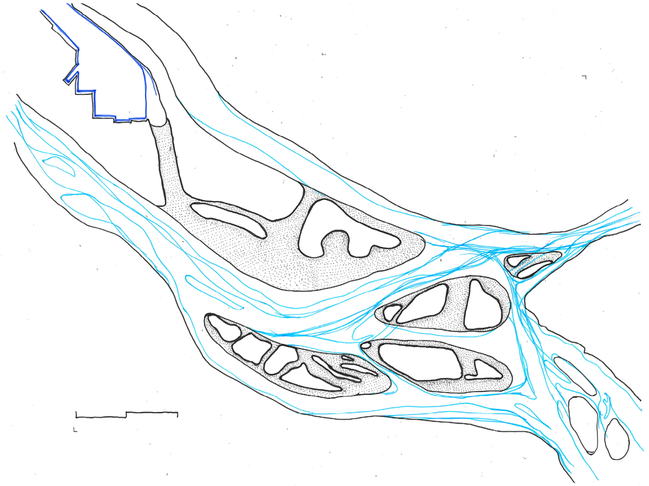


Fig 7.15: Map of historical water flow near Botlek island
Source: author

7.5.1 Design exploration - Rhine archipelago

Botlek Island

- Design exploration starts with understanding the flow of river through time.
- The new landform has strong foothold and is stable through time.
- The interaction between land and water has been further defined.
- The water edge is further defined to enrich biodiversity.
- These regions could be grouped under limnetic zone and littoral zones. Littoral zones consist of shallow water which allows sunlight through for plant photosynthesis. This region is rich in biodiversity.
- Limnetic zones are far from shore and consist of deeper water zones where depth is high and light reaching riverbed is no longer sufficient for photosynthesis



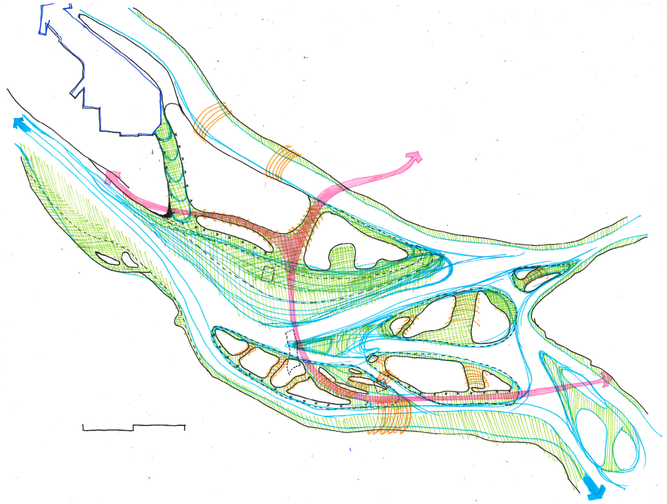


Fig 7.16(top): Map showing the exploration of new landforms
Source: author

Fig 7.17(bottom): Map showing the design sketch of new islands
Source: author

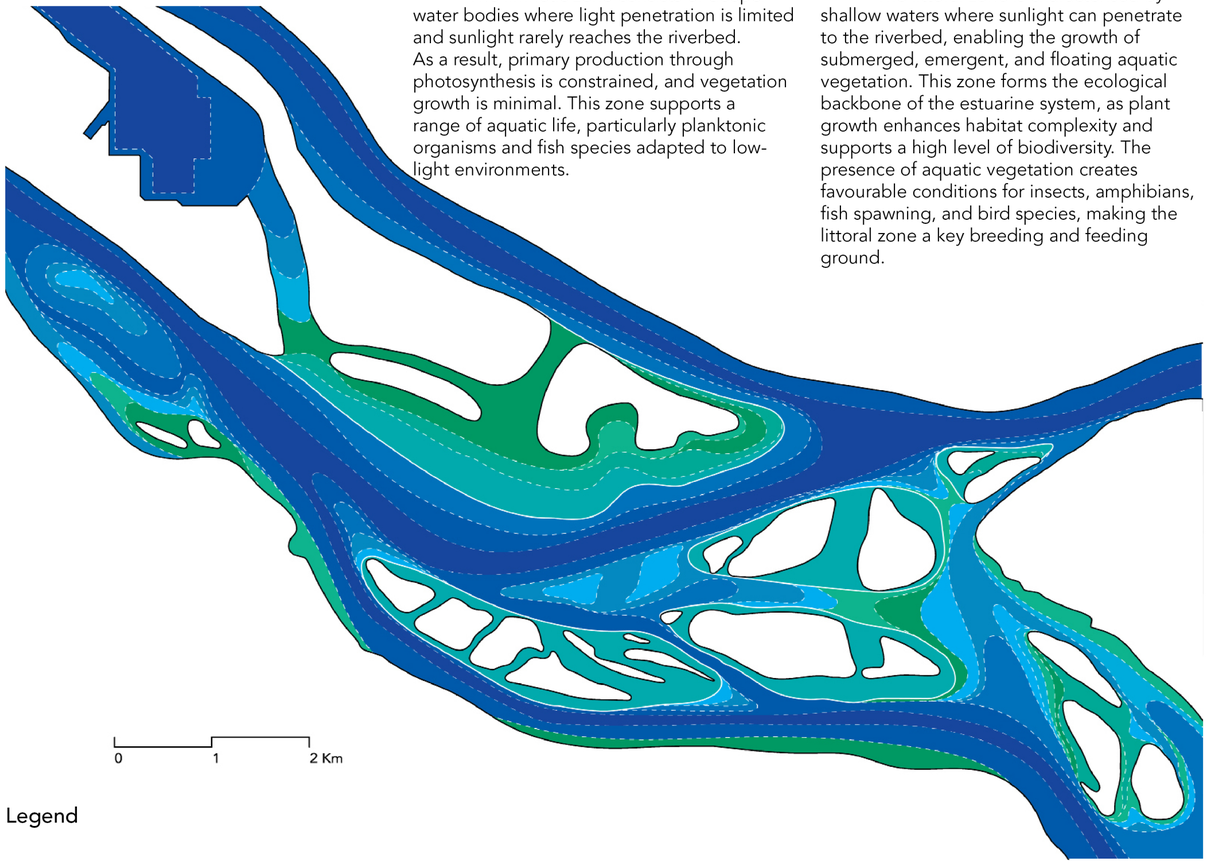
Fig 7.18(right): Map of new water character of Rhine archipelago
Source: author

Limnetic zone

The limnetic zone consists of deeper water bodies where light penetration is limited and sunlight rarely reaches the riverbed. As a result, primary production through photosynthesis is constrained, and vegetation growth is minimal. This zone supports a range of aquatic life, particularly planktonic organisms and fish species adapted to low-light environments.

Littoral zone

The littoral zone is characterised by shallow waters where sunlight can penetrate to the riverbed, enabling the growth of submerged, emergent, and floating aquatic vegetation. This zone forms the ecological backbone of the estuarine system, as plant growth enhances habitat complexity and supports a high level of biodiversity. The presence of aquatic vegetation creates favourable conditions for insects, amphibians, fish spawning, and bird species, making the littoral zone a key breeding and feeding ground.



Legend

Deep water (-15m) For ships
Water depth -8m (max.)
Water depth -5m (max.)
Water depth -3m (max.)
Water depth -1m (max.)
Water depth Swamps 0.0m (max.)
Level 0.5m Mash lands
Level 1.0m Wetlands
Level 1.5m Tidal forest

Limnetic zone
Littoral zone

7.5.2 Design exploration - Rhine archipelago

Flora and Fauna

The new landscape of the Rhine archipelago provides highly favourable conditions for the development of a resilient estuarine ecosystem. This landscape can be ecologically structured into two primary zones: the limnetic zone and the littoral zone, each playing a distinct yet complementary role within the river estuary system.

Beyond biodiversity support, the littoral zone performs critical ecosystem services. Dense root systems stabilise sediments and reduce shoreline erosion, while vegetation acts as a natural biofilter that absorbs nutrients and pollutants from the water column. This filtration capacity improves water quality and mitigates the impacts of upstream contamination. Littoral zones buffer hydrodynamic forces during high water events, contributing to flood resilience and prevents erosion within the delta.

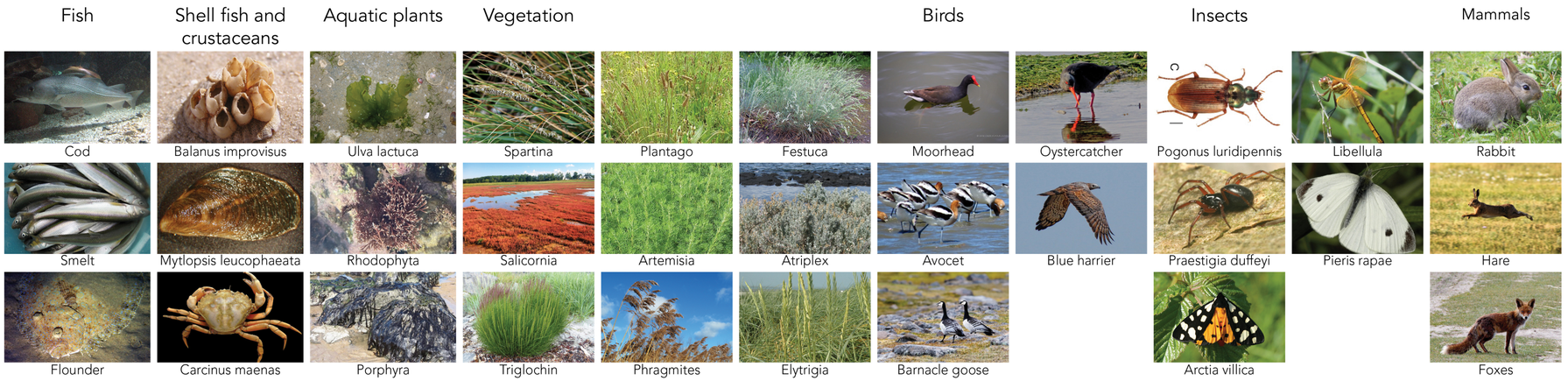
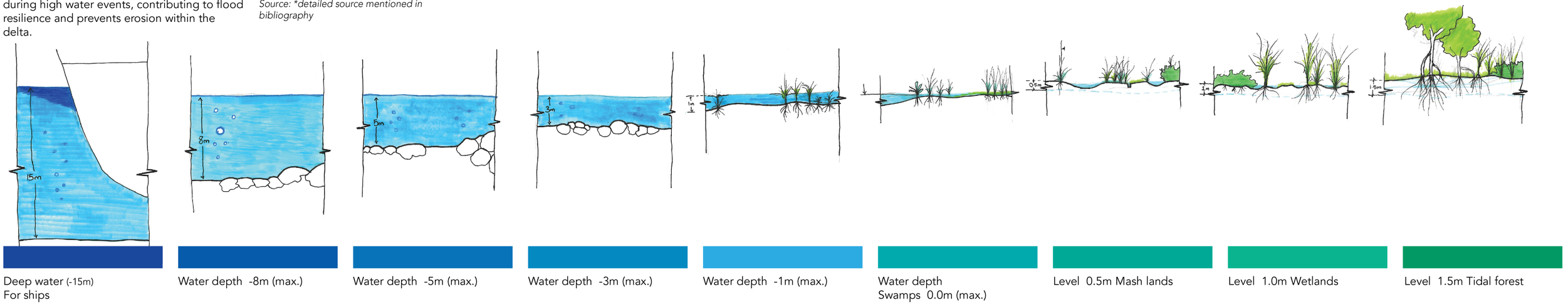


Fig 7.20: Flora and fauna of the new landscape
*Source: *detailed source mentioned in bibliography*



Deep water (-15m)
For ships

Water depth -8m (max.)

Water depth -5m (max.)

Water depth -3m (max.)

Water depth -1m (max.)

Water depth
Swamps 0.0m (max.)

Level 0.5m Mash lands

Level 1.0m Wetlands

Level 1.5m Tidal forest

Limnetic zone

Littoral zone

The limnetic and littoral zones form an integrated estuarine system in which hydrological processes, ecological functions, and landscape dynamics reinforce one another. In the context of the Rhine archipelago, prioritising the expansion and connectivity of littoral zones alongside stable limnetic channels enhances ecosystem health, strengthens climate resilience, and re-establishes the delta's capacity to function as a living landscape rather than a purely engineered system.

7.5.3 Design exploration - New landsapes

High water scenario

On the event of high discharge from upstream river basins or high tidal region, the shallow part of the marshes and wetlands goes under water leading to clearly define different different islands of archipelago. They are connected by by networks that are raised above ground, and these networks are built take into the consideration of dynamism in the landforms and water levels.

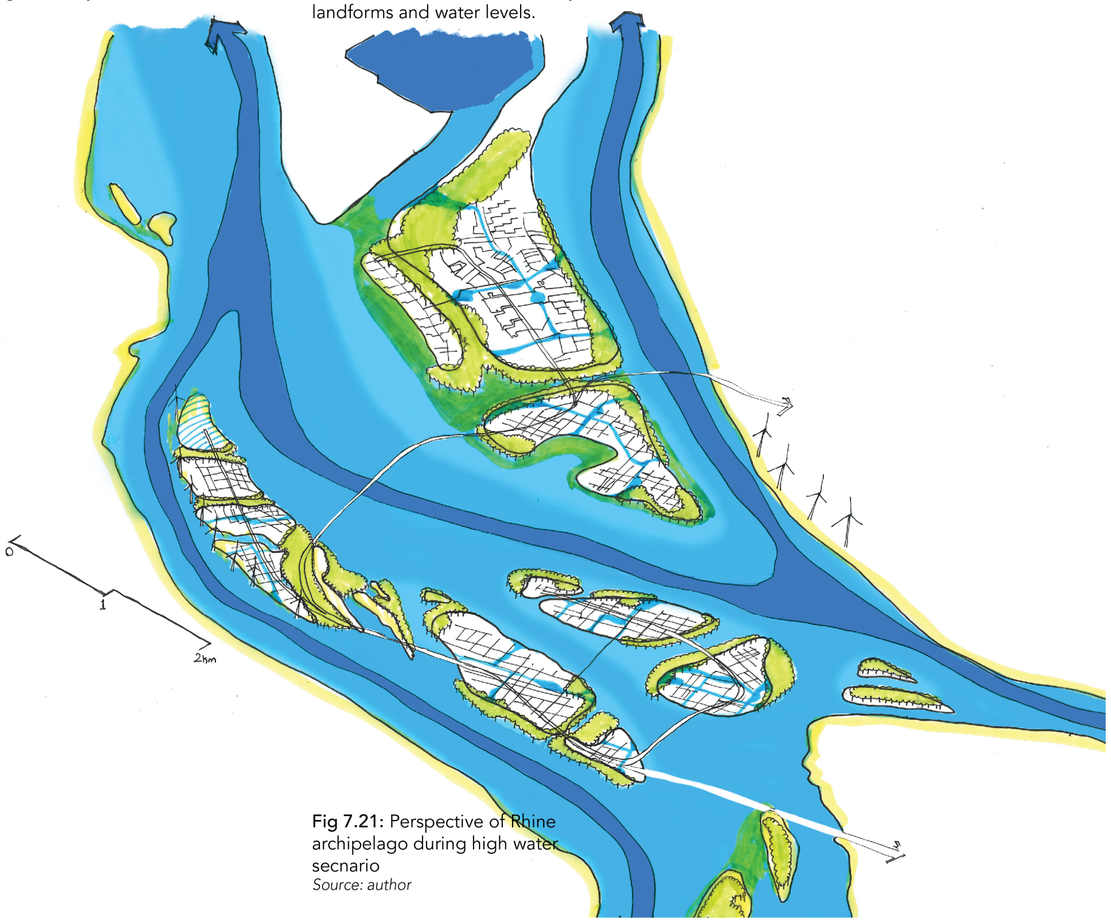


Fig 7.21: Perspective of Rhine archipelago during high water secnario
Source: author

Low water scenario

Low tidal period or during peak summer where the river discharge reduces. The marshes and wetland and floodplains are covered in green and attracts new typology of biodiversity. Low tidal period also groups certain islands to form new landforms. These regions help mitigate ground water tables and address salination from sea.



Fig 7.22: Perspective of Rhine archipelago during low water secnario
Source: author

7.6.1 Rhine archipelago - Networks

Critical networks

Islands of archipelago in urban environments need to be connected for safe human habitation. Apart from connecting the islands to Rotterdam city, the port connection runs through this archipelago in the form of TEN-T corridors and rail network. The movement of people to these islands is through elevated roads and metro networks

Public transport exporation

Connection the islands was essential but connecting them though public transport network is crucial for environmental sustainability and livability. Elevated metro lines have been used as primary networks while the neighborhood is developed with transit-oriented development strategies. The metro network has 4 iterations with certain efficiency, adapting multi modal transit systems. Primary connection points are metro line B to Hoek van Holland and metro line D to De Akkers extending to connect these islands. These two lines create access to both Rotterdam central and Rotterdam Zuidpoort.

Street profiles

Streets within the neighbourhood are designed to incorporate the overarching idea of tidal living. The main road networks are ~24m with motorways and dedicated bike and walking paths. The artillery roads are of ~12m with integrated/ shared street both for bikes and motorways while having the characters to encourage walking. Both these streets would run parallel to a blue green zone.

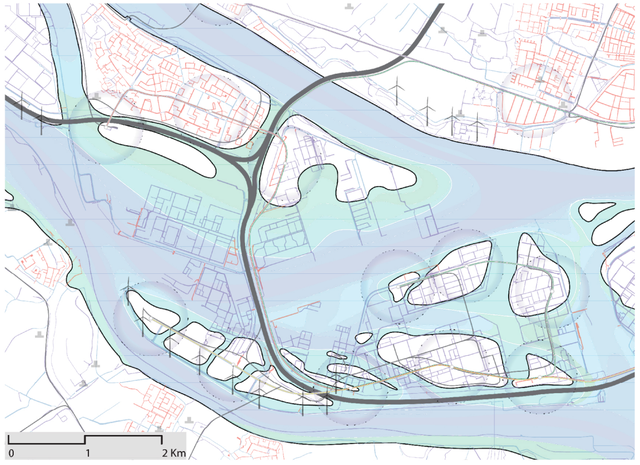


Fig 7.23: Existing network layout
Source: author



Fig 7.24: Proposed public network layout
Source: author

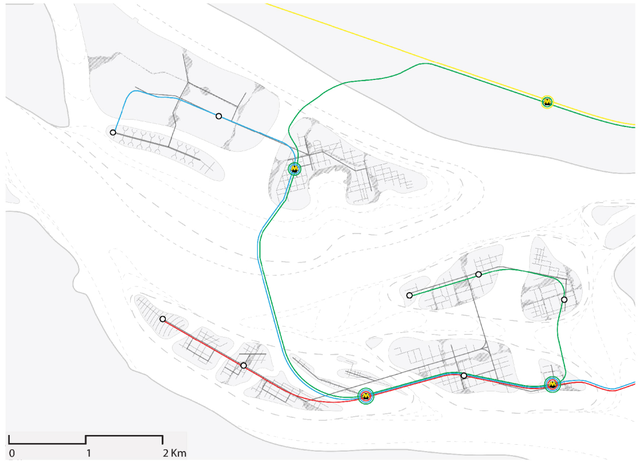


Fig 7.25: Proposed network layout with metro lines
Source: author



Fig 7.26: Proposed network layout optimised with feeder system
Source: author



Fig 7.27: Proposed optimised metro network layout
Source: author

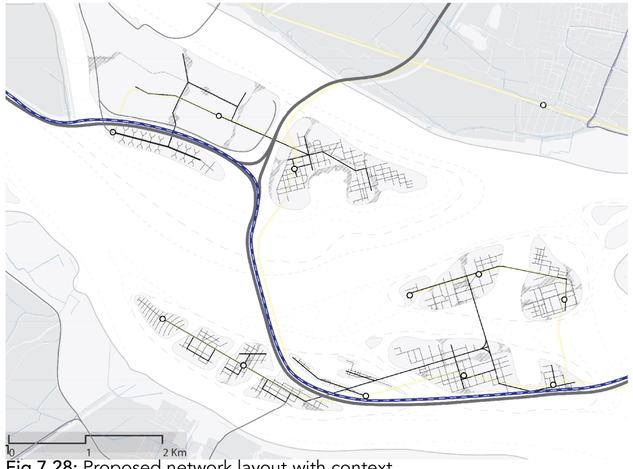


Fig 7.28: Proposed network layout with context
Source: author

7.6.2 Rhine archipelago - Networks

Botlek Archipelago

The elevated metro lines, main roads and artillery roads form a ridged gridded layout. While the island tends to form a new identity of incorporated tidal living. The network tends to replicate a traditional urban planning setup. To overcome this. Blue green axis is introduced into the neighborhoods. These axes bring in the dynamism that's seen around the islands into the neighborhood.

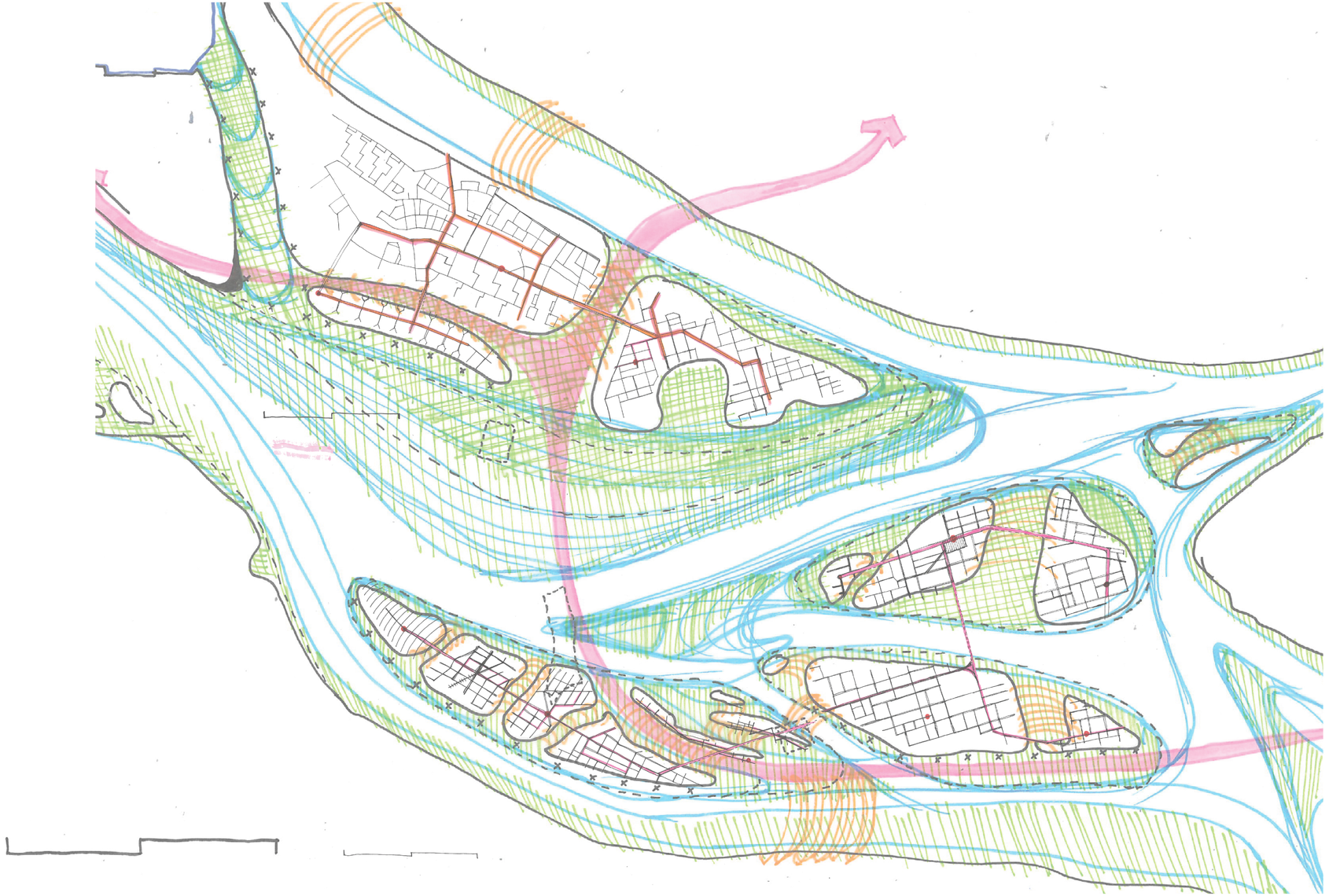


Fig 7.29: New network layout of Rhine archipelago
Source: author

7.6.2 Rhine archipelago - Networks

Blue-green networks

Blue green corridors are introduced into the neighborhood to bring in the tidal aspect of living.

These blue-green corridors function as the spatial and ecological backbone of the island landscape, facilitating the integration of tidal processes into the urban and productive environments. By enabling controlled water flow, ecological connectivity, and vegetated buffers, the corridors link the islands to the surrounding estuarine system, enhancing biodiversity while mitigating flood risks.

Each island has its own center, connected to a metro. This center is equipped with activities such as commercial and public spaces alongside having characters of walkability and sense of space. The blue green corridors/ tidal axis of each island passes through the centers. This brings dynamism into the center but also enhances Co living aspects between humans and biodiversity.

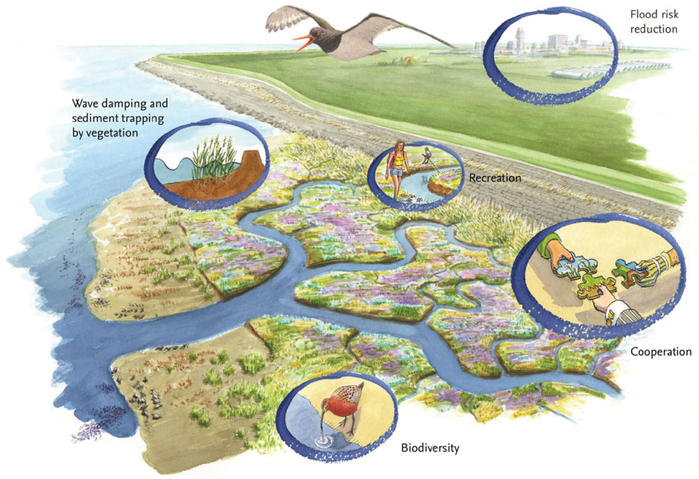
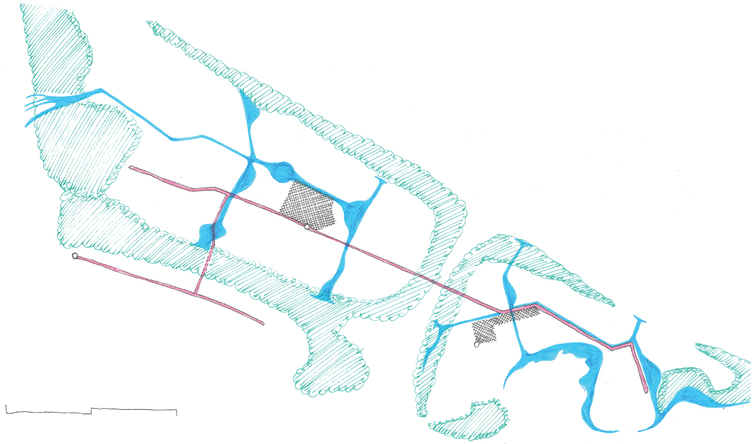


Image from PBL



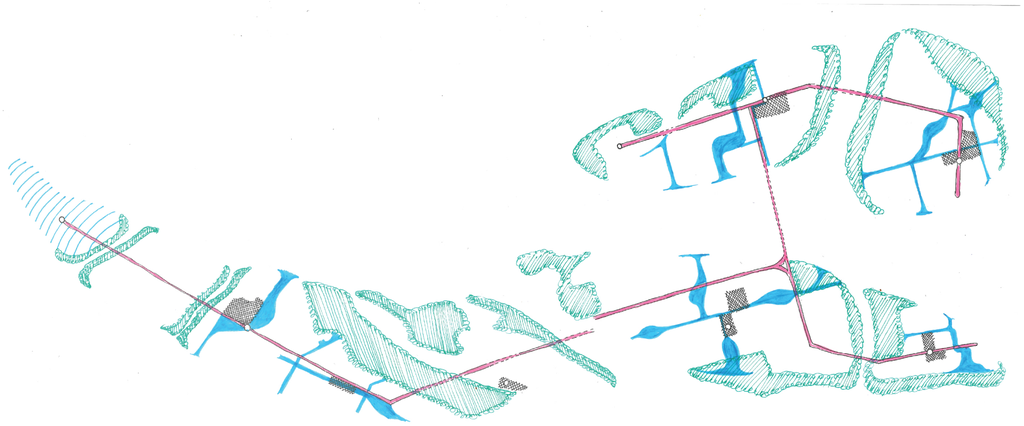


Fig 7.30(right): New blue green network layout of Rhine archipelago
Source: author

7.6.2 Rhine archipelago - Blue green

Blue-green networks

The islands of the Rhine archipelago are embedded within a biodiversity-rich landscape that is inherently resilient to evolving climate risks. While the surrounding tidal ecosystem operates as a dynamic and adaptive landscape, the islands themselves are conceived as more rigid landforms within this fluctuating system. To reconcile this contrast and ensure ecological and spatial continuity, a network of blue-green corridors is introduced across the islands, aligned with their primary functional structures.

Built form along these corridors is strategically designed to accommodate fluctuating water levels. Buildings and mobility on public regime are elevated and articulated through adaptable plinth systems that can withstand both high and low water conditions, ensuring long-term resilience without compromising spatial quality. In this way, the blue-green corridors not only structure the landscape but also mediate the relationship between water dynamics, ecological systems, and human occupation, reinforcing the islands' capacity to function within a living, tidal delta.

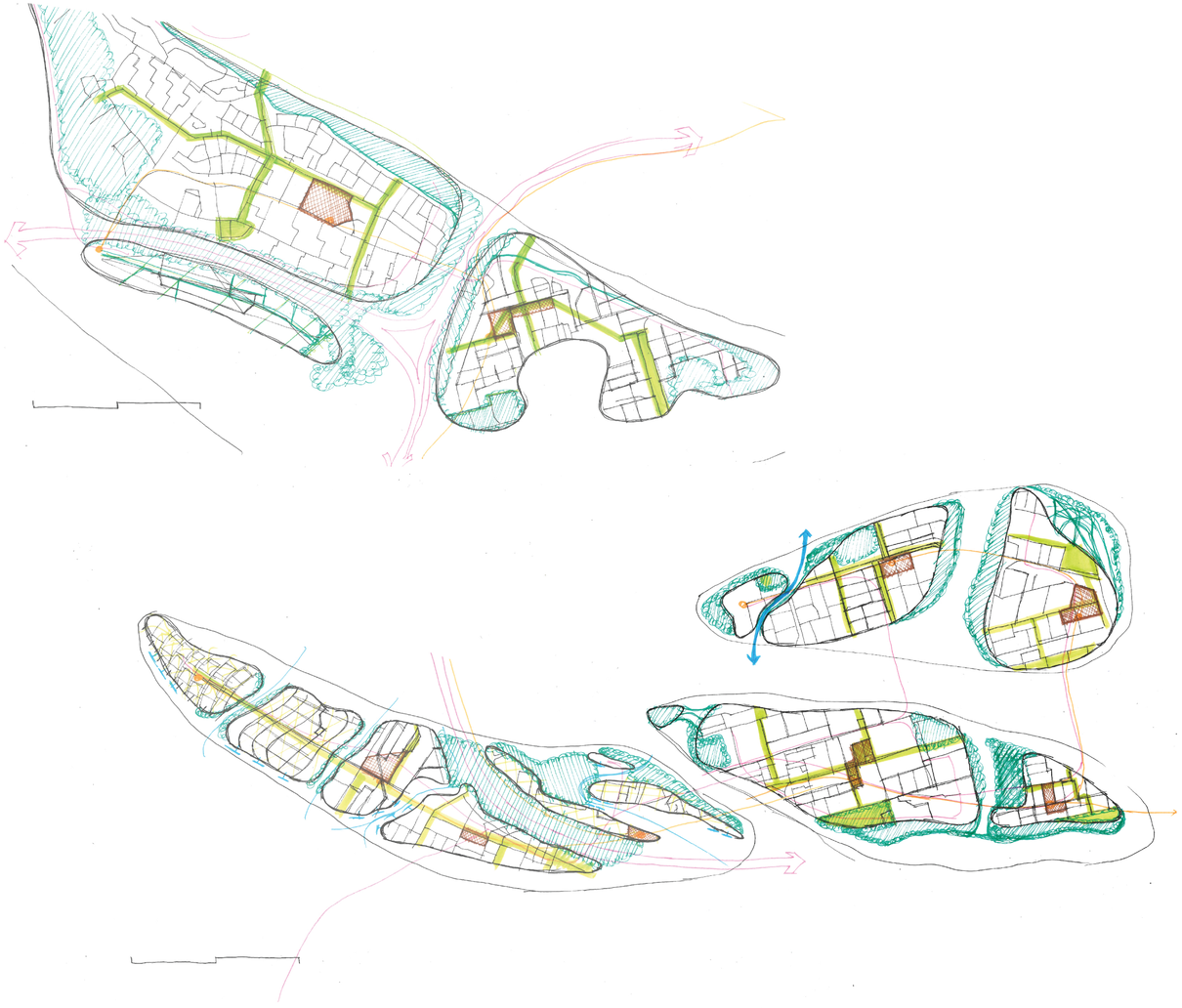
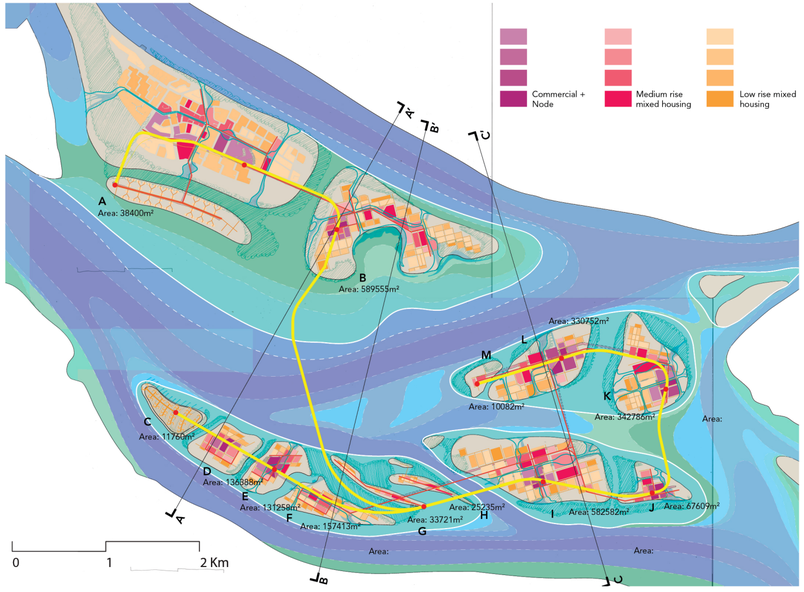


Fig 7.31: New network layout with blue green corridor in Rhine archipelago
Source: author

7.6.3 Rhine archipelago - Design exploration

Once region of Botlek stood as a solid dense industrial port that is now given back to nature. The section denotes how little the islands are developed in comparison to regions dedicated to nature. The section also shows how the water depth is shallow in most regions while still allowing some routes for ships and inland barges.



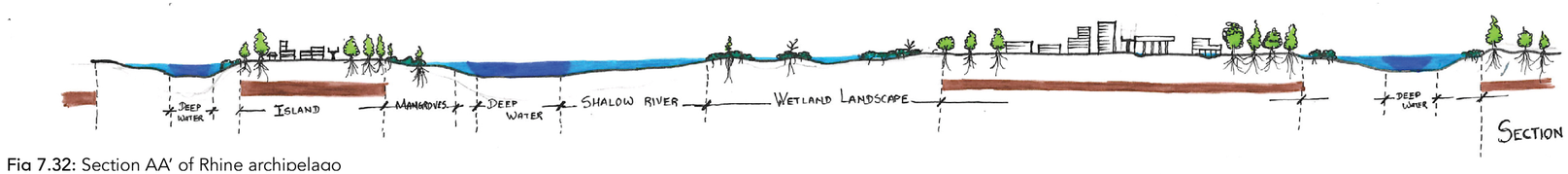


Fig 7.32: Section AA' of Rhine archipelago

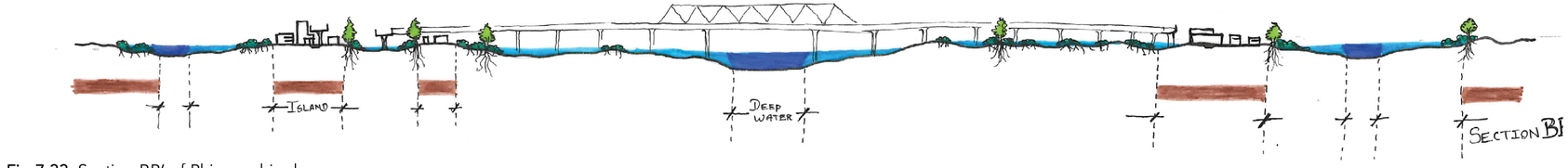


Fig 7.33: Section BB' of Rhine archipelago

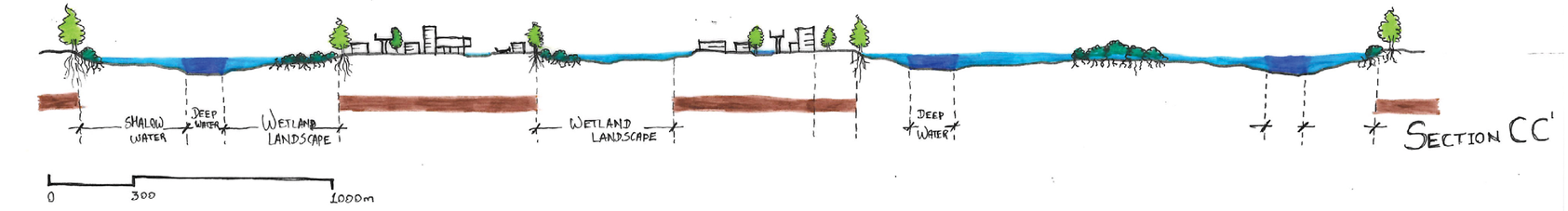


Fig 7.34: Section CC' of Rhine archipelago
Source: author

7.6.4 Rhine archipelago - Urban development

Developing islands with boundaries that don't resemble traditional geometric layouts posed a significant challenge. To overcome this, the historical layout was traced, and the current islands are now developing with grids that resemble the existing industrial layout. This brings the contrast in identities of how each neighborhood, once had array of storage tanks in both directions now stand as a testimony to new urban development, denoting how blue green networks in the neighborhood brings tidal living the new norm. These grids are divided into block sizes referenced by the Ijburg development in Amsterdam.

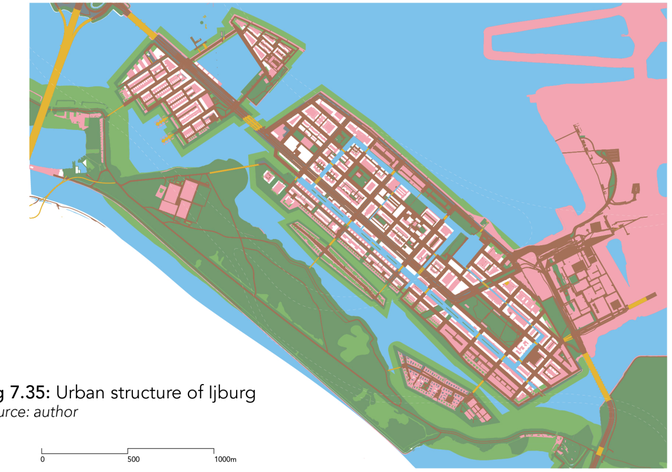


Fig 7.35: Urban structure of Ijburg
Source: author

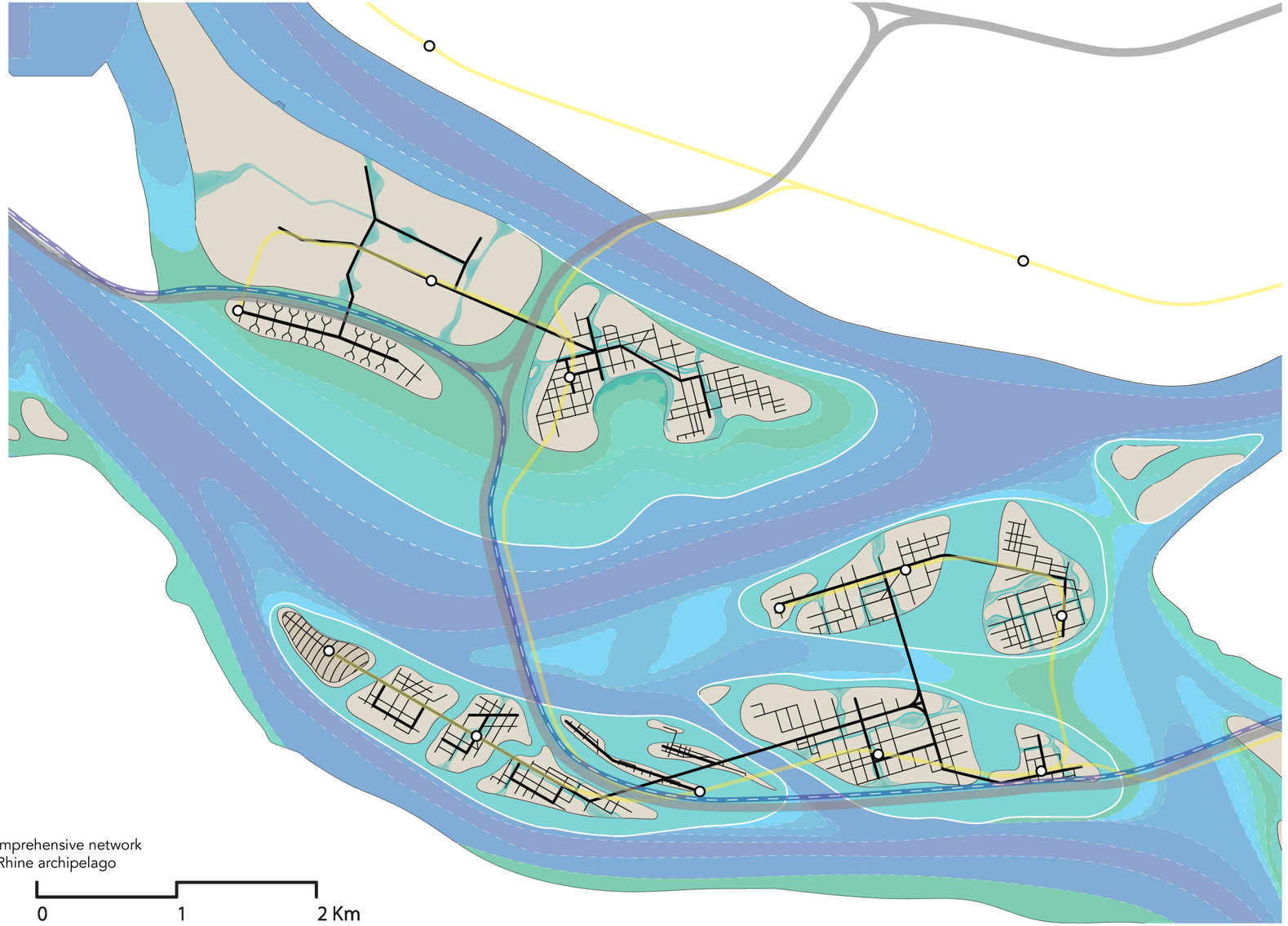


Fig 7.36: Comprehensive network structure of Rhine archipelago
Source: author

7.6.5 Rhine archipelago - Urban identities

Island identities

The irony of the development is how once Botlek was chosen to cater for one of the biggest industrial port expansions in Rotterdam port, post-world war through botlekplan now aims to bring back the tidal quality and breakdown the industrial mass into fragments of landforms enclosed by nature.

The Botlek archipelago now is tidal, but nature incorporates water within the neighborhood and is well connected to the city center of Rotterdam through public transport networks. Each island has its own transit node, and urban development follows a transit-oriented structure, with the center being dominated by medium rise commercial and recreation spaces followed by medium raise high density residential neighborhood, the spatial planning follows a gradient finally ending up in low raise low density neighborhood

The islands currently do not have names, hence labels in alphabets for the time being.

Island A - low-density low-rise development, catered for villas and holiday homes having tidal grounds as backyards

Island B - consists of medium rise development and low rise developed at medium density. This island is one of the biggest new islands, primarily focused on permanent residential neighborhoods.

Island C - purely floating development focuses on caterer recreation and serves as an incubation center for innovation in building on water. This landscape acts as real live experimental neighborhood for people to visit and experience it.

Island D and E - focused on tourism with docks for small vessels, this island holds residents in a much denser setting

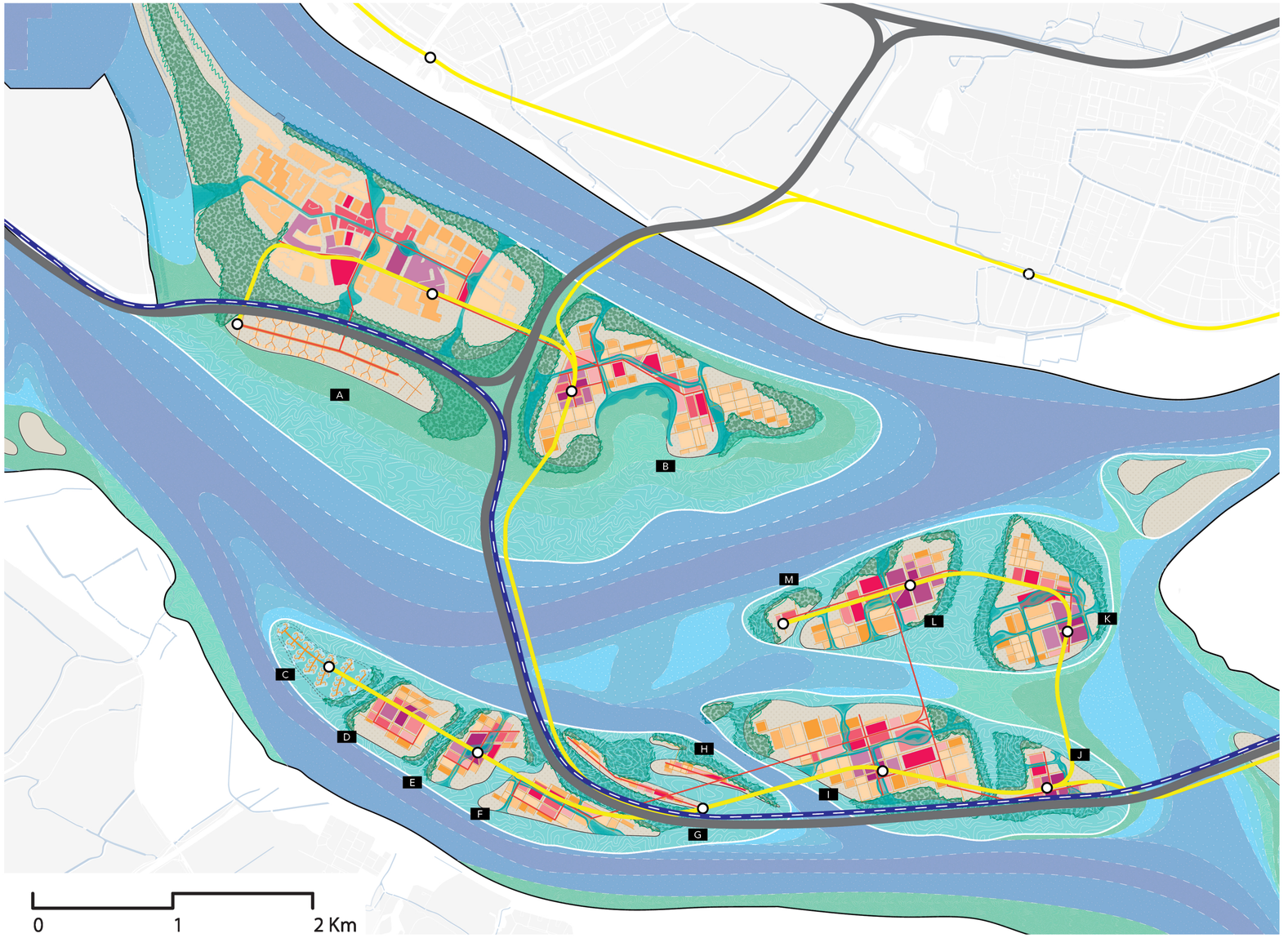


Fig 7.37: Urban plan of Rhine archipelago
Source: author

7.6.5 Rhine archipelago - Urban identities

Island identities

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The islands currently do not have names, hence labels in alphabets for the time being.

Island F - planned to be a medium density low raise neighborhood

Island G, H, M - small, fragmented island predominantly dominated by nature but still have some residents. These residents tend to embrace living with natives and paddling along tidal wetlands as their evening commute

Island J- planned to be high dense medium and low-rise development. Compact in its functions yet delivers the alternate lifestyle while not compromising any aspects in functionality and connectivity

Island I, K, L - medium island of the archipelago. It has a mix-use of medium and low-rise development. The density follows a standard normal curve, where the areas next to transit node have higher density than the edges of the islands

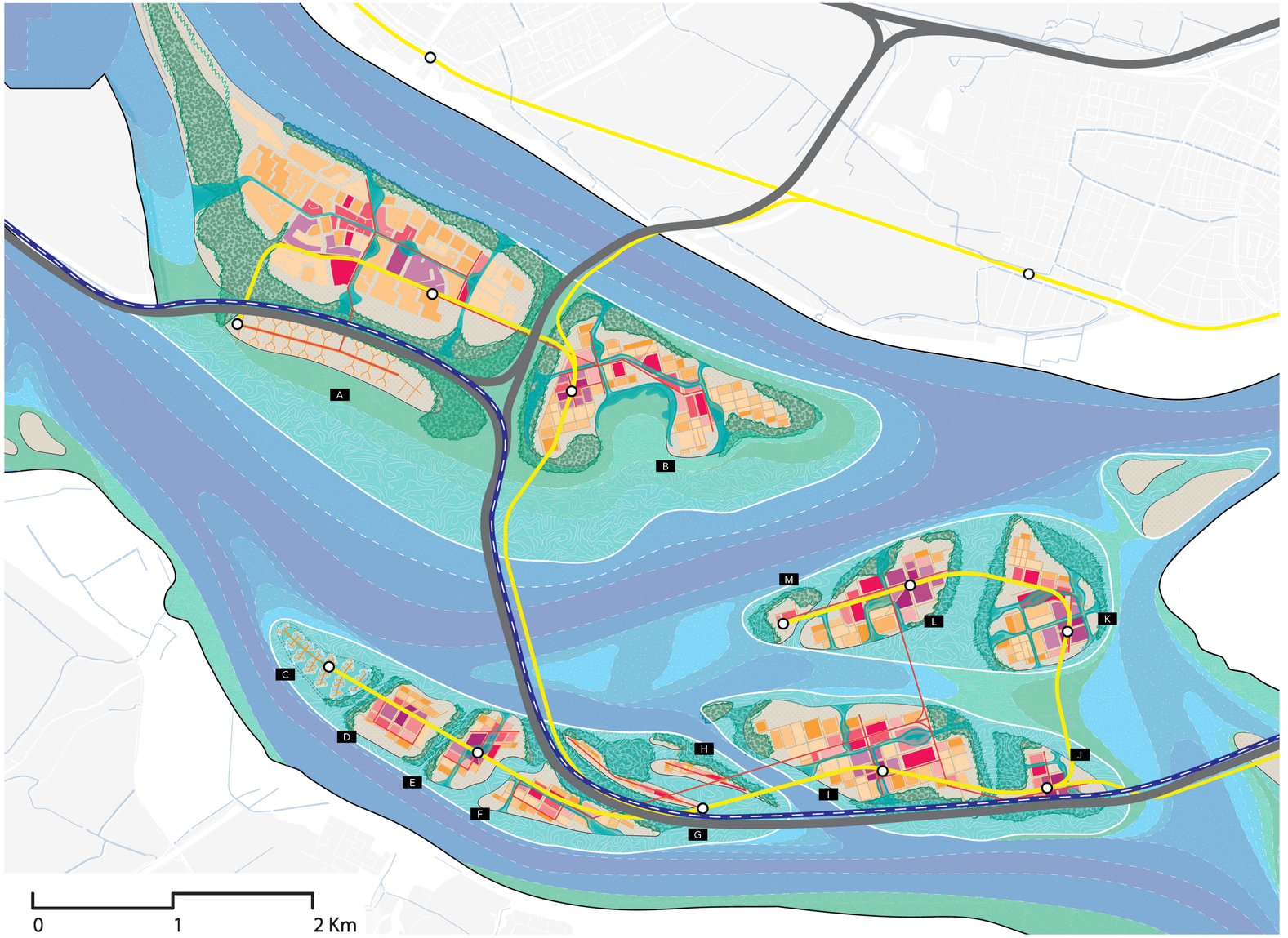


Fig 7.37: Urban plan of Rhine archipelago
Source: author

7.6.6 Rhine archipelago - Spatial framework

Island B

Island B is one of the largest islands in the Rhine Archipelago and is located adjacent to the Rozenburg neighborhood. With approximately 59 hectares (589,555 m²) of developable dry land, the island functions as a vibrant urban district accommodating a diverse mix of residential, commercial, and recreational uses. Its development is structured around a transit-oriented design (TOD) approach, ensuring efficient land use and strong connectivity while supporting a compact urban form.

The spatial organization of Island B follows a bell-curve distribution of density, in which the highest concentration of functions and building intensity is located around the central transit node and gradually decreases with distance. This spatial logic promotes walkability and public transport use while reducing dependency on private vehicles, reinforcing sustainable mobility as a defining characteristic of the neighborhood.



Fig 7.38: Spatial framework of Island B of Rhine archipelago
Source: author

7.6.6 Rhine archipelago - Spatial framework

Isometry – Island B

Isometric view of Island B illustrates the close integration of urban living with the surrounding tidal landscape. The elevated transit infrastructure is designed to remain functional under fluctuating water levels, allowing the island to operate within changing hydrological conditions. This configuration demonstrates how infrastructural resilience can be embedded into everyday urban systems.

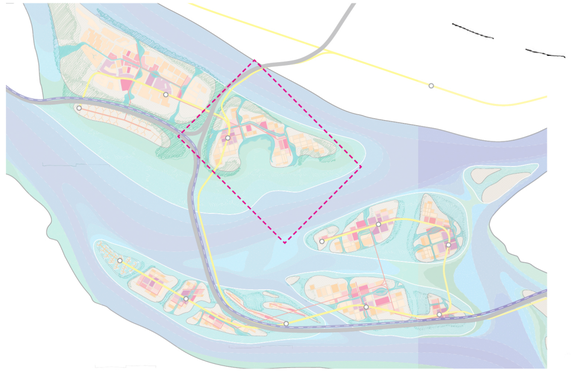


Fig 7.39(right): Aerial view of Island B of Rhine archipelago
Source: author

7.6.6 Rhine archipelago - Spatial framework

Island I

Island I, situated in the southeastern part of the archipelago, is directly connected to Rotterdam Zuid through an extended metro line. As one of the most densely developed islands, it accommodates a broad range of urban typologies, including medium-rise, high-density mixed-use blocks and low-rise, low-density individual housing, ensuring diversity in both built form and housing options.

The urban center of Island I is defined by the superimposition of a transit node and a blue-green corridor. This spatial overlap strengthens accessibility while integrating ecological systems into the urban core, establishing a multifunctional center that supports mobility, social activity, and environmental resilience simultaneously.

Buildings located along the blue-green corridor adopt adaptive construction techniques, including pile-supported plinths. These structural systems allow public movement and daily activities to continue during both high and low water conditions, ensuring spatial continuity and reinforcing the island's capacity to function within a tidal environment.

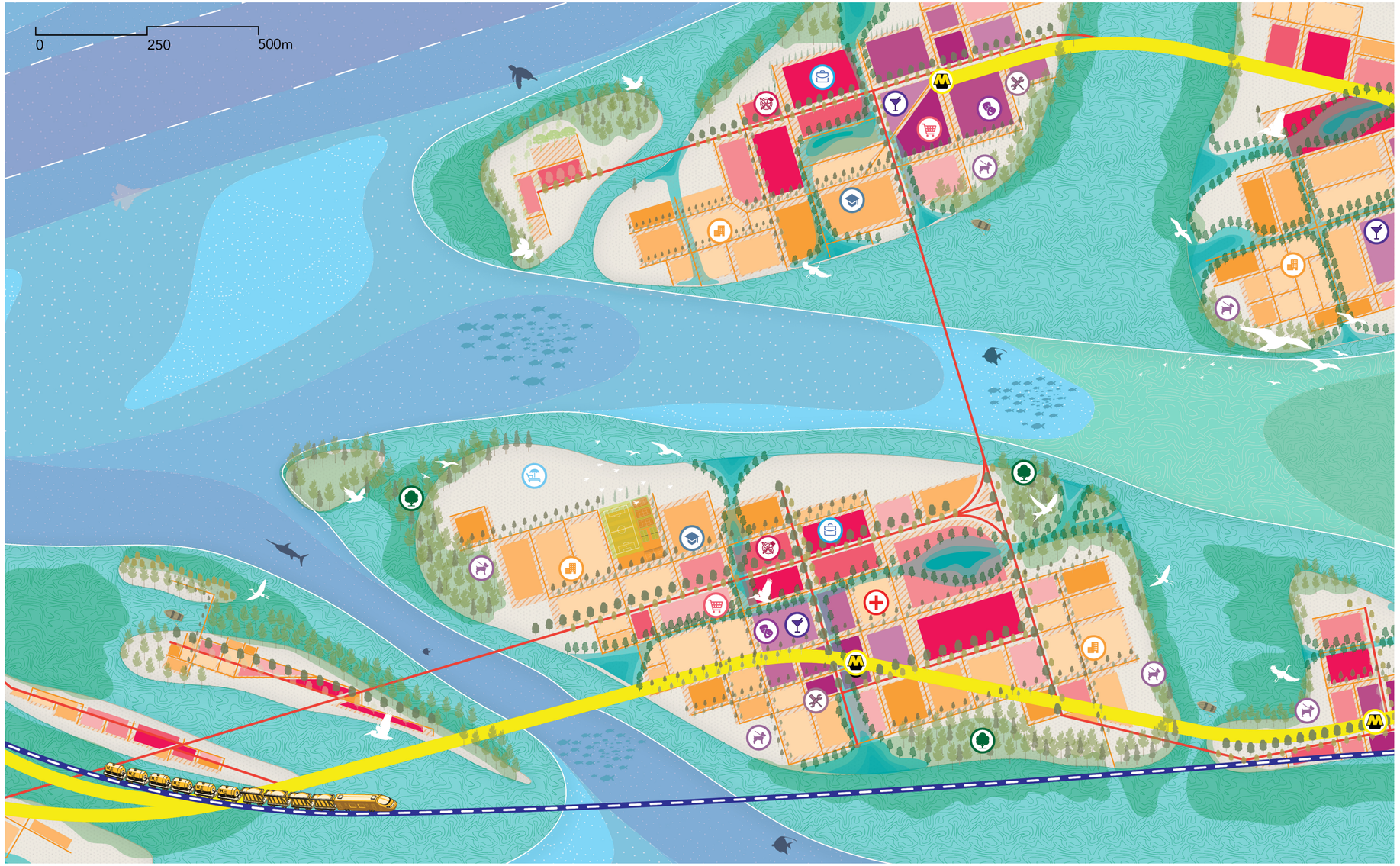


Fig 7.40: Spatial framework of Island I and L of Rhine archipelago
Source: author

7.6.6 Rhine archipelago - Spatial framework

Isometry – Island I

Isometric view of Island-I highlights its distinct urban character, shaped by the interaction between dense urban programs, transit infrastructure, and ecological corridors. This configuration fosters a culturally vibrant and disaster-resilient neighborhood, where tidal dynamics are not treated as constraints but as defining spatial qualities.

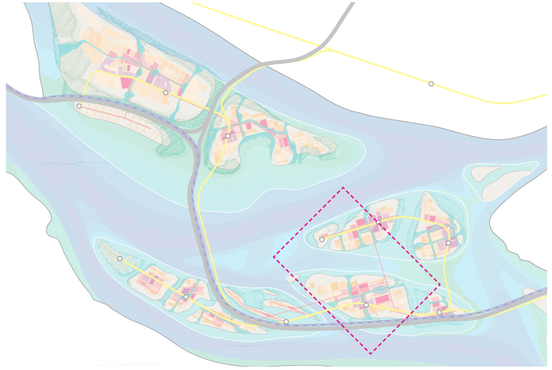


Fig 7.41(right): Aerial view of Island I and L of Rhine archipelago
Source: author

7.6.7 Rhine archipelago - Spatial character

Transit node

Developing islands with boundaries that don't resemble traditional geometric layouts posed a significant challenge. To overcome this, the historical layout was traced, and the current islands are now developing with grids that resemble the existing industrial layout. This brings the contrast in identities of how each neighborhood, once had array of storage tanks in both directions now stand as a testimony to new urban development, denoting how blue green networks in the neighborhood brings tidal living the new norm. These grids are divided into block sizes referenced by the Ijburg development in Amsterdam.

This is a zoom in of the transit node of the island I. This shows how the building is developed with stilts and spaces to incorporate high and low water levels. The development is detailed considering both biodiversity and humans living in a co living habitat. (Building sizes might vary when detailed)

The development incorporates living with active green and neighbourhoods who public spaces which is tidal in nature and has sense of new identity for disaster resilient liveability. The development is functional for human needs and is resilient to disasters. When disaster flows, (event of high-water level) residents of this neighbourhood lives with it. As their daily livelihood is built around these water dynamics

The transit node on Island I demonstrates how elevated buildings on stilts accommodate fluctuating water levels. Public spaces are designed to support both human use and biodiversity, creating a co-living environment in which ecological processes and urban life coexist. This design approach ensures adaptability while maintaining high spatial quality.



Fig 7.42: Zoomed in map of transit node in island I
Source: author

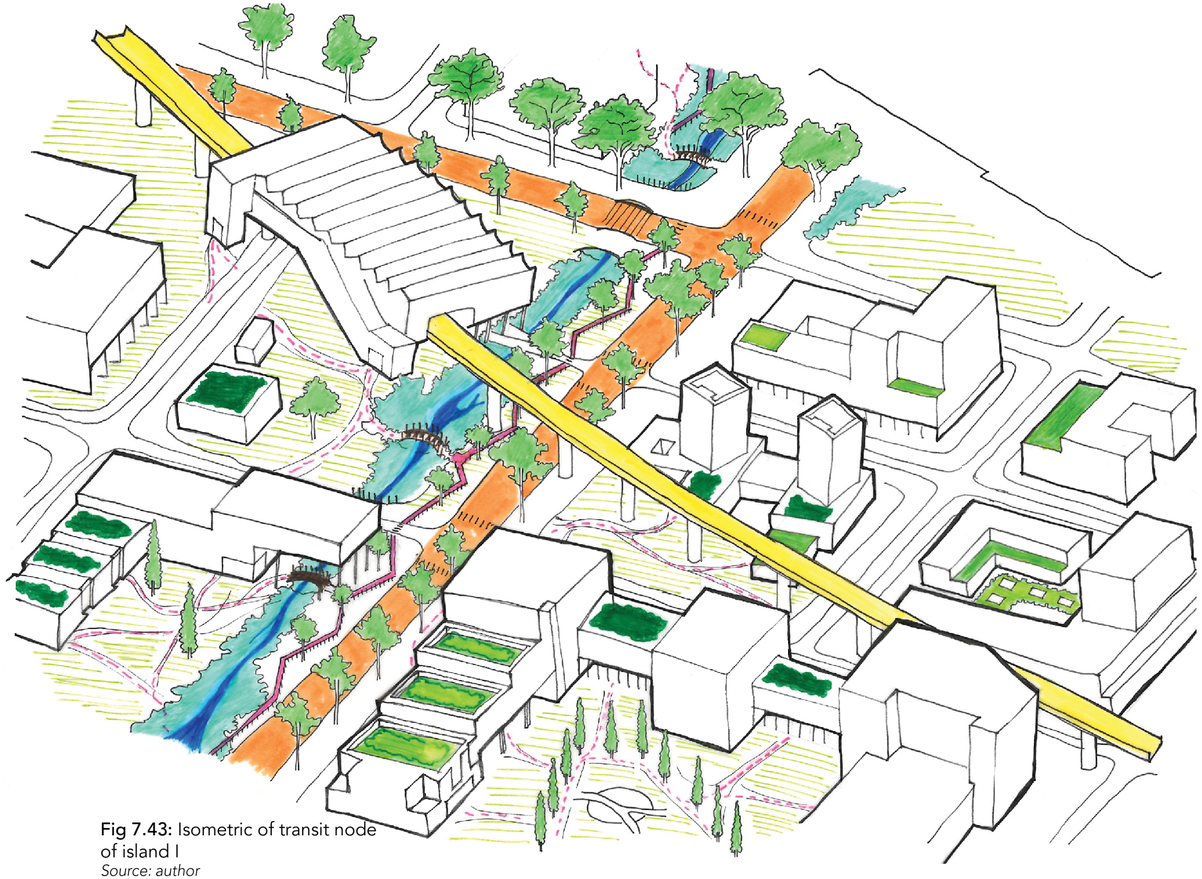


Fig 7.43: Isometric of transit node of island I
Source: author

7.6.7 Rhine archipelago - Spatial characte

Section – Tidal character

Section through a building near the node shows how the development is built around the dynamism of high and low water levels within the neighbourhoods. Public spaces across Island I are conceived as tidal landscapes, forming an integral part of daily life. During high-water events, residents continue to occupy and use these spaces rather than retreating from them, reflecting a shift toward living with water rather than resisting it. This spatial logic strengthens the neighbourhood's ability to absorb and adapt to climate-related risks.

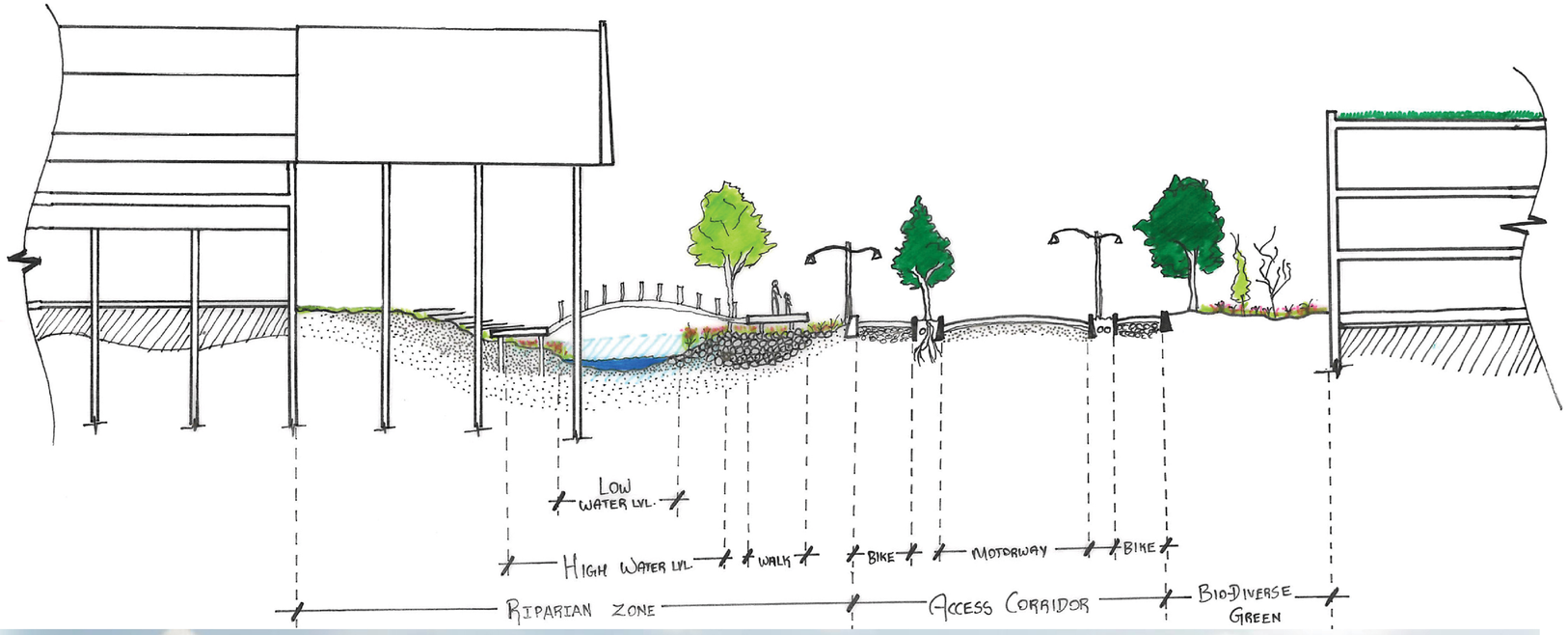




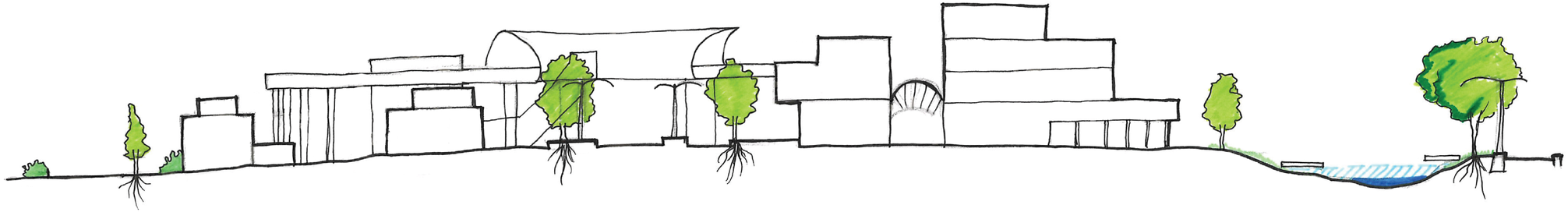
Fig 7.44(top): Section of transit node of island I
Source: author

Fig 7.45(bottom): Section of transit node of island I rendered through Gemini
Source: author

7.6.7 Rhine archipelago - Spatial character

Section – Urban character

The urban section of Island B near its transit node demonstrates the effectiveness of concentrating density and functions around public transport infrastructure. This configuration creates highly functional urban centres that support both human activity and ecological value, reinforcing transit-oriented development as a viable strategy for resilient delta urbanism.



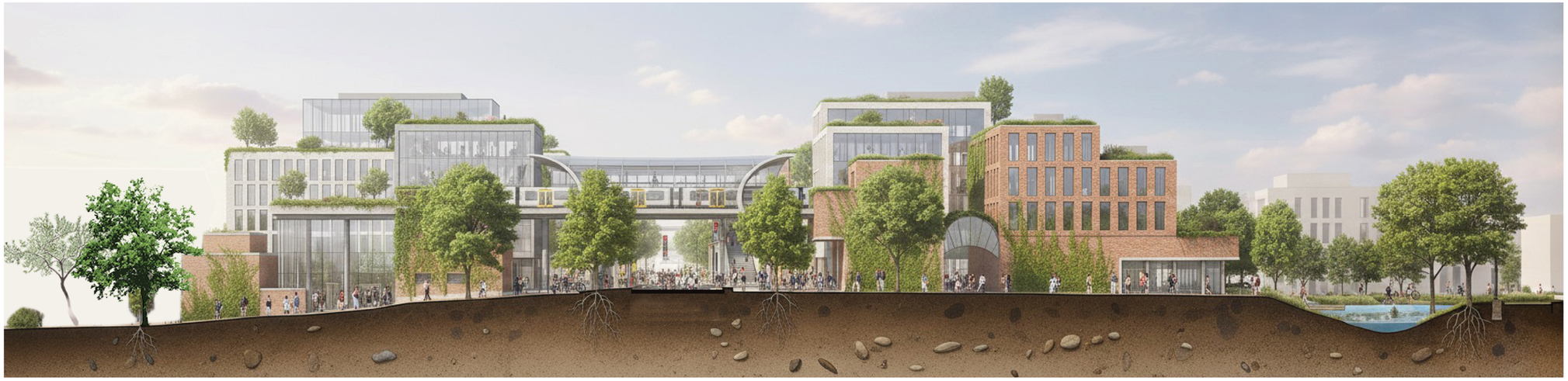


Fig 7.46(top): Section of commercial zone of island B
Source: author

Fig 7.47(bottom): Section of commercial zone of island B rendered through Gemini
Source: author

7.6.8 Rhine archipelago - Spatial capacity

Functions

Urban development in the islands is focused on human habitation within a dynamic tidal region. Blocks are formed in sizes referring to Ijburg development and their functions vary from a transit node to commercial to residential to recreational. Predominantly the development ranges from medium rise to low rise with high density along the nodes and low density along the edges. Block heights and density follow a standard normal distribution curve in almost all island with transit node being the center of the curve.

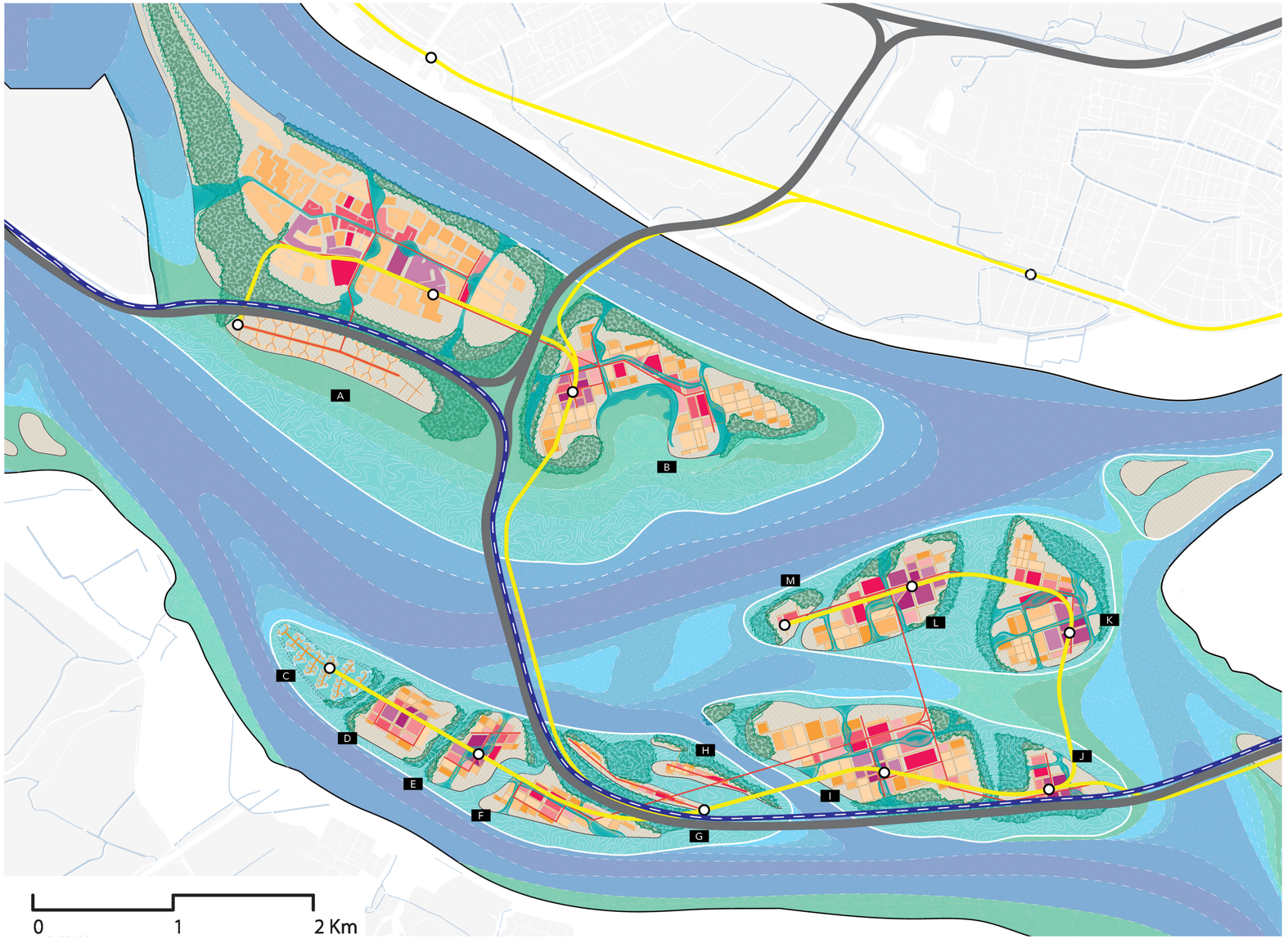
With total dry land of 245.75 Ha, Urban amenities such as shopping, commercial space, public greens, transit nodes, innovation centers, recreational areas (indoor and outdoor), cultural area, education centers and sports amenities are integrated within each island of this tidal development.

The Rhine archipelago has proposed 83,600 dwelling units to be built across different typologies, from mid-rise dense housing to low-rise individual houses.

83,600

dwellings

Area of Islands	(in m^2)
Island A	38,400 m^2
Island B	589,555 m^2
Island C	11,760 m^2
Island D	136,388 m^2
Island E	131,258 m^2
Island F	157,413m^2
Island G	33,721m^2
Island H	25,235m^2
Island I	582,582 m^2
Island J	67609 m^2
Island K	342,786 m^2
Island L	330,752 m^2
Island M	10,082 m^2



Legend

Land-use type

- Commercial mixed use
- Medium rise mixed use
- Low rise mixed housing

Network

- TEN-T corridor
- Metro line
- Regional road
- Local road

Fig 7.48: Urban development of Rhine archipelago
Source: author

7.6.8 Rhine archipelago - Spatial capacity

Urbanisation

Of the total 3,684 hectares comprising the Rhine Archipelago, approximately 240 hectares are allocated for urban development, representing only 6.5% of the overall area. Within this developed portion, around 40% is designated as built-up land. This spatial distribution establishes a deliberate balance between accommodating human settlement and preserving extensive areas for biodiversity and ecological processes.

The proposed land-use framework is organized into three primary categories: **transit-oriented commercial mixed-use, general mixed-use development, and low-rise residential housing**. These categories are further structured into **three density zones** based on their proximity to transit nodes, ranging from high-density areas near public transport to medium and low-density zones toward the periphery. The accompanying table details the spatial allocation and projected dwelling units within each land-use category.

	Commerical		Mixed height			Low rise		
	High desinty	Medium density	High desnity	medium density	low density	High density	Medium denisty	low density
	121892.75	264544.88	247496.22	335509.09	181706.6	480863.57	386572.05	438960.19
* 40% (builtup area	48757.1	105817.952	98998.488	134203.636	72682.64	192345.428	154628.82	175584.076
FSI value	12	10	9.375	6.25	7	5	4.25	1.375
Builtup area	585085.2	1058179.52	928110.825	838772.725	508778.48	961727.14	657172.485	241428.1045
Area per unit	200	250	35	60	144	45	70	144
Dwelling unit	2925.426	4232.71808	26517.45214	13979.54542	3533.18389	21371.71422	9388.178357	1676.584059
	3000	4250	27000	14000	3600	21000	9500	2000
83624.80217								

Total area: 36,847,923 m²
(3684 ha)

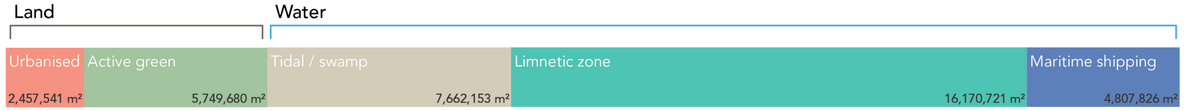


Fig 7.49(right): Table showing the area calculation of different land use in Rhine archipelago
Source: author

Fig 7.50(top): Barcode of Rhine archipelago
Source: author

Area calculation was done from FSI deriving from Dutch neighborhoods, These FSI were considered as thumb rule to calculate the density of each category and zones.

Source: Spatial density and mix use in the Netherlands (RUDIFUN)					
		FSI	GSI	OSR	
Low raise	Low density	0.4-0.7	25-35%	0.65-0.75	Yepenburg, The hague
	Medium density	1.5-1.9	45-55%	0.45-0.55	Jordaan, Amsterdam
	High density	1.8-2.2	55-65%	0.35-0.45	Delft Binnenstad
Medium raise	Low density	1.2-1.6	20-30%	0.7-0.8	Kanaleneiland, Utrecht
	Medium density	2.0-3.0	30-40%	0.6-0.7	Ijburg, Amsterdam
	High density	3-4.5	28-36%	0.64-0.72	Rotterdam Blaak-Goudsesingel blocks
Average size of dutch household = 177m²					
(world population review)					

7.7 Rhine archipelago - Phasing

Phasing overview

Preperation

Make contamination visible, manageable, and governable, without disrupting essential operations prematurely.

Site & Risk Diagnosis
- Detailed soil, groundwater, and sediment contamination mapping
- Identification of pollutants (hydrocarbons, heavy metals, PFAS, solvents)
- Risk zoning: hot spots, buffer zones, low-risk areas

Regulatory & Governance Setup
- Alignment with environmental authorities
- Definition of clean-up standards per future land use

Spatial & Functional Decoupling
- Separate
- Active industrial zones,transition zones, future redevelopment zones
- Introduce temporary land-use buffers
- Capping contaminated soils
- Controlled access zones

Transformation

Gradually reclaim land by coupling remediation with spatial and ecological transformation.

Phased Decommissioning
- Step-by-step shutdown of refineries and tanks
- Removal of hazardous installations
- Safe dismantling and material recycling

Active Remediation Strategies

Use a combination of methods depending on contamination depth:
- Soil washing
- Bioremediation (microorganisms, phytoremediation)
- In-situ chemical oxidation
- Pump-and-treat for groundwater

Nature-Based Remediation
- Constructed wetlands for water purification
- Reed beds and marshes for hydrocarbon breakdown
- Phytoremediation landscapes

Infrastructure Transition
- Convert pipelines to new energy carriers (e.g., hydrogen)
- Remove obsolete infrastructure
- Retain adaptable industrial assets

Process

Deliver safe, productive, and resilient urban or ecological environments.

- Soil and groundwater compliance checks
- Health and safety certification for new uses
- Long-term risk mitigation plans
- Continuous groundwater monitoring
- Soil quality tracking
- Ecosystem health indicators
- Cultural reuse of industrial heritage

Fig 7.51: Maps showing overall phasing of Rhine archipelago
Source: author



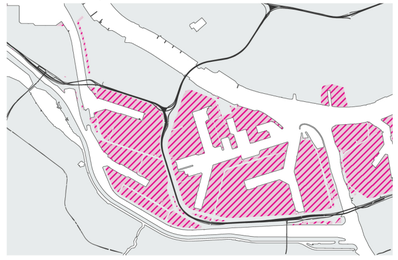
2035

- Built Maasvlaket-III
- Assess chemical and petroleum plant
- Assess storage tanks
- Start moving port activites to Maasvlakete-III
- Phytoextraction in uncalssified hotspots
- Re-purporse pipelines
- Dike strengthening



2045

- Port industries in Maasvlaket-III
- Shitting chemical and petroleum plant
- Clean storage tanks
- Make TEN-T corridors into highline
- Phytoextraction in industry hotspots (5yrs)
- Finish monitoring over lowspot (dense tree cover over)
- Remove maeslantkering
- Extract resuabel from industrues



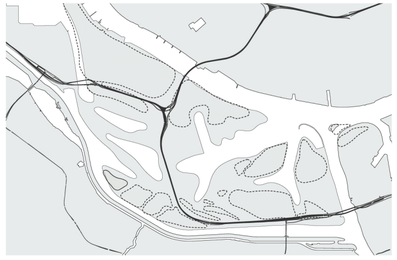
2050

- Phytoextraction implemended in industrial site
- Remove edges
- Remediate region



2060

- Harvest phytoextraction in industrial site
- Remove edges
- Monitor soil
- Monitor ground water quality
- Start hydrologial works
- Develop transit layout



2070

- Phytoextraction complete in indistrial site
- Monitor surface and ground water quality
- Start design process for urban development
- Prototype tidal construction techniques



2075

- Monitor and evaluate soil and surface water
- Design public spaces
- Start tidal urban development construction

7.7 Rhine archipelago - Phasing

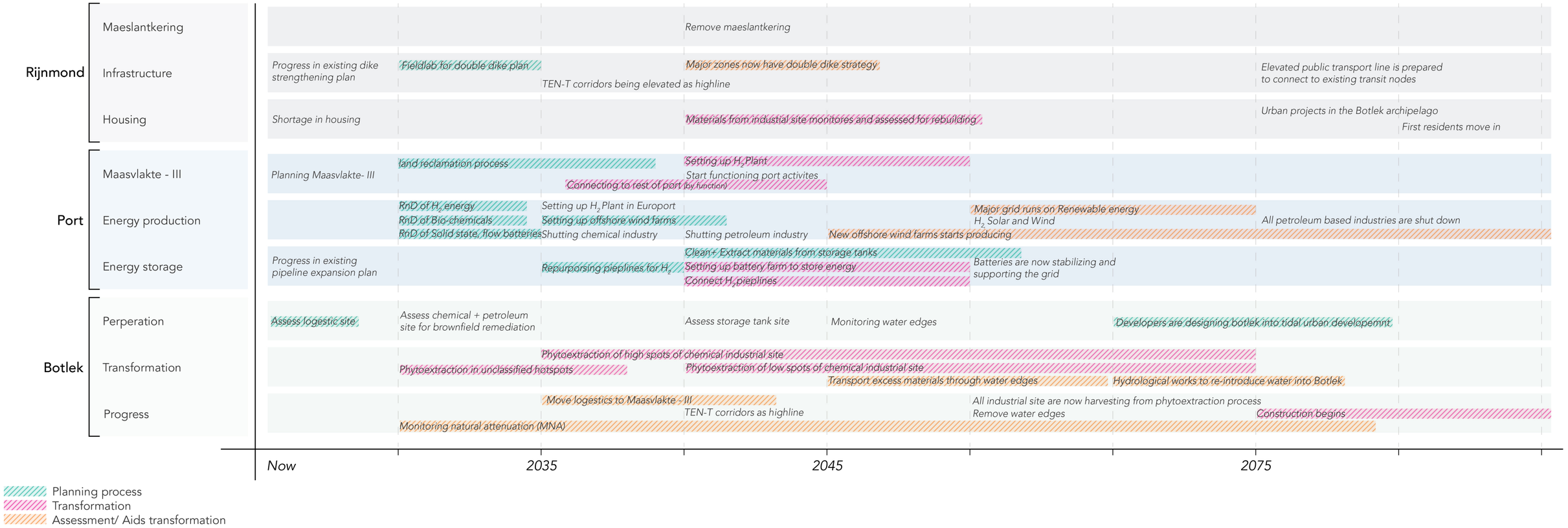


Fig 7.52: Overall phasing of Rhine archipelago
Source: author

7.8 New Rijnmond

Charecters of new Rijnmond

1. Delta mail

Randstad protected by delta. (*mail as in chainmail which is flexible yet functional)

2. Connect Rijnmond

Connected to the port by TEN-T corridors and pipelines, Neighborhoods connected by transit-oriented development and Nature through landscapes

3. Open Haringvliet

Rhine's major deposit flows through haringvliet then nieuwe maas.

4. Port and Coast

Safe and green port with landscape enriched coast

5. Relocating port

Port moving towards North Sea

6. Protect and enclave

Drechtsteden and Voorne enclave protected by flood plains, inland water landscape

7. Climate buffer

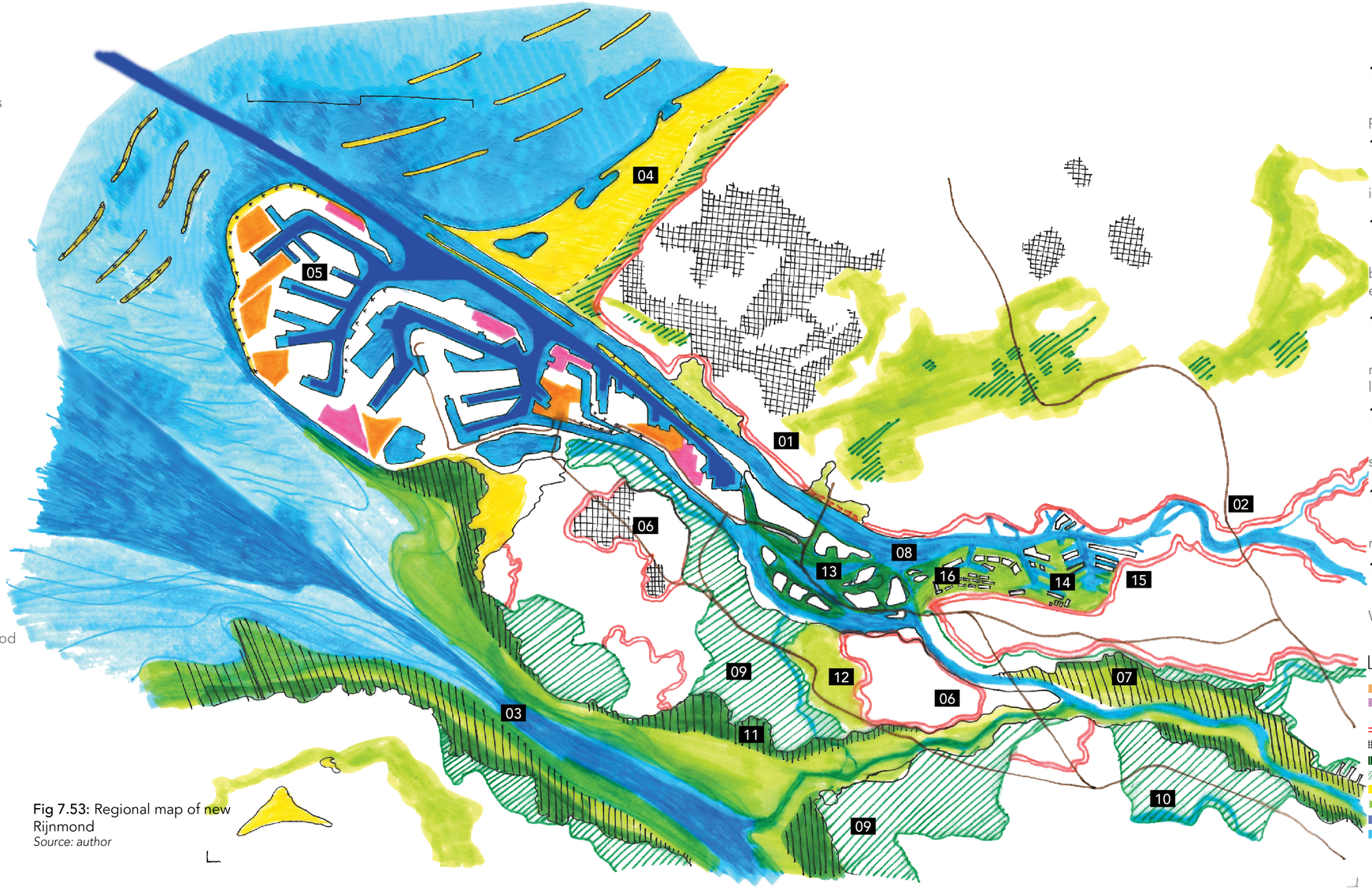
Between water and city, the boundary expands into marshes, riparian zones and flood plains.

8. Water buffer

Islands of the Botlek archipelago and outer dike region of maas is protected and bounded by water landscapes

9. Regional swamps

High/ low tidal region is adapted into regional scale planning



10. Freshwater buffer

Inland wetlands address salination and protect freshwater sources

11. Purification swamps

Swamp landscapes purify naturally for inner regions

12. Wet crops

More space for production landscape but in the form of salt/ wet crop-based ecosystem

13. Botlek archipelago

Islands of new botlek attracts new regime of livability with future sustained lifestyle

14. Tidal city/ sponge city

Neighborhoods which infiltrate and sustain high water levels

15. Safe residential areas

Climate resilience strategy for residential areas on rijnmond region

16. New water homes

Water related residential typology near Waal, Mathenesse and Vondelingenplaat.

Legend

- H_2 Industry
- Renewable energy production
- Windmills
- Dikes
- Glasshouse
- Tidal swamp
- Regional swamp
- Sand
- Protected biodiversity
- Deep-sea waterways
- Water

Fig 7.53: Regional map of new Rijnmond
Source: author

08

Conclusion

8.1 Design process

How can systemic transition in Rijnmond region incorporate a disaster resilience, future proof region which enhances livability while addressing effects of developing climate risks, resulting in excess water in the region?

Through researching this topic and analyzing the region through different methods and understanding. The Rijnmond is an engineered delta developed focusing on human needs. The development was traditional and doesn't think about future proof or sustainability on a longer run. By focusing on water-based disasters, with presumption that water plays a key role in sustaining the delta. Water could ultimately bring the whole delta down. And there is proof from the past that civilization ended over a big calamity. With a modern, connected world, we take initiatives and invest in knowledge programs to better understand how to live in a region while caring for the biodiversity around us. Methodologies used in the project help narrow down the issue spatially and investigate the operationally and feasibly for new approaches.
Ultimately choosing Botlek region of Rotterdam to investigate was one such coincidence in a big cycle. Seventy years ago, once the dying tidal region was seen as a prospectus, ideal space for expanding the industries towards coal and crude based economy. Now it is seen as a place seventy years from now to start a revolution in spatial planning, giving back the reclaimed land back to the tides and developing with them. Acknowledging the vulnerable nature of the river/ delta and incorporate spatial planning with not just roads, streets and blocks but with biodiversity and long term sustainably in mind.

With the current political stands of building new cities to achieve housing crisis of the Netherlands, as development like botlek archipelago can alone cater **84,350 dwellings**, not by draining water from polders but by giving back the region to the nature. This would be a way to go soon to see how we step from a crude-based system into a green energy based, resilient neighborhood lifestyle.

How disaster resilience, future proof region impact regional development?

The project adopts a holistic approach to climate risk by acknowledging the cascading nature of environmental threats across multiple sectors. Conventional disaster prediction methods rely heavily on historical data, often overlooking the uncertainty inherent in future climate dynamics. As such, disaster resilience cannot be achieved through resistance alone. Instead, it requires a paradigm shift toward strategies that accommodate and adapt to natural processes. Flood protection, for example, should not be limited to reinforcing barriers but should be embedded within spatial systems that can function under rising water levels.

Guided by this understanding, the Rijnmond region is envisioned to undergo a gradual transformation over the next fifty years, evolving into a landscape that is resilient to climate extremes. This transformation prioritizes coexistence with natural systems and promotes spatial strategies that actively enhance biodiversity. Regional planning frameworks introduce landscape zoning for wetlands, marshes, and tidal environments, reframing the relationship between land and water. Rather than treating them as separate entities, transitional zones between river and land are designed to minimize human interference while allowing natural hydrological processes to operate.

To what extend, the project goals were achieved?

The overarching project goals focus on three key dimensions: disaster resilience, enhanced liveability, and sustainable future pathways.

To a considerable extent, these goals are achieved within the scope of the project. Limitations related to time, data availability, and resource constraints are acknowledged, yet feasibility checks and phased systems thinking reinforce the credibility of the proposed development. While the design zooms in on Botlek Island, a location particularly suited for intense transformation due to its proximity to the port. The underlying methodology and strategic framework are transferable to other delta regions. Selecting a context that aligns with the project's ambitions functions as a deliberate sub-research question, allowing the broader problem statement to be meaningfully grounded in a specific case.

It is recognized that urban designers operate within a limited scope when addressing transformations of this magnitude. The realization of such systemic change depends heavily on governance structures, stakeholder collaboration, institutional frameworks, and public participation dimensions that lie beyond the scope of this research. Nonetheless, the project contributes academic value by demonstrating how urban development can be used as an instrument to directly address climate-related challenges, positioning environmental risks as key stakeholders within the planning process.

What are the limitatations and uncertainities that might hinder the process amidst using adaptive pathway planning techniques?

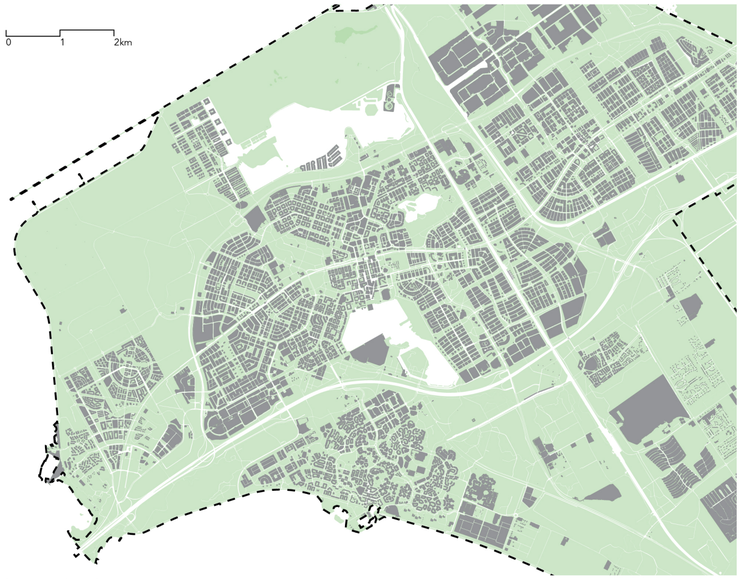
Adaptive Pathway Planning can be understood as a navigational tool comparable to a GPS, that guides decision-making toward an uncertain future while allowing for course adjustments along the way. While the project aims to steer development toward a sustainable and disaster-resilient trajectory, unforeseen "black swan" events may significantly alter these pathways. Geopolitical shifts, particularly those related to energy resources, have the potential to redirect technological and spatial priorities.

Historical precedents illustrate this uncertainty. During the late twentieth century, nuclear energy was widely regarded as a sustainable alternative to fossil fuels, supported by technological innovations aimed at waste recycling and long-term energy generation. However, the 1986 Chernobyl disaster profoundly altered public perception and policy trajectories, leading to widespread resistance against nuclear energy despite its scientific viability. This event demonstrates how singular incidents can redirect long-term transition pathways.

Climate uncertainty and technological innovation represent two distinct but interrelated variables. Over a fifty-year horizon, advancements in energy production, mobility, food systems, and healthcare are likely to redefine human lifestyles in unpredictable ways. This research therefore focuses on current positive trends and feasible transitions, acknowledging that future innovations and historical events may introduce new variables that either accelerate or delay the proposed pathways. Adaptive Pathway Planning remains valuable precisely because it accommodates such uncertainty, allowing strategies to evolve in response to changing conditions.

How can we justify massive industrial zone into primary residential neighborhood?

This project originates from a problem statement addressing escalating climate risks in urban regions. Within the Rijnmond delta, where spatial development has historically been driven by economic and logistical ambitions, the consequences of intensive human intervention have become increasingly evident. Heavily industrialized areas contribute significantly to environmental stress and vulnerability, positioning them as critical sites for transformation. Through the application of Adaptive Pathway Planning, the research explores how disaster resilience and future-proof neighborhoods can be achieved by aligning spatial development with long-term climate adaptation goals. Driven by parallel ambitions in water defense and energy transition, Botlek Island was selected as a strategic intervention area.



Almere builtup



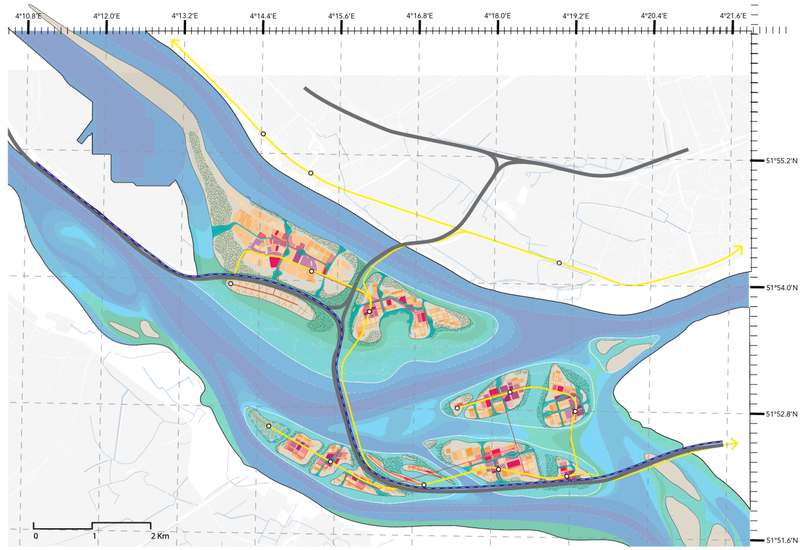
Botlek builtup

Fig 8.1(top): Almere builtup
Source: author
Dataset: RUDIFUN 2024

Fig 8.2(bottom): Botlek builtup
Source: author
Dataset: RUDIFUN 2024

The proposed development accommodates approximately **83,600 dwelling** units, a scale comparable to **Almere in the Flevopolder**, which currently houses around **94,040 dwellings**. While both developments operate at a similar magnitude, their spatial structures differ significantly. Almere's development pattern is characterized by relatively low-density and dispersed urbanization, whereas the Rhine Archipelago adopts a more compact and concentrated urban form. Despite this density, only **6.5%** of the total archipelago area is allocated to urban development, as illustrated by the built-up and barcode diagram Fig 8.3. This comparison highlights an alternative model of urbanization that balances spatial efficiency with extensive ecological preservation.

The Rhine Archipelago presents a development paradigm that integrates biodiversity and embraces living with water, without compromising urban functionality or quality of life. Rather than separating urbanization from natural systems, the project proposes a model in which ecological processes are embedded within the structure of daily living.



Total area: 36,847,923 m²
(3684 ha)

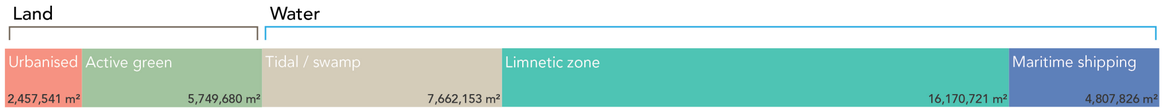


Fig 8.3: Urban development of Rhine archipelago
Source: author

09

Reflection

Relation between your graduation topic, master track, and your master programme (MSc AUBS)?

When Disaster Flows: A systemic overview for climate resilient spatial framework in the Rijnmond delta region is a project that demands integrated approaches throughout the research stages, and role of different expertise through stages. The systems thinking approach of the studio helps in bringing the research techniques together. The role of an urbanist plays a major role in this process to translate the regional strategy from policies to spatial implications from a delta scale to be reflected on human perspective.

The design not just caters human needs but plays a positive impact in various ecosystem services. The project is holistic in a way that it utilises the studio's approach to effectively impact on the process. I chose to investigate my research on water systems and how water plays a major role in delta region, with increasing urban ambitions parallel to climate change.

By selecting this topic, I explored the various possibilities and interventions and design visions that has already been worked on the existing context. As the need for action today lacks in the existing context, I formulated a way to address some major aspect of the existing innovation using my research and design skillset that I learned through the master program and landed a design intervention that shows a non-conflicting future scenario of the region.

Relation between research and design in your graduation project.

The research component of my graduation project provides the foundation for developing a **climate-resilient spatial framework for the Rijnmond delta region**. Because the region faces increasing climate extremities alongside growing human and economic demands, a systemic understanding of the delta is essential. My research therefore began with an exploration of how the **Dutch have historically engineered and transformed their river delta** balancing water defence, economic growth, logistics, and urban development. This historical lens helped me understand the evolution of key spatial decisions and the cultural and political forces that shaped today's landscape.

As the topic spans a broad regional scale, I focused on analysing **existing governmental plans and policies**, including the NOVEX and NOVI development perspectives. These documents articulate future ambitions and constraints for the Rijnmond region and directly frame the challenges of climate resilience, spatial scarcity, and transitions in energy, housing, and mobility. Studying these perspectives allowed me to identify the strategic dilemmas and opportunities that my design must respond to.

The **core relationship between research and design** in my project lies in how the research outcomes are translated into a **spatial decision-making framework.** The research clarifies the systemic problems, historical trajectories, and transition trends; the design uses this knowledge to test, synthesize, and visualize future-proof spatial interventions. In this way, research is not separate from design it guides, structures, and justifies the design process.

A pivotal moment came after my P3 presentation, when feedback highlighted the need to move beyond descriptive analysis. As a spatial planner and regional designer, I realised that the value of my work lies in **applying systemic knowledge spatially, rather than only documenting it.** This led me to develop a design framework that incorporates research insights into concrete decisions about spatial structure, land-use transitions, and climate-adaptive strategies. Through this shift, the design phase became a platform to explore, test, and operationalize the ambitions identified in the research.

Ultimately, the relationship between research and design in my project is iterative and mutually reinforcing. Research establishes understanding and direction, while design synthesizes and materializes that knowledge into a coherent vision for a future-proof and liveable Rijnmond delta.

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

My project aims to develop **a systemic and climate-resilient spatial framework for the Rijnmond region,** a task that requires dealing with complexity, uncertainty, and multiple scales. Because of this, a single method would not be sufficient. Instead, I adopted a **non-linear, multi-method approach**, where different tools support different phases of understanding, analysis, and design. This integrative way of working is one of the main values of my approach: it allows me to capture the breadth of regional dynamics while still enabling focused decision making.

The combination of literature study and policy analysis provided a strong factual and institutional foundation. These methods clarified the existing future visions for the region, the ambition levels set by governments, and the degree of innovation already embedded in regional strategies. This broad understanding was essential for positioning my project within ongoing transitions and ensuring relevance to real planning discussions.

The DPSIR method added analytical depth by helping me sequence my understanding of the system. It allowed me to identify the drivers, pressures, and resulting impacts, but more importantly, **the critical choke points and bottlenecks** where interventions would have the most leverage. This systemic insight guided the narrowing down of my research focus and clarified which aspects of the region were most vulnerable or transformative.

Because planning for climate resilience involves deep uncertainty, the Adaptive Pathway Planning method was crucial. It enabled me to work with climate scenarios and to develop a pathway configuration **that integrates ongoing positive trends while avoiding conflicting future outcomes.** The value of this method lies in its capacity to show how the region could evolve over time, not as a single solution but as a dynamic and flexible decision-making structure. It strengthened the futureproofing and robustness of my design proposals.

Once a regional strategy was established, research by design allowed me to translate abstract frameworks into human-scale spatial visions. Through iterative drawing and experimentation, I was able to test the feasibility of ideas, explore alternatives, and ensure that the broader regional logic also made sense when grounded in everyday lived experience. This iterative, design-led inquiry added creativity, tangibility, and empathy to the project.

Although this multi-method approach is valuable, it also has limitations. It requires substantial time to integrate the methods coherently, and it demands constant switching between scales and mindsets. Some methods, rely on assumptions that cannot be fully validated. Furthermore, the non-linear nature of the approach may introduce complexity for stakeholders unfamiliar with systemic or iterative design processes.

Overall, the value of my way of working lies in its **holistic, structured, and adaptive character.** The limitations primarily relate to the complexity and time-intensity of coordinating multiple methods. Yet, together, these tools enabled me to produce a design and strategy that is grounded not only in regional systems thinking but also in human-centred spatial experience.

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

The academic value of my graduation project lies in its attempt to address a critical gap in contemporary spatial planning: the challenge of managing **multiple climate risks occurring within the same urban or regional structure.** The Rijnmond delta experiences a range of climate-related threats flooding, extreme rainfall, heat, drought, and ecological degradation each traditionally treated through separate, sectoral interventions. My project proposes a unifying, systemic spatial framework capable of responding to these diverse risks in an integrated manner. This contributes academically by advancing methods for complex risk resilience, by connecting environmental planning tools with design thinking, and by offering a pathway-based approach that can be theoretically transferred to other delta regions.

The societal value of this project emerges from its focus on enhancing both resilience and liveability. By developing a single spatial strategy that addresses multiple climate threats simultaneously, the project has the potential to reduce fragmented investments, avoid redundant spatial claims, and streamline long-term planning efforts. This more coordinated approach not only increases cost-efficiency but also helps safeguard human health, protect critical infrastructure, and support community wellbeing. The project also promotes the restoration and strengthening of ecosystem services, leading to healthier biodiversity and improved environmental performance across the region. This has direct implications for the long-term sustainability and liveability of the Rijnmond area, particularly for vulnerable neighbourhoods exposed to climate extremes.

Ethically, the project positions climate resilience as a shared responsibility that must consider intergenerational equity, environmental justice, and responsible land-use management. The proposed interventions aim to ensure that current strategies do not **privilege short-term gains over long-term security, nor disproportionately burden specific communities.** By framing resilience planning as a holistic, inclusive, and future-oriented process, the project acknowledges the moral obligation to protect both human populations and ecological systems. It also **emphasises transparency and adaptability in decision-making, which are essential when dealing with uncertainty and the long-term consequences of spatial interventions.**

The scope and implications of the project are therefore significant. It introduces a strategic framework that bridges the gap between high-level environmental planning documents and fragmented on the ground interventions, turning them into a coherent pathway toward disaster-resilient, future-proof, and liveable neighbourhoods. In doing so, the project suggests a new paradigm for understanding spatial planning and neighbourhood development in delta regions one **that integrates systems thinking, climate adaptation, and human-centred design into a unified approach.**

Assessing the transferability of your project results.

The transferability of my project results lies not only in the spatial strategies developed for the Rijnmond region, but more importantly in the **methods and decision-making framework** used to produce these strategies under deep uncertainty. My research began by exploring the fundamental role of water in shaping cities, and by analysing how delta regions historically enabled urban prosperity. At the same time, the project criticises the tendency of human and economic ambition to dominate and engineer deltas in ways that undermine the natural systems that originally made these landscapes resilient. This tension between engineered control and natural functioning is common across many delta regions worldwide, which increases the relevance and transferability of the project.

The Rijnmond case study presented unique challenges because it is governed by a highly regulated water management system. Although this system appears future proof at first glance, it relies **heavily on hard, engineered solutions** such as dikes, storm surge barriers,

and the boezem system. These methods, while effective in the short term, are increasingly questioned for their long-term robustness as climate extremes intensify. In contrast, nature-based systems such as dunes, estuarine landscapes, and wetlands have **shown greater sustainability and added ecological and social value.** The methods developed in this project, systemic analysis, pathways thinking, resilience strategies, and research by design demonstrate how **an engineered, industrialised delta can transition toward a more landscape-oriented regime without compromising economic vitality.**

This methodological framework is transferable to other deltas facing similar pressures, particularly those struggling to balance industrial activity, dense urbanisation, and climate uncertainty. The project provides a **blueprint for rethinking regional strategies,** showing how spatial planning can evolve from fragmented interventions to **coherent, long-term pathways that strengthen both climate resilience and liveability.** The transferability therefore lies in the adaptable structure of the approach. It can be customised to different governance systems, environmental conditions, or cultural settings while maintaining its core principles of systemic understanding, adaptive pathway planning, and integration of natural landscape processes.

Ultimately, the project demonstrates how existing planning approaches in delta regions worldwide can be transformed into future-proof strategies that bridge the gap between technical water management, environmental planning, and spatial design. While specific spatial solutions may differ from place to place, the conceptual framework and methodology of this project offer strong potential for broader application.

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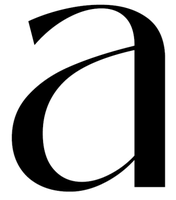
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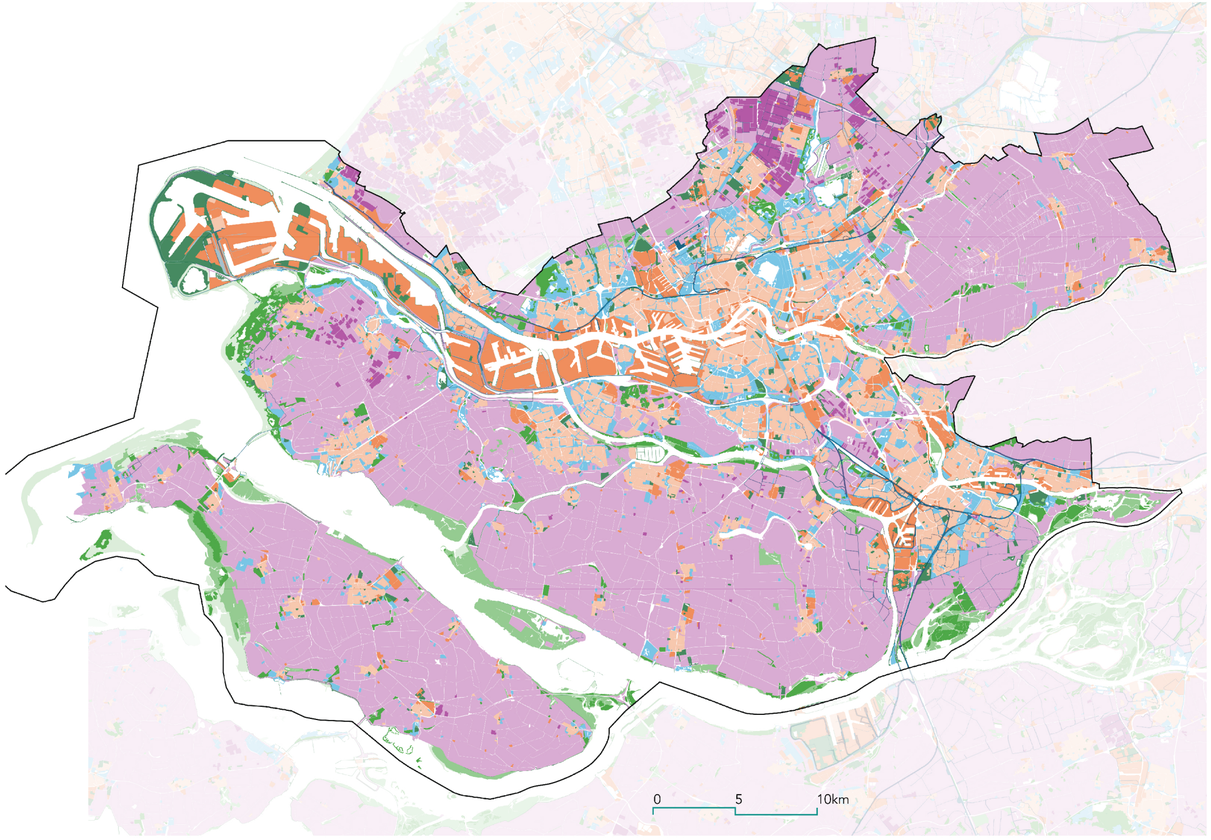


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Source: author

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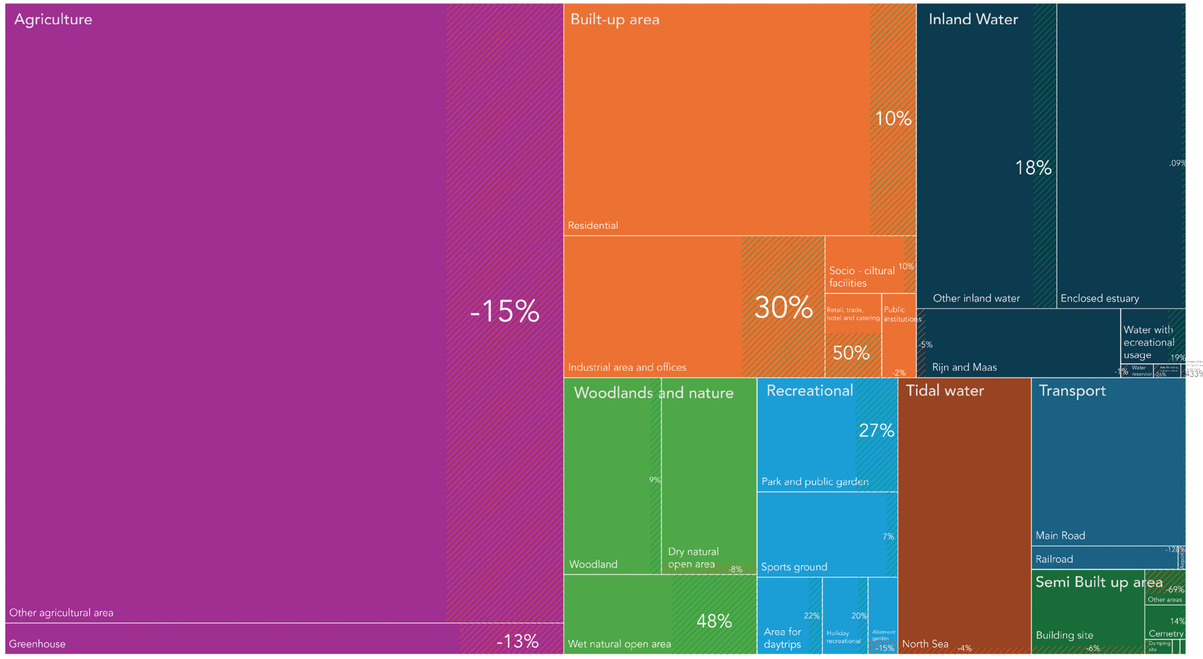
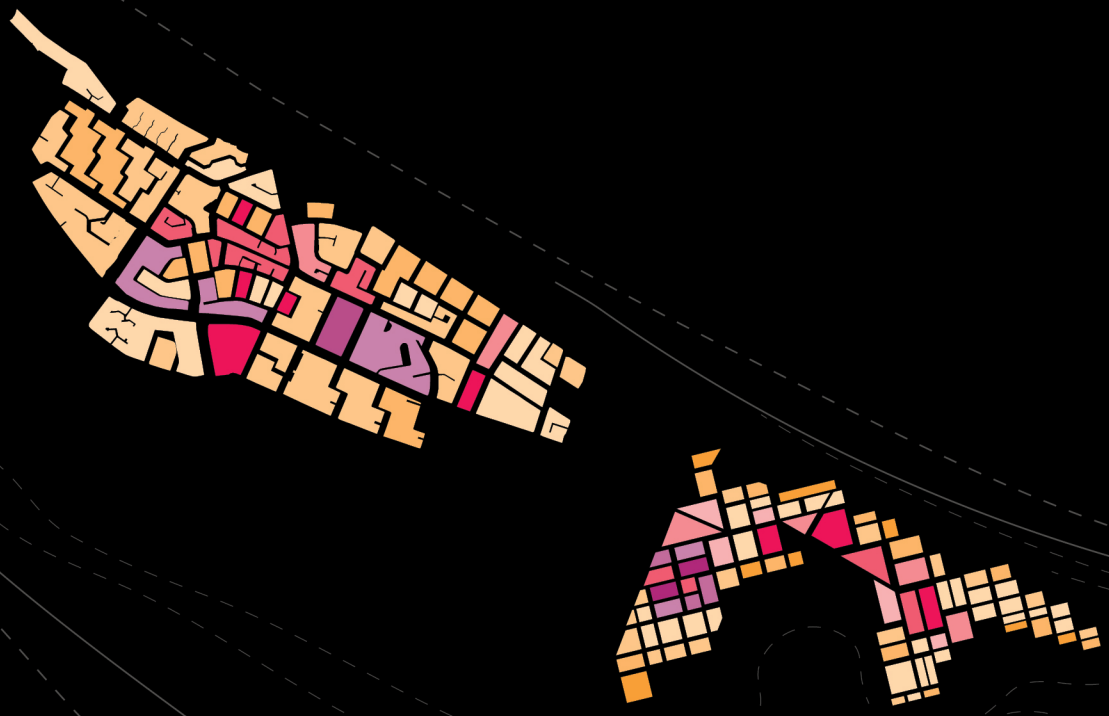


Fig a.1: Simplification of landuse in Rijnmond region
Source: author
Dataset: CBS



When Disaster Flows

A systemic overview for climate resilient spatial framework in the Rijnmond delta region



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