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Adaptive strategies for achieving dynamic water equilibrium in a climate-responsive Rhine basin

Colophon

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Context and Acknowledgment

My research focuses on addressing hydrological challenges along the Rhine, with a particular emphasis on dynamic water equilibrium to safeguard Europe's vital trade heritage. By examining cross-border water management practices and exploring adaptive infrastructure and policy measures, this study aims to ensure the continuity of the Rhine as a critical transport corridor. The research prioritizes maintaining the functionality of this economic lifeline while proposing strategies to manage water effectively in the face of a changing climate.

I would like to express my sincere gratitude to my thesis supervisor, Ir. Francesca Rizzetto, my second mentor - Dr. Claudiu Forgaci, my third mentor - Johanna Bouma, and my company supervisor - Luuk Cornelissen for their guidance, constructive feedback and encouragement throughout this research. Their expertise and mentor-ship have shaped the direction and depth of this research.

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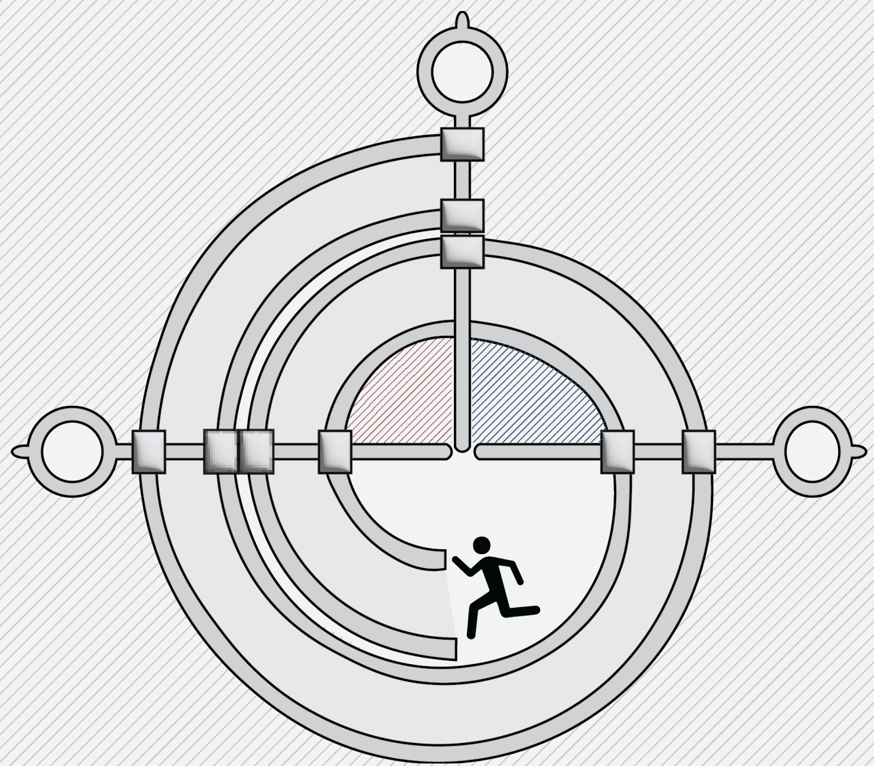

Abstract

The Rhine River, Western Europe's most vital waterway, supports diverse economic, ecological, and cultural systems. As Europe's busiest inland trade channel, it is critical to regional connectivity and prosperity. However, the Rhine faces unprecedented challenges due to climate-induced droughts, floods, rising sea levels, and soil subsidence. These pressures, compounded by urbanization, intensive resource use, and cross-border dependencies, threaten ecological stability, agricultural productivity, freight transport, and infrastructure resilience. By 2100, longer and hotter summers, coupled with intensified hydrological variability, are expected to exacerbate these issues, posing significant risks to urban areas, polder systems, and shared governance structures across the Netherlands and Germany.

This thesis explores how dynamic water equilibrium can be achieved through spatial, infrastructural, programmatic, and policy-based design principles, focusing on three interrelated lenses: economy, ecology, and society. By proposing adaptive freight regulation, ecological flow corridors, and socially embedded infrastructures, the research aims to rebalance water systems across scales, from transboundary coordination to regional and local interventions. Special attention is given to vulnerable transport corridors like the Gelderse Poort, which serve as testing location for scalable strategies.

Through a system of design principles with flexible interventions, the study reimagine the Rhine as both a functional infrastructure and a living cultural entity. Supported by cartographic analysis, cross-border insights, and systems thinking, this work offers a framework for climate-responsive river basin design—one that stabilizes freight movement, restores ecosystems, and reinforces the river's identity as a shared space of resilience, memory, and flow. The findings aim to contribute to sustainable water governance, infrastructure planning, and regional cooperation, enhancing the Rhine's role as a resilient and adaptive lifeline for Western Europe.

Key words:

Flooding, Droughts, Climate adaptation, Dynamic water equilibrium, ecology, economy, society

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Glossary of terms

1. **Adaptability** – Capacity of systems to adjust to changing conditions like floods and droughts.
2. **Aquifer** – Underground layer of water-bearing rock used for groundwater storage.
3. **Biodiversity** – Variety of living organisms within ecological habitats.
4. **Biofiltration** – Using natural systems like plants and soils to purify water.
5. **Buffer** – Zone or element that absorbs or mitigates environmental impacts.
6. **Channel** – Watercourse, natural or artificial, directing flow within a basin.
7. **Commons** – Shared resources managed collectively by communities or governments.
8. **Connectivity** – Ecological and infrastructural linkages between fragmented areas.
9. **Corridor** – Linear space facilitating movement of water, people, or wildlife.
10. **Conflict** – Incompatibility between strategies or uses in a shared space
11. **Cycling** – Reuse and circulation of resources like water or nutrients.
12. **Delta** – River mouth zone where sediment deposits form land expansions.
13. **Detention** – Temporary water storage method to reduce flooding intensity.
14. **Dredging** – Removal of sediment to deepen waterways for navigation.
15. **Drought** – Extended period of deficient rainfall causing water scarcity.
16. **Dynamic Strategy** – A flexible, responsive design or policy that can adapt to changing conditions.
17. **Ecology** – Study and system of interrelationships between organisms and environments.
18. **Economy** – Regional trade, industry, and infrastructure linked to water.
19. **Equilibrium** – Balanced state between fluctuating forces like water levels.
20. **Evapotranspiration** – Combined water loss through evaporation and plant transpiration.
21. **Flooding** – Overflow of water onto normally dry land, often due to heavy rain.
22. **Floodplain** – Low-lying area adjacent to rivers that floods periodically.
23. **Freight** – Cargo transported via ships, rail, or road, especially on the Rhine.
24. **Governance** – Structures and systems for managing water and land resources.
25. **Habitat** – Environment where a specific species or community lives.
26. **Hydrology** – Study of water movement, distribution, and properties.

27. **Infrastructure –** Physical systems supporting society, like dikes and ports.

28. **Inundation –** Overflowing of land areas with water, usually from rivers.

29. **Landscape –** Spatial composition of natural and built environments.

30. **Logistics –** System of transportation and supply chain management.

31. **Marsh –** Wetland dominated by herbaceous plants, storing excess water.

32. **Meadow –** Open grassland ecosystem that can support seasonal flooding.

33. **Mitigation –** Actions aimed at reducing adverse environmental effects.

34. **Mobility –** Movement of people and goods across landscapes.

35. **Monitoring –** Continuous observation to assess changes or performance.

36. **Morphology –** Shape and structure of rivers or landscapes over time.

37. **Navigation –** The ability of ships to travel waterways efficiently.

38. **Pattern –** A recurring spatial or strategic design element.

39. **Pilot –** A small-scale implementation is used to test ideas or strategies.

40. **Polders –** Low-lying tracts of land protected by dikes and water control.

41. **Principle –** A guiding rule or idea behind a spatial or planning intervention.

42. **Resilience –** The capacity of systems to recover and sustain functions under stress.

43. **Replication –** Reusing a strategy or method in another context.

44. **Retention –** Holding water in a place to prevent excess runoff or save for drought.

45. **Riparian** – Relating to riverbanks and their associated vegetation and wildlife.

46. **Scalability –** The ability to apply a strategy at different spatial levels.

47. **Scenario –** A projected or hypothetical situation to explore possible futures.

48. **Sediment –** Particles carried by water, affecting depth and flow.

49. **Society –** Communities and human systems interacting with the water landscape.

50. **Stakeholders –** People or organizations with interests in water management decisions.

51. **Subsidence –** Gradual sinking of land, often due to groundwater extraction.

52. **Synergy –** Positive interaction between multiple strategies or systems.

53. **Wetlands –** Water-saturated areas supporting biodiversity and water retention.

54. **Zoning –** Dividing land into designated uses based on analysis and water levels.

55. **Temporal Zoning –** Use of land that shifts according to seasonal water availability.

56. **Transboundary –** Spanning across national or regional borders, requiring international cooperation.

Figure 01 | Droughts in the Rhine in Bacharach, Germany
Source: The New York Times, (2018)

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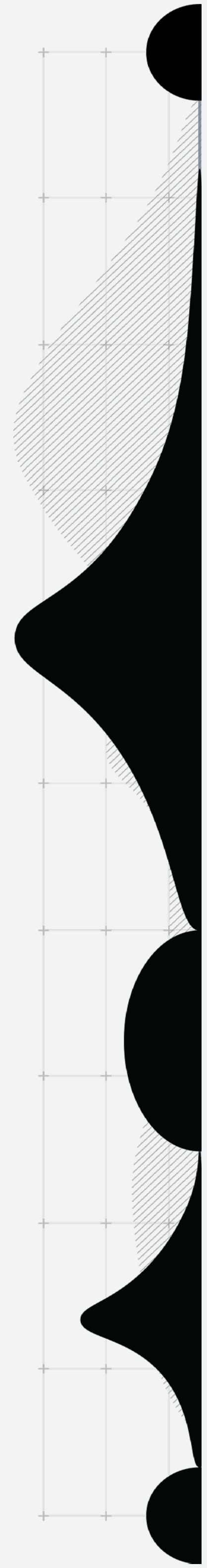


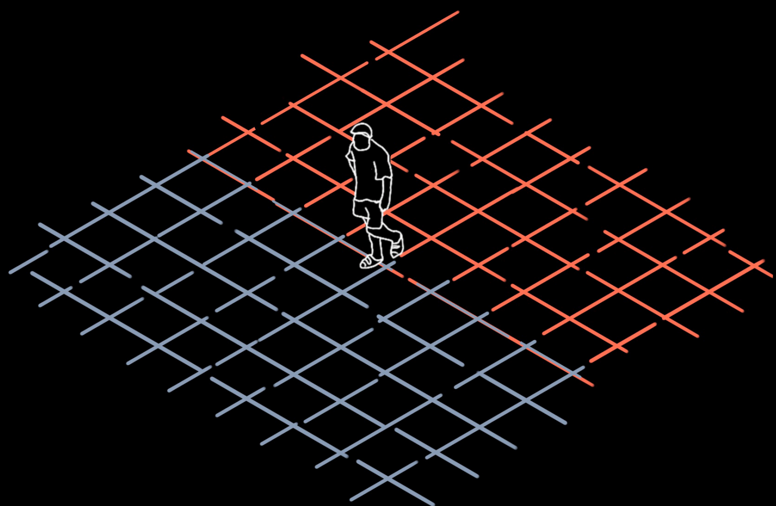


Illustration 01 | Positioning
Source: Author

Positioning

My positioning derives from personal motivation and an awareness of global issues where regions face similar challenges of managing water extremes. The focus lies on addressing these interconnected problem fields and a strategic project focus.. It consists of:

1. Personal motivation
2. Area of Interest (the Rhine River)
3. Matrix of investigations
4. Problem fields
5. Project focus

Illustration 02 | Personal motivation
Source: Author

Personal motivation

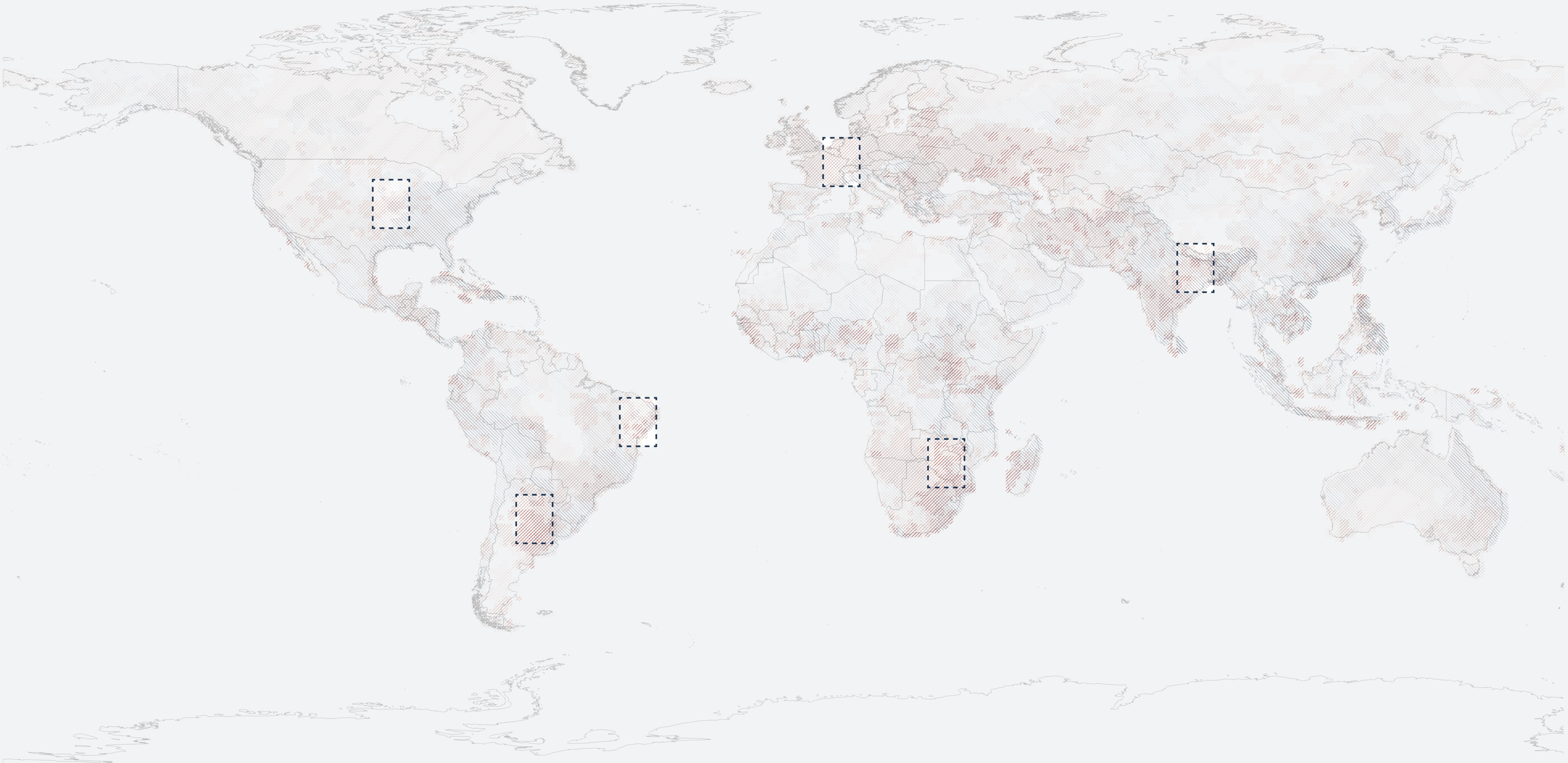
In my hometown, I often sit on the terrace during the comfortable months and admire the serene landscape of the Himalayas. These moments of calm are bittersweet, as they carry the inevitable reminder of the approaching summer heat, which disrupts this tranquillity. Living in the north-central part of India, I experience a moderate climate where temperatures range from freezing in winter to a sweltering 47°C in summer. The monsoon brings around 600mm of rainfall in just two months, leaving the rest of the year predominantly dry.

As a child, I often wondered why the seasons had to change so drastically and why the climate couldn't be more balanced and consistent. Over time, I began to observe how human-induced activities exacerbate these transitions. For instance, in my region, a massive dam built by the government has altered the micro-climate, intensifying evaporation during summers and influencing rainfall patterns n a macro scale during the monsoon. This sharp interchange of flooding and drought in the same location incited my curiosity and motivated me to dig deeper into these phenomena.

During my master's program,...

...I extended this exploration beyond my region, identifying similar patterns of extreme climate transitions across the world. My focus turned to Western Europe, where predictions highlight its transition into a critical zone for climate impacts. While this region has historically dealt with flooding, the 2018 droughts revealed a contrasting challenge. This shift towards drier conditions could have profound consequences, particularly as countries like the Netherlands and Germany are well-prepared for floods but remain vulnerable to droughts...

Map 01 | World map with severe flooding and droughts highlighting spaces where it is happening together.
Source: Copernicus 2018 et Dartmouth 2021 | adapted by Author



...Now, floods and droughts are occurring in the same regions, yet strategies typically address one issue at a time, overlooking their interconnected impacts. The 2018 global drought and the catastrophic flooding of 2021 highlight the urgent need for integrated approaches that consider both extremes. In one place, a river runs dry, halting its role in supplying water for daily life and disrupting industries, transport, and communities dependent on its flow. In another, the same river overflows, bringing such excess that people are unable to work as flooding damages infrastructure and livelihoods.

Figure 02 | 2018 Droughts in Germany
Source: AP News

Figure 03 | July 2021 Floods in Cologne, Germany
Source: News Talk

Water crisis that came dangerously close to depleting the city's supply was narrowly avoided whereas during floods people lost their lives in South Africa.

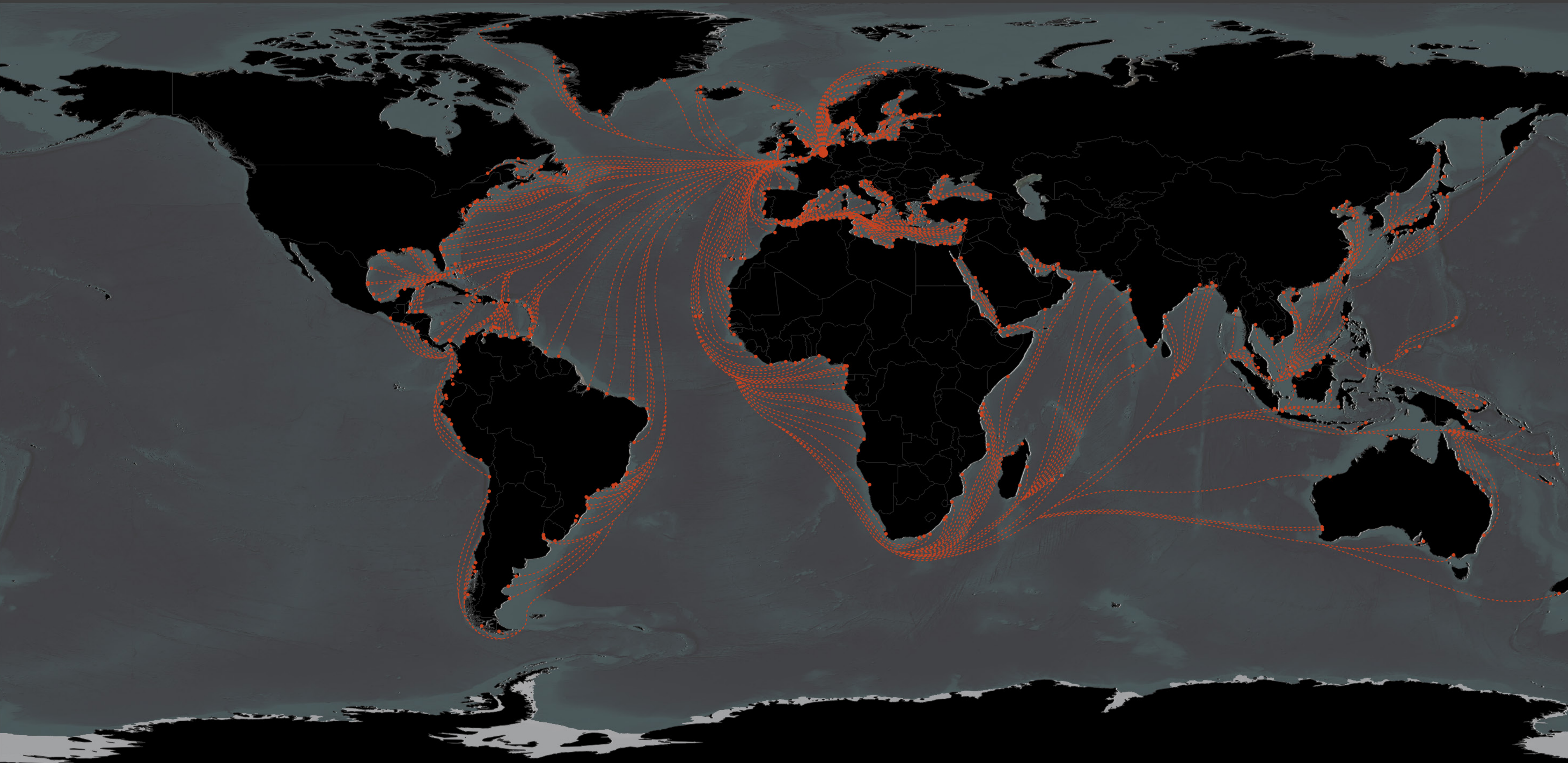
Figure 04 | Droughts in South Africa
Source: National Geographic

Figure 05 | Floods in South Africa
Source: euronews

Same place different story in different season. In Ahmedabad (India), the same areas face drastically different challenges across seasons—floods in one season and droughts in another.

Figure 06 | Droughts in Ahmedabad, India
Source: India today

Figure 07 | Floods in Ahmedabad, India
Source: Reuters



Map 02 | Flow of goods from Rhine through Rotterdam
Source: rotterdamtransPORT | adapted by Author

Effect?

The Rhine, Europe's busiest inland waterway, facilitates the export of goods worth over €500 billion annually and supports the livelihoods of 60 million people across nine countries within its catchment area. For many, it serves as a lifeline, providing essential jobs and sustaining entire communities but these extreme conditions of climate disrupts the flow and negatively impact the transport corridor and people associated with it.

Background

Research area is focusing on the Rhine River, spanning over nine countries starting from the Alps in east of Switzerland and drains into the North Sea in the Netherlands crossing Austria, Belgium, France, Germany, Italy, Liechtenstein, Luxembourg. It is one of Europe's most significant waterways stretching 1,250 km with a drainage area of 185,260 km² and an average discharge of 2,300 m³/s, it ranks as the 9th largest Eurasian river. The Rhine supports a densely populated basin of 60 million population, many residing in major urban centres from Rotterdam to Basel, contributing to an annual GDP of $1,750 billion. The Rhine basin comprises six distinct sections: the Alpine Rhine, High Rhine, Upper Rhine, Middle Rhine, Lower Rhine, and Delta Rhine, each shaped by unique geological and hydrological processes, playing a vital role in Europe's history, culture, and economy. (Uehlinger et al., 2009)

As a multi-purpose waterway, the Rhine serves transportation, energy production, drinking water for 25 million people, agriculture, tourism, and industrial needs. However, over the past two centuries, its ecological integrity has been profoundly impacted by human activity.

Geologic History

The Rhine's watershed extends into the Alps today, but this was not always the case. During the Miocene period, the Rhine's watershed only reached as far south as the Eifel and Westerwald hills, approximately 450 km north of the Alps. The northern Alps, instead, were primarily drained by the Danube River. At the start of the Holocene, the Rhine occupied its Late-Glacial valley, reshaping its ice-age floodplain as a meandering river. Around 8,000 years ago, with continued sea-level rise in the Netherlands, the Holocene Rhine-Meuse delta began to form. Human impact on the Rhine delta has been evident since ~3000 years BP, beginning with Bronze Age agriculture in upland areas (central Germany). Increased land clearance led to a rise in sediment load, accelerating delta growth and causing more frequent flooding and sedimentation, which ended peat formation in the delta. Over the past 6,000 years, the delta experienced approximately 80 avulsions, as river channels shifted across the floodplain to distribute sediment.

Direct human intervention intensified during Roman times with peat mining for salt and fuel. From the 11th to 13th centuries, major tributaries were embanked, and minor ones dammed. Subsequent modifications included the construction of canals, straightening of bends, and building of groynes to stabilize river channels and prevent silting. These actions have profoundly shaped the delta's landscape and functionality. (Berendsen et al., 2001)

Map 03 | Evolution of the Rhine basin
Source: Preusser, F. (2008) | adapted by author

Grid 50x50km
Map 04 | Rhine Basin
Source: Copernicus | adapted by author

Matrix of Investigations

Rivers in deltas worldwide have experienced significant anthropogenic alterations, largely due to human-induced hydro-morphological changes. These changes result from activities like embankments, damming, bifurcation stabilization, and land use that increase sediment yield, trap sediment upstream, and lead to sediment mining. Additionally, enhanced subsidence occurs due to land drainage and groundwater extraction, oil, and gas. The Rhine River is a clear example, shaped by over 2000 years of urbicene-related interventions for military strategies, flood safety, erosion control, land reclamation, navigation, freshwater supply, and ecological restoration. Starting with Roman-era canal construction and river training, and followed by medieval dike-building efforts, the Rhine's natural flow and sediment deposition were heavily altered. These dikes prevented natural sediment deposition on reclaimed land, increasing sediment accumulation within the dikes. Human activities like sediment mining increased sediment transport capacity, causing ongoing riverbed incisions. The alluvial architecture of the Rhine tributaries is now strongly influenced by human interference. Embankments, straightening, and stabilization have significantly impacted both in-channel and over bank sedimentation processes. Consequently, floodplain deposits in embanked regions differ from their natural equivalents in lithology and sedimentation. After embankments were constructed between 1050 and 1350 AD, lateral within-channel accretion became the primary process. Residual channel infill during this period is distinguished by the absence of peat, while thick layers of sandy and clayey deposits form on the embanked floodplains. These human-driven modifications have left a profound and lasting effect on the Rhine's floodplain landscape, permanently altering its sedimentary and structural characteristics.

In this exercise, I investigated the extreme situations of floods and droughts along the Rhine River, focusing on their respective impacts. The upper section of my research analyses the consequences of these extreme events, including environmental, social, and economic disruptions. Another section below explores the complex system of the river, studying it's hydrological behaviour, water management strategies, and how these extremes affect it's functioning. Together, these sections helped in developing comprehensive understanding into the river's vulnerability and resilience.

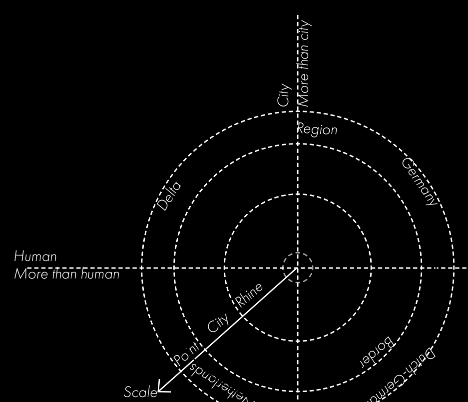
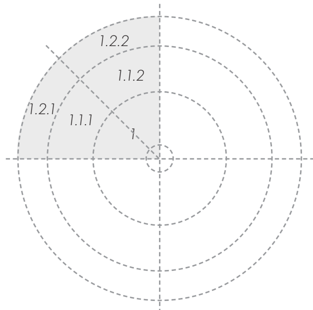


Illustration 03 | Matrix of investigations
Source: Author



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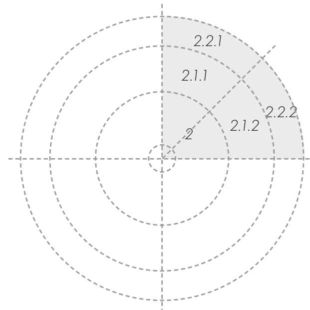

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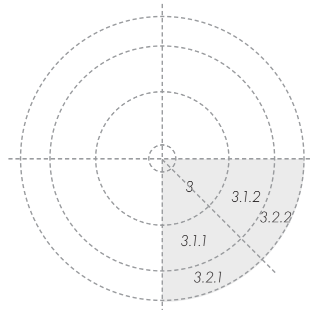

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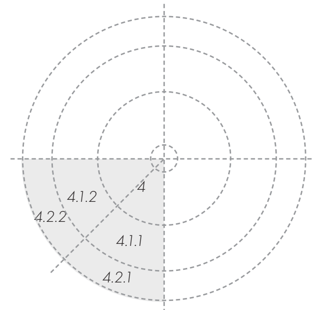

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Problem fields

Through matrix of investigations and exploring various focal points on impacted fields, I identified three critical problem fields that require attention:

Floods

Flooding along the Rhine River basin has become a growing concern, driven by the increasing intensity and frequency of extreme weather events caused by climate change. The devastating floods in 2021, which severely impacted several regions, underscore the vulnerabilities of both urban and rural areas to these phenomena. Rising river levels overburden existing flood defences, damage critical infrastructure, and disrupt daily life, leading to significant economic and social repercussions. Urban expansion and land use changes have further reduced the natural capacity of floodplains to absorb excess water, escalating the severity of these events. The impacts are not only immediate, with property damage and displacement, but also long-term, as communities face prolonged recovery periods and increasing strain on resources.

Droughts

The 2018 drought was a stark reminder of the Rhine basin's vulnerability to extended dry periods, which have been predicted to become more frequent and severe due to climate change (Drought Risk Atlas). Critically low water levels during the drought disrupted the availability of water for agricultural irrigation, industrial processes, and municipal needs. Groundwater resources were overdrawn in many areas, threatening both ecosystems and water supply security. Drought conditions also had high effects on biodiversity, as aquatic habitats and dependent species suffered from reduced water availability. The increasing unpredictability of water resources creates tension between competing demands, particularly in densely populated regions, and places immense pressure on water management systems designed for more stable hydrological patterns.

Transport Disruption

As Europe's busiest inland waterway, the Rhine River is a critical transport corridor for trade and economic activity. However, its reliability has come into question due to extreme hydrological events, particularly during droughts. The 2018 drought caused water levels to drop to record lows, making it difficult for cargo ships to navigate certain sections of the river. This led to reduced shipping capacities, logistical delays, and significant economic losses across multiple industries. Key sectors such as manufacturing, energy, and agriculture, which rely on efficient and consistent transport along the Rhine, were severely impacted. The disruption also exposed the vulnerability of the broader supply chain network, highlighting the interconnectedness of water levels and economic stability in the region.

Project Focus

Due to fluctuations in water levels due to flooding or droughts, obstruction is created in the flow of goods through cargo and general ships. Hence, the project will be focusing on maintaining the water levels throughout the year by implementing strategies and design.

- **Dynamic water equilibrium in the Rhine basin**: safeguarding Europe's trade and transport heritage amid climate Extremes.
- **Navigating extremes**: addressing floods, droughts, and transport disruptions in the Rhine river basin.
- **Adapting to climate variability**: ensuring continuity in the Rhine river's role as Europe's transport lifeline.

Figure 08 | Deutsche Post is flooded next to the Rhine river following heavy rainfalls in Bonn, Germany. Source: Reuters

Figure 09 | The water level gauge in Kaub, Germany, passed below 40 centimetres. Source: voanews

Figure 10 | Parts of Rhine closed to ships due to low water levels and navigational issues. Source: ShippingWatch

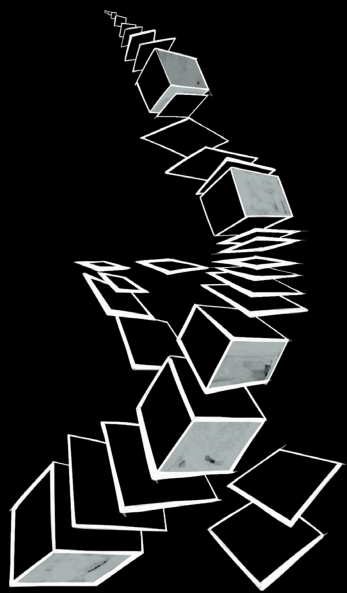


Illustration 04 | Methodology
Source: Author

Methodology

The methodology integrates theoretical and analytical frameworks with research aims and practical considerations to address flooding, drought, and transport challenges in the Rhine Basin. It aims to develop a scalable pilot project for resilient transboundary water management. It consists of:

1. Problem statement
2. Theoretical underpinning
3. Conceptual framework
4. Research framework
5. Methodological framework
6. Analytical framework

Problem statement

The Rhine River basin is not only Western Europe's most crucial waterway but also a lifeline for the region's economy, ecology, and cultural heritage. As Europe's **busiest inland water channel**, it supports extensive **trade activity**, sustains vibrant **ecosystems**, and plays a central role in **agricultural, industrial**, and **urban processes** across multiple countries. However, the Rhine is increasingly vulnerable to a range of environmental and infrastructural stresses caused by **climate-induced droughts and floods**. These challenges are compounded by human interventions, urban development, and intensive resource use, particularly within the densely populated regions of the Netherlands and Germany.

Predictions for 2100 indicate that **longer, hotter, and drier summers**, coupled with rising sea levels and soil subsidence, will exacerbate both **water scarcity and flood risk**. Such changes **threaten ecological stability, agricultural productivity, industrial processes**, and the Rhine's essential role as a **freight transport corridor**. The implications are profound, as urban areas and economic sectors throughout the basin rely heavily on consistent water availability. (Delta Scenarios 2024)

Cities along the Rhine are experiencing intensified pressures to secure water resources while balancing the needs of agriculture, industry, and urban development. These pressures are further complicated by **inter-polder dependencies**, where regions must increasingly share scarce water resources, especially during periods of drought. Similarly, infrastructure vulnerabilities—such as **dikes built from moisture-sensitive materials** and foundations at risk of **pile rot due to lowered groundwater levels** - underscore the need for **resilient water and flood management strategies**. Given the cross-border nature of the Rhine, the role of international cooperation is also paramount; cities in both the Netherlands and Germany must work together to address these shared challenges.

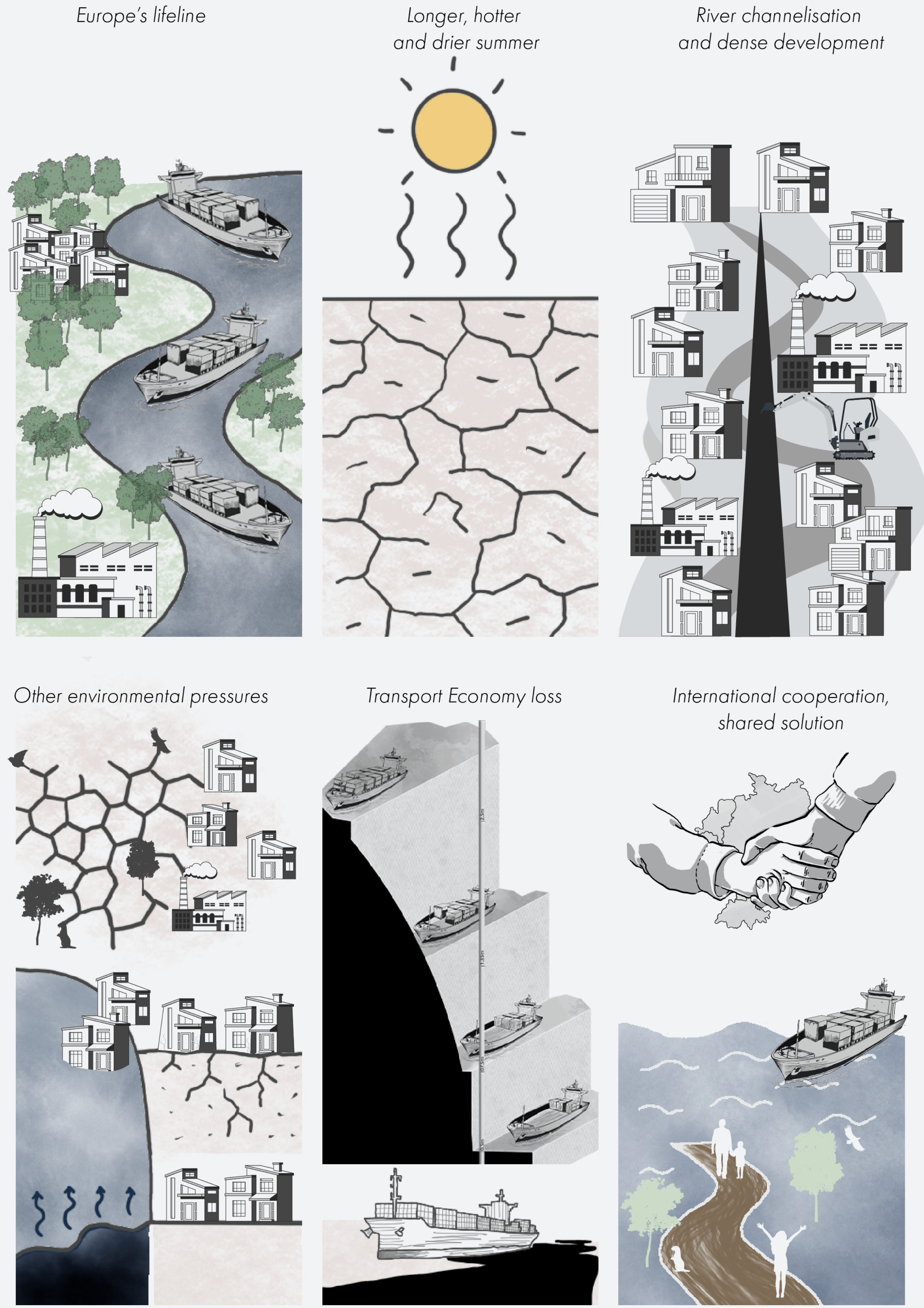


Illustration 05 | Challenges associated by intensive human interventions
Source: Author

Theoretical Underpinning

Climate Adaptation

At the core of the theoretical framework is Climate Adaptation, which refers to the strategies, policies, and measures employed to adjust to the changing climate and mitigate its adverse impacts. It responds to the urgent need to rethink how landscapes and cities engage with increasingly unpredictable water systems, especially in highly urbanized and infrastructurally dense regions like the Rhine delta. Rather than viewing adaptation as a defensive or static act, this project embraces it as a **transformative design process**, one that anticipates change, accepts uncertainty, and enables flexibility across scales and functions. In this sense, climate adaptation is not only about managing risk but about building the capacity of places to **absorb, reorganize, and evolve** in response to environmental shifts (Folke et al., 2005; IPCC, 2022).

In the context of this research, climate adaptation is achieved through a multi-scalar and cross-sectoral framework that integrates hydrological systems with socio-economic and cultural structures. Theoretical framework is informed by two pillars: Water Governance and Infrastructure Economics. These two frameworks guide how adaptation is understood not only in terms of ecological flows and water dynamics, but also through the lens of economic decision-making, trade-offs, and governance complexity. Strategies such as socio-hydrological zoning, economic retention basins, and ecologically buffered infrastructure were tested across Rhine basin (macro), regional (meso), and site-specific (micro) levels. Drawing from Integrated Water Resources Management (GWP, 2000), resilience theory (Walker et al., 2004), and polycentric governance (Ostrom E., 2010), the design interventions aim to create a condition of **dynamic water equilibrium**: a state where economic, ecological, and societal demands can coexist and respond fluidly to change. This has been translated into a pattern language of design principles that both spatially and institutionally embody the values of long-term adaptability.

This framework recognizes the need for integrated, proactive measures to ensure the resilience of urban areas, infrastructure, and transboundary water systems, focusing on dynamic water equilibrium to sustain Europe's critical trade and balance ecology, economy and society. It is based on two major frameworks:

1. Water governance framework
2. Infrastructure economics framework

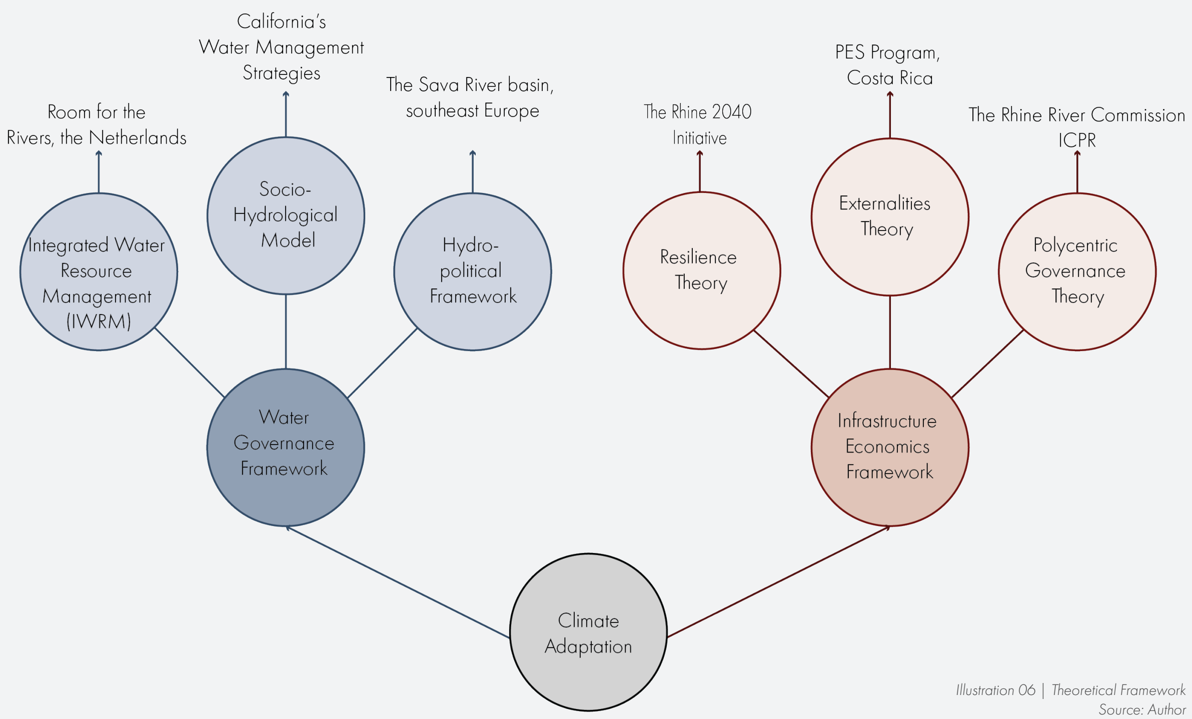


Illustration 06 | Theoretical Framework
Source: Author

Water Governance Framework

Water governance refers to the political, social, economic, and administrative systems in place that influence how water is managed, distributed, and protected. Unlike traditional water management, which often focuses on technical control or supply-demand equations, water governance emphasizes the institutions, stakeholders, rules, and power dynamics that shape decisions around water. It acknowledges that water is not just a resource to be engineered, but a social-ecological system deeply interlaced with cultural values, economic structures, and ecological processes (Pahl-Wostl et al., 2008).

In this research, water governance plays a central role in understanding how different regions along the Rhine, particularly between the Netherlands and Germany, respond to water-related stress. From droughts affecting freight logistics to floods disrupting urban areas and agricultural zones, water governance is what determines who decides, how decisions are made, and whose interests are prioritized. This becomes particularly critical in the Gelderse Poort region, where the intersection of ecological zones, cultural landscapes, and economic corridors demands not a single authority, but coordinated, polycentric decision-making across actors and borders.
This research integrates water governance into design by mapping institutional responsibilities, and imagining policy-informed spatial strategies. For example, the introduction of economic retention basins and no-dredge zones responds not just to hydrological logic but also to governance gaps where existing authorities struggle to keep up with increasing climate variability.

Water Governance framework encapsulates:
- Integrated water resource management
- Socio hydrological model
- Hydro-political framework

- **Integrated Water Resource Management**

IWRM is a globally recognized framework that promotes the coordinated development and management of water, land, and related resources across sectors, in order to maximize economic and social welfare without compromising the sustainability of vital ecosystems (GWP, 2000). It is based on the understanding that water management cannot be compartmentalised into technical or sectoral tasks, but must integrate ecological systems, human needs, and long-term resilience.

In the context of research, IWRM guided the development of design principles that support dynamic water equilibrium by acknowledging the interconnectedness between river flows, land-use patterns, and social livelihoods. For instance, when designing multifunctional spaces such as economic retention basins or eco-tourism hubs, the IWRM framework helped balance water storage needs, biodiversity support, and economic uses. It reinforced the need for stakeholder-informed and cross-scalar interventions, especially in a complex system like the Rhine, where upstream and downstream decisions are tightly interlinked.

By integrating IWRM principles, the project avoided treating ecology, economy, and society as separate identities. Instead, design strategies were layered with seasonal adaptability, shared uses, and system-wide awareness, translating policy goals into spatial and experiential realities.

Project -
1. Room for the Rivers (Ruimte voor de Rivier) project in the Netherlands, which aimed to increase flood safety and improve the ecological value of river landscapes through integrated approaches.

References -
1. Governance arrangements water safety programme 'Room for the River' are enabling a transition towards integrated river basin management in the Netherlands. (Rijke et al., 2012)

2. Global challenge of providing balanced and sustainable solutions to urgent water problems, exploring our dependence on water and the need for integrated management approaches. (Agarwal et al., 2000)

- **Socio-Hydrology Model**

The socio-hydrological model (Sivapalan et al., 2012) provides a way to study the co-evolution of human and water systems, recognizing that societal behaviour affects hydrology, and vice versa. It offers a dynamic approach where feedback loops such as how people respond to floods or how economic systems adapt during drought — shape the overall water balance over time.
This model became especially important when analysing how human interventions like dredging, embankment, or urban expansion have historically altered the Rhine's natural rhythms. It offered insights into how certain economic decisions (e.g., over-reliance on water transport) lead to vulnerabilities, and how design could influence public behaviour such as engaging

people through eco-monitoring platforms or adaptive communal housing in high-risk zones. This model helped formulate temporal and spatial dynamics in the design strategies phase. The idea of seasonal wetland expansion zones or dual-use floodplains stemmed from understanding that people will only accept certain interventions if they bring co-benefits. It emphasized the need for social learning, iterative feedback, and participatory design in making water systems resilient and just.

Project -
1. California's Water Management Strategies, which examine how socio-hydrological dynamics shape water allocation and conservation practices.

References -
2. Socio-hydrological frameworks within European river basins and understanding how human-water interactions shape policy and management strategies. (Sivapalan et al., 2012)

3. Rhine's historical and contemporary water management challenges, including flood and drought responses shaped by socio-hydrological dynamics. (Blöschl et al., 2013) .

Hydro-political Framework

The hydro-political framework examines how power relations, international politics, and identity shape transboundary water systems. In a river like the Rhine, which flows through multiple countries, water is not only a natural flow but also a political construct tied to heritage, sovereignty, and shared futures (Zeitoun et al., 2006).

This framework gave critical weight to the Rhine's identity as a trade heritage corridor, beyond just a physical waterway. It helped me understand how Germany and the Netherlands have different planning cultures and governance systems, and how this affects collaborative water management. It shaped my design argument that multi-scalar, transboundary, and culturally sensitive strategies are essential when working across borders. The hydro-political framework also informed my use of storytelling and spatial narratives, such as memory islands and cultural riparian trails, which anchor ecological strategies in cultural memory. It also justified the inclusion of policy-based zoning recommendations, where political negotiations could align around ecological and infrastructural interventions that offer mutual benefit.

Project -
1. The Sava River Basin, shared by multiple countries in South-eastern Europe, serves as a toolbox for transboundary water contingency management and has improved resilience against flooding, and pollution events, highlighting the importance of coordinated efforts in shared watercourses.

References -
1. Analysis of the political, economic, and social dimensions of managing shared water resources across borders including practical insights and theoretical frameworks essential for understanding transboundary water governance. (Earle et al., 2010)

2. Shared water resources can serve as a platform for cooperation and peace-building, addressing the hydro-political aspects of transboundary water management. (Abukhater et al., 2013)

Infrastructure Economics Framework

This framework helped frame the Rhine not just as a geographic or hydrologic entity, but as a layered economic system — where infrastructure, trade, ecology, and spatial justice all interact. In my project, this framework helped reimagine design principles especially the Gelderse Poort area not as a static logistic corridor, but as a dynamic socio-economic landscape, whose resilience depends on its ability to absorb, adapt, and transform in response to climate-induced extremes.

By applying this framework, design process explored how economic infrastructure (freight, trade, tourism) could be restructured to reduce environmental harm, adapt to fluctuating water levels, and offer inclusive public value. This shift in perspective laid the groundwork for developing flexible, low-impact, and regenerative design principles like Modal Shift Infrastructure, Hydro-Economic Synergy, and No-Dredge Economic Zones.

Infrastructure economics framework encapsulates:
- Resilience theory
- Externalities theory
- Polycentric governance theory

- **Resilience Theory**

Rooted in systems thinking, resilience theory (Holling, 1973; Walker & Salt, 2006) posits that socio-ecological systems should not aim for stability but for the capacity to absorb shocks and continue functioning. It acknowledges that rivers like the Rhine are in a constant state of flux and that infrastructure should be designed not to resist change, but to evolve with it.

This principle directly shaped multi-seasonal and reversible design strategies. For instance, seasonal wetland expansion zones, economic retention basin clusters, and floating wetlands are spatial interpretations of resilience, they embrace flood pulses, offer temporary uses, and morph over time. These spaces perform ecologically and economically by buffering risk and supporting small-scale industries or social activities during low-water periods. This was adopted not just as a design idea but as a planning ethic, one that moves beyond traditional flood control or engineering into fluid, adaptive zoning that is future-proof.

Project -
1. The Rhine 2040 Initiative is a long-term vision to improve water quality, mitigate flood risks, and enhance cross-border cooperation between countries sharing the Rhine River. It is rooted in resilience theory by developing adaptive strategies to manage water levels and quality.

Reference -
1. Resilience, adaptability, and transform ability in social-ecological systems emphasizing the interaction between human and natural systems. (Walker et al., 2004)
2. Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics. (Holling et al., 1973)

Externalities Theory

Externalities theory, rooted in environmental economics, refers to the unpriced consequences of economic activities both negative (pollution, biodiversity loss) and positive (clean air, cultural landscapes). This research used this theory to expose the hidden costs of current water-borne trade practices, such as dredging, riverbed degradation, and ecological fragmentation.

These issues are responded by proposing designs that internalize these externalities, turning invisible costs into visible, measurable, and spatially addressed opportunities. For example: No-Dredge Economic Zones reduce sediment disturbance while boosting alternative economies, Biodiversity Buffer Rings and Eco-Threshold Infrastructure soften the impact of roads or ports, Pollution-Responsive Zones and Water-Purifying Biofilters mitigate runoff and clean ecosystems passively. This theory helped quantify the multi-benefit value of hybrid ecological-infrastructural interventions and formed the backbone of economic design lens where "cost-effectiveness" includes long-term ecological gain.

Project -
1. Payment for Ecosystem Services (PES) programs in Costa Rica provide economic incentives for landowners to manage their land for ecosystem services.

Reference -
1. Analysing how the transboundary governance framework, including the ICPR, addresses the environmental and social externalities stemming from economic activities in the region. (Blöchliger et al., 2018)

2. Meuse River Basin Management Program: A multi-country approach to addressing externalities in water governance. (MRBC 2016)

Polycentric Governance Theory

It emphasizes that multiple governing bodies at different scales and jurisdictions can collaboratively manage shared resources more effectively than a single centralized authority. It aligns closely with the complex nature of the Rhine, a transboundary river shared across cultures, interests, and administrative boundaries.

This theory shaped how this research viewed decision-making beyond engineering, inviting community input, municipal cooperation, and international coordination. It supported your use of: Participatory fieldwork and interviews with experts, Bottom-up design cards that reflect varied needs, Flexible zoning responsive to both Dutch and German contexts. Design process was built to allow multiple actors to adapt and co-own interventions, especially in shared or contested terrains like the Gelderse Poort. The idea of placing "cards" to test synergy or conflict is itself a method of polycentric learning, where the best design is not top-down but co-produced.

Project -
1. The ICPR is an example of polycentric governance where various national and regional bodies collaborate to manage the shared water resource. This governance structure integrates a variety of stakeholders from different scales and sectors to address issues like water quality, flood protection, and ecosystem restoration along the Rhine River.

Reference -
1. Multi-scaler governance cooperation to manage common-pool resources where overlapping institutions operate at different levels helps to govern shared resources effectively while preventing over-exploitation by ensuring sustainability. (Ostrom E., 1990)

Conceptual Framework

Conflicts and Interests

There are different groups and organisations of people who have their own agenda of running the system. Major shift can be seen between the groups who support economic activities and they often overlook the need of ecological balance. On the other hand, there are groups who focus on ecological balance but overlook societal integration and when they achieve the goal, they make the area protected habitat which refrains it from becoming a source of economy (for eg. Biesbosch area in the Netherlands).

Hence, this diagram shows two contrasting activities having no integration with each other and seen as two distinct parties having different goals rather than achieving unified outcome. So, this thesis proposes a middle way where the integration of both the goals i.e. ecology and economy can be merged with a focus on societal needs.

It has been approached through top down approach in EDS and bottom up approach in NBS with a collaboration of transboundary governance. This helped in creating a conceptual framework which illustrates how this goal can be achieved.

Nature protected areas

Economy driven areas

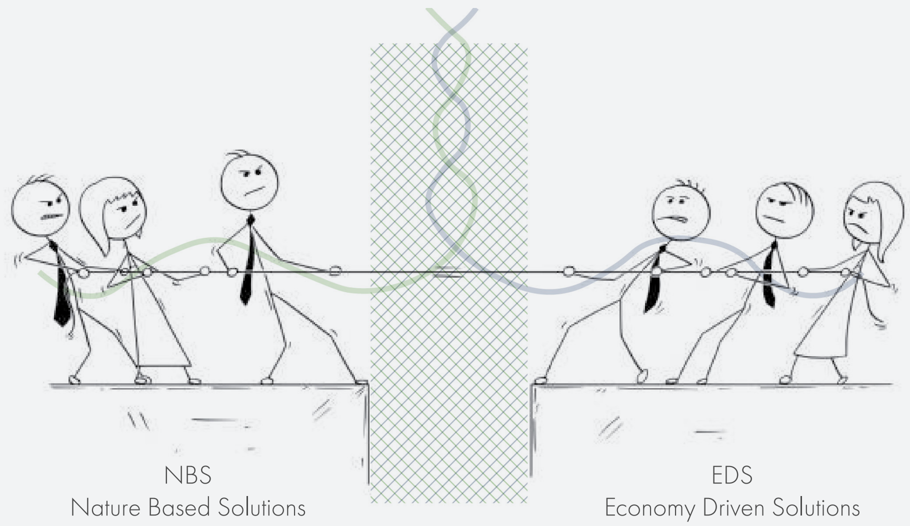


Figure 11 | Images; Top left - Biesbosch | Bottom left - Biesbosch | Top right - Amsterdam South | Bottom right - Rotterdam Port Source: Google images | adapted by author

Illustration 07 | Tension between EDS and NBS experts Source: Author

Conceptual Framework

Ideology

I am particularly drawn to MVVA's philosophy, which places the spirit of the place at the centre of design, grounding each intervention in its natural and cultural context. Their work embodies powerful images of nature, not as static ideals, but as evolving systems shaped by time, use, and ecology. MVVA designs with a vision of a desired future, embracing transformation over fixed ideologies, and creating landscapes that are resilient, layered, and inclusive. What I deeply appreciate is their integration of social spaces with water and green systems, where parks become more than infrastructure—they become platforms for public life, ecological recovery, and sensory experience. Through positive ecology, visual and spatial sequencing, and moments of hyper-nature, MVVA's projects re-imagine urban nature as vibrant, adaptive, and people-centric.

This philosophy made me rethink how nature can be a powerful tool when intertwined with society and can create smaller economy in the region instead of going solely for protected areas or economic infrastructure. This shapes the ideology of this research to intertwined three distinct lenses into one and create a unified structure for society which can bring ecological and economical balance.

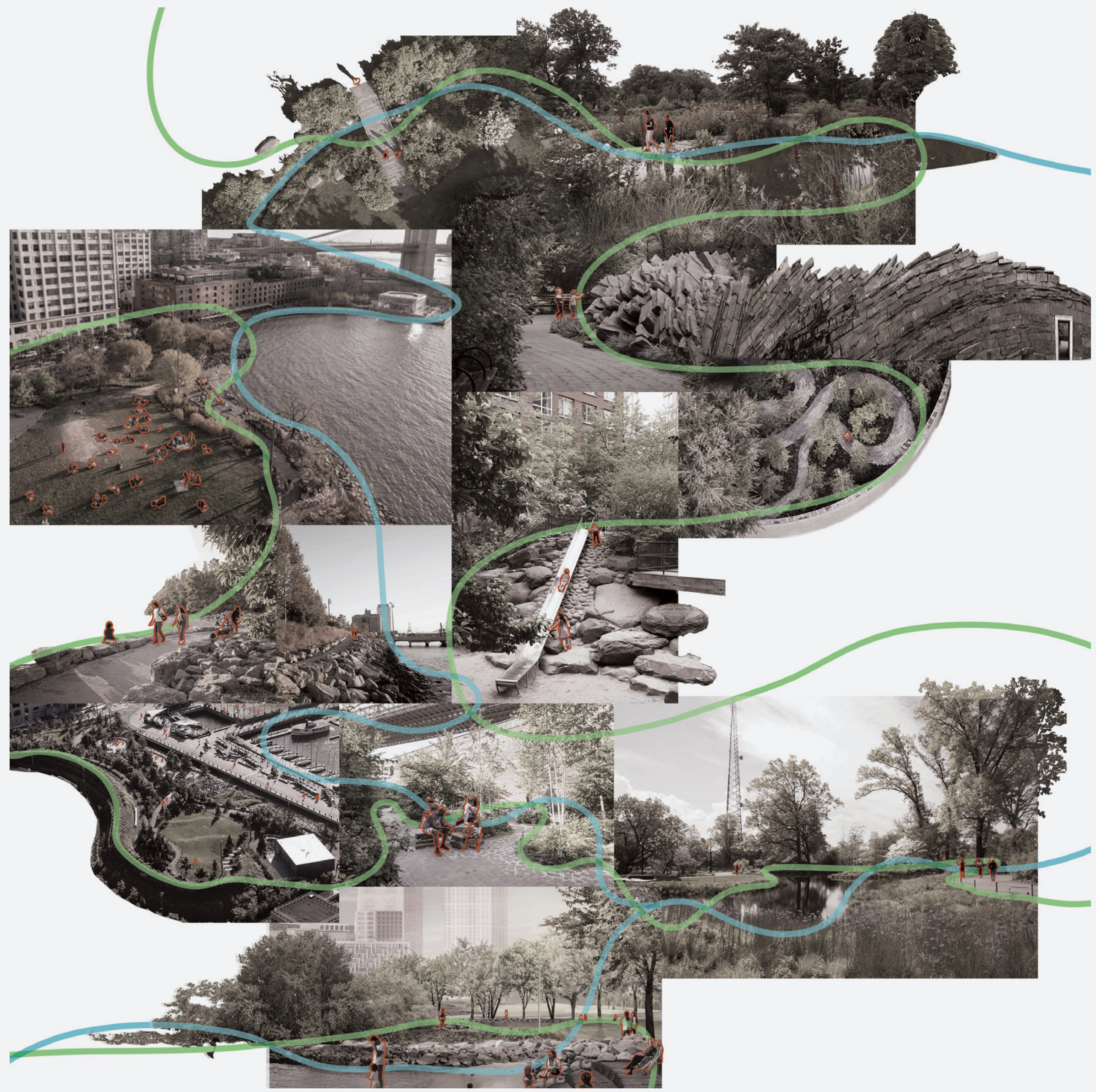


Illustration 08 | Integration of social, nature and water balance
Source: MVVA

Conceptual Framework

This framework visualizes the intersection of two traditionally opposing paradigms in spatial and environmental design: economy-driven solutions and nature-based solutions. The inverted pyramids represent these two paradigms, each bringing different priorities, stakeholders, and methodologies into the design process.

Economy-Driven Solutions
In this framework, economy-driven solutions represent strategies that prioritize infrastructure, logistics, and market-based mechanisms. These approaches often aim for efficiency, scalability, and profitability, addressing regional development and investment objectives overlooking ecological nuances.

Top-Down Approach
The top-down approach involves centralized planning, policy-making, and institutional governance. It is crucial for setting regulations, securing funding, and driving large-scale change.

Nature-Based Solutions
Nature-based solutions emphasize ecological processes and landscape resilience. These strategies work with natural systems such as wetlands, riparian zones, and biodiversity corridors to mitigate climate risks and restore ecosystems.

Bottom-Up Approach
The bottom-up approach values community knowledge, local initiatives, and participatory governance. It is rooted in site-specific contexts and create socially inclusive outcomes.

At their intersection lies a shared zone of collaboration, shaded to emphasize the overlap between ecological sensitivity and economic pragmatism. It marks the path toward integrated solutions, showing that through this middle ground where top-down planning aligns with bottom-up initiatives can be resilient and context-responsive strategies emerge. The horizontal loop symbolizes transboundary collaboration which is a critical component in resolving climate-driven challenges, especially within complex territorial systems like river basins that cross political and administrative boundaries.

This framework underpins the design logic of the thesis, emphasizing synergy over opposition, and offers a spatial logic for integrating cross-scalar, cross-disciplinary interventions along the Rhine River (for previous conceptual framework refer appendix 1).

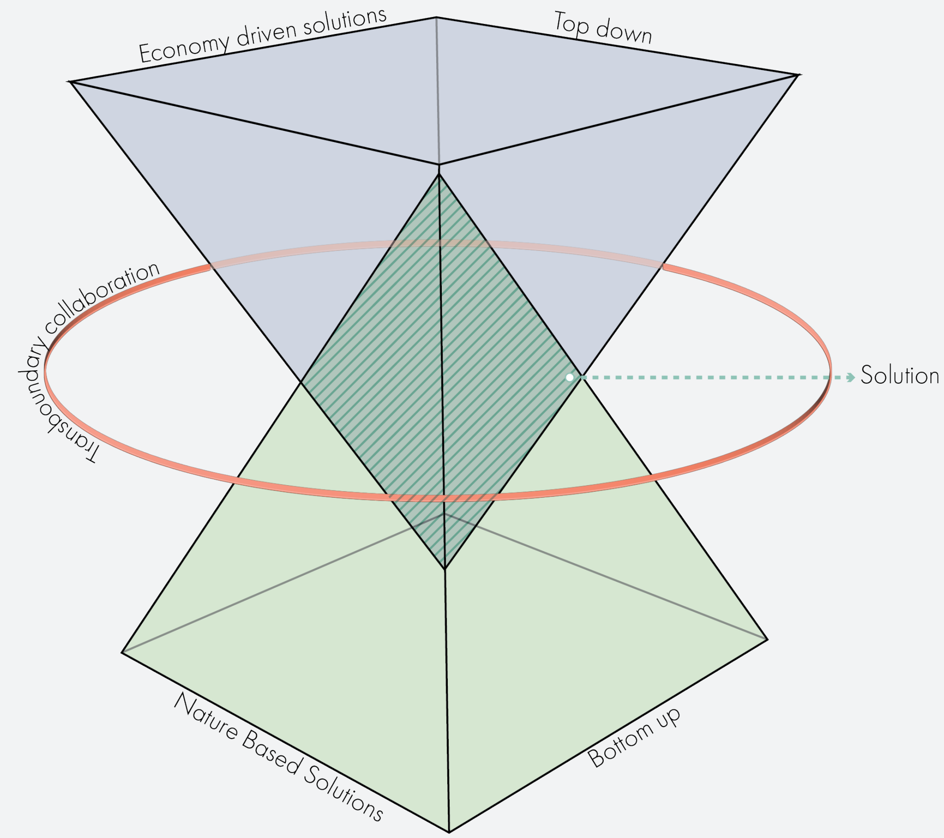


Illustration 09 | Conceptual Framework
Source: Author

Research Framework

This section outlines the structure of the research by breaking down the main research question into focused sub-questions, addressing specific aspects of the study. It provides an overview of the approach, detailing the methodologies and processes guiding the investigation, ensuring clarity in addressing the research objectives. A timeline will also be presented to illustrate the key stages and milestones, ensuring the research progresses in a structured and timely manner.

Research Question

How can multi-scalar water interventions along the Rhine balance economy, ecology, and culture while preserving its trade heritage across the Netherlands and Germany?

Sub-research Questions

1. What types of multi-scalar water management strategies can be adapted in response to fluctuating water levels along the Rhine?
2. How can hydro-ecological actions improve ecological flow and support the resilience of natural systems within the Rhine basin?
3. How can water-based design respect and reinforce the Rhine's historic and cultural landscape identity?
4. What role can adaptive water infrastructure play in stabilizing freight transport and economic activity along the Rhine?
5. How can collaborative governance between the Netherlands and Germany sustain the Rhine's shared identity and ecological preservation?

Steps of Research:

The steps throughout the research have been explained and a timeline (figure 17) is suggesting how the study is being conducted.

Problem Statement

The problem is developed based on personal interests, current issues that might get as severe as predicted, and the scope of the graduation studio. It is updated regularly through ongoing analysis, projections, and extensive literature reviews.

Research Aim

The research aim is derived from the problem statement and is adjusted accordingly to state this research's goal.

Research and sub-research Questions

Research question is formulated to structure the study and to explore the topic more deeply. By dissecting the main research question, further sub-research questions emerged to delve deeper into the particulars.

Cartography

The analysis phase initiated with the creation of detailed maps that are arranged to unfold different layers of existing, predicted conditions and possible challenges from them. It has been divided into three major parts: Climate Induced challenges, urban landscapes, natural and anthropogenic Layers

- Macro Scale (Rhine Basin)
- Meso Scale (Affected regions)
- Micro Scale (Gelderse Poort)

Field Trip

Following a comprehensive understanding of the research site, a field trip will further deepen this knowledge. The trip's objective is to engage with local experts for specialized insights and to examine the location's social conditions. Field trip is carried out on two scales:

- Meso Scale
- Micro Scale

Analysis

Based on the cartography, field trip, reference studies, and data collection on policies and management plans, analysis was done to prepare the base for design.

Research by Design

When a strong foundation of knowledge regarding the problems, theories, and site conditions was established, the design phase began. 'Research by Design' was the primary method, integrating theories and approaches into the case study. The unique conditions of the location required adjustments to the theories and methods applied to ensure their relevance.

Conclusion

This research addresses critical water management and transport resilience challenges within the transboundary Rhine River basin. The outcome is guiding design principles addressing flood and drought resilience, supported by a pilot project in one key location as a test site, offering insights for broader application across similar contexts.

Evaluation

The research process and outcomes critically evaluated to assess the effectiveness of the proposed strategy and pilot project. Two workshops with experts in the company and students from Poland were organised to evaluate the design principles. Insights gained from these workshops inform further research and refine approaches for broader implementation in comparable regions.

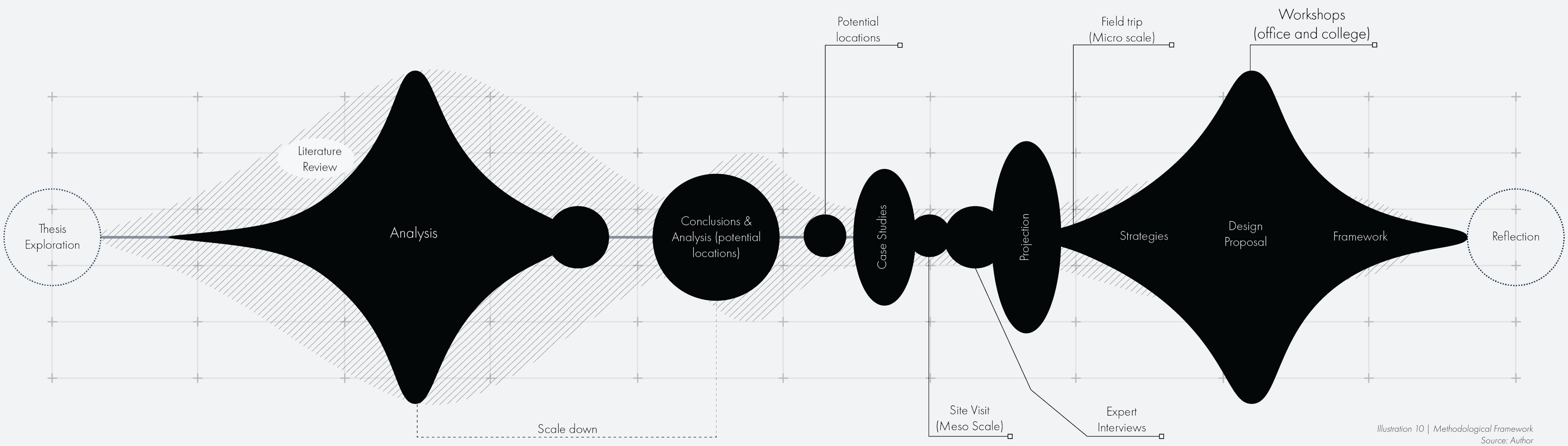
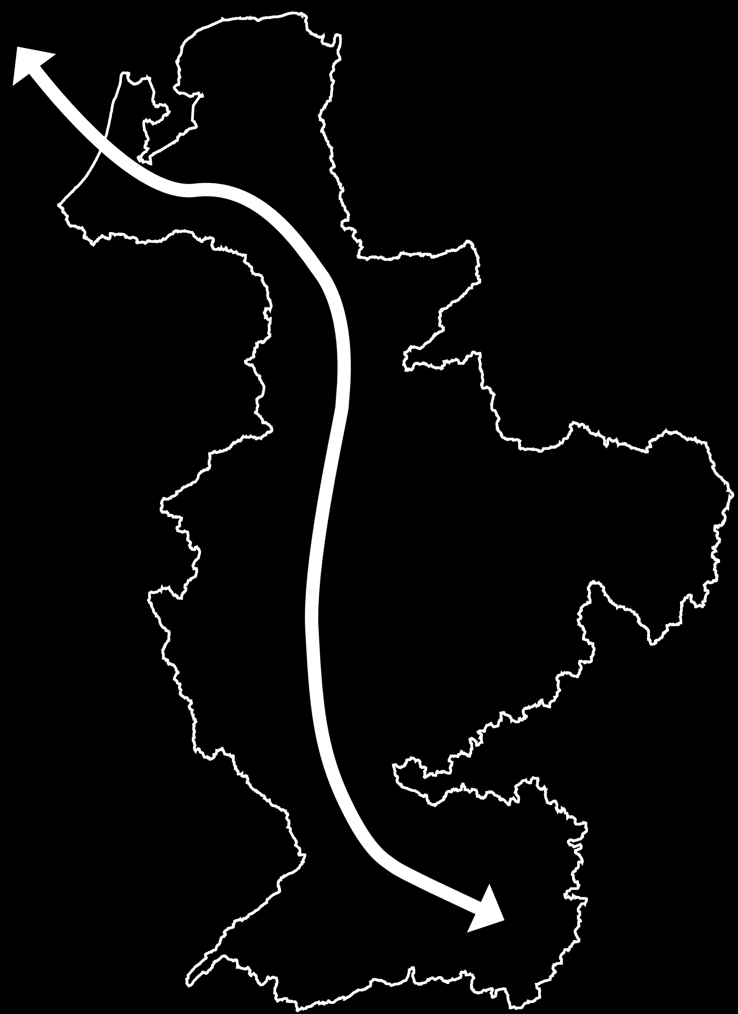


Illustration 10 | Methodological Framework
Source: Author



Research Aim

The major goal of this project is to explore how dynamic water equilibrium can be achieved along the Rhine through multi-scalar water management interventions that balance economic infrastructure, ecological systems, and cultural-societal landscapes, while preserving the river's identity as a cross-border trade heritage corridor between the Netherlands and Germany.

Outcome

This project is expected to yield comprehensive strategies aimed at minimizing floods and drought consequences in the Rhine River Basin. The primary predicted outcomes are:

Design Principles

As part of this research, a comprehensive set of design principles is developed to address the Rhine's climate-induced water challenges through the interconnected lenses of economy, ecology, and society. These principles form a pattern language (based on Christopher Alexander and referenced from Donut Diet project) of spatial, programmatic, infrastructural, and policy-based strategies that respond to fluctuating water levels, transport disruptions, ecological degradation, and socio-cultural vulnerabilities. Categorized across macro, meso, micro, and local scales, the principles aim to create dynamic water equilibrium while preserving the Rhine's identity as both a trade corridor and a living landscape. They not only serve as a design toolkit for the Gelderse Poort pilot area but also offer a replicable framework for future climate-resilient planning across transboundary river systems.

Pilot Project Proposal

A thorough pilot project is designed for a specific, key region in the Rhine Basin (i.e. an area in Gelderse Poort). This project serves as a proof of concept, addressing localized flooding and drought challenges while focusing on the ecological stability, economic activities, and societal values.

Integrated Framework for Water Management

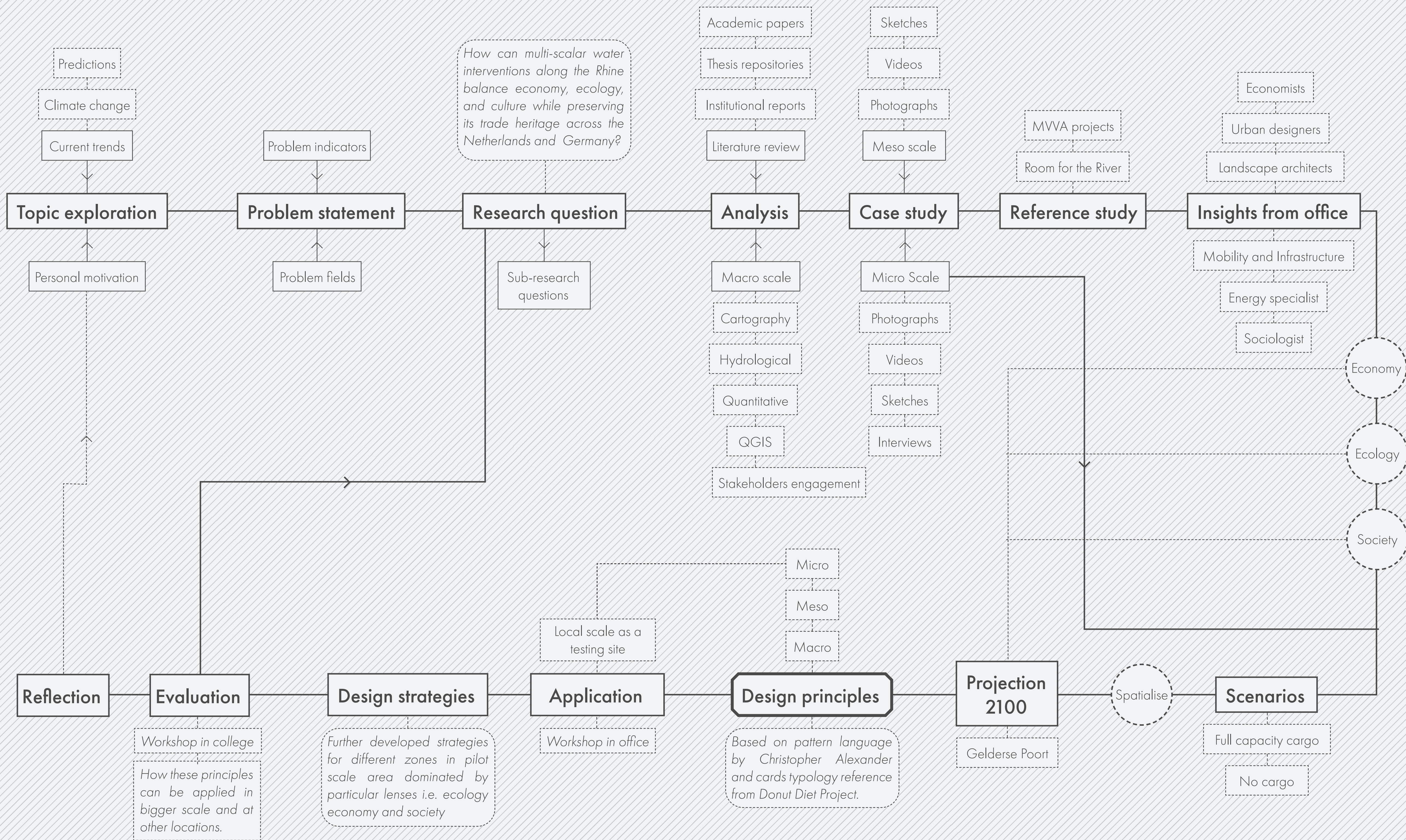
A framework that combines water governance, infrastructure economics, and socio-hydrological principles is laid out practical ways for cross-border cooperation, equitable water resource distribution, and long-term climate adaptation along with policy recommendations.

Scalable Strategies

While working on the Rhine basin, the research has detailed out how the recommended techniques can be modified and scaled to other river basins with a context facing similar challenges, ensuring that the findings are as widely applicable as those from the Room for the River initiative.

Figure 12 | Intended Outcome
Source: Author

Methodological Framework



Refer appendix 2 for previous methodological framework

Analytical framework

The analytical framework for this research is structured to systematically address the complex challenges of managing water systems in the Rhine River Basin under the pressures of climate change. It establishes a cohesive approach to analyse the existing conditions, design interventions, and evaluate their impacts across various scales and dimensions.

Scale

This research envisions a multi scalar approach to understand back and forth process as how an implementation on molecular level might affect the entire basin and vice versa. So understanding the river on basin scale and analysing on regional scale has helped me in developing the pilot project on local scale which might be an strategy for whole basin in future.

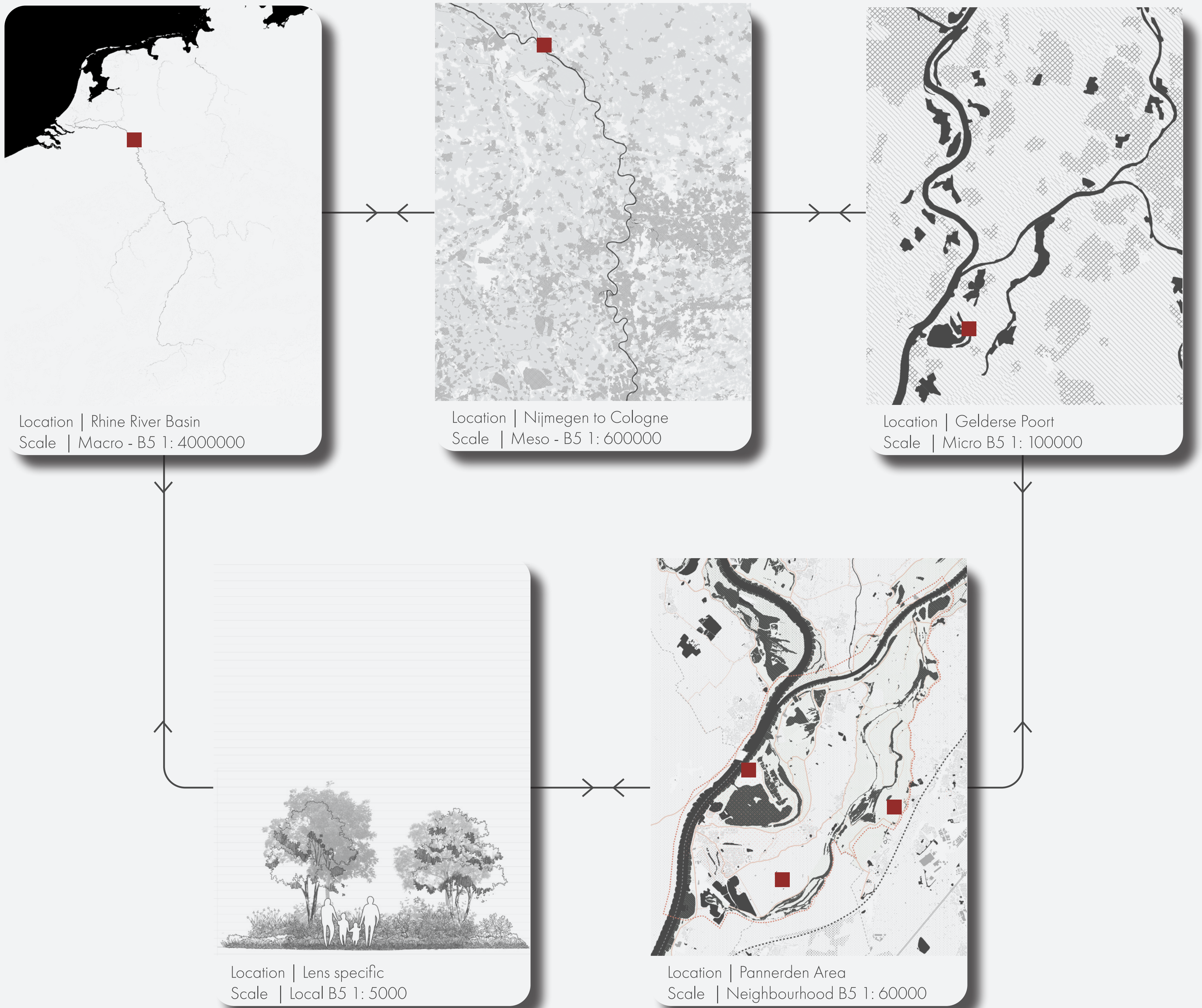


Illustration 11 | Distinct Scales of the Project
Source: Author

Cartography

It is crucial to understand the spatial dynamics of flooding and drought through detailed mapping determining water sources, flow patterns, landform influences, and governance structures. These maps guide analysis, projections, and decision-making, ensuring that proposed strategies are grounded in spatial and contextual realities. It consists of:

1. Climate Induced challenges
2. Urban expansion
3. Anatomy of the River Basin
4. Intersecting Lenses
5. Natural and Anthropogenic Layers
6. Historic evolution of ports
7. Rhine as transport corridor
8. Critical Zones for Future Development

Illustration 12 | Cartography
Source: Author

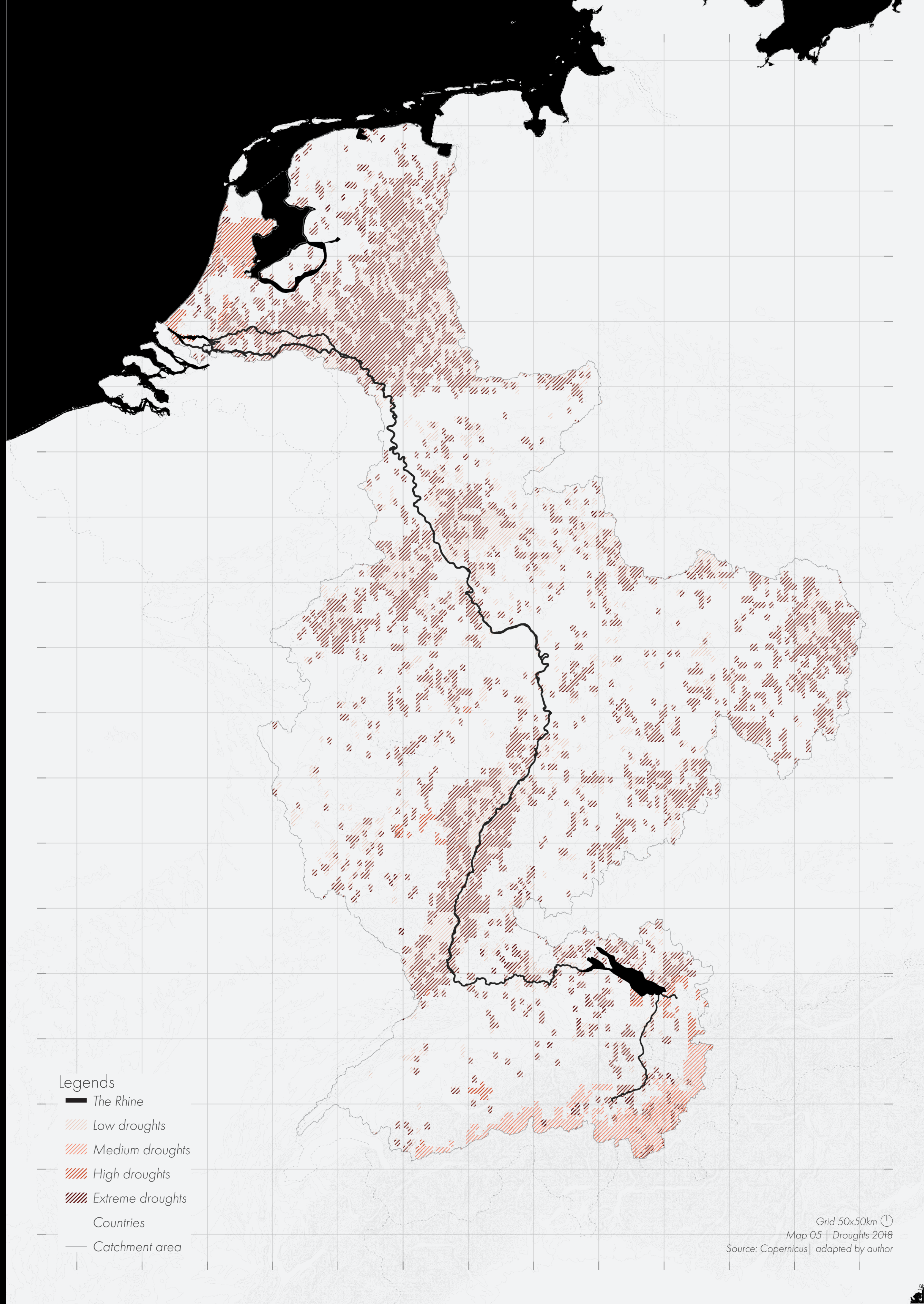
Climate Induced Challenges

Droughts

The 2018 drought along the Rhine River marked a critical turning point, highlighting the vulnerabilities of Europe's busiest waterway to extreme climate events. Prolonged heat and minimal rainfall led to historically low water levels, severely disrupting inland navigation and freight transport. Cargo ships were forced to reduce loads, increasing transportation costs and impacting industries reliant on Rhine-based logistics. The drought also revealed the delicate balance of water dependencies in the Rhine basin, affecting agriculture, energy production, and urban water supplies.

This 2018 August drought map shows that some sections along the Rhine were hit. Mainly, the border between the Netherlands and Germany between Nijmegen and Duisburg and another section close to Mannheim. This drought in 2018 indicates that the change in climate resulting into longer drier periods in western Europe which has a high impact on the Rhine river and population associated with it.

By 2100, an additional 1 billion people are expected to live with extremely high water stress, even if the world limits global temperature rise to 1.3 degrees C to 2.4 degrees C (2.3 degrees F to 4.3 degrees F) by 2100, an optimistic scenario. Germany and the Netherlands are expected between medium-high (20-40%) change. (Federal water, Deltascenarios and CCNR - Refer Factsheet 1)



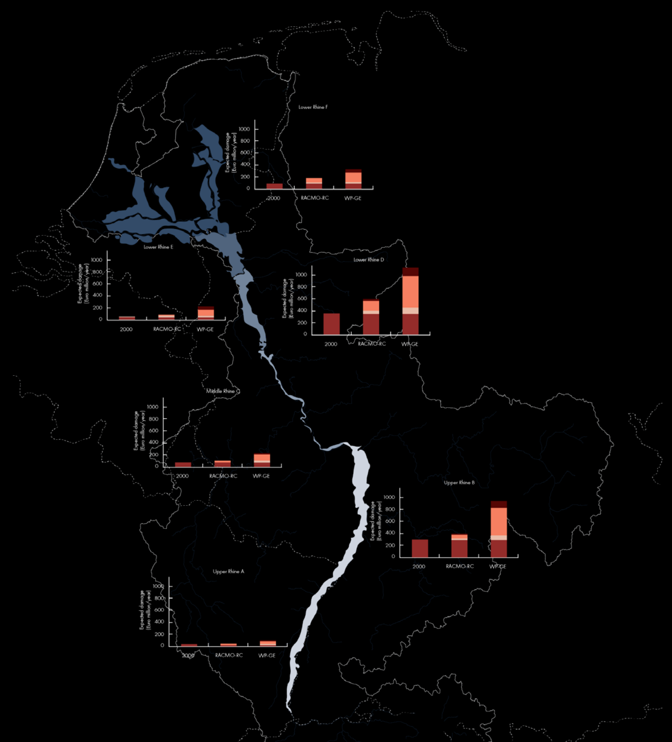
Flooding 2021

The map is showing the flooding happened from 13-17th July, 2021 and causing the damage along with it. The flooding in the Moselle river which is a tributary to the Rhine close to Bonn was the major contributor in the Rhine for flooding in the Rhine. From Bonn till the Delta it became impossible to manage the floods, there were dikes breach in many places and so many lives were lost. High precipitation in the catchment where due to low infiltration capacity caused flash floods and all the water discharged into the basin. Many cities were on high alert and people were being evacuated along the Rhine.

62 deaths in Mayschob, 110 death deaths in Schuld, 2220 people were at risk of flash floods in Musch due to high curresnts and velocity.

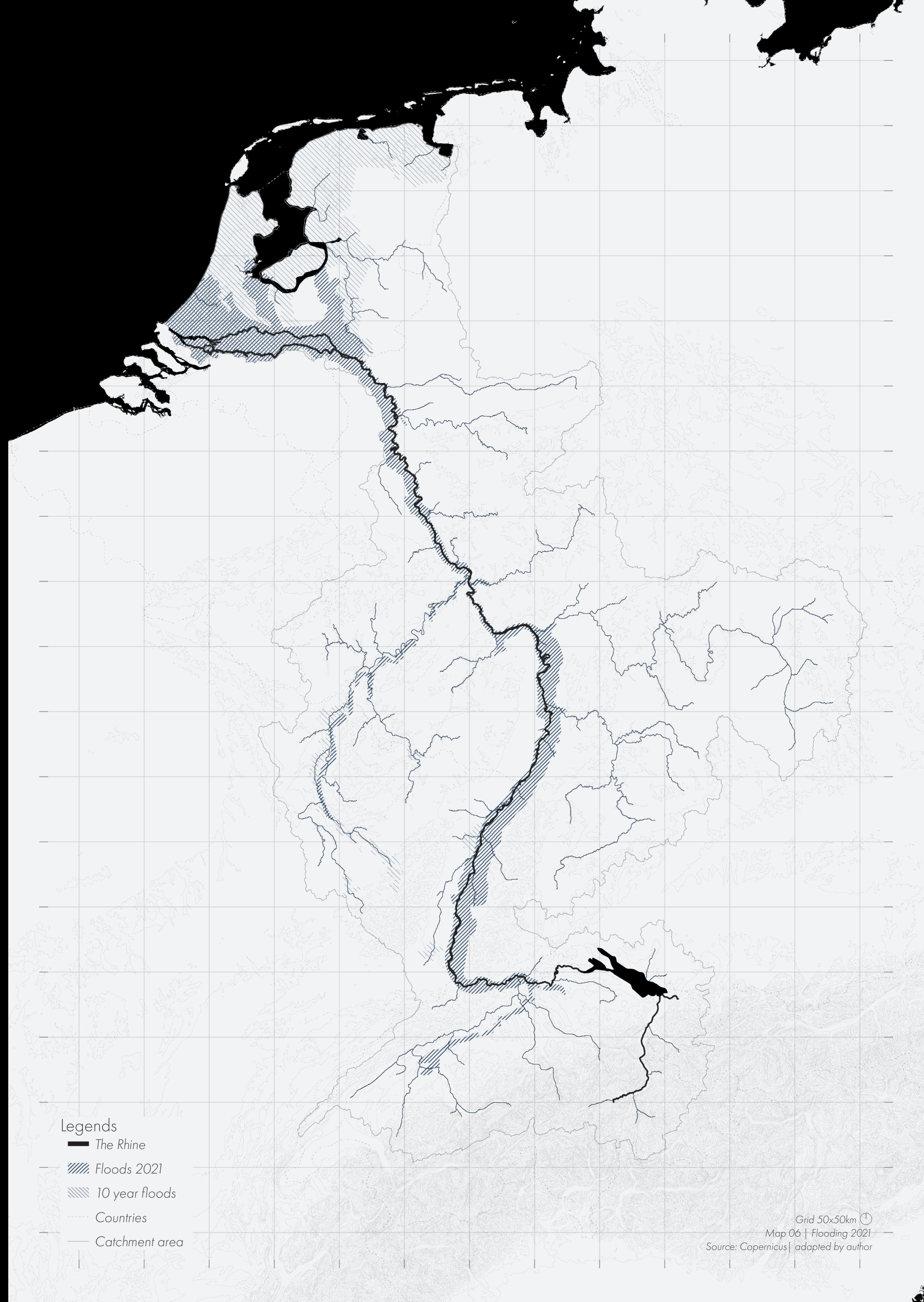
Projections

The projections were analysed flood risk across the entire Rhine basin, using the year 2000 as a reference. Climate change scenarios were modelled to evaluate changes in flood probability, while land-use change scenarios assessed shifts in potential damage. The combined simulations offered various projections for future flood risk. (Copernicus, 2010)



Legends
The Rhine
Socio-economic
Climate
Socio-economic + climate
Catchment area

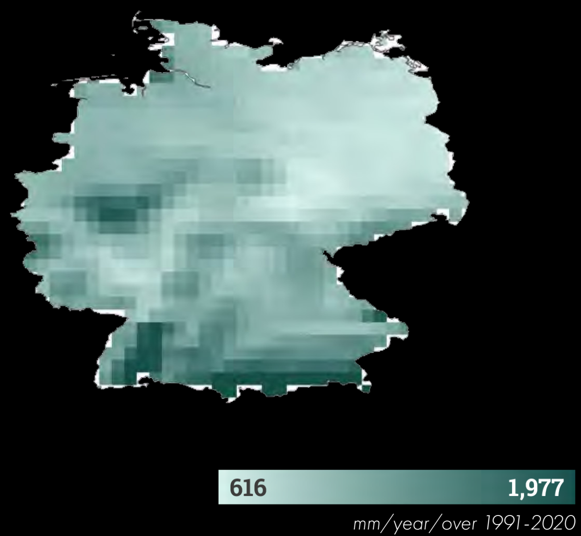
Figure 13 | Annual expected flood damage, for the reference situation and projections, aggregated into seven regions along the Rhine.
Source: Copernicus | adapted by author



Precipitation

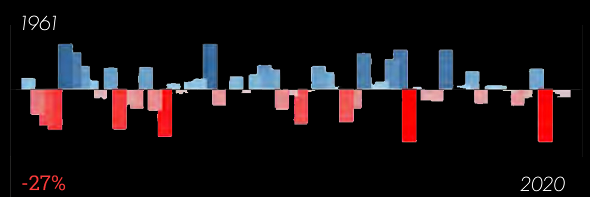
Precipitation in Germany is more-than-abundant, well-distributed and varies between regions. It is lowest in the North German Plain and increases in the Central German Uplands and Alpine regions where annual mean precipitation is up to and exceeding 2,000 mm per year. In general, annual precipitation features a relevant inter-annual variability. This may be related to the complexity of the precipitation regime and to possible compensation between opposite patterns reported at a more local level.

Mean precipitation



Anomalies

Precipitation anomalies over the last 60 years with respect to the annual mean of 839 mm/year in Germany during the 1961 - 1990 period



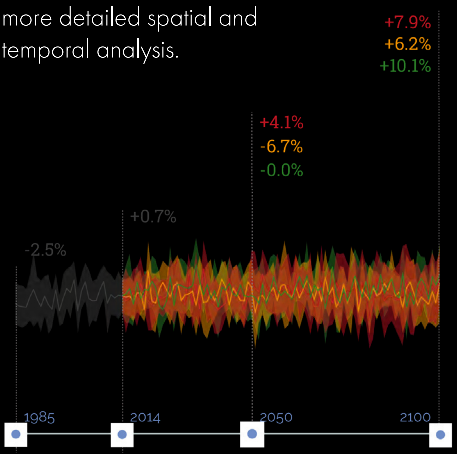
Variation of specific climate indicators

Climate indicators variation showing impacts of climate change on sectors such as agriculture, health and water. Analysis considers 3 threshold average temperature increase: +1.5°C, +2°C, +4°C.

Figure 14 | All figures on this page
Source: G20 Climate Risk Atlas, 2021)

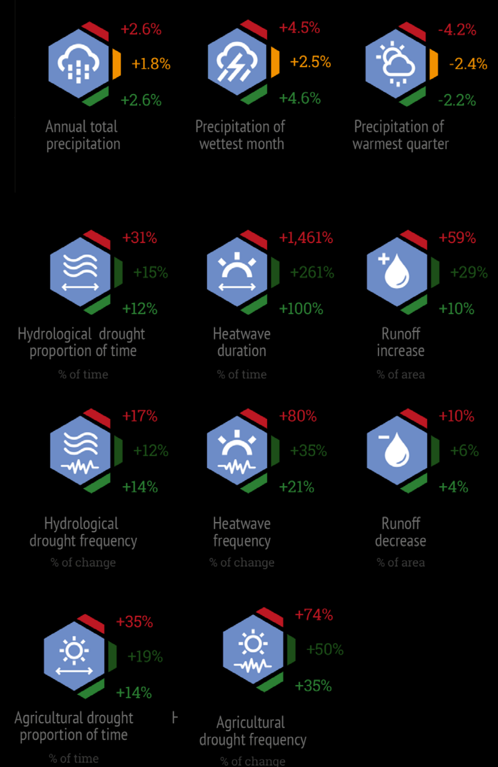
Projections

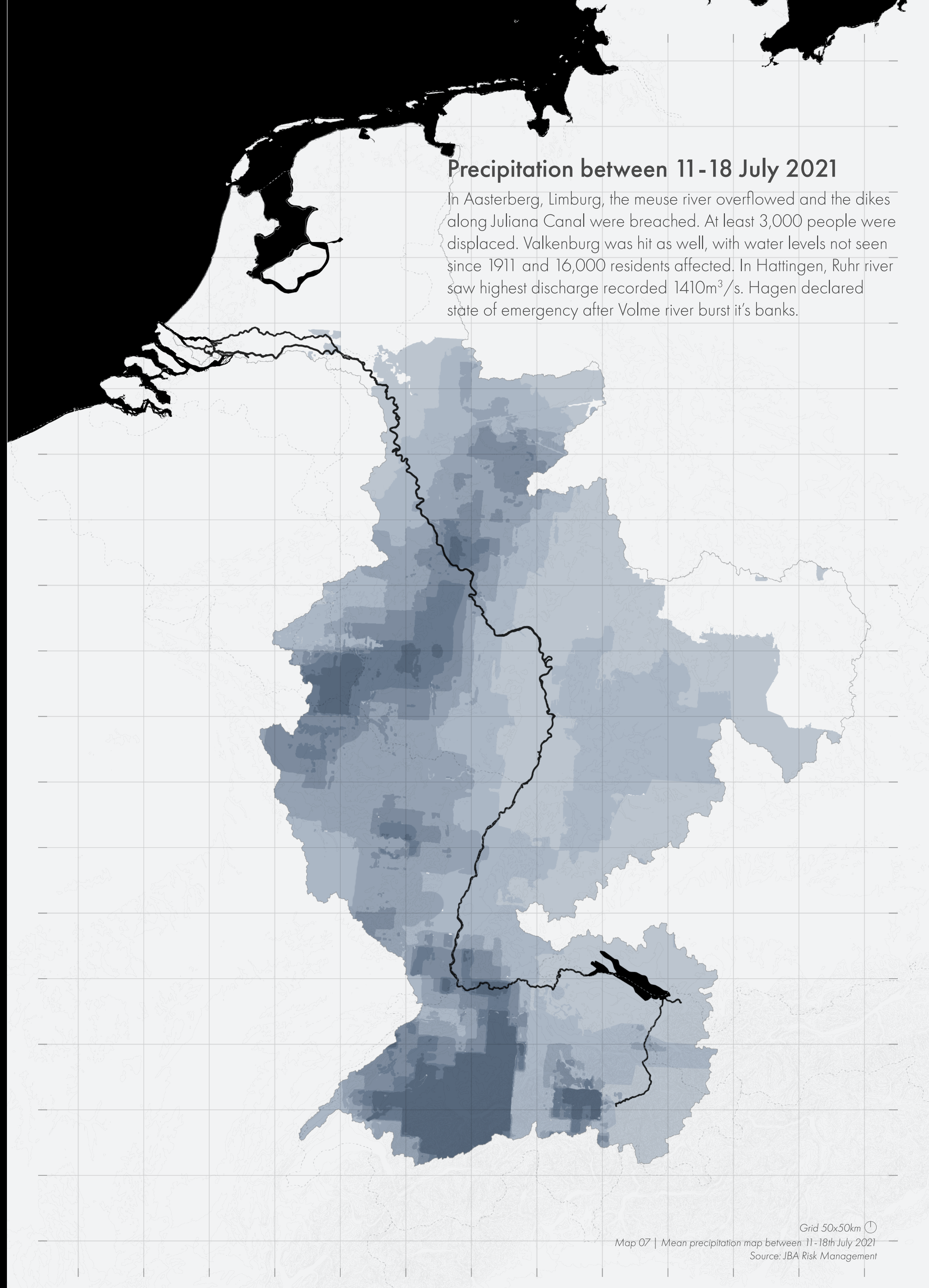
Precipitation trends show a very complex signal, under all emissions scenarios, with a very large variability among climate models. This can be explained considering the complexity of the precipitation regime and dynamics requiring more detailed spatial and temporal analysis.



Precipitation projections

The indicators show variations in selected precipitation characteristics for a thirty-year period centred on 2050 (2036-2065) with respect to the reference period 1985-2014.





Precipitation between 11-18 July 2021

In Aasterberg, Limburg, the meuse river overflowed and the dikes along Juliana Canal were breached. At least 3,000 people were displaced. Valkenburg was hit as well, with water levels not seen since 1911 and 16,000 residents affected. In Hattingen, Ruhr river saw highest discharge recorded 1410m^3/s. Hagen declared state of emergency after Volme river burst it's banks.

Grid 50x50km

Map 07 | Mean precipitation map between 11-18th July 2021
Source: JBA Risk Management

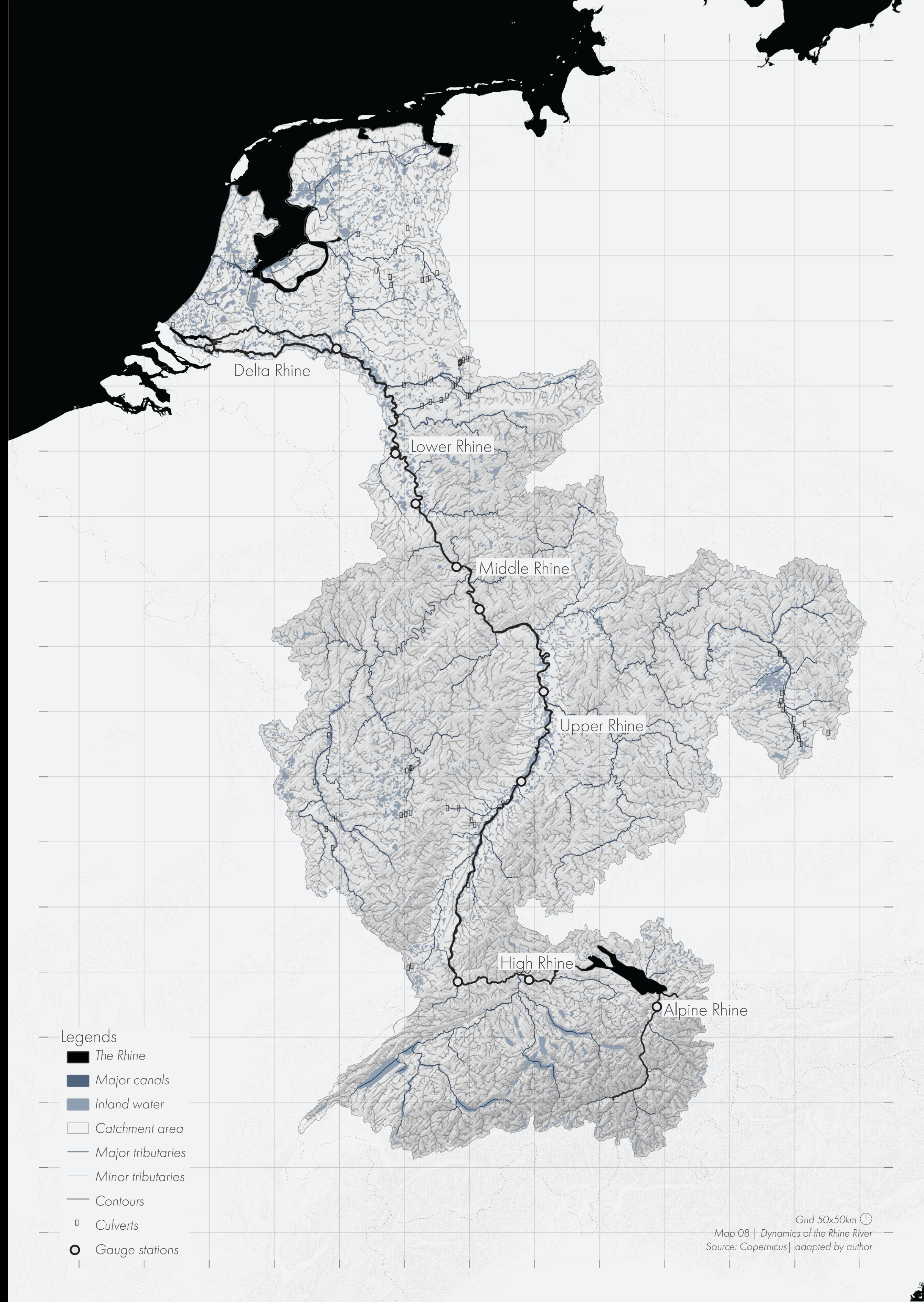
River Dynamics: Physiography

The Rhine originates in the Swiss Alps, with its two headstreams—the Vorderrhein from Lake Toma near the Oberalp Pass and the Hinterrhein from near San Bernardino Pass—merging at Reichenau above Chur. It flows northeast, forming borders between Switzerland, Liechtenstein, and Austria, before creating a delta at Lake Constance. Below the lake, the Hochrhein defines the Swiss-German frontier and features notable sites like the Rhine Falls. As it moves between the Alpine forestland and the Black Forest, the Rhine is joined by tributaries like the Aare and Wutach, with dams facilitating navigation since 1934.

Below Basel, the Rhine flows north through a broad valley framed by the Vosges, Black Forest, Haardt, and Odenwald. Key tributaries include the Ill at Strasbourg, the Neckar at Mannheim, and the Main at Mainz. Remnants of its historical meanders appear as backwaters near Breisach and Karlsruhe.
The middle Rhine, a 90-mile stretch, winds through a deep gorge flanked by the Hunsrück and Taunus mountains. Vineyards line the slopes to Koblenz, where the Moselle River meets the Rhine.

Below Bonn, the Rhine flows through a broad plain, passing Cologne on its left bank, where modern bridges span the river. Düsseldorf, a major business hub, dominates the North Rhine–Westphalia coalfield, while Duisburg, at the Ruhr River's mouth, handles coal, coke, iron ore, and oil shipments.
The Rhine's final section flows through the Netherlands' delta, splitting into branches like the Lek and Waal, eventually becoming the Merwede. The Delta Project (1986) closed off main branches to prevent flooding, with sluices directing water to the sea. Since 1872, the New Waterway Canal, housing Europoort—one of the world's largest ports—has been the primary navigation route to the North Sea. (Sinnhuber et al., 2024)

Grid 50x50km
Figure 15 | Dynamics of the Rhine River
Source: Copernicus| adapted by author



Grid 50x50km
Map 08 | Dynamics of the Rhine River
Source: Copernicus| adapted by author

Hydrology

The total length of the Rhine River is 1232kms from the sources Voderrhein and Hinterrhein to it's mouth in the Netherlands and drains into the North Sea. The Alpine Rhine features a steep gradient and an Alpine regime marked by snow-melt-driven spring highs, heavy summer rain peaks, and a winter minimum. Lake Constance moderates flow variations but they rise again after the Aare's confluence, which carries more water than the Rhine itself. Below Basel, tributaries further balance flow, creating a steady regime favourable for navigation, with freezing occurring only in rare, severe winters. (Sinnhuber et al., 2024)

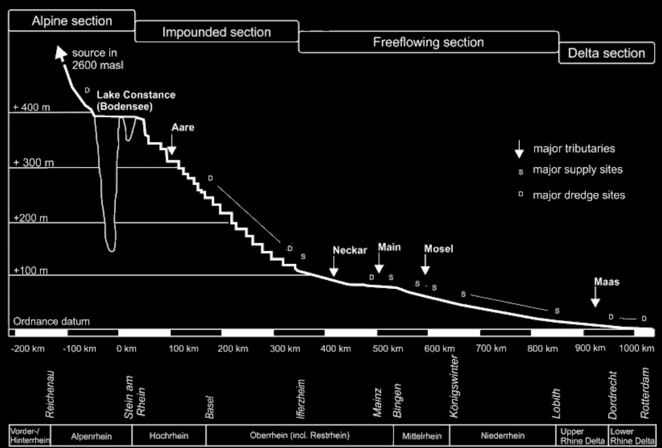
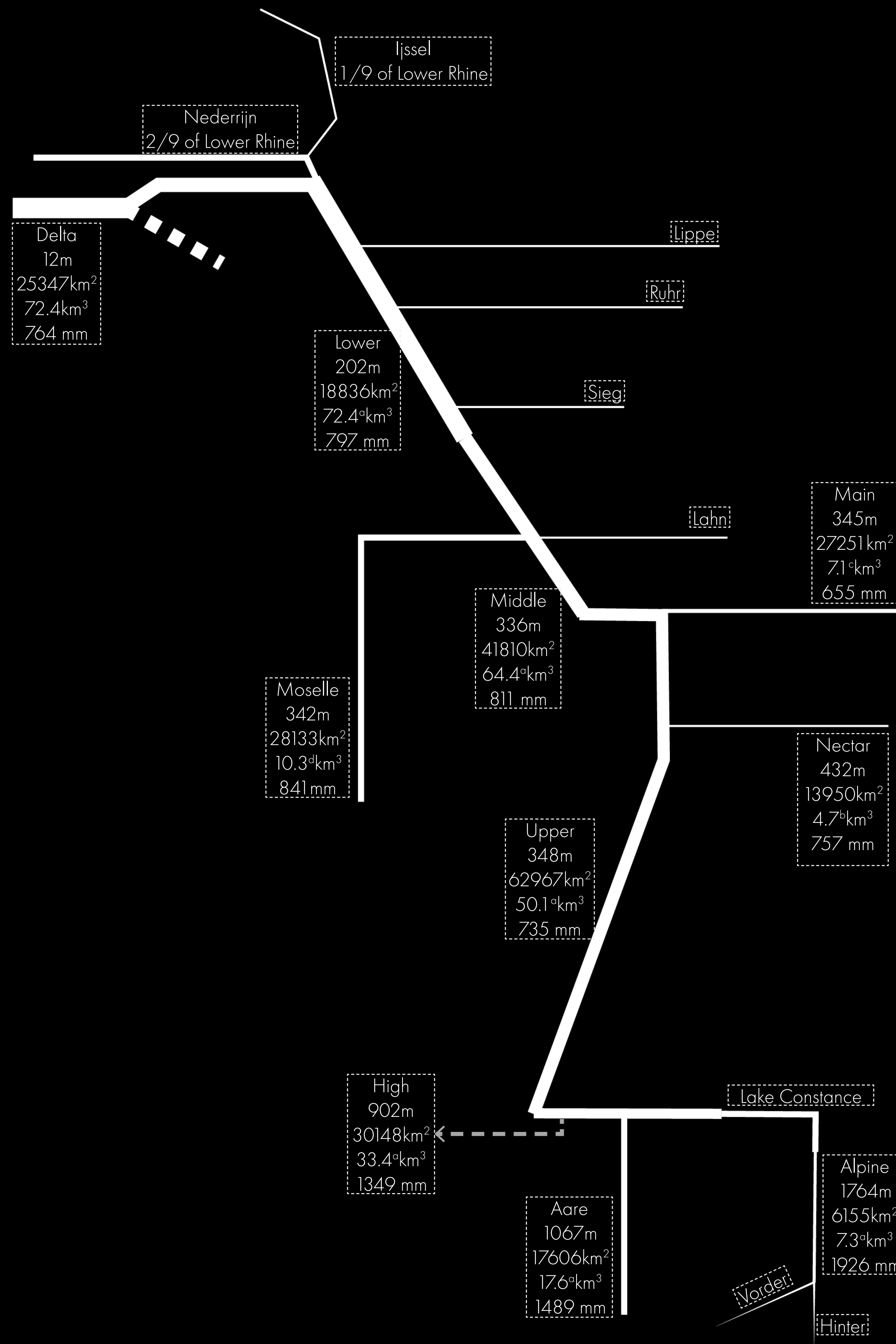


Figure 16 | Longitudinal elevation profile of the Rhine River
Source: Frings et al., 2019

This section illustrates the profile of the river, Upperrhein (Oberrhein) is the middle point from where the river goes from high flow into a low flow stream as the steep is stagnant.



Refer:
Name
Mean catchment Elevation
Catchment area
Mean annual discharge
Mean annual precipitation

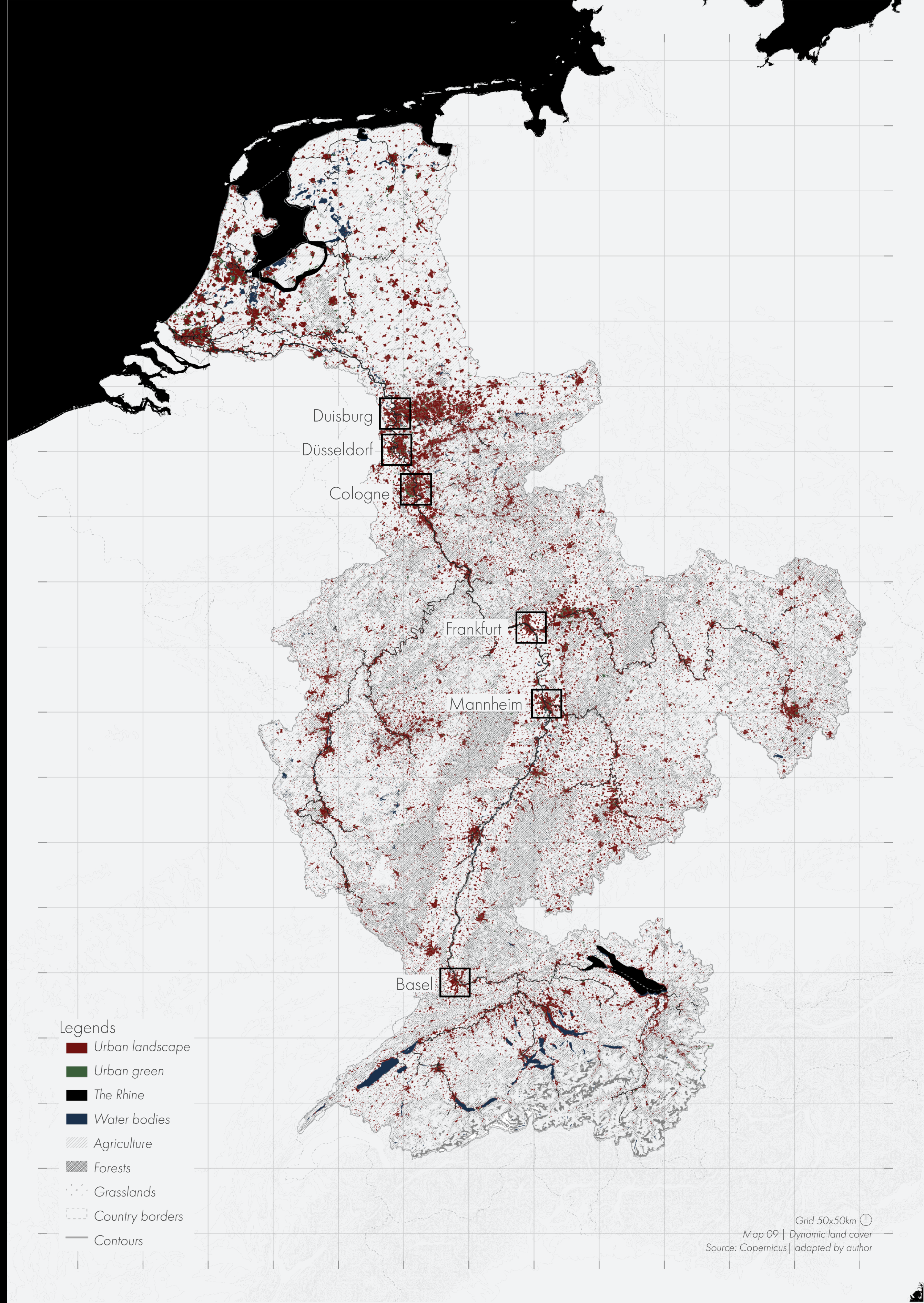
Urban Landscapes

Dynamic Land cover

The 18th and 19th centuries saw the Industrial Revolution, which marked the beginning of the landscape's true urbanization. Since then, there has been a constant movement of people from rural to urban areas. Cities have a significant impact on the environment, both positively and negatively. On the one hand, urban sprawl produces a lot of pollution and invades natural areas. Large-scale infrastructure projects, on the other hand, might have a less environmental impact per person because resource consumption is usually more efficient.

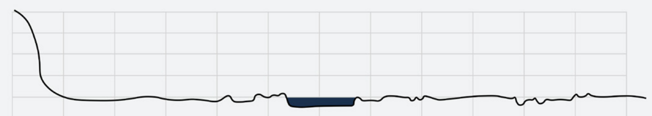
This map illustrates how urbanisation follows water, with urban centres and industries located wherever there is a water channel However, the Rhine is one of Europe's most significant economic contributors and a symbol of its trading legacy. Large cities are expanding along the Rhine, and major industries have caused bottlenecks in the cities, reducing the amount of space available for water penetration. During periods of intense rainfall, these bottlenecks cause flash floods, which then directly pour into the river, creating river flooding. This expansion of cities also took the floodplains along with it leaving no room for river to breath.

Major cities in this basin are Basel, Strasbourg, Mainz-Frankfurt, Cologne, Düsseldorf, Duisburg, and Rotterdam. These major cities with heavy urbanisation causing bottlenecks and results into heavy flooding during intense rainfall as indicated before in figure 33. Further investigations of these bottlenecks have been illustrated in the figure.

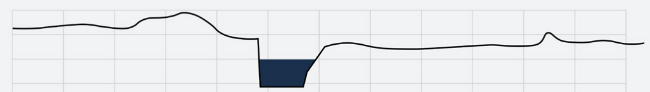


Highly Urbanized Cities

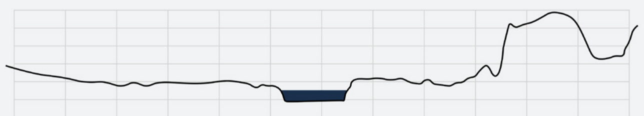
The sections and Noli maps highlight these bottlenecks, showing impervious urban surfaces and their impact on water flow, emphasizing the need for hydrological resilience in urban planning. It offers a comparative lens to understand spatial density, permeability, and the interface between built and open spaces. By studying the void-solid relationships in cities like Cologne, Düsseldorf, or Duisburg, these maps helped identify how urban morphology interacts with river fronts and flood-prone zones. These mappings reinforces the importance of integrating economic activity, ecological resilience, and public realm through adaptable urban patterns.



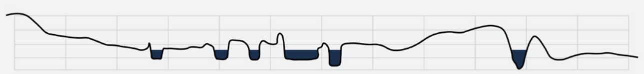
Duisburg



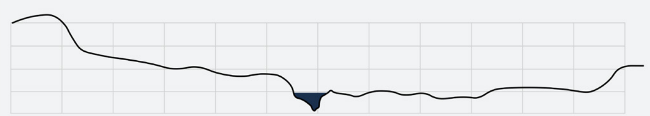
Cologne



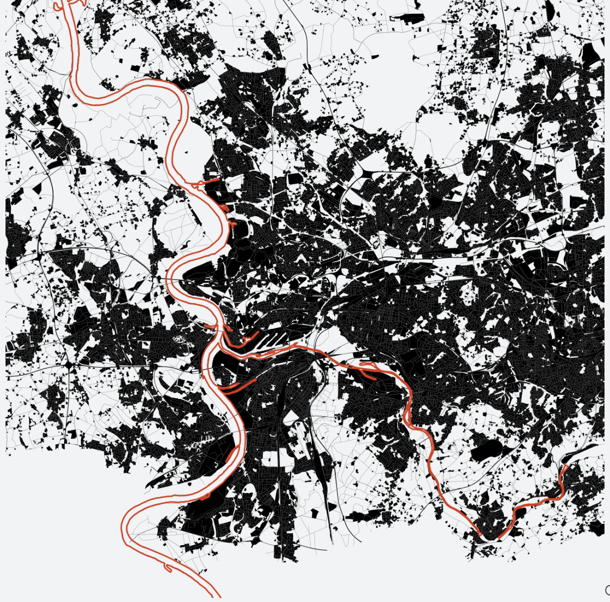
Mainz

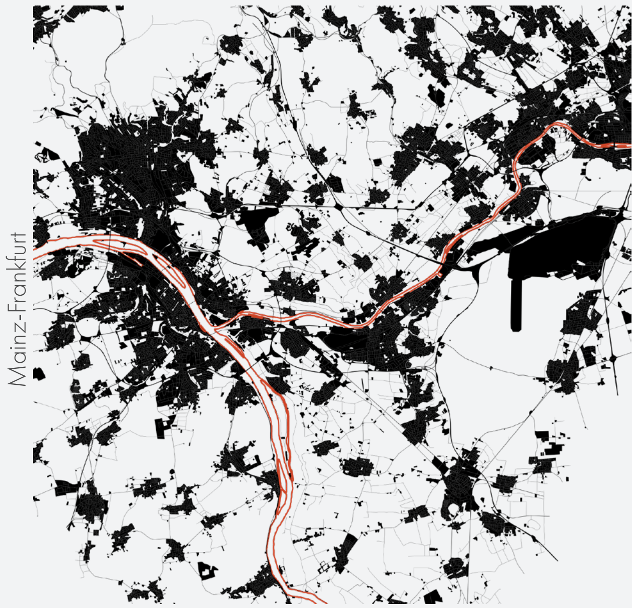


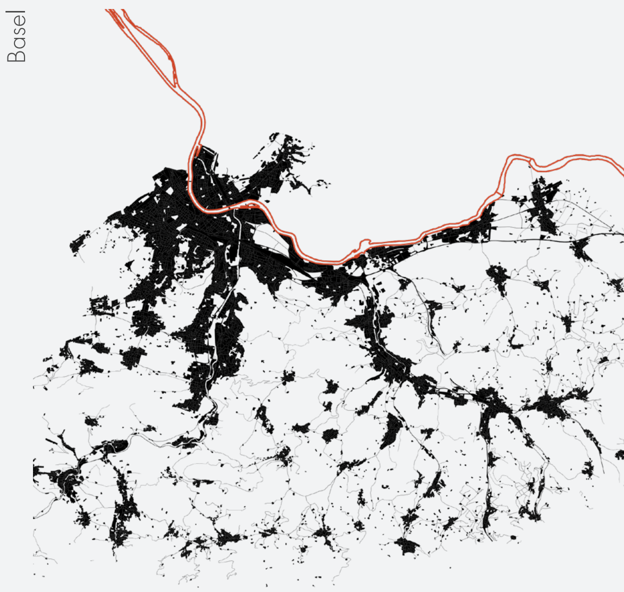
Mannheim



Basel







Scale 1:300000
Map 10 | Built-Unbuilt
Source: Copernicus| adapted by author

Temporal Evolution

Geological History to Urban Expansion along Rhine

Looking at the Rhine through various lenses, such as natural development, settlement growth, port activities, and major engineering efforts from 337 BC to 2013, highlights its evolving relationship with human activity. After the first Saint Elizabeth flood in 1424, the need for engineering interventions emerged to control the river and mitigate flooding risks. Since then, the demand for control has intensified, as safety and urbanization are closely interconnected. .

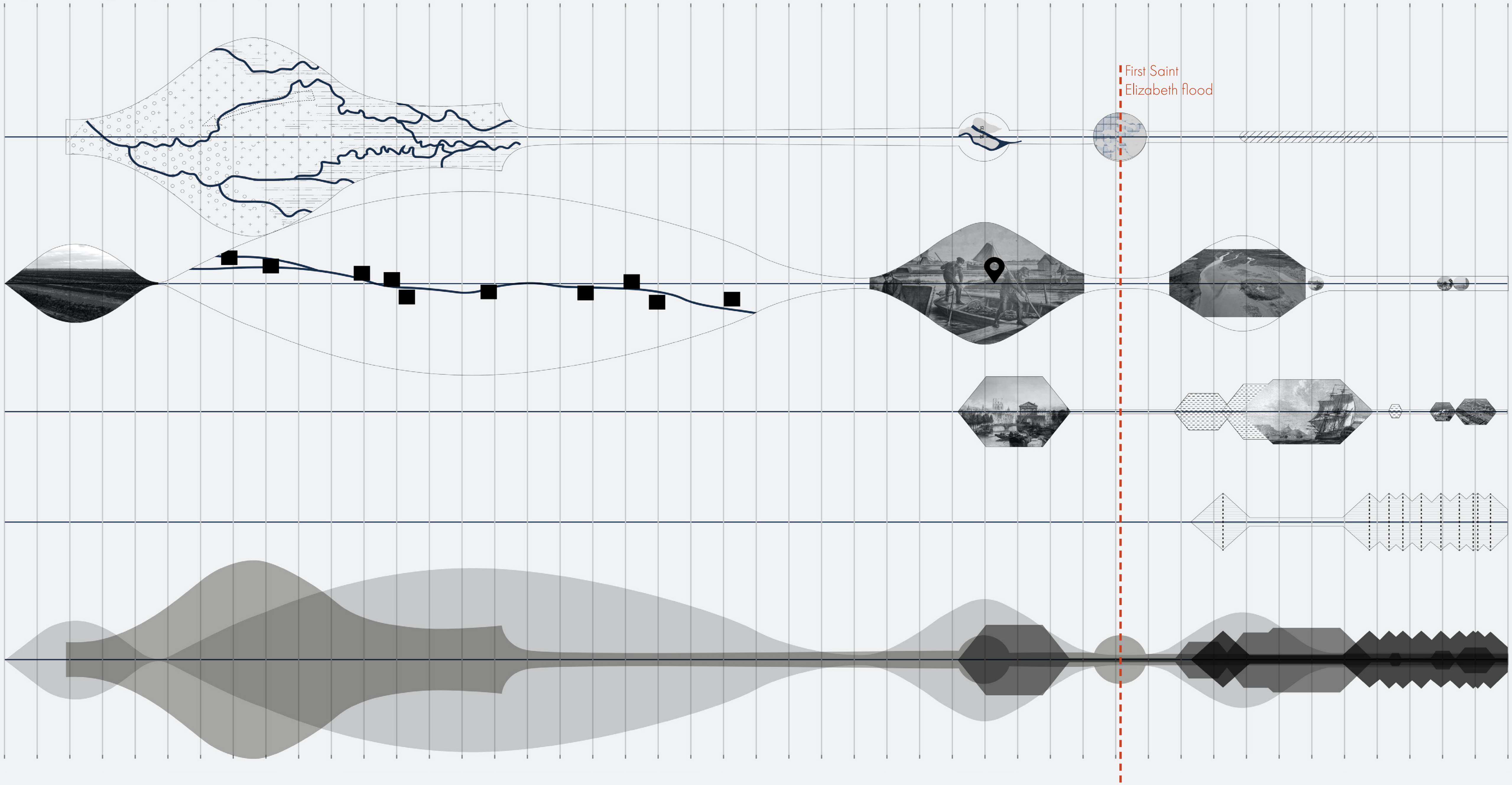
50 Year interval from 337BC to 2013
Natural development : 250 BC-500 Series of upstream avulsions divert Rhine discharge | 1216 Vorne and Flakkee islands separate | 1421-1424 Saint Elisabeth flood | 1600-1800 Little ice age

Settlement development : 800 BC - 12 BC First occupation of peat bogs | 12BC-1000AD Romans' settlements around Rhine | 1050-1350 Fixing of Rhine and Meuse river courses and peat reclamation | 1250 Town of Rotterdam founded | 1500-1700 Biesbosch and Haringvliet reclamations | 1740 Rozenburg island diked, 1940 Rotterdam bombed WWII | 1955 Post World war reconstruction

Port or Trade activity : 1283 Port of Rotterdam founded | 1590-1720 Dutch golden age | 1602-1799 Dutch East India company domination | 1850 Industrial revolution | 1907-1920 Port development of docks around Rotterdam | 1958-1970 Botlek, Europoort and Maasvlakte ports construction | 1962-2004 Rotterdam port domination

Major engineering activity : 1597 Dordtse Kil cross-cut channel deepened | 1829 Canal Voorne completed | 1850-1855 Niewe Merwede | 1868-1872 Niewe Waterweg | 1904 Bergsche Maas canal | 1932 Zuiderzee dammed | 1954-1971 Delta-works | 1984 Deliberate shoaling of Niewe Maas | 1987 Alufter storage | 1997 Maeslantkering storm barrier | 2013 Maasvlakte 2 offshore

Illustration 13 | Dynamics of the Rhine River
Source: Copernicus| adapted by author



Engineered Rivers

Since Saint Elizabeth flood, the engineering process started with dikes, straitening the rivers from meandering and protected dikes or ditches along the banks of the river for the safety of people. After the flood, the first major engineering intervention was in 1597AD to deepen the Dordtse Kil crosscut channel. Since the this co-relation of safety and build started. For instance, when people feel safe, they tend to urbanize more, but when nature strikes back, they feel threatened and respond by building more structures (see figure).

In the map, the whole Rhine changed with straitening, deepening, widening or narrowing as required to counter the flood measures or personal gain. But, along with it's advantages it also has multifaceted or underlying disadvantages which emerges immediately or after decades. A small intervention can have impacts on bigger level in another region.

Ecologically, these interventions have significant societal and ecological consequences. Habitat destruction occurs as changes in flow and structure disrupt aquatic and riparian ecosystems. This often leads to a loss of biodiversity, as many species depend on natural flow patterns and floodplain habitats that may disappear with such alterations. Additionally, sediment transport is altered, leading to downstream habitat degradation, including deltas and estuaries. Faster river flow can increase erosion and pollutant transport, resulting in water quality degradation. Furthermore, straightening rivers disconnects them from their floodplains, reducing their ability to support biodiversity and act as natural water storage systems, ultimately impacting both ecosystems and human communities.

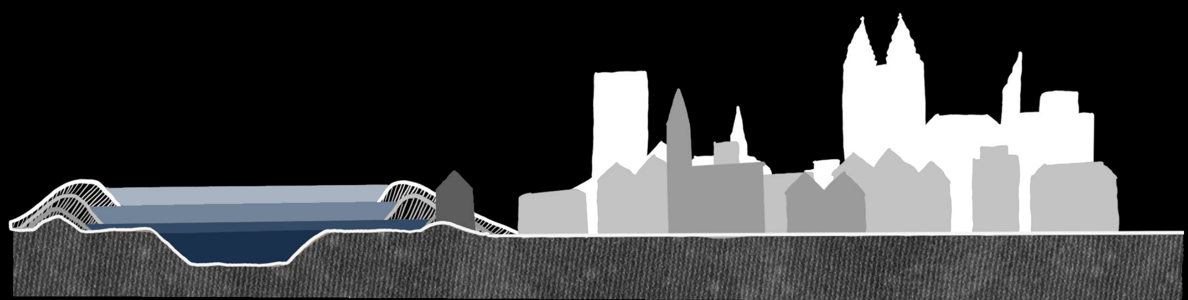
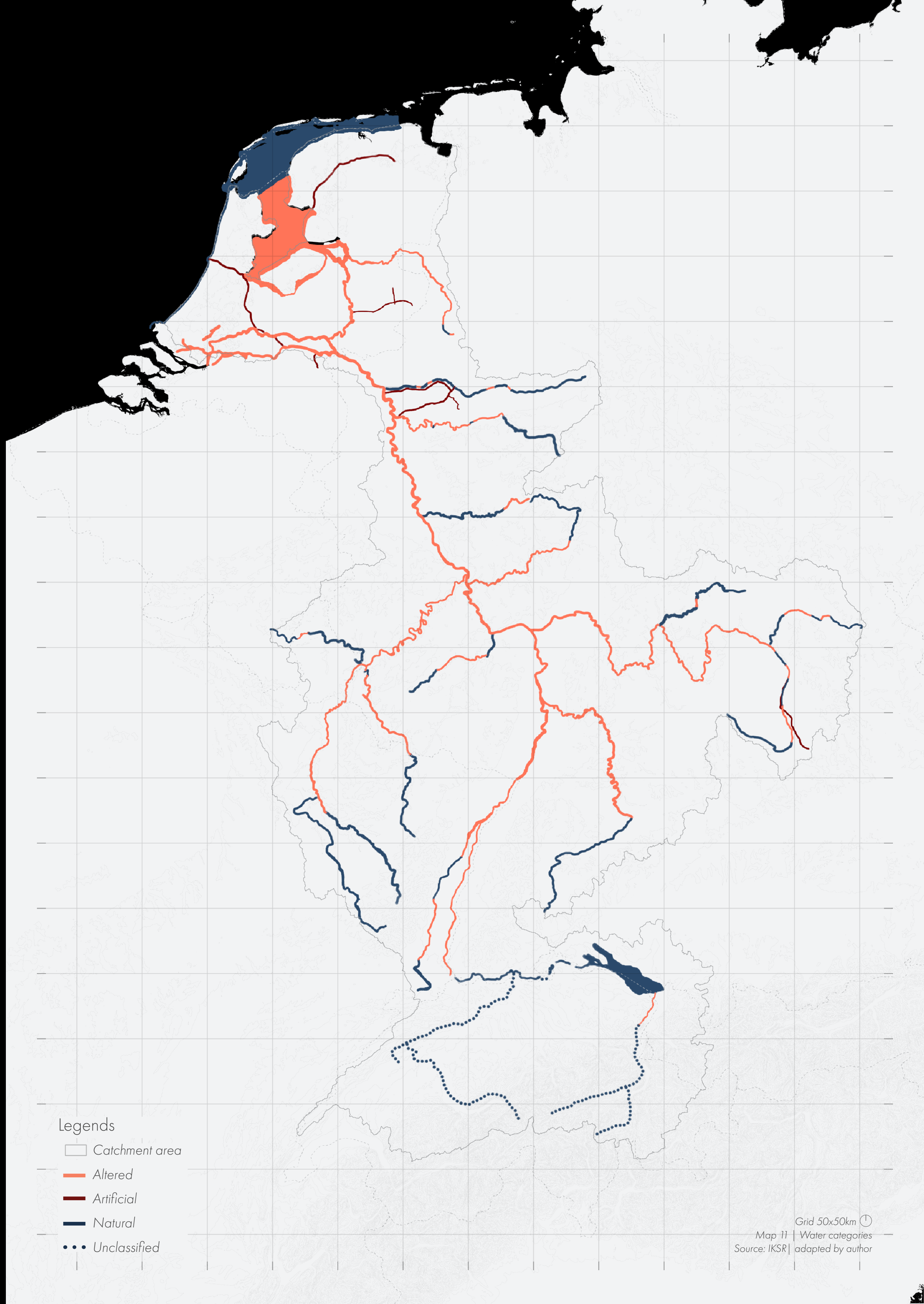


Illustration 14 | More urbanisation more safety measures
Source: author



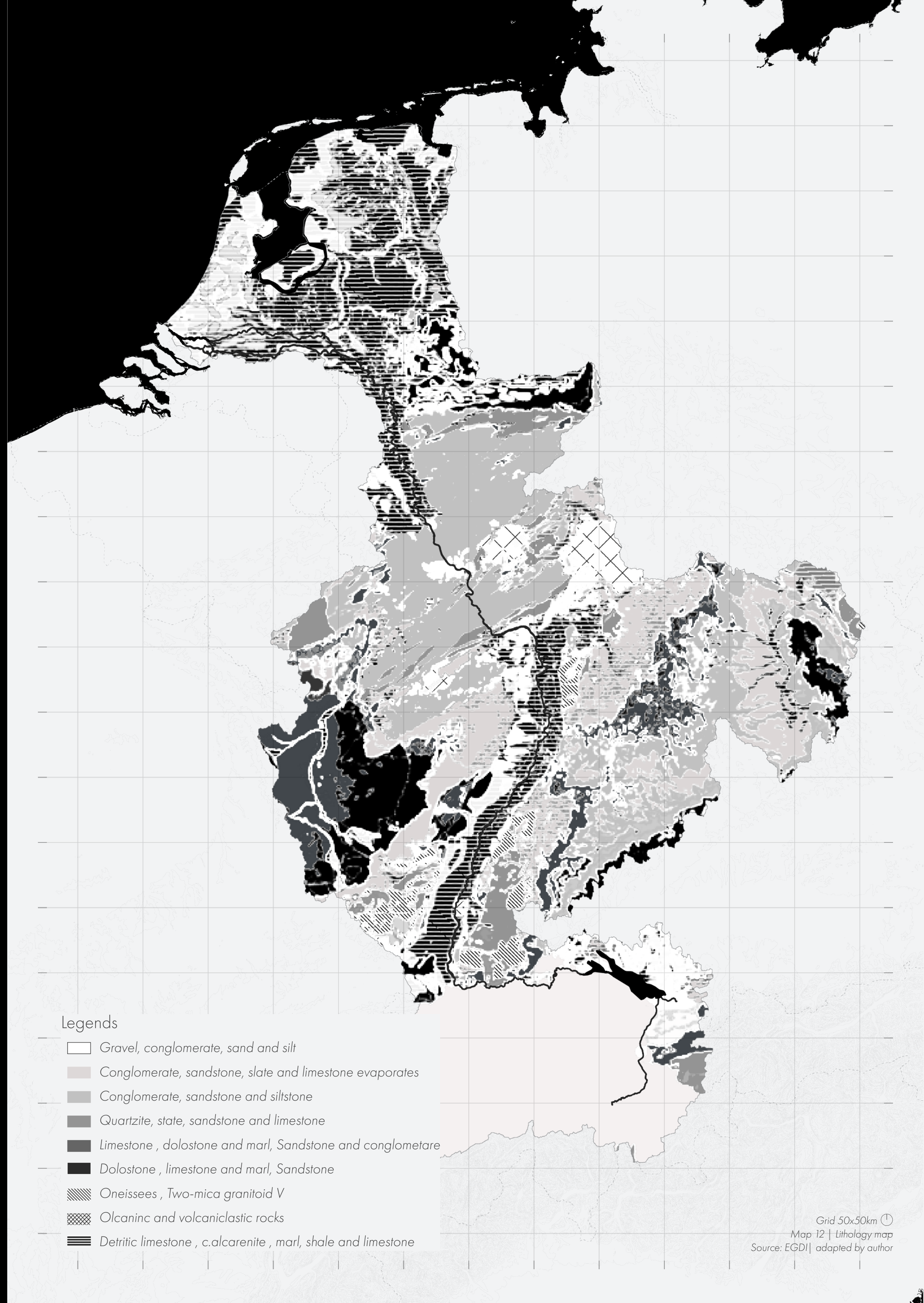
Map 11 | Water categories
Source: IKSR| adapted by author

Natural and Anthropogenic Layers

Lithology

Understanding the lithology is crucial in my research as it determines the physical and chemical characteristics of the area's surface and subsurface, which directly influence hydrological processes. It will help in assessing groundwater storage capacity, infiltration rates, and soil stability, all of which are critical for designing resilient water management solutions. For example, the type of rock or sediment can dictate how water flows through the landscape, affecting flood risks, drought resilience, and urban subsurface infrastructure. Incorporating lithological analysis allows for a more precise understanding of riverbed dynamics, subsidence risks, and water dependencies, to address the challenges of flooding and drought along the Rhine.

Particularly in this map, data for Switzerland could not be determined. But other data suggests that mainly Rhine is formed over sand or silt from Basel to Mainz and then from Bonn to Delta in the Netherlands which suggests the sedimentation process along the floodplains during Holocene and Pleistocene. This section is plains so the sedimentation formed over thousands of years and formed floodplains along the Rhine. The part between Mainz and Bonn is mainly clay-stone or shale during lower Devonian period. This section of Rhine is along the mountains so they have clay-stone or shale.



Natura 2000 water-dependant Flora-Fauna habitat areas

Investigating Natura 2000 areas is crucial for me because these sites represent ecologically significant zones where biodiversity and ecosystem health are prioritized under EU legislation. As my research involves interventions in river systems and urban expansion, understanding these habitats ensures that the strategies respect conservation goals and avoid harm to protected species rather enhance ecological resilience. Additionally, these areas provide critical ecosystem services, such as water filtration, flood mitigation, and climate regulation, which are vital for balancing human activities with environmental sustainability. This perspective might support the development of integrated, nature-based solutions in my research work.

Riparian zones

Riparian zones act as transitional areas between land and waterways, mixing aquatic and terrestrial habitats that support diverse plant and animal species. These zones offer crucial ecosystem services, including pollutant filtration, flood regulation, and soil enrichment. Additionally, they contribute to local climate stability by providing shaded, moisture-rich environments that help moderate temperatures and support surrounding ecosystems.

It is crucial to study riparian zones because they are integral to understanding the interplay between natural systems and human interventions, particularly in water management. These areas not only support biodiversity but also serve as natural buffers that enhance water quality, mitigate flood risks, droughts, and improve soil health.

Map 13 | Natura 2000 protected areas and riparian zone
Source: IKSR et Copernicus| adapted by author

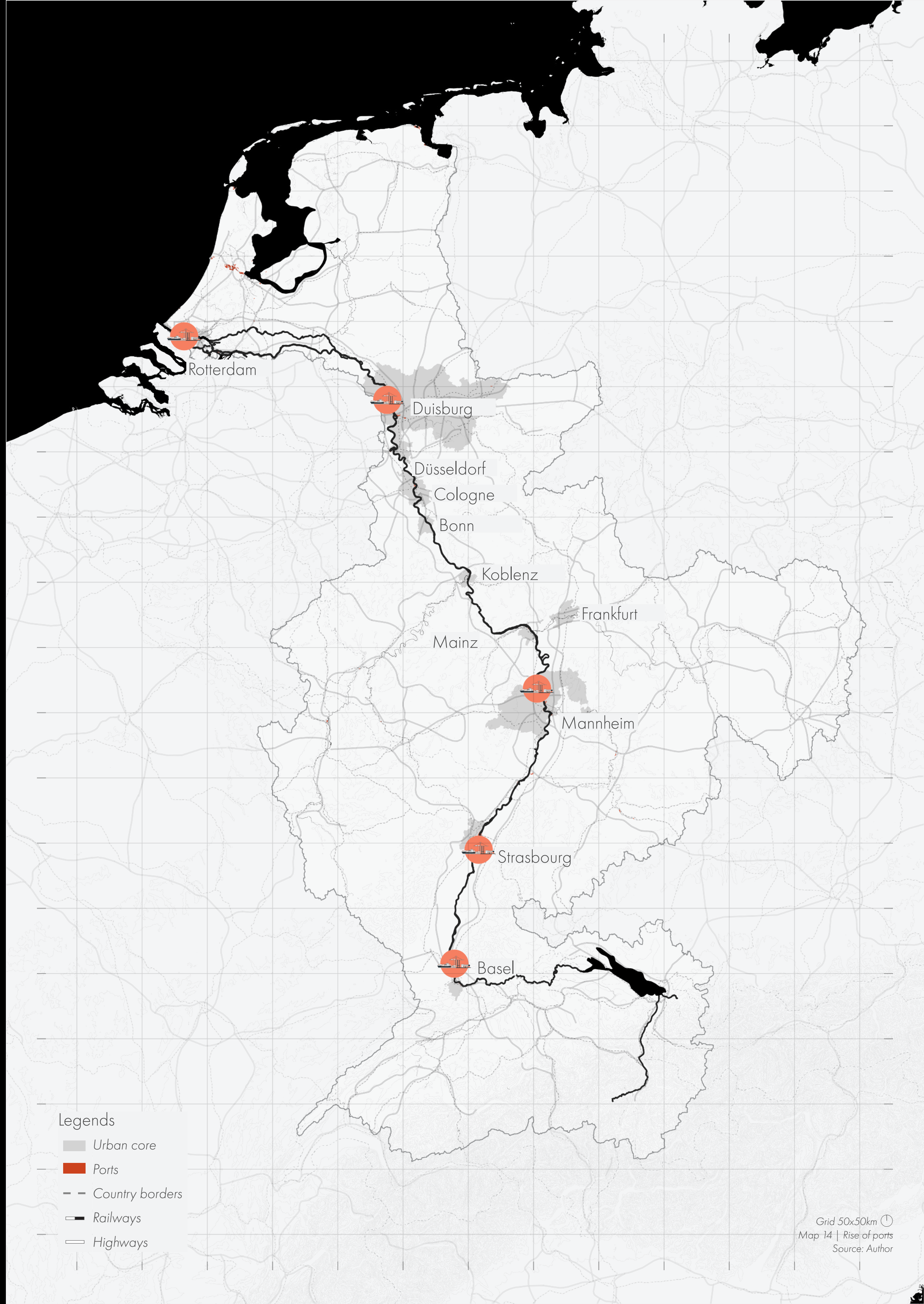
Historic evolution of cities

The path to becoming a trade route

Trade in the Rhine started blooming during Roman times, while Cologne became a European metropolis. For 600 years, all ships on the Rhine had to put their goods on sale in the cathedral city before they were allowed to continue. Free shipping along the Rhine has only been possible since 1868, when the Mannheim Act was signed, alongside the obligation from the neighbouring countries to maintain the river. And this agreement is still valid to this day, with Baden, Bavaria, Hesse, France and the Netherlands all signatories of it, therefore providing the foundation for a free transport market on the Rhine. The means of transport were improved by the introduction of steam-powered, and later diesel-powered, tugs; prior to the mid-19th century, barges moving upstream were towed either by teams of horses or gangs of men. Despite the improvement of the navigation and means of transport, there was at first little growth in the volume of transport. Increase came with the rise of modern industry in the 19th century, which necessitated the bulk movement of coal, ore, building materials, raw material for the chemical industry, and (since about 1950) oil. Although coal and ore transport declined, there was an overall increase in the volume of transport until the mid-1960s; since then, however, freight tonnage has decreased significantly. (Sinnhuber et al., 2024)

However, numerous measures were required to ensure that shipping on the Rhine is possible at all times. Even in the middle of the 19th century, floods threatened residents and businesses along the river, Islands were created and disappeared again, settlements were built and destroyed. The constantly changing river bed also led to land disputes. Johann Gottfried Tulla came up with a solution to ensure both protection against flooding and land reclamation, namely by straightening the Rhine, a project which was completed in 1876. At the beginning of the 20th century, Max Honsell, an engineer, further refined Tulla's previous work by narrowing the river and using the erosive force of the water to deepen the shipping lanes, therefore enabling large ships to travel along the river all the way to Strasbourg. More and more people started settling along the course of the Rhine for work and prosperity. (BASF)

The Final Protocol of the Revised Convention for Rhine Navigation of 1868 specified the free ports existing at the time Strasbourg, Kehl, Maxau, Leopoldshafen, Mannheim, Neuburg, Spire, Ludwigshafen, Mainz, Biebrich, Oberlahnstein, Koblenz, Cologne, Neuss, Düsseldorf, Uerdingen, Duisburg, Ruhrort, Wesel, Emmerich, Amsterdam, Rotterdam and Dordrecht. Out of these the major ports under my area of investigation are Basel, Strasbourg, Mannheim, Mainz-Frankfurt, Bonn, Koblenz, Cologne, Düsseldorf, Duisburg, Rotterdam as shown in the map.

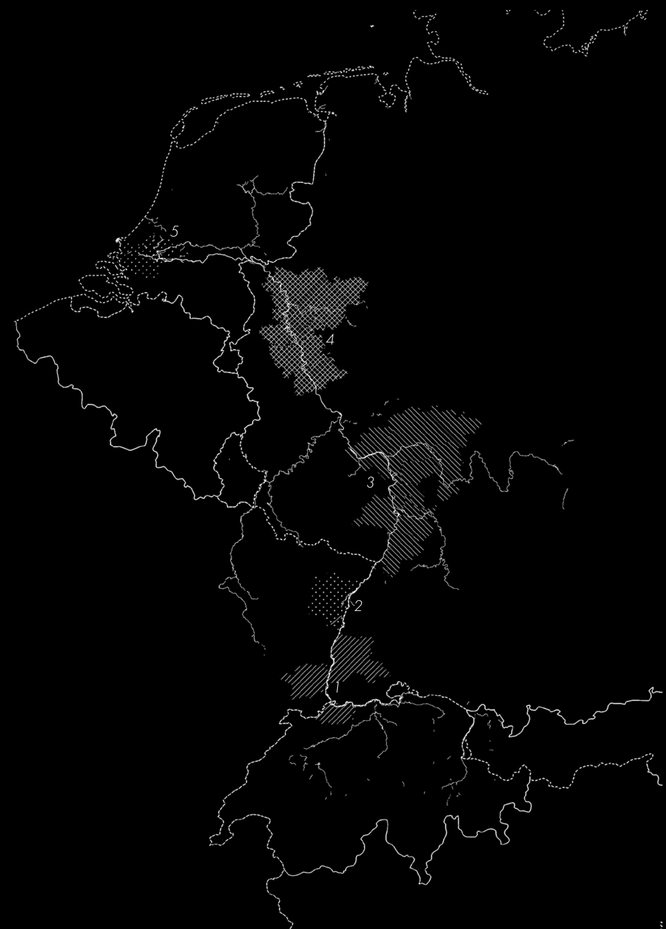


Map 14 | Rise of ports
Source: Author

Freight Network

Raw materials

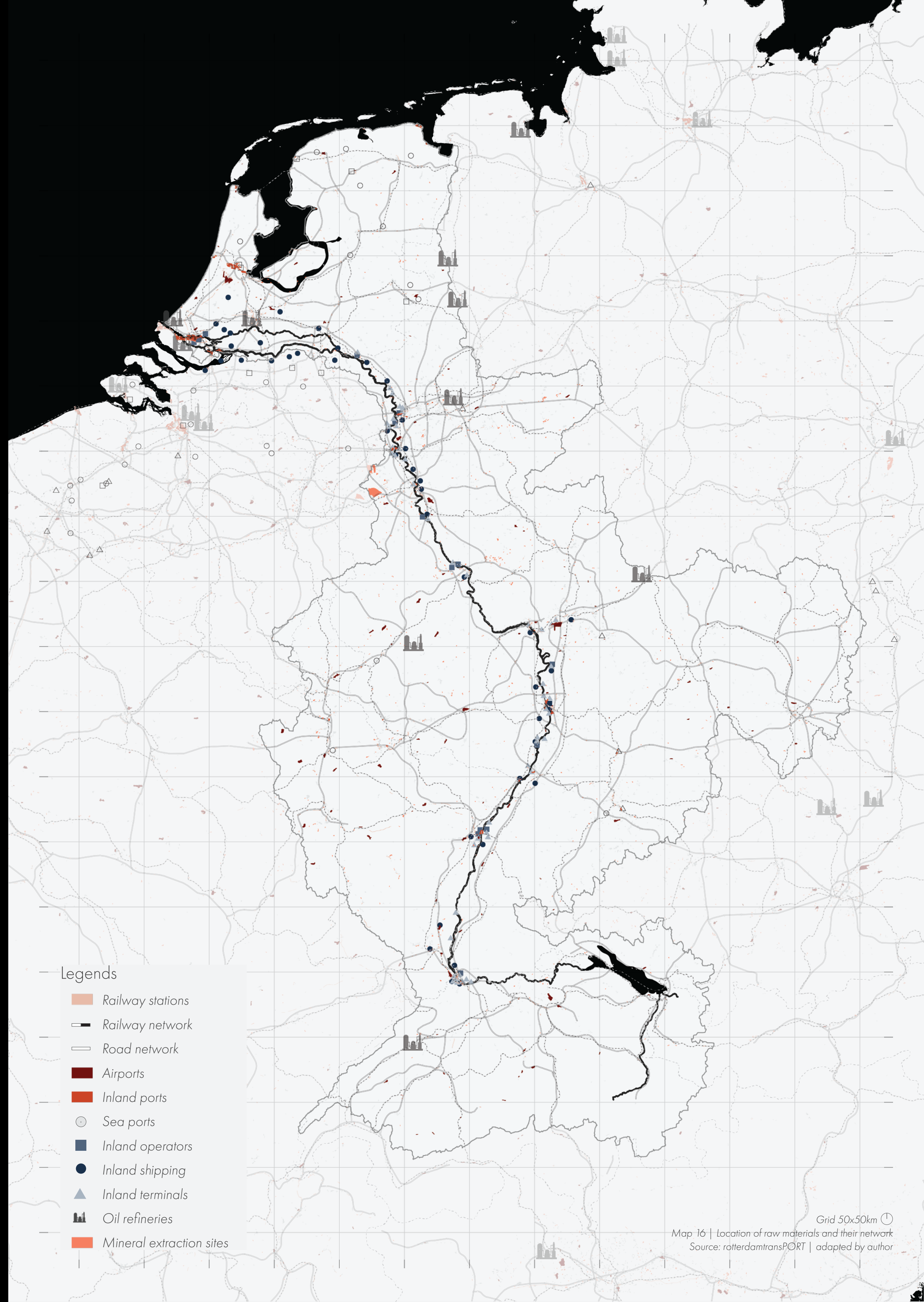
To understand the shipping routes of goods, materials and oil cargo ships, it is crucial to understand the sources of raw materials such as minerals extraction sites, their operators' location from where they operate. Oil refineries locations are important to understand the flow of oil within the areas and from the sea. There are multiple shipping operators along the Rhine and their terminals or offices. This gives a broader view that the most crucial locations for raw materials and goods flow is three major sections: Mainz-Strasbourg area, Bonn-Duisburg area, and Rotterdam.
More than two thirds (69%) of the freight handled in Rotterdam was inwards transport, underlining Rotterdam's central role as a hub for import to the EU. Almost half of the freight handled in Rotterdam was liquid bulk cargo. In contrast, Antwerp and Hamburg mainly handled container freight, with large containers accounting for 51% of the freight handled in Antwerp and 61% in Hamburg (Eurostat, 2020).
Further details on transport quantities can be referred from appendix 3 and factsheet 2.



Map 15 | Industrial centres along the Rhine
Source: CCNR| adapted by author

There are major six industrial centres along the Rhine and the regions are also illustrated in figure 42.

1. **Basel/Mulhouse/Freiburg:**
   Chemical industry, food industry, textile and metal industry.
2. **Strasbourg:**
   Cellulose industry, food industry, textile and metal industry.
3. **Rhine Nectar and Frankfurt-Rhine-Main:**
   Chemical industry, rubber industry, electrical industry and Metal industry.
4. **Rhine-Ruhr Metropolitan area:**
   Petrochemical industry, refineries, metal and car production, service and trade centres.
5. **Rotterdam Europoort:**
   Shipyards, refineries, chemical plants, metal and car production, European service centre.



Map 16 | Location of raw materials and their network
Source: rotterdamtransPORT | adapted by author

Impacts of climate change

These graphs illustrate 2018 droughts along the Rhine river in which the impact of water levels and water discharge can be seen on transport corridor. The hatched section between September to November was hit the lowest and therefore it had an impact on the society on the economic level. There are 550 million lives in this catchment area and 60 million lives are dependant on the river. This corridor has a big contributor towards the economy of the Netherlands and Germany so climate change with droughts and flooding impacts the whole system in the basin. (For impact chain refer appendix 4)

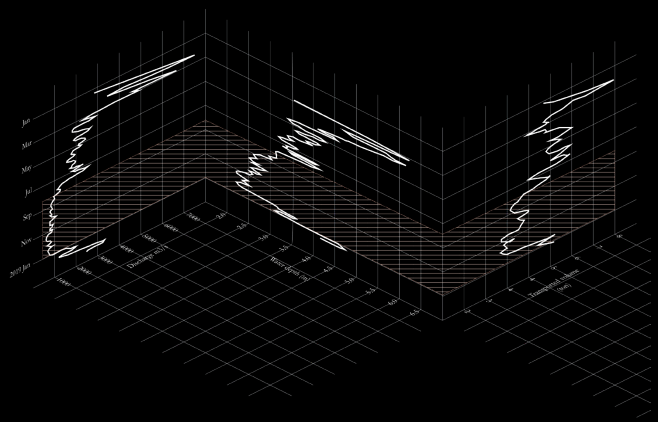


Figure 17 | Water levels and their impact on transport in Lobith, the Netherlands Source: Vinke et al., 2022 | adapted by author

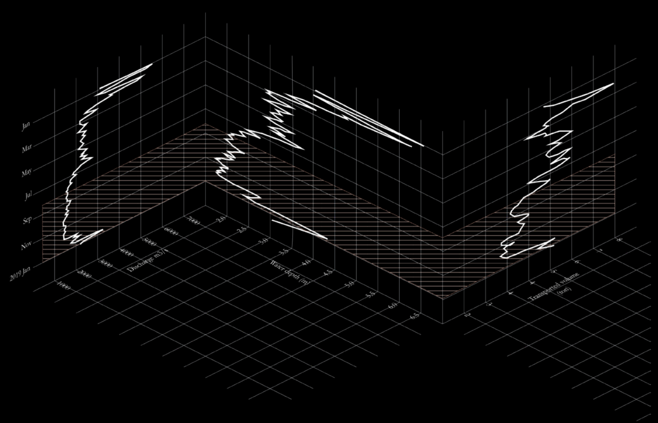
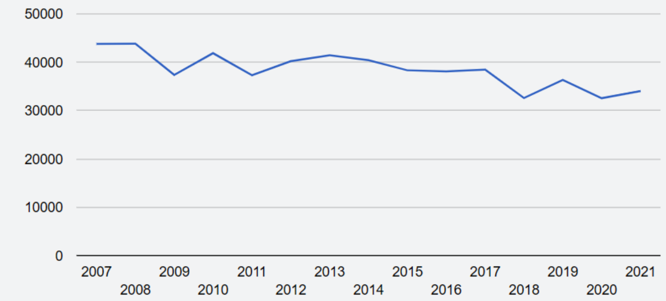


Figure 18 | Water levels and their impact on transport in Kaub, the Netherlands Source: Vinke et al., 2022 | adapted by author

The transport performance in the Rhine is decline since 2017 and plummeted in 2018 during the 2018 droughts. However, the number of companies for freight transport keeps increasing specially after 2021 and passenger transport is increasing gradually. This is a conflicting graph which might suggest that the companies are splitting into smaller groups but on the other hand employment graph is not doing well as compared to increase in number of companies.



Source: CCNR analysis based on Destatis

Figure 19 | Transport performance on the traditional Rhine (in million tonnes) Source: CCNR

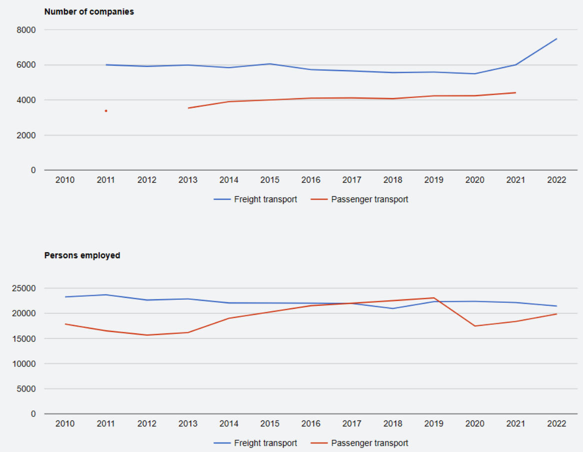


Figure 20 | Development of number of companies and passenger transport Source: CCNR

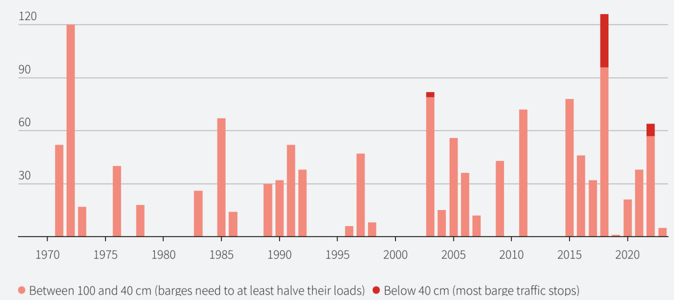
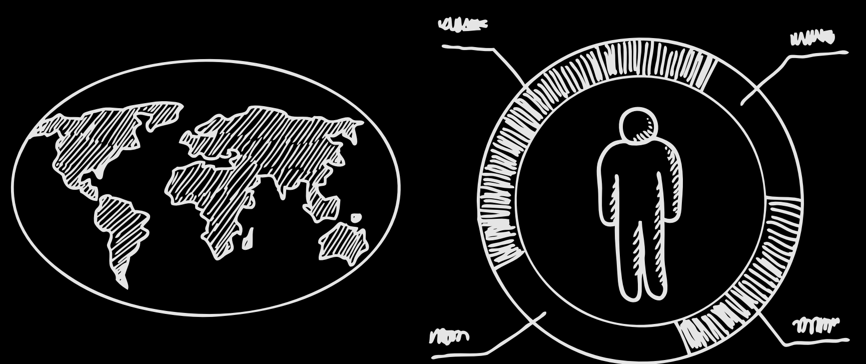


Figure 21 | Dry days below 100cm at Kaub Source: Federal waterways



Analysis

Conducting a thorough analysis was crucial to understanding the layered challenges and interdependencies within the Rhine River basin. This step was essential to guide decisions, test assumptions, and ensure that proposed interventions were grounded in real spatial, ecological, and socio-economic conditions. It consists of:

1. Cartographic analysis
2. Stakeholders
3. What if...
4. Field trip
5. Expertise
6. Scenarios

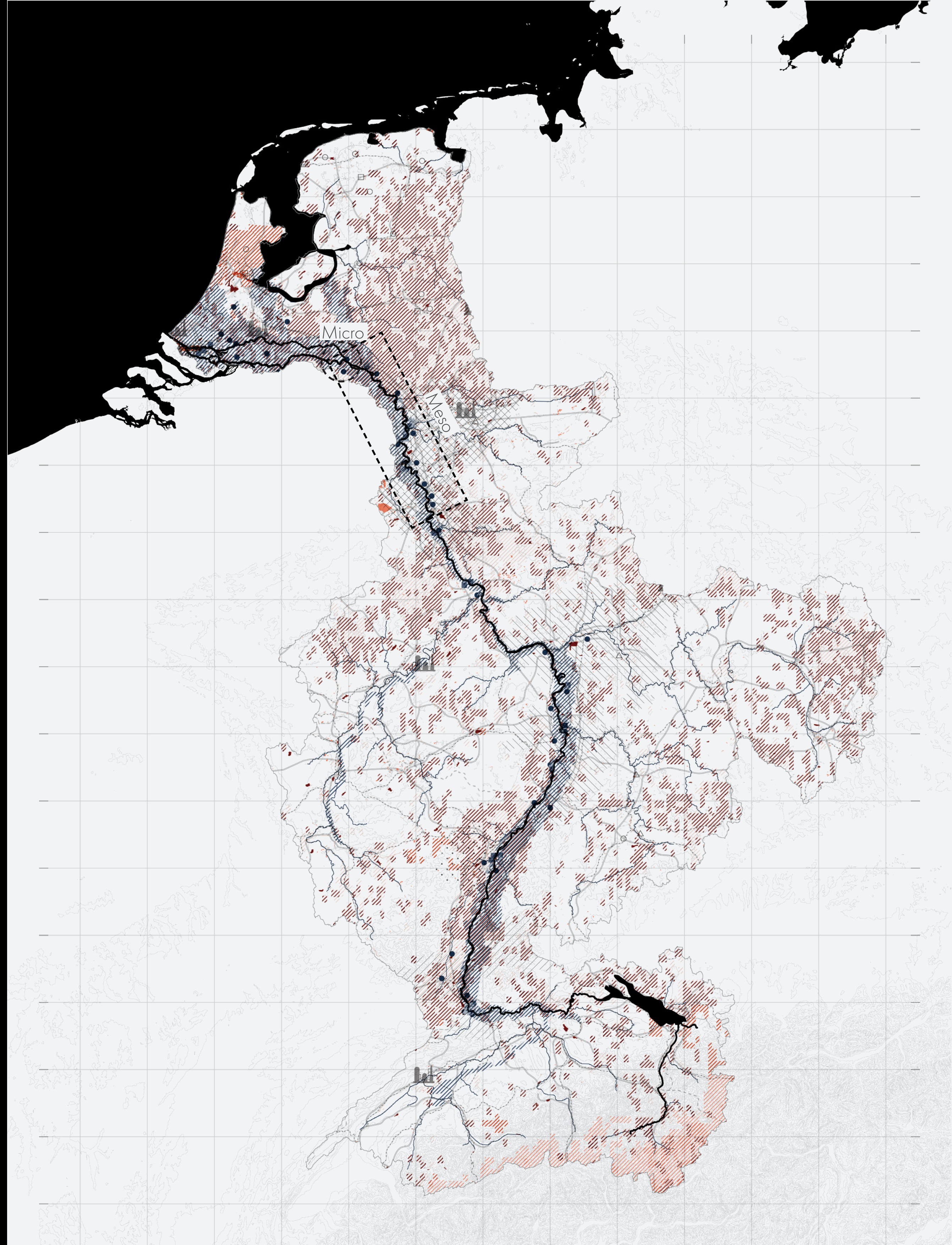
Illustration 15 | Analysis
Source: Author

Cartographic Analysis

This map is the overlaying multiple challenges and areas with high industrial use which are vital for the economy of the Netherlands and Germany. The preliminary analysis highlights critical patterns of vulnerability and resilience along the Rhine, driven by the interplay between natural processes and human interventions. The findings highlight areas where urbanization, infrastructure, and land-use practices have intensified the impacts of floods and droughts, disrupting ecosystems and essential socio-economic functions such as transport and trade. By examining patterns of vulnerability and resilience, a key location have been identified as critical section where these challenges are converging for further investigation. This area shows significant issues, including compromised water flow, ecological stress, and vulnerabilities within transport and industrial networks, making them focal points for understanding the broader impacts on the Rhine basin. These findings provide a foundation for deeper exploration and potential future strategies to address these interconnected challenges.

A large section is carefully chosen for meso scale in the lower Rhine section from Cologne, Germany to Nijmegen, the Netherlands because it overlaps all the parameters for which this research is based on. This area has one of the biggest port in Duisburg, Germany which is a part of Rhine-Ruhr metropolitan area with multiple petrochemical industry, refineries, metal and car production, service and trade centres. It has one of the oldest city Cologne, Germany with rich history of trade activities. This section has also suffered same climate induced challenges and faced many casualties during the disasters. Another interest in this area for me was it lies on the border of the Netherlands and Germany and therefore working on the transboundary water management would be critical to form an integrated plan. It has heavy industrialization, big nature reserve areas, intense urbanisation, river diverging and converging points, and administrative border. So, both EDS and NBS can be seen here on distinct scales.

Furthermore, to visualise these challenges and opportunities, a smaller area on micro scale i.e. Gelderse Poort area on the border of the Netherlands and Germany is taken into consideration. It defines how transboundary collaboration may work to augment the balance in the basin, it is also the first diverging point for the Rhine which splits into river Waal, Lek, and Issel river. So this micro scale intervention might become a program for bigger scale interventions.



Map 17 | Overlaying multiple layers of challenges and opportunities
Source: Author

Stakeholders

Low Power, Low Interest (Engage)

1. Academic Research and institutions: They are interested in data but less direct decision-making power.
2. Local Communities: Impacted by floods and droughts but often lack power to influence large-scale decisions.
3. Tourism and Recreation Industry: Interested in water levels for their operations but peripheral to basin-wide management.
4. Climate Change Activists: High awareness but low decision-making authority.

Low Power, High Interest (Empower)

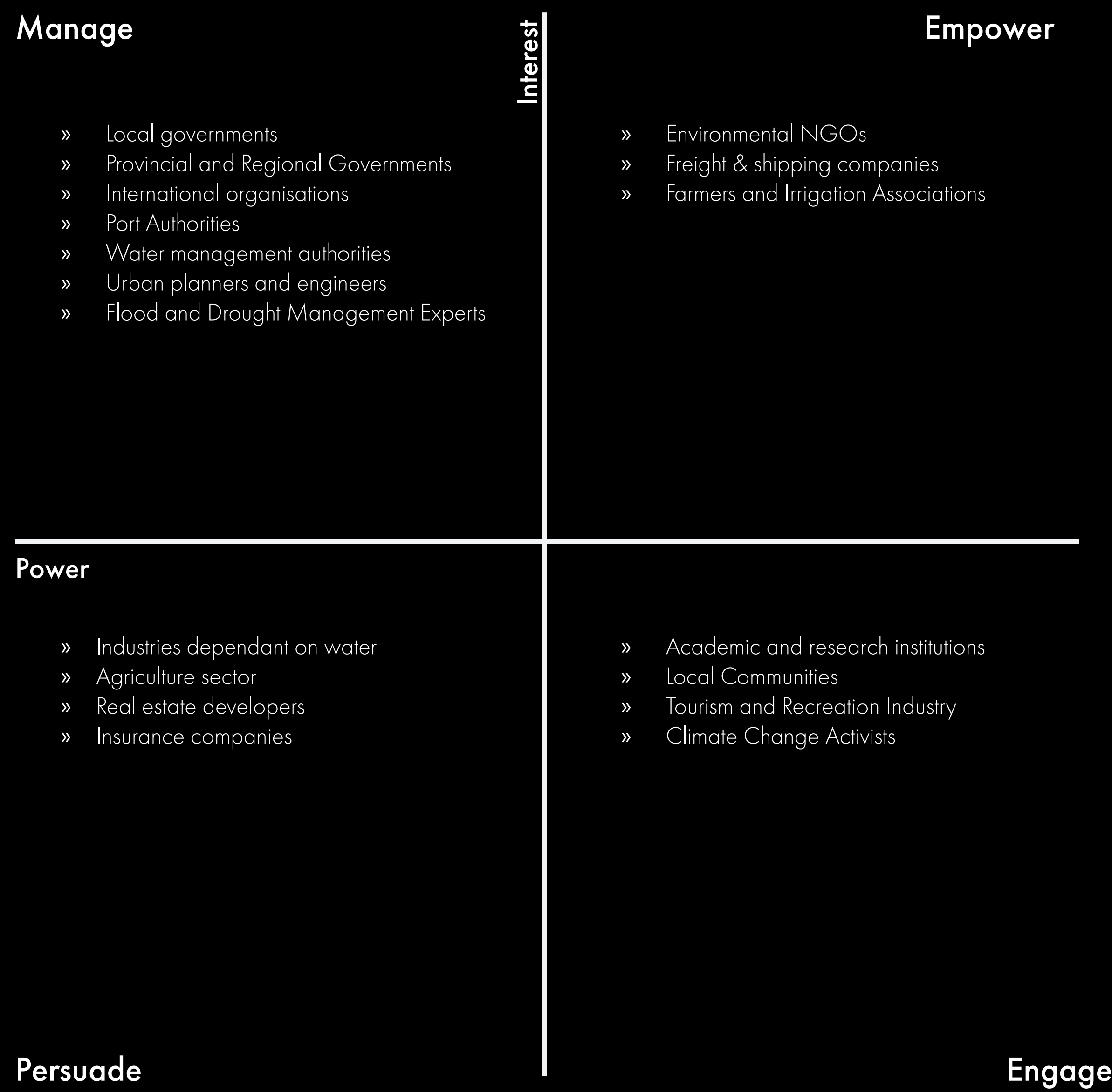
1. Environmental NGOs: Actively advocate for sustainable solutions but rely on government and policy support to implement changes.
2. Freight and Shipping Companies: Highly dependent on water levels but have limited control over broader hydrological or policy decisions.
3. Farmers and Irrigation Associations: Directly affected by droughts and water policies but often lack systemic influence.

High Power, Low Interest (Persuade)

1. Industries Dependent on Water: Critical for regional economies but may prioritize immediate business interests over long-term water management strategies.
2. Agriculture sector: Heavily reliant on water but might focus more on immediate needs rather than basin-wide strategies.
3. Real Estate Developers: May overlook water resilience unless directly impacted.
4. Insurance Companies: Financially involved in flood risk but may not actively engage in prevention strategies.

High Power, High Interest (Manage)

1. Local Governments: Control urban planning and water policies at the municipal level.
2. Provincial and Regional Governments: Coordinate broader policies and allocate resources for water management.
3. International Organizations: Oversee cross-border cooperation and regulations for Rhine basin management.
4. Water Management Authorities: Operate key hydrological infrastructure, such as polder and dikes, with direct control over water systems.
5. Port Authorities: Vital for managing economic activities tied to water transport, ensuring resilience in freight operations.
6. Urban Planners and Engineers: Responsible for designing and implementing adaptive infrastructure solutions.
7. Flood and Drought Management Experts: Provide critical expertise for actionable strategies.



What if

The analysis on macro scale leads me to further what if questions in which exploration of distinct lenses have been created. When we think, do we have an ecological and societal balance in the basin or are we thinking only from the economic perspective leads to questions -

'Are we exploiting the Rhine's trade heritage and exceeding planetary boundaries?'

The drier and hotter period is increasing so the water level in the Rhine goes below the required level for navigation but it also raises a question -

What if these transport disruptions are good for societal and ecological balance?

But these transport disruptions create a huge impact on the economy in the region so it is critical to know what impact it may have in the region if the transport is deliberately reduced. It leads to a new questions -

What impacts will cargo transport have on economy, ecology and society if it is reduced between 30- 50%.

But shifting to new modal will require collaborative governance approach and other means of transport such as intra model with rail transport or road transport to fulfil the demands in the market for economy resilience. So the next question raises -

How sustainable and adaptive this hybrid system can become?

This might also create a conflict among general population and industries as the prices will go higher when transport through water is reduced but also might benefit many groups. This also helps the Rhine to recover from the damage caused by the transportation industry during non transport days. So there goes a new question -

What conflicts and interests might arise from this permanent disruption of 30-50%.

WHAT/IF

Field trip

Meso scale

Case study on meso scale was carried out to understand the region and find out which area can be chosen for intervention. Different cities like Cologne, Düsseldorf, Duisburg, and Nijmegen were explored and get the essence of cities what they stand for. Each city has unique identity along the Rhine such as Cologne gives a historical view whereas Duisburg is completely industrial based and Nijmegen can be seen as nature based solutions area, more vibrant in nature. So, these sketches gives an overview of how these cities interact with the Rhine.

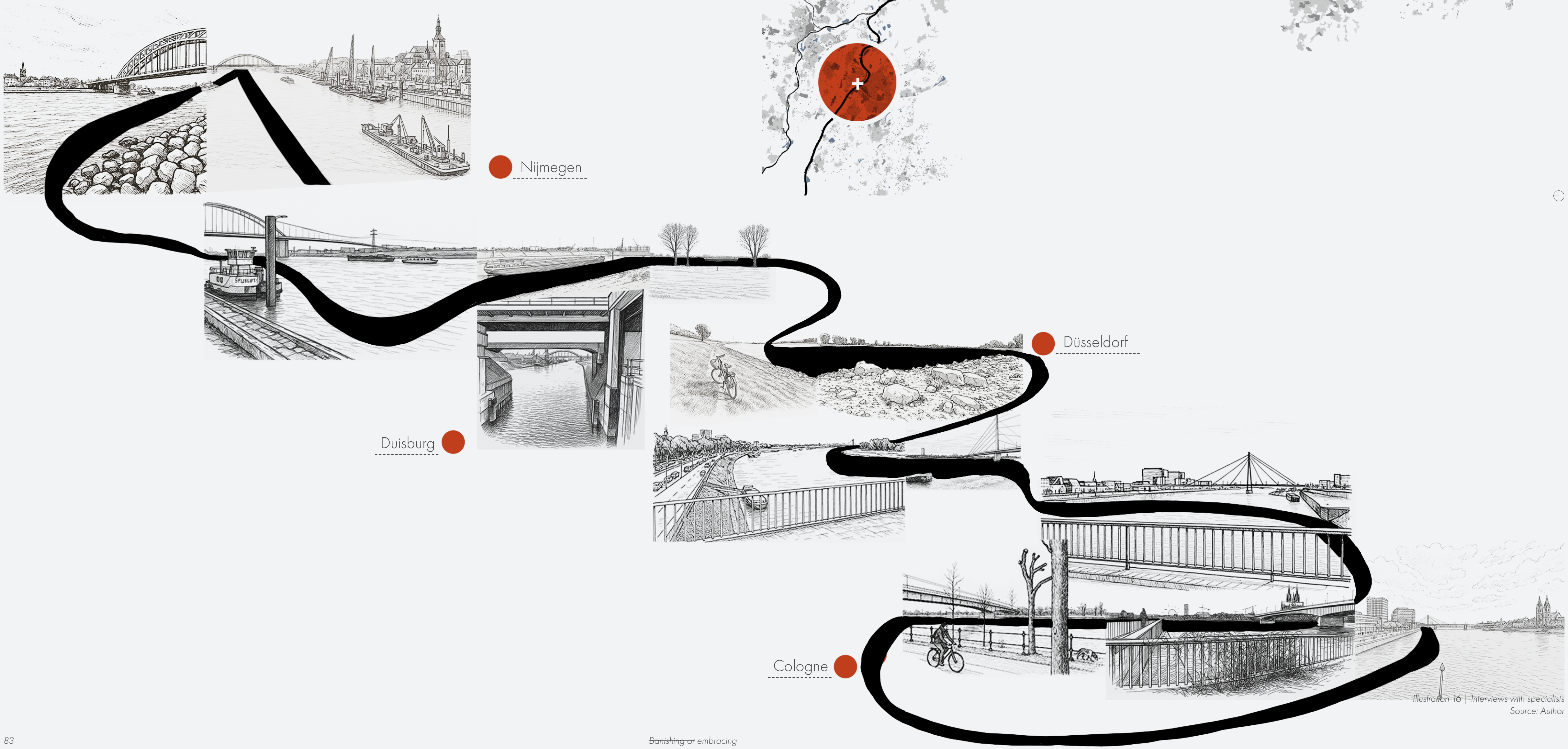


Illustration 16 | Interviews with specialists
Source: Author

Expertise

During this research, several interviews were conducted with specialists and experts within the office to gain a deeper understanding of the complex dynamics surrounding water management, infrastructure resilience, and spatial design. These conversations offered invaluable professional insights drawn from years of practical experience across fields such as hydrology, landscape architecture, urban planning, energy, mobility and infrastructure planning, and environmental policy. The dialogue with experts not only provided clarity on real-world constraints and opportunities but also contributed significantly to shaping the conceptual and strategic direction of the project. Their diverse perspectives helped identify key challenges, inform design thinking, and ground the theoretical framework in applied knowledge. Ultimately, the interviews played a critical role in building credible and adaptable future scenarios for the Rhine basin, refining the relevance and robustness of the design interventions proposed in this thesis.

Refer appendix 5 for some of the detailed interviews

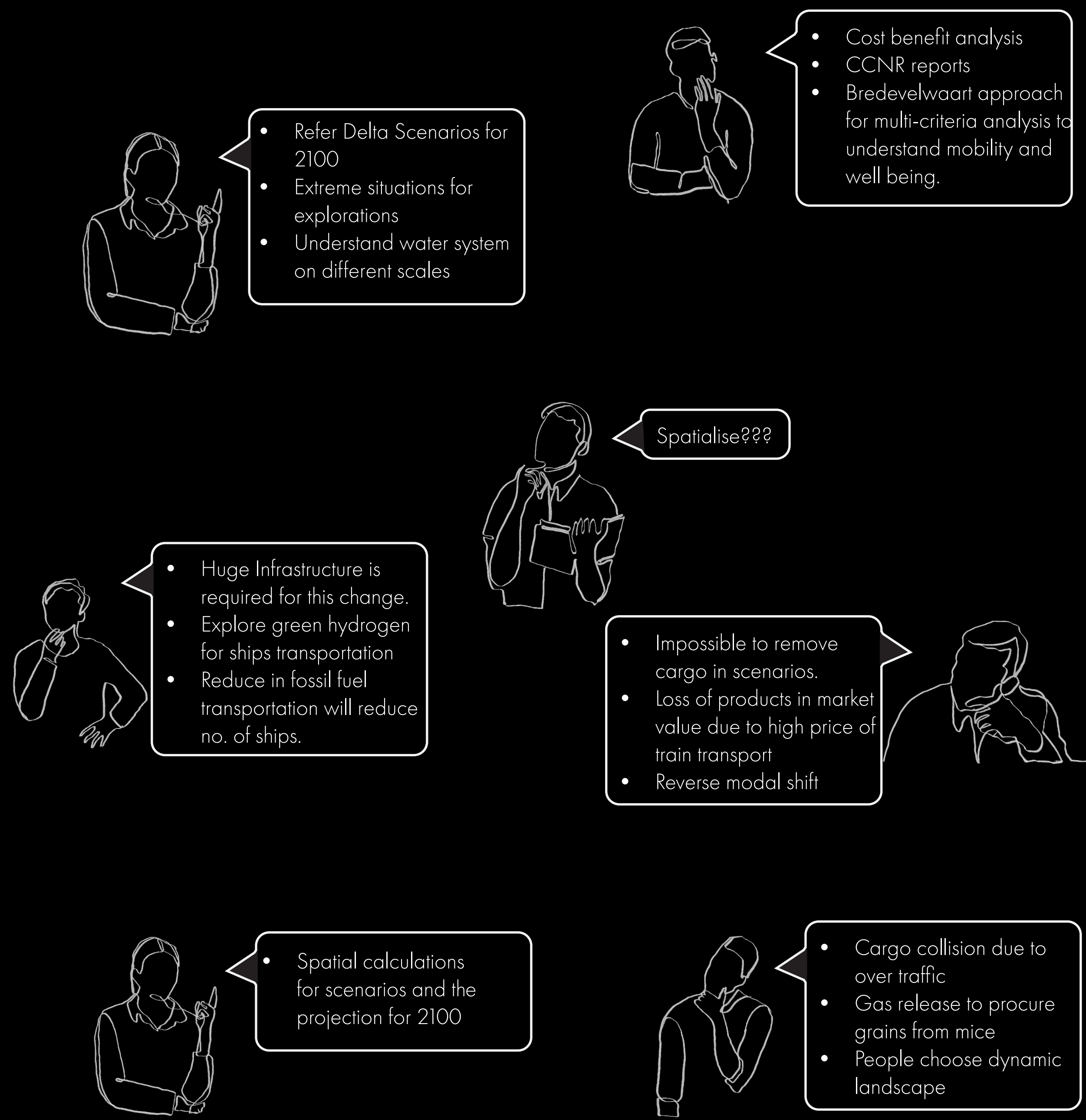
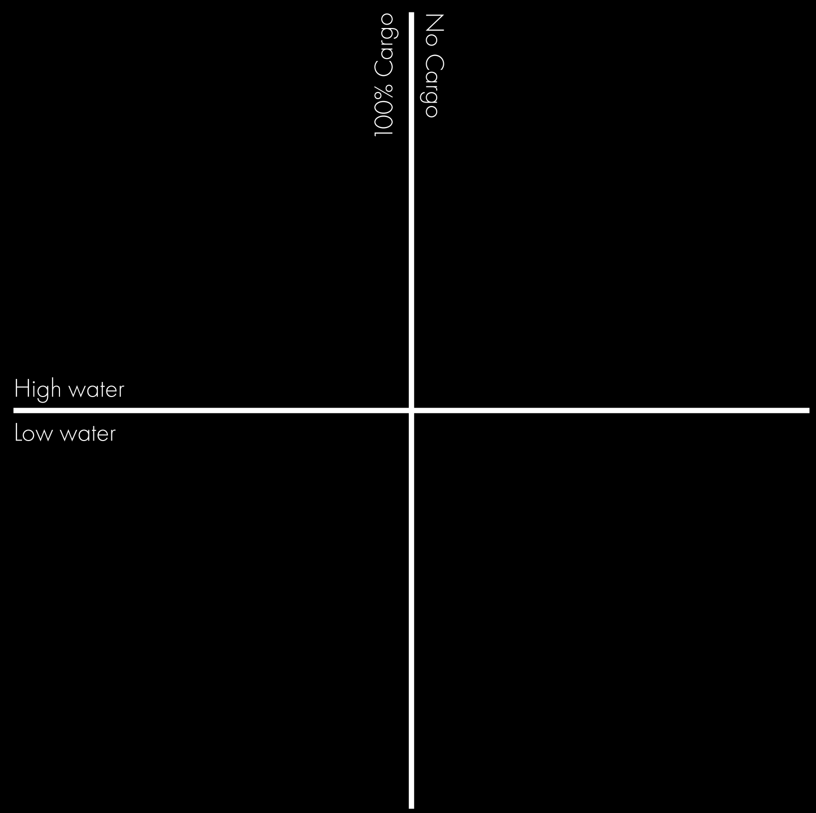


Illustration 17 | Interviews with specialists
Source: Author



Scenarios

As part of the research, two contrasting scenarios were developed to critically explore the impact of climate variability and cargo dependency on the Rhine River Basin. These scenarios were grounded in a comprehensive methodology that combined literature review, hydrological models, policy documents, and expert interviews with specialists from the water management, logistics, and ecology sectors in the office, Haskoning. The objective was to frame the possible extremes of waterway usage, recognizing that while these extremes may not be fully realistic, they help test the boundaries of resilience and adaptability.

Gelderland area is chosen very carefully to explore this scenario as the area serves the purpose of all the parameters this research encapsulates. It lies on the border of the Netherlands and Germany, it is the first point in river where the water has distributaries and get directed into three different water channels i.e. waal, Ijssel, and lek. The landscape in the area is very diverse with expanding cities like Arnhem and Nijmegen.

The first scenario imagines a Rhine where 100% cargo traffic is maintained at full capacity, regardless of water conditions whereas the second one envisions the opposite extreme, no cargo transport on the Rhine. These scenarios serve as speculative yet analytical tools for examining the consequences of continued or withdrawn reliance on the river as a freight corridor. The choice to explore these extremes arises from the Rhine's dual identity: as Europe's most vital inland trade route and as a fragile ecological system increasingly stressed by climate change.

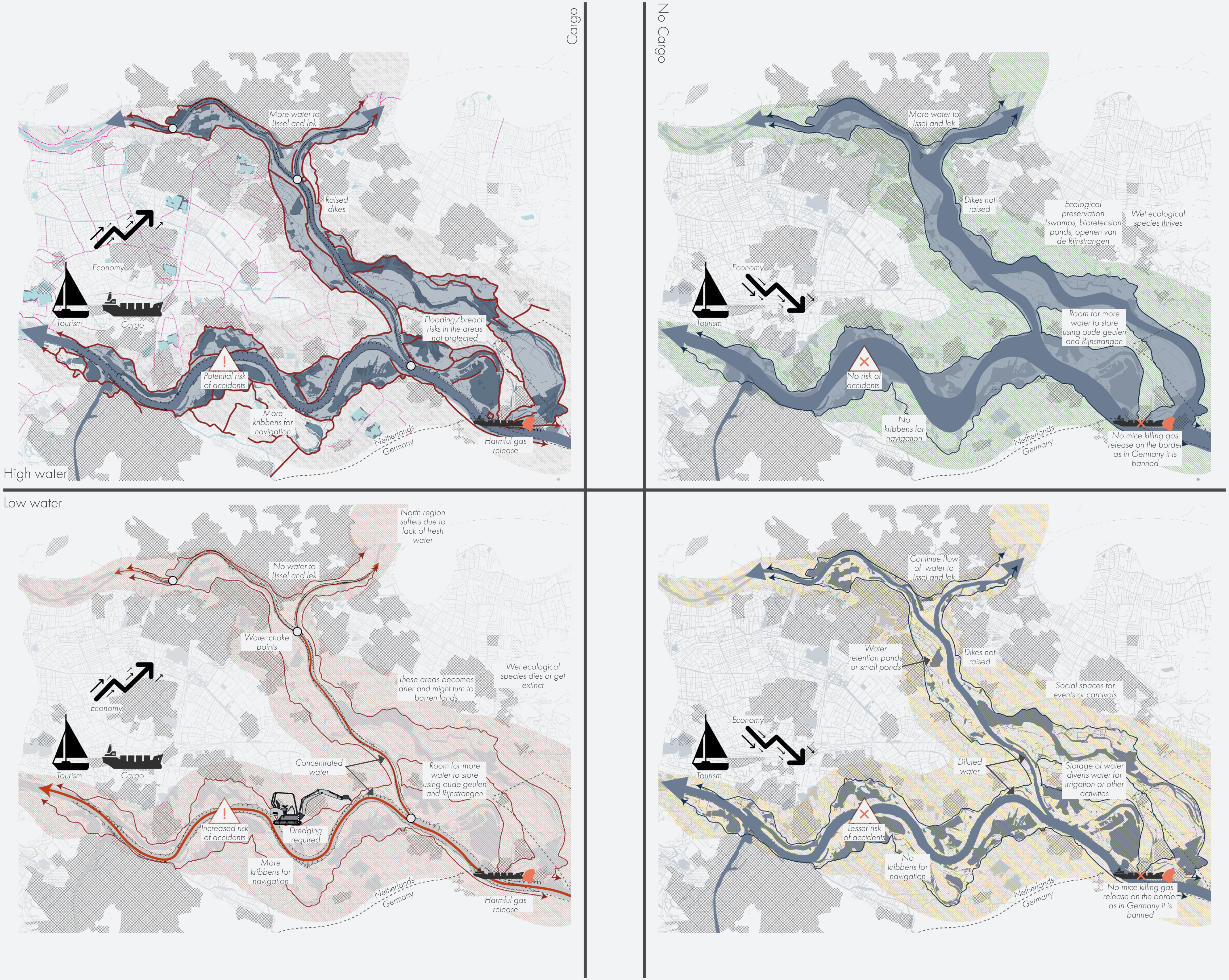
Each of these two cargo-related scenarios is further divided into high water and low water situations. This categorization allows for a nuanced analysis of how water levels shaped by climate-induced events such as prolonged droughts or excessive rainfall—might influence not only navigation but also the spatial, societal, and ecological dynamics of the Rhine Basin.

For instance, a full-capacity cargo scenario under low water conditions would require excessive dredging and deeper navigation channels, risking ecological degradation, altering river morphology, and disturbing habitats. It would also increase infrastructure stress and operational costs, while failing to consider nature-based adaptability. On the other hand, a scenario with no cargo movement would reduce industrial pressures and ecological disruptions but might shift the burden to land-based transport, leading to emissions rise, congestion, and economic slowdowns in river-linked cities.

These extreme scenarios also assess societal implications that how communities adapt when economic or ecological priorities are skewed. For example, while reduced cargo activity may allow for more recreational or ecological use of the riverbanks, it might simultaneously jeopardize livelihoods tied to logistics and port economies.

Consequently, these scenarios (high water & low water × full cargo & no cargo) do not propose direct solutions, but instead offer a critical lens through which the interconnected risks, dependencies, and trade-offs of water-based transport in a climate-uncertain future can be understood. They serve as provocations that help sharpen the need for balanced, adaptive strategies that don't seek to freeze the river's function in one role but allow it to dynamically shift in tandem with ecological and societal needs and help in developing a projection for a sustainable, adaptive and resilient future.

Scenarios Matrix



Key plan

Map 18 | Scenarios
Source: Author

Scenarios Analysis

In conclusion, the developed scenarios have offered valuable foresight into the potential futures of the Rhine River Basin under extreme cargo conditions and shifting water levels. They underline the urgency of implementing nature-based solutions and fostering a collaborative, adaptive approach to regional planning. As climate variability continues to intensify, it becomes evident that freight transport systems, especially those heavily reliant on stable water levels will face increasing levels of disruption, putting pressure on both economic continuity and ecological balance.

To assess the broader impact of these scenarios, an evaluation was carried out using the *Brede Welvaart en Mobiliteit framework* (Snellen et al., 2021). This framework enabled a multi-dimensional analysis across key sectors including health, accessibility, economy, environment, and safety. Through this lens, the positive and negative externalities of each scenario were compared to understand which approach offers the most balanced outcome. The findings helped identify where trade-offs occur, which sectors are most vulnerable, and how integrated planning can mitigate the effects reinforcing the importance of dynamic, multi-scalar strategies in future river basin design.

Refer factsheet 3 for calculations

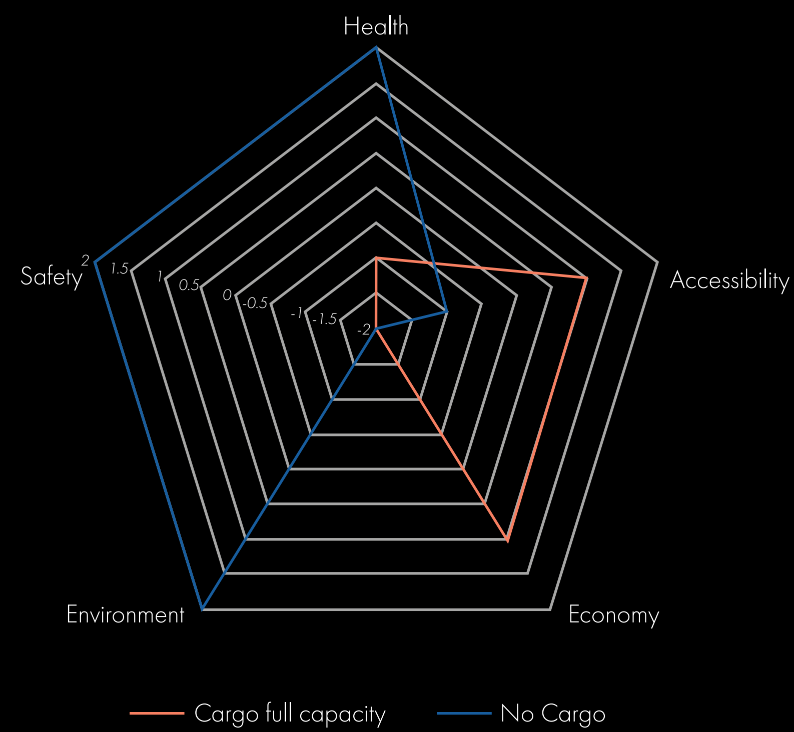


Illustration 18 | Brede Welvaart Diagram
Source: Author

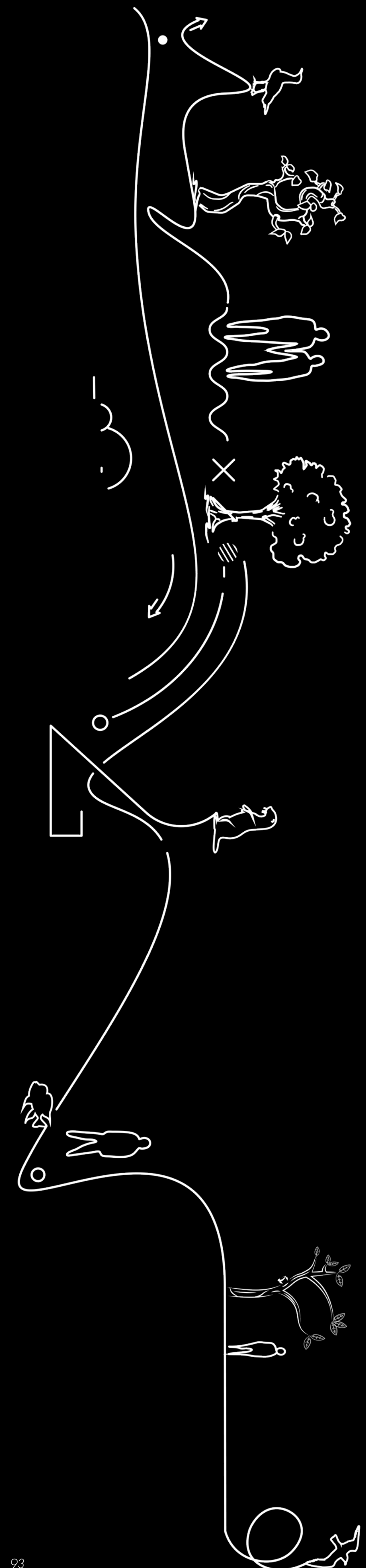


Illustration 19 | Projection
Source: Author

Projection

The vision phase of the project translated analytical insights into forward-looking, site-specific strategies through projections based on future climate scenarios. Design principles were formulated across macro, meso, and micro scales to guide this vision—each rooted in spatial, infrastructural, programmatic, and policy-based interventions. Together, this phase offered a cohesive design strategy that reimagine the Rhine as a shared, living system of adaptation and resilience.. It consists of:

1. Projection 2100
2. Field trip
3. Governance structure
4. Design principles
5. Pilot project
6. Design strategies

Projection 2100

A projection is generated for 2100 of reduction in water transport by 30-50% based on the analysis of scenarios, positive goals were considered from both the scenarios and a synergy is created between them on more realistic grounds which becomes an adaptive system for climate variability. Gelderse Poort area has an eclectic nature from agricultural fields to industrial areas, so it exemplifies a robust area to intervene and become motivation for other regions.

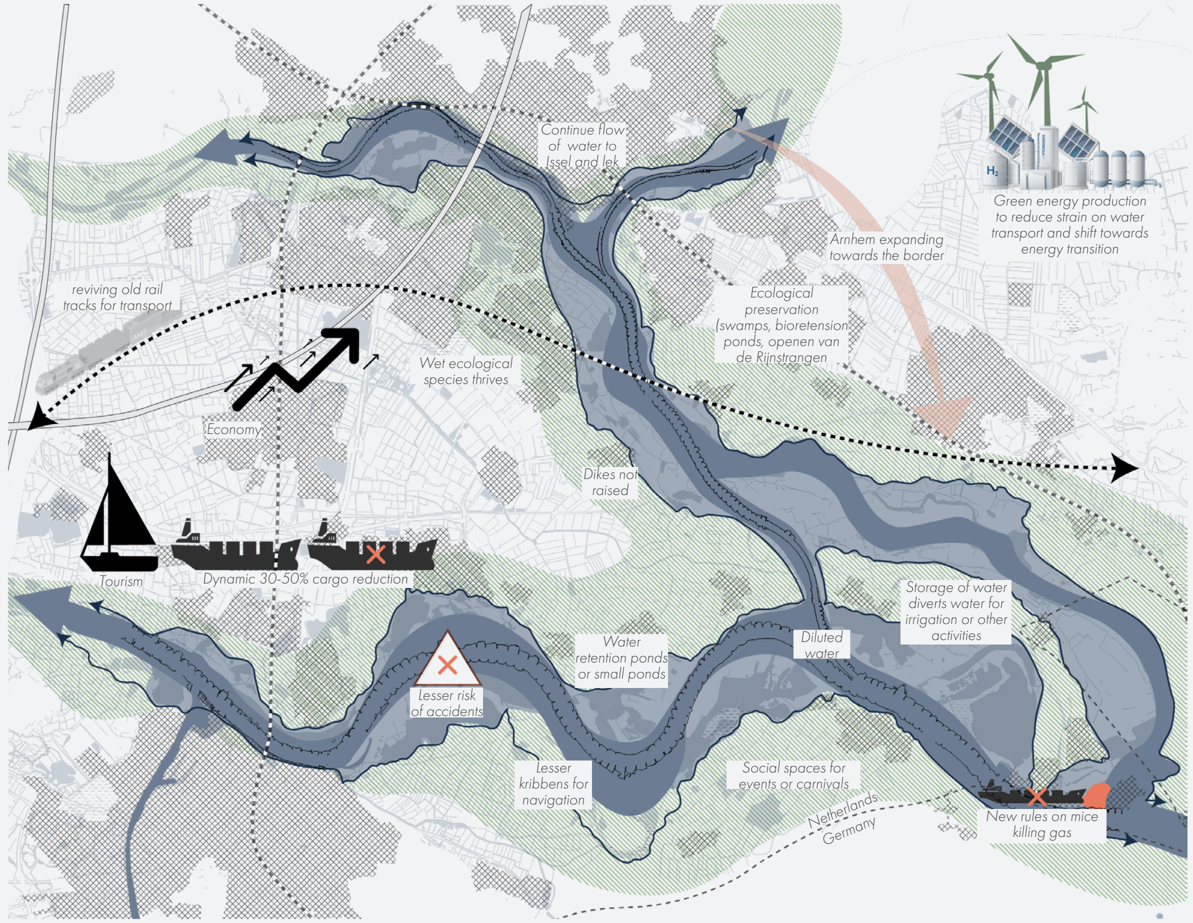
In the new projection for 2100, it is evident that transport system cannot rely completely on the water channel itself because in recent years there have been more than 50 number of days when the water was below required levels and ships could not transport goods. Therefore, the transport price for those goods increase because they are transported through trucks which are approximately 12 times higher whereas if there is competition in the market then the price of goods cannot be increased which results into loss. To cater this challenge, provisions for hybrid system need to be achieved so that the whole economy is relying on two sectors rather than one. So, a dynamic system of water transport is required to be adapted with 30-50% reduction in the water transport and slowly shifts to rail transport as well.

In the projection, a new system of rail transport is indicated which becomes an intra-model system along with water transport as the number of drier days and low water is increasing with changing climate. So, a new strategy of hybrid model is required for seamless flow of goods across the regions. This hybrid system will also help in achieving natural embankments rather than kribbens on the banks for navigation as there will be no need to transport over water during low water levels. Furthermore, it reduces the need for more dredging as some parts are highly dredged and now those surfaces are self eroding resulting into very water current.

Reverse modal shift to rail transport will require clean energy production and storage, this projection also envisions energy transition in the region. Energy is not only required for rail transport but also shifting the ships to hydrogen based rather than conventional non-renewable fuels. It also urges industries to shift towards energy transition because transporting coal or fuels to run industries is not an energy transition solution instead if industries are energy efficient than it helps in envisioning of reduction of water transport by 30-50%.

These solutions would work efficiently if it is approached through collaboration with Germany because this region shares border with Germany. If Germany decides not to approach through NBS and raise the dikes instead then there might be a chance that this areas floods relatively higher than the normal. Consequently, this area has to act as a reservoir for the Netherlands when water is crossing the boundary if the transboundary collaboration doesn't work out. Germany also has rules for not releasing gases which are used to keep mouse away from grains in the ship containers, the Netherlands also has to adopt the same rules and create a new policy for using another medium.

With changing nature of the Rhine, some days have high water which floodplains are unable to accommodate and then low water levels even below the required limit for navigation purposes demands dynamic spaces along the riverbanks rather than just the floodplains which can aid both the situations in different seasons.



Legends
- the Rhine
- Existing water bodies
- Floodplains
- Dikes
- Existing railways
- Proposed railways
- Solar fields
- Windmills
- 30-50% Cargo
- No gas release
- Green hydrogen plant

Map 19 | Projection 2100 for Gelderse Poort area
Source: Author

Field trip

Micro scale

A field trip on bike was done to get an in-depth overview if the area on local scale. Some interviews were done in order to understand people's perspective that how these dynamic areas interact with people. This area is very diverse in nature having all the attributes from a small towns to heavy nature to eco-retreats and the popularity of the area is increasing year by year. This area is managed by Waterschap Issel en Rijn water management board as it is on a crucial point where water is diverted into three different directions i.e. Waal, Lek and Issel. So, this marks the importance of this area and became a reason to chose this area for small scale intervention to test the design strategies.

Illustration 20 | Field trip
Source: Author

Governance Structure

For intervention in sites like Gelderse land because the site has many protected habitats and areas by Natura 2000and national government, requires the whole governance structure and strict rules need to be followed. Referring to the diagram, it shows step by step approach to intervene in gelderse poort area. There are many rules set by European Union for nature and water which has to be followed by the national government and then the government make sure that the provinces follows them through Ministerie van Infrastructuur en Waterstaat and Rijkwaterstaat. Then the provinces reviews the plans in Nature policy, recreation and spatial that how the interventions fits in the overall structure of their policies. As Gelderse poort area has varied landscapes from forests to large rivers to rural areas, there is also Waterschap Issel en Rijn which governs the water management in the area. So, an integration in the strategies is needed for the approval from province and Waterschap. Lastly, on design scale, local municipalities work on dwellings, so any dwelling proposal goes through the municipalities in the area. These all are government bodies in order for the approval of a design intervention.

Apart from these bodies, there are other agencies and stakeholders which takes place influencing the decision making such as:

1. Nature Staatsbosbeheer (asset management of the area).
2. Local population
3. Farmers
4. Shipping organisations
5. Small groups of same interest

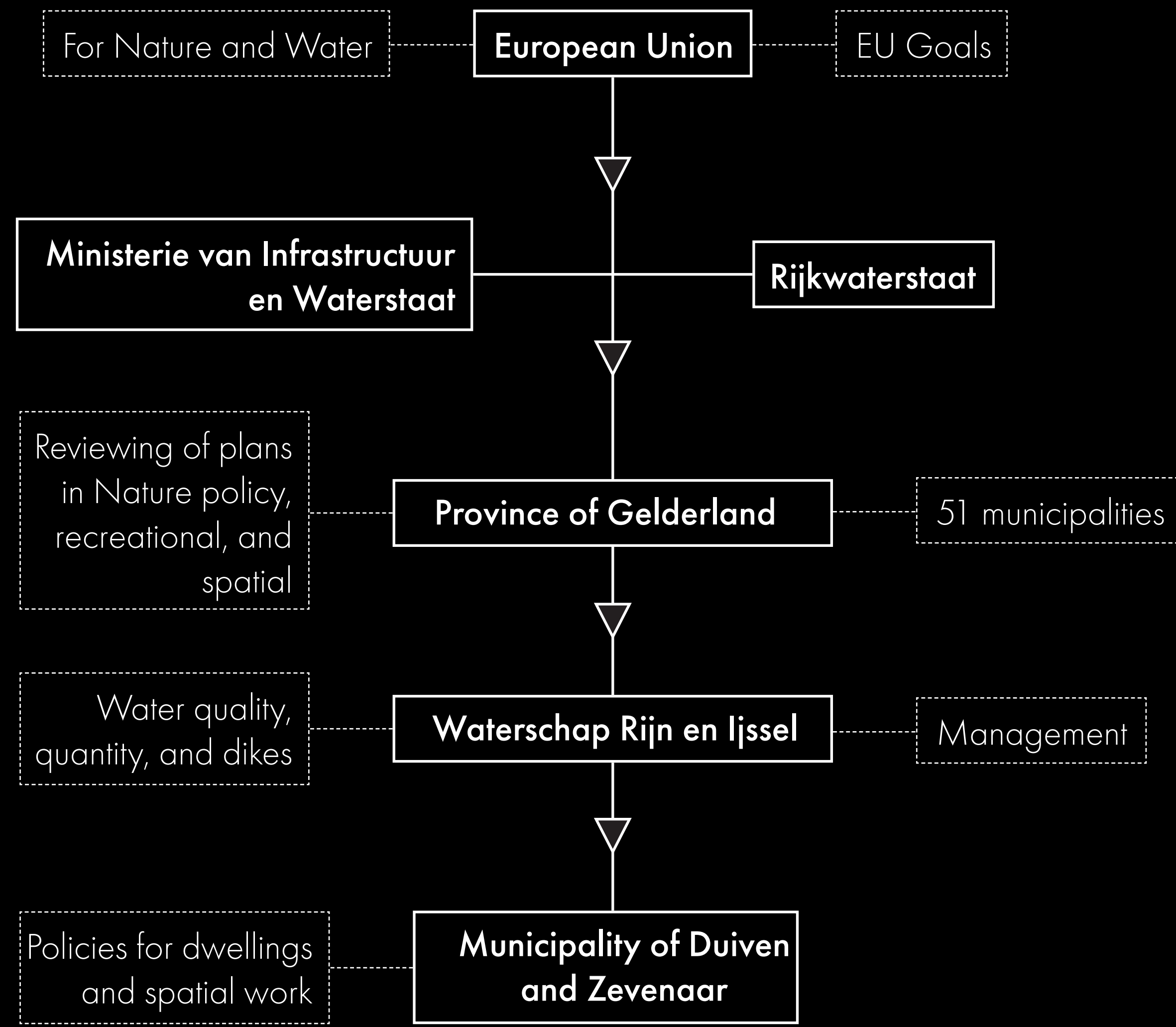


Figure 22 | Governance structure
Source: Author

Illustration 21 | Showing how a decision was made to introduce design principles
Source: Author

Design principles

The methodology of developing design principle cards is chosen to translate the complexity of the research into an actionable and adaptable framework. These cards serve multiple purposes:

1. Simplification of Complexity: The challenges in the Rhine basin are multi-layered and systemic, so design cards break these down into clear, targeted interventions categorized by typology (spatial, infrastructural, programmatic, policy) and scale (macro, meso, micro).

2. Strategic Decision-Making: By using the lenses of economy, ecology, and society, the cards help prioritize interventions based on synergy and conflict providing a structured way to choose context-specific strategies.

3. Flexibility and Replicability: The card format allows them to be used across different locations and scales. They are tested in pilot project (like Gelderse Poort) and adjusted or transferred to other parts of the Rhine or similar river basins.

4. Engagement and Collaboration: The cards became a key toolkit in workshops and discussions, enabling experts, students, and stakeholders to interact with the research in a tactile, visual, and participatory way.

5. Bridge between Research and Design: They served as the turning point from analytical research into concrete design exploration, allowing the thesis to evolve from theoretical frameworks into visionary spatial solutions.

Design Principles cards

Based on the literature study, analysis and insights from experts, guiding principles have been created in order to make strategies for the chosen areas. These cards help in creating a framework and envisioning how the specified area can be transformed. By structuring the principles through the lenses of economy, ecology, and society, and categorizing them into spatial, infrastructural, programmatic, and policy-based strategies, they form a pattern language that enables adaptable design thinking. This approach allowed the project to move from abstract challenges such as droughts, floods, or trade disruptions toward concrete, actionable strategies that could be tested at the micro-scale in Gelderse Poort while remaining relevant across the Rhine basin. These principles are created on three scales i.e. macro, meso, and micro. Ultimately, the principles serve as the backbone for integrating water-sensitive planning with cultural, ecological, and infrastructural narratives, ensuring that design interventions are not only resilient but also place-specific and inclusive.

Each card represents a design strategy that responds to climate-induced water challenges through one or more of the following lenses: economy, ecology, and society. These strategies are categorized into four typologies—Spatial, Programmatic, Infrastructural, and Policy-based—and mapped across three geographical scales: Macro (Rhine Basin), Meso (Regional/Cities), and Micro (Local/Neighbourhood – e.g., Gelderse Poort). Each card includes:

- A clearly articulated design strategy.
- Its potential impact (economic, ecological, or social).
- A short title and typological classification.
- In earlier stages, illustrative sketches or diagrams for spatial understanding.

The creation of these cards followed a rigorous process:

1. Literature & Precedent Study: Theoretical frameworks such as Integrated Water Resources Management (IWRM), Socio-Hydrology, Infrastructure Economics, and Polycentric Governance were reviewed to extract applicable strategies.
2. Fieldwork & Mapping: Observations, interviews, and analysis at the meso and micro scales (e.g., visits to Nijmegen, Cologne, Duisburg) informed context-specific insights.
3. Synthesis of Theory and Design: Ideas were formulated by bridging abstract concepts (e.g., climate adaptation, dynamic water equilibrium) with real-world urban-river interfaces.
4. Iteration & Categorization: Principles were iteratively refined and grouped by typology and scale for coherence. Cross-cutting connections and synergies/conflicts between cards were later studied.
5. Workshops & Feedback: The cards were tested in participatory workshops—both with professionals and students—to validate placement and interaction. The feedback loop helped strengthen the relevance and adaptability of each card.

The cards serve multiple critical purposes in this thesis:

1. Translating Theory into Practice: They ground abstract frameworks into visual, tangible strategies that can guide real-world interventions.
2. Design Toolkit: They offer a scalable, transferable, modular system of design tools that can be applied in diverse contexts—from regional policy planning to neighbourhood-level projects.
3. Scenario Building: By placing the cards in different scenarios (e.g., high water, drought), dynamic zoning patterns and synergies/conflicts could be explored.
4. Stakeholder Communication: The card format is accessible and effective in engaging policymakers, designers, citizens, and researchers alike.
5. Pilot Testing: Through placement in the Gelderse Poort area, they tested the applicability of multi-scalar, multifunctional interventions in a real, dynamic landscape.

Ultimately, the Design Principle Cards form the operational core of this thesis, allowing for critical engagement with the Rhine's evolving landscape. They provide both a strategic framework and a practical language for envisioning climate-adaptive, socially integrated, and economically resilient river systems.

A brief explanation of the cards, how they can be read and one card from each lens is shown for the overview of the entire deck of cards. Further, cards and the explanations can be referred in the factsheet 4.

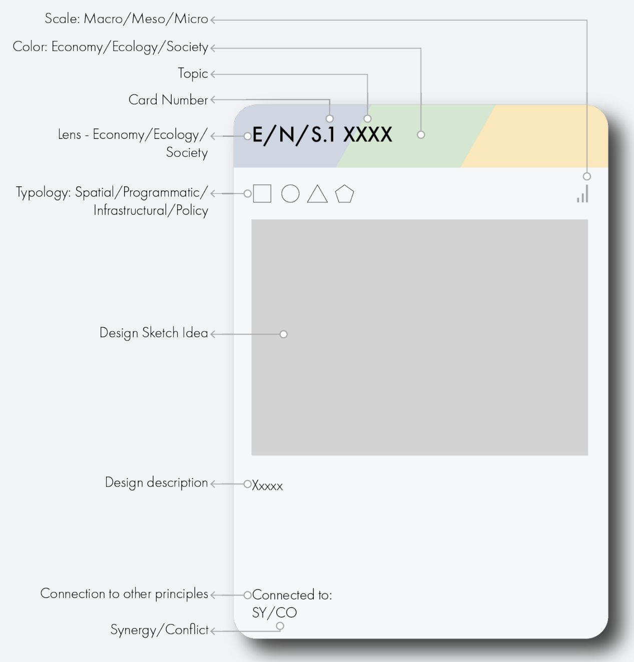


Illustration 23 | Descriptor card
Source: Author

Illustration 22 | Exemplary cards from each lens
Source: Author

Overview of all the cards

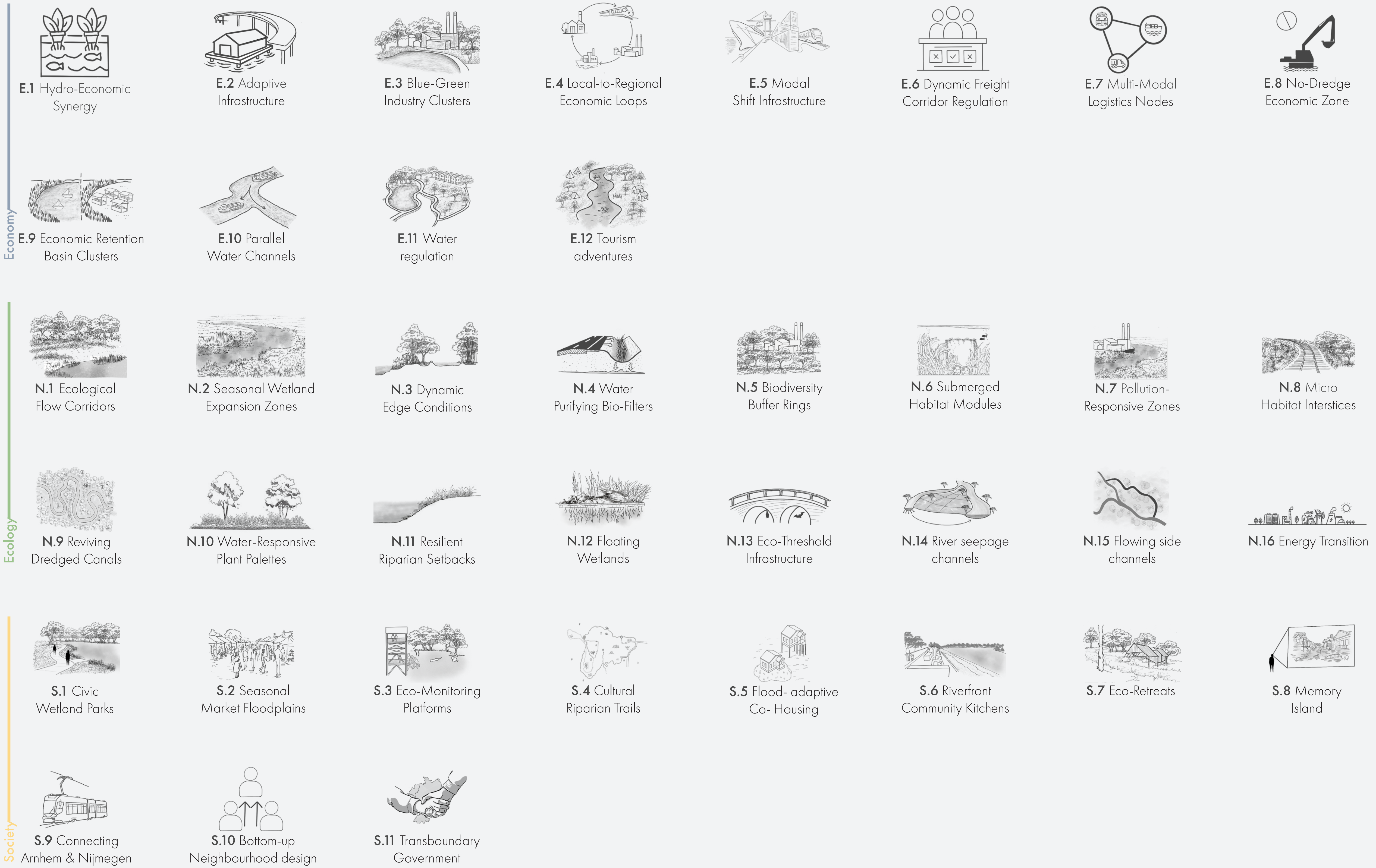


Illustration 24 | Design principles
Source: Author

Connections of cards

As part of the thesis methodology, the Design Principle Cards were not developed as isolated interventions, but as interconnected elements within a larger spatial system. Each card represents a unique strategy, yet many overlap in intention, location, or function. The meaningful outcome of this system occurred when the cards were placed in relation to one another, creating a network of interactions positive, negative, or mixed that allowed a better understanding of how space, people, ecology, and infrastructure interact across scales. Further relationships were established based on:

- Synergies (SY)
  Cards that complement and enhance each other's goals. For example, N1 (Hydro-Economic Synergy) supports E1 (Ecological Flow Corridors), as both involve multifunctional water landscapes that balance ecological flows and economic use. When implemented together, they increase the efficiency and resilience of the landscape.

- Conflicts (CO)
  Cards that clash due to competing land uses, environmental needs, or social implications. For instance, E8 (Micro-Habitat Interstices) may conflict with S9 (Connecting Arnhem & Nijmegen) if infrastructural expansion threatens biodiversity corridors. These help to highlight sensitive areas that require negotiation, trade-offs, or mitigation.

A network map was developed as a conceptual graphic to visually represent how cards are connected (created through online website Kumu.io). Each card was tagged with its category (E, N, S), and directional arrows illustrated synergy or conflict. This map:

- Helped identify clusters of highly compatible principles
- Flagged design principles that needed moderation or adaptation to coexist with others.
- Revealed gaps where additional interventions might be needed to mediate conflicts or reinforce synergy.

These connections are helpful for diverse teams such as Designers or planners to help in scenario mapping, layered zoning or conflict resolution, policy makers or institutions to help in multi-scalar planing, regulatory clarity or cross border negotiation, communities or stakeholders to help in participatory workshops, narrative formation etc.

By embracing synergies, and negotiating conflicts, the card system becomes a living framework that adapts with changing water conditions, community needs, and ecological thresholds. In this way, the cards mimic the Rhine itself: ever-flowing, sometimes in tension, often interconnected, and always shaping the landscapes it touches.

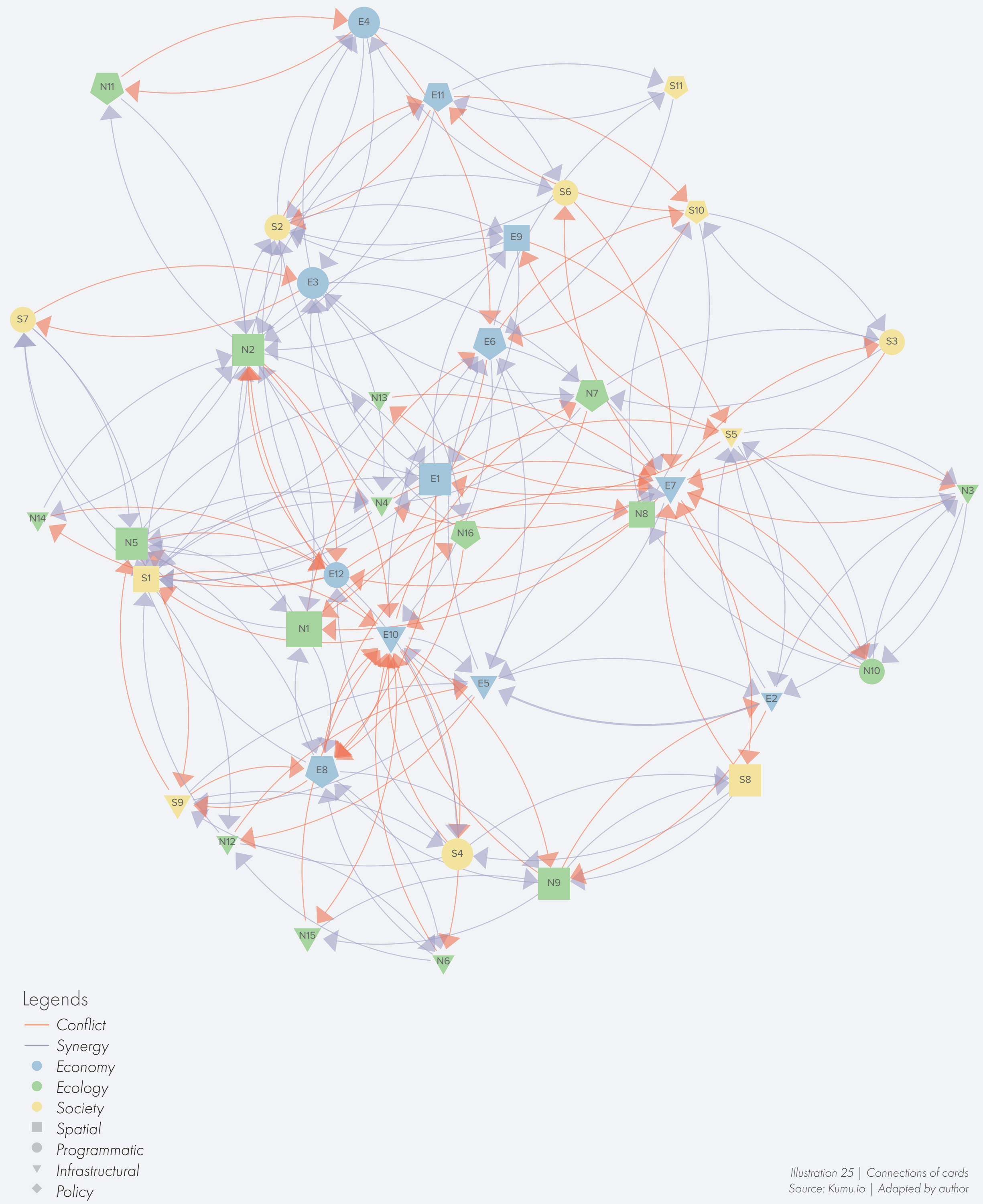


Illustration 25 | Connections of cards
Source: Kumu.io | Adapted by author

Example: Connections of cards

Illustrating how the connection of design principles work, an example of one card N5 is given. The design principle **N5 – Biodiversity Buffer Rings** envisions encircling critical infrastructural and urban edges with thick layers of vegetation, forming green buffers that protect habitats, reduce noise and pollution, and enhance biodiversity. This card plays a pivotal role in ecologically sensitive zones, especially near mobility corridors, industrial belts, or transition zones between the built and natural environments.

When this card is placed within a design area, it naturally triggers a web of interconnected strategies both supportive and competitive shaping a holistic spatial outcome.

Synergistic Connections
- » S7 – Eco-Retreats
- » N13 – Eco-Threshold Infrastructure
- » N4 – Water Purifying Bio-Filters
- » N1 – Ecological Flow Corridors
- » E8 – No-Dredge Economic Zone

Conflicted Connections
- » E12 – Tourism Hub
- » S9 – Connecting Arnhem & Nijmegen

This example illustrates how selecting a single card automatically suggests a family of compatible or incompatible strategies. It serves as a central node, from which a designer can expand outwards, layering in other cards to build a multi-functional space. In doing so, one begins to understand that no design principle operates in isolation and each one pulls or pushes on others depending on location, intent, and contextual constraints.

These connections were developed through my research synthesis, field observations, stakeholder feedback, and iterative testing during workshops. However, it is important to acknowledge that these relationships are not fixed. Depending on one's design values, spatial constraints, or priorities, a card that appears in conflict in one scenario may be synergised in another which makes this network of cards a tool for negotiation and adaptation.

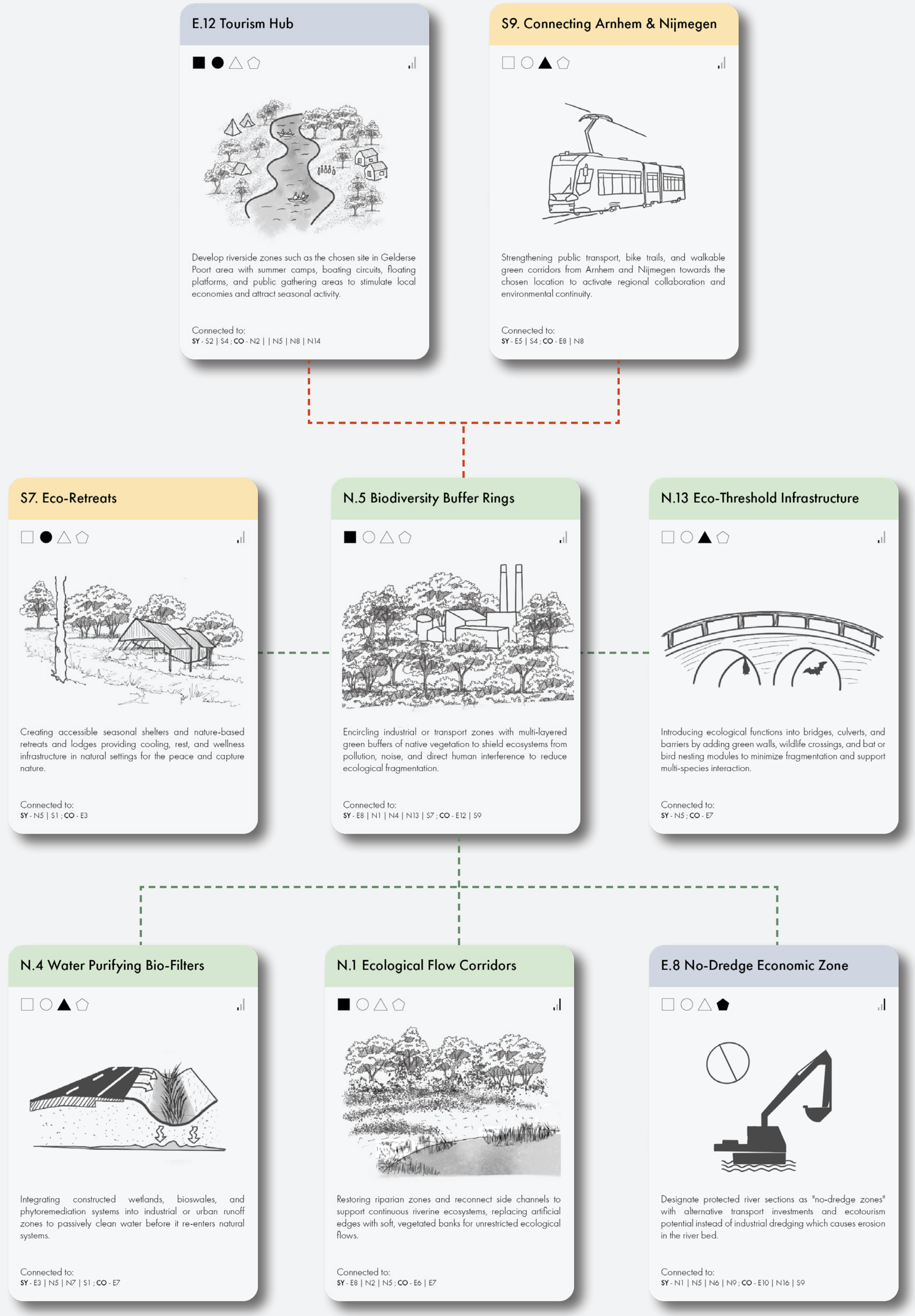


Illustration 26 | Exemplary Connection of cards
Source: Adapted by author

Testing location - Pilot project

Site

This mall section in Gelderse Poort region was selected as the pilot site for testing the design principle cards due to its unique hydrological, ecological, and socio-economic complexity, which aligns perfectly with the objectives of this research.

Situated at the border of the Netherlands and Germany with a critical hydraulic juncture where the Rhine splits into the Waal, Nederrijn, and IJssel, the area plays a pivotal role in water regulation for the entire Dutch delta and demands a collaborative approach between the two nations. This makes it a natural testing ground for exploring dynamic water equilibrium, where drought and flood conditions coexist in close succession. Managed by Waterschap Rijn en IJssel, it reflects the challenges of real-time water governance and water dependencies that this research seeks to address.

Ecologically, the Gelderse Poort is a high-value Natura 2000 zone, home to floodplain forests, dynamic meadows, migratory bird habitats, and rare wetland species. It represents an excellent area to experiment with strategies such as biodiversity buffer rings, ecological flow corridors, and habitat-responsive interventions. These allow for meaningful testing of design principles at both micro and meso scales.

Socially and economically, the area lies between two rapidly urbanizing cities, Arnhem and Nijmegen and is witnessing increased recreational demand, housing pressure, and tourism development. Furthermore, this area stands out for its multi-scalar relevance. At the macro scale, it connects to Rhine-wide flood safety strategies; at the meso scale, it forms part of an urban-natural corridor between German and Dutch cities; and at the micro scale, it offers a variety of landscapes where individual cards can be applied with precision. It allows for testing the synergies and conflicts between economy, ecology, and society, helping validate the adaptability and robustness of the design principle cards developed in this research.

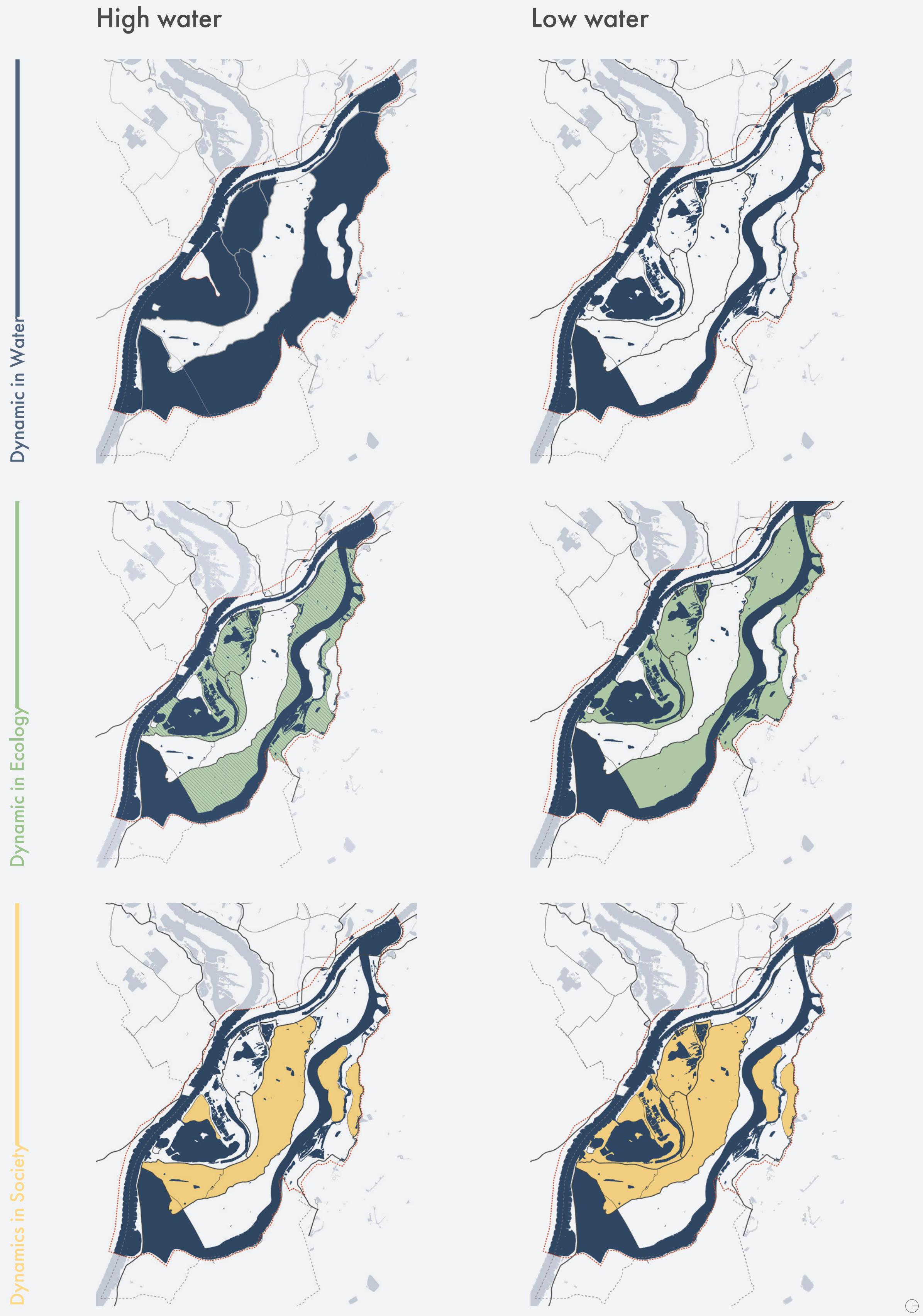
Legends

- *Site area*
- *the Rhine (Waal)*
- *Grasslands*
- *Agriculture*
- *Forests*
- *Builtup*
- *Natura 2000*
- *Protected sites*
- *Dikes*
- *Smaller dikes*
- *Rail track*
- *Roads*
- *Border*

Map 20 | Existing Plan
Source: Author

Zoning

Two scenarios: high water and low water, were envisioned for the chosen area to explore how the three lenses of economy, ecology, and society interact and integrate under varying hydrological conditions. These zoning diagrams illustrate the creation of dynamic zones that adapt to shifting water levels. During periods of high water, the area can function as a flood retention basin, storing significant volumes of water. In contrast, during droughts or low water periods, this stored water can be strategically utilized—for agricultural irrigation or flow support into the IJssel or Waal rivers, depending on regional needs. Zones have been delineated using the existing dike systems to identify which areas can safely remain dry and which can be temporarily flooded. This enables a multi-functional landscape where adaptive activities are introduced: boating, eco-tourism, and water-based recreation during high water; and floodplain markets, festivals, and seasonal events during low water. Ecologically, water-tolerant plant palettes and habitat zones are designed to thrive in fluctuating conditions, reinforcing the area as a dynamic ecological corridor. On the societal front, with Arnhem expanding toward this zone, a network of public green spaces and park islands is proposed to create a sense of inhabitable landscape fragments, creating both climate resilience and community identity.



Map 21 | Zoning scenarios
Source: Author

Dynamics of the site

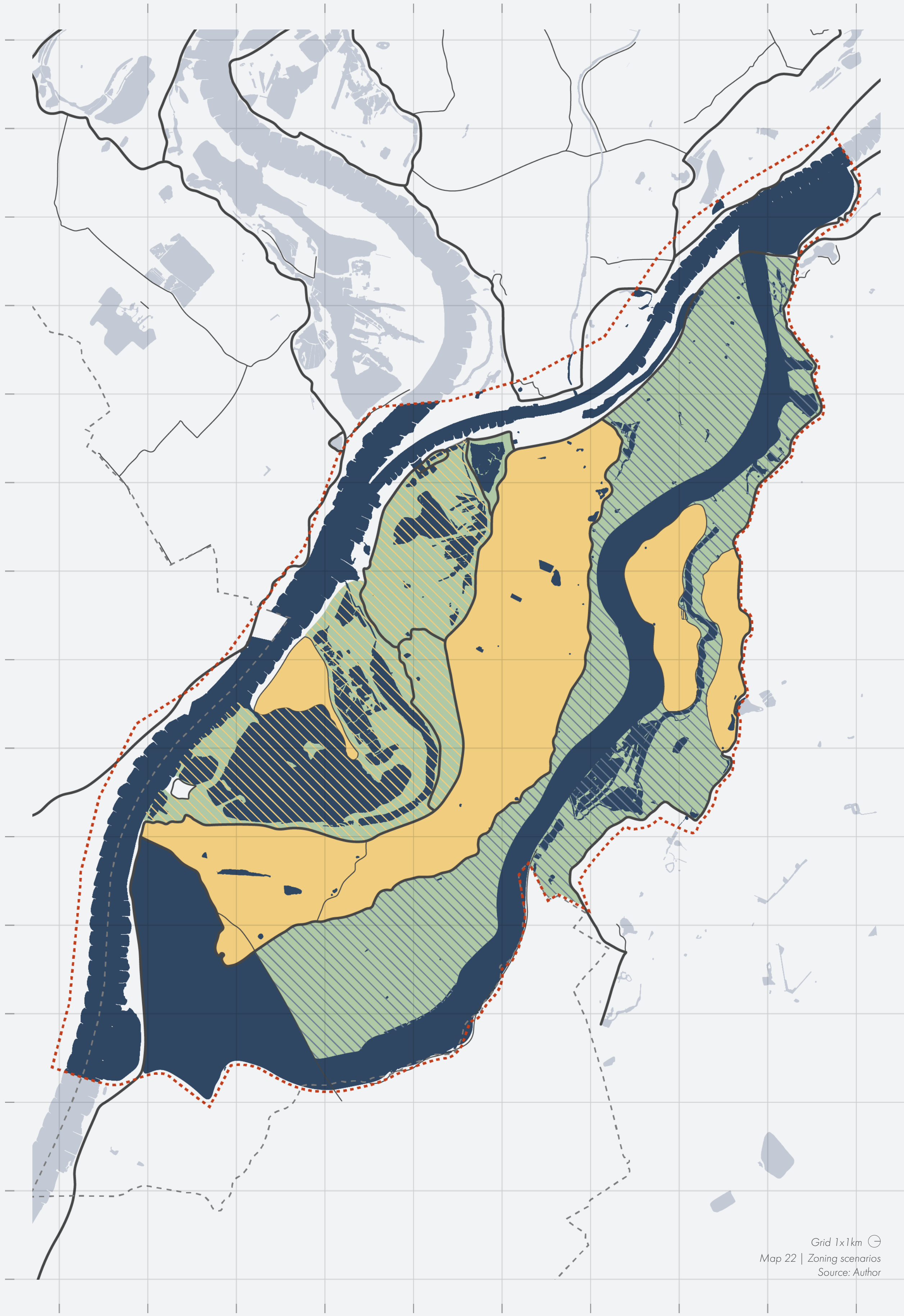
The zoning strategy developed for the pilot project is fundamentally rooted in the concept of dynamic water equilibrium, a balance between high and low water scenarios that enables both ecological resilience and socio-economic adaptability. By identifying zones that can safely accommodate seasonal water fluctuations, this approach creates a flexible, responsive water landscape that supports long-term sustainability and resilience.

During high-water periods, selected zones are designated as retention areas, allowing them to temporarily store floodwater. These areas not only help prevent downstream flooding but also support wetland restoration and habitat creation, enhancing ecological diversity. Conversely, during droughts or low-water periods, this stored water can be redirected strategically, for example, into the Waal, Lek, or IJssel rivers, or toward agricultural lands helping to stabilize regional water supply and reduce stress on the wider basin.

This adaptive dual-use zoning allows for a unique overlap between ecological and economic functions. Zones that flood seasonally can also host seasonal economic activities during dry months, such as floating markets, recreational areas, or pop-up agricultural processing hubs. This duality transforms potential flood-prone land into an economic asset, reinforcing both climate adaptation and local livelihoods. It also integrates societal functions ensuring people are not only protected but actively engaged with the water landscape. This vision of integration where society, economy, and ecology interact dynamically in a spatial and temporal rhythm forms the foundation of what I name:

iSEEC – Integrated Society with Economy and Ecology enhancing Collaboration

ISEEC is more than a design concept, it's a philosophy of coexistence that invites collaboration between disciplines, stakeholders, and natural systems. It reflects a future in which water is not simply managed but embraced as a living force that binds people, productivity, and the planet in a fluid, mutually beneficial relationship.



Legends
- *Dynamic areas*
- *Society*
- *Water*
- *Ecology*

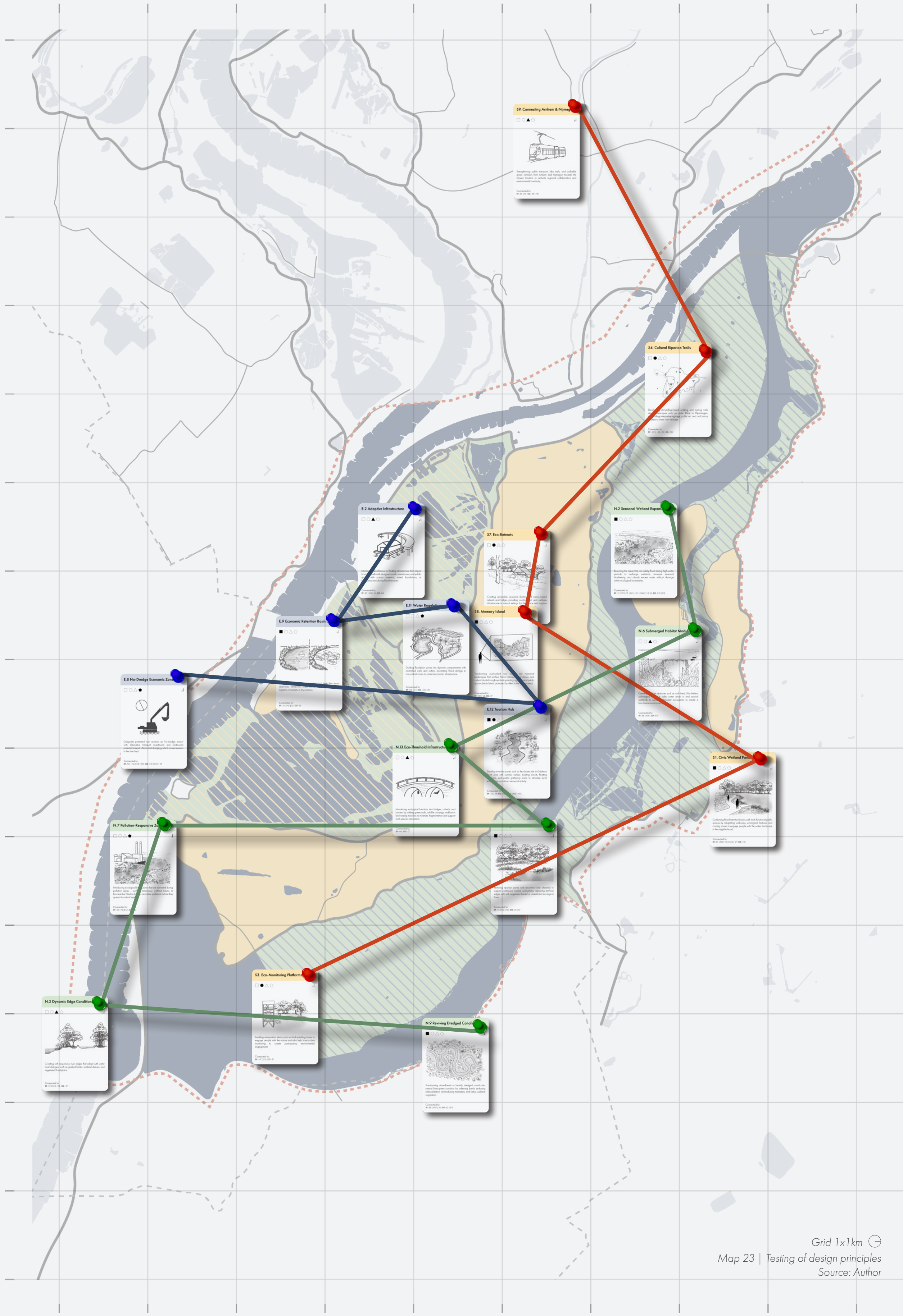
Grid 1x1km
Map 22 | Zoning scenarios
Source: Author

Placement of design principles

Following the development of the design principle cards, they were strategically placed on the site plan of the test site based on a comprehensive zoning analysis. This zoning process took into account the hydrological characteristics, ecological sensitivities, urban growth pressures, and socio-economic dynamics of the region. Each zone was evaluated for its potential to accommodate high or low water, its relationship to existing infrastructure, and its proximity to natural habitats or urban centres.

The cards representing spatial, programmatic, infrastructural, and policy-based strategies are then carefully positioned in areas where their intended impact could be most effectively realized. For example, ecological flow corridors are mapped along dynamic river edges, flood-adaptive housing is placed in transitional floodplains, and multi-modal logistics nodes are located near transport-accessible zones. Once placed, the cards were connected based on synergies, and conflicts, revealing a network of interdependencies.

This method of placement and interconnection not only tests the feasibility and adaptability of the design principles but also reflects the layered complexity of real-world decision-making. It allows the area to be visualized as an integrated system of water, people, and ecology, while also offering flexibility for future stakeholder engagement and iteration. This gives an overview how and where cards can be placed and in further steps how these cards can turn into design strategies or masterplan of the area.

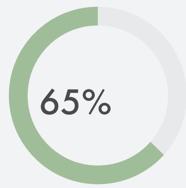


Grid 1x1km

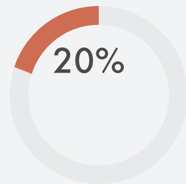
Map 23 | Testing of design principles
Source: Author

Testing of design principles

To test the design principles at the pilot scale, individual design cards were placed onto the existing site plan of the Gelderse Poort area, guided by an initial zoning framework. Cards that demonstrated synergies or conflicts—as identified through earlier matrix mapping—were positioned accordingly to explore how dynamic zones could emerge in response to layered water, ecological, and societal needs. To further validate the approach, a design workshop was conducted within the office setting, involving experts from diverse backgrounds. In this interactive session, a card-based game was introduced: after a brief project presentation, participants were invited to place selected cards onto the site based on their professional vision for the area. The results of the workshop were then analysed, revealing that 65% of the cards showed clear synergy, often aligning spatially across different participants' layouts. Meanwhile, around 20% of the cards resulted in conflicting placements or interpretations, though due to time constraints, some of these differences could not be discussed in depth. Nonetheless, the exercise provided valuable insights into how stakeholders perceive the integration of ecological, economic, and social values, reinforcing the importance of flexible, site-specific adaptation in future planning.

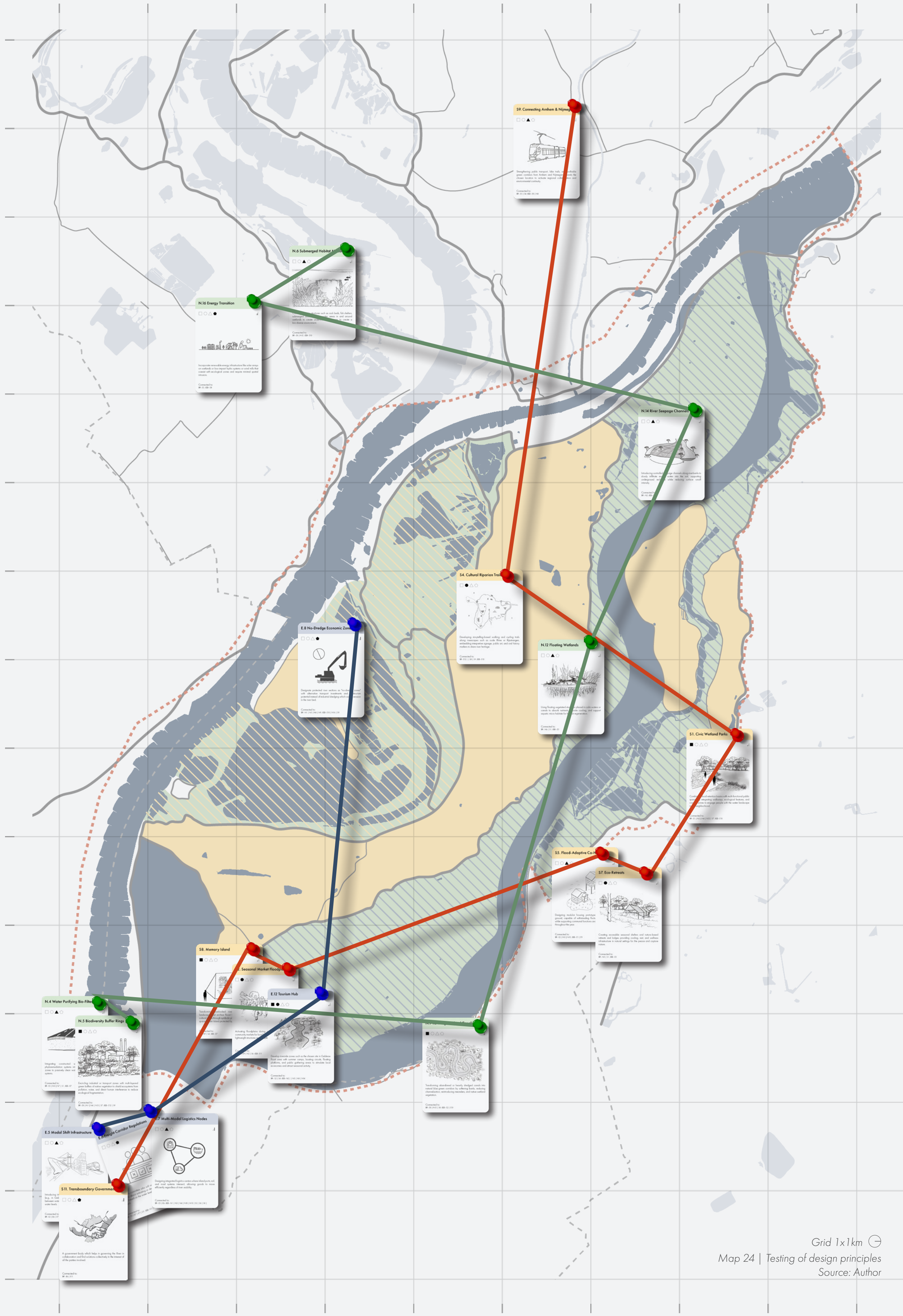


Synergy



Conflict

Figure 23 | Office workshop
Source: Author



Map 24 | Testing of design principles
Source: Author

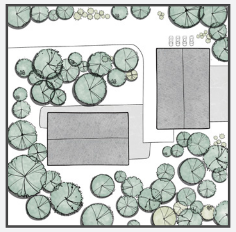
Design Strategies

Developing Context-Driven Design Strategies

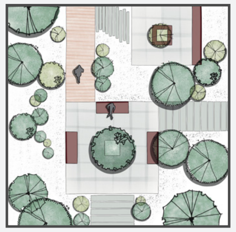
The design strategies developed in this project are a direct outcome of a systematic, multi-scalar design process created based on zoning analysis and spatial logic. These strategies evolved as a means to translate abstract design principles into tangible spatial interventions, adapted specifically to the conditions of the Gelderse Poort region.

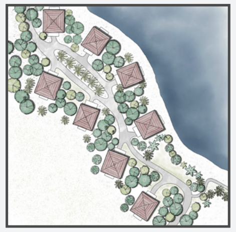
From this matrix of design principles and zoning, design strategies have been introduced. These strategies represent site-level operations that synthesize multiple principles into coherent, contextual design ideas. For instance, civic wetland parks are now evolved into strategies like break out spaces, tree courts, open plazas, and kids play area whereas economic retention zone evolved into seasonal market floodplains, elevated paths or decks, seasonal ponds, blue green industry clusters etc.

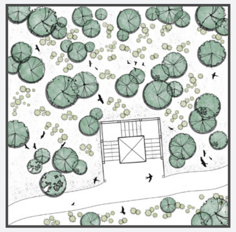
What makes these strategies particularly effective is their modular nature, they can be adjusted, recombined, and scaled depending on hydrological conditions, community needs, and policy goals. Their development bridges vision and implementation, serving as tools for designers, policymakers, engineers, and local stakeholders. The design strategies are the operational arms of the design principles, grounded in the realities of zoning and adaptable to changing water dynamics. They provide a clear path from theory to action enabling spaces that are dynamic, resilient, and deeply integrated with the flows of people, water, and time. From this strategic intervention phase, a direct master plan can be directed and place into action.

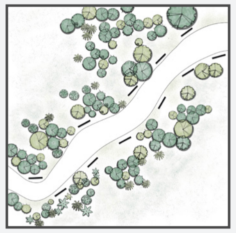

Blue Green industry clusters

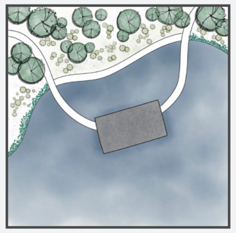

Board walk

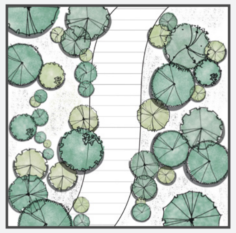

Breakout spaces

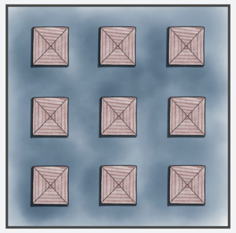

Camping

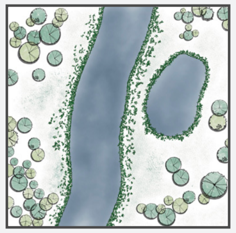

Community eco monitoring

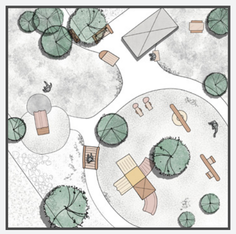

Cultural riparian trails

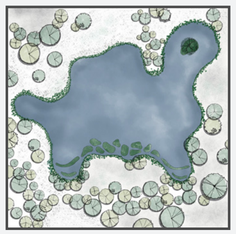

Seating decks

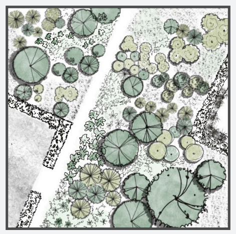

Elevated walkway

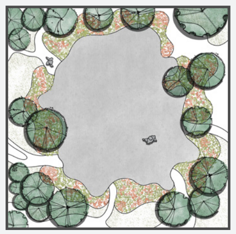

Flood adaptive housing

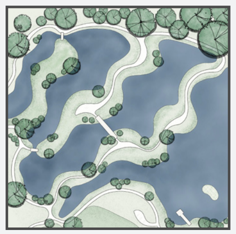

Habitat modules

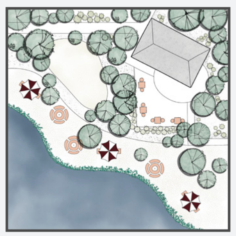

Kids' play area

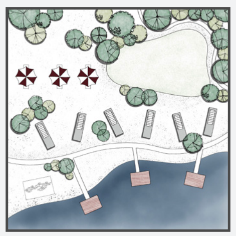

Lake restoration

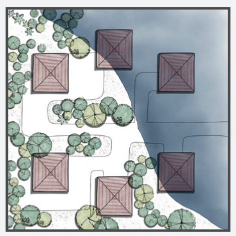

Native plant species

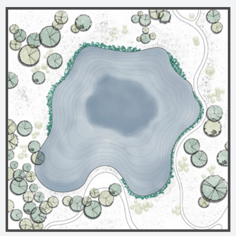

Open plaza

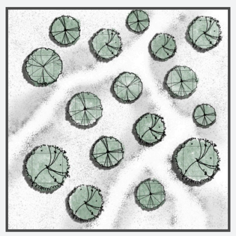

Wetlands

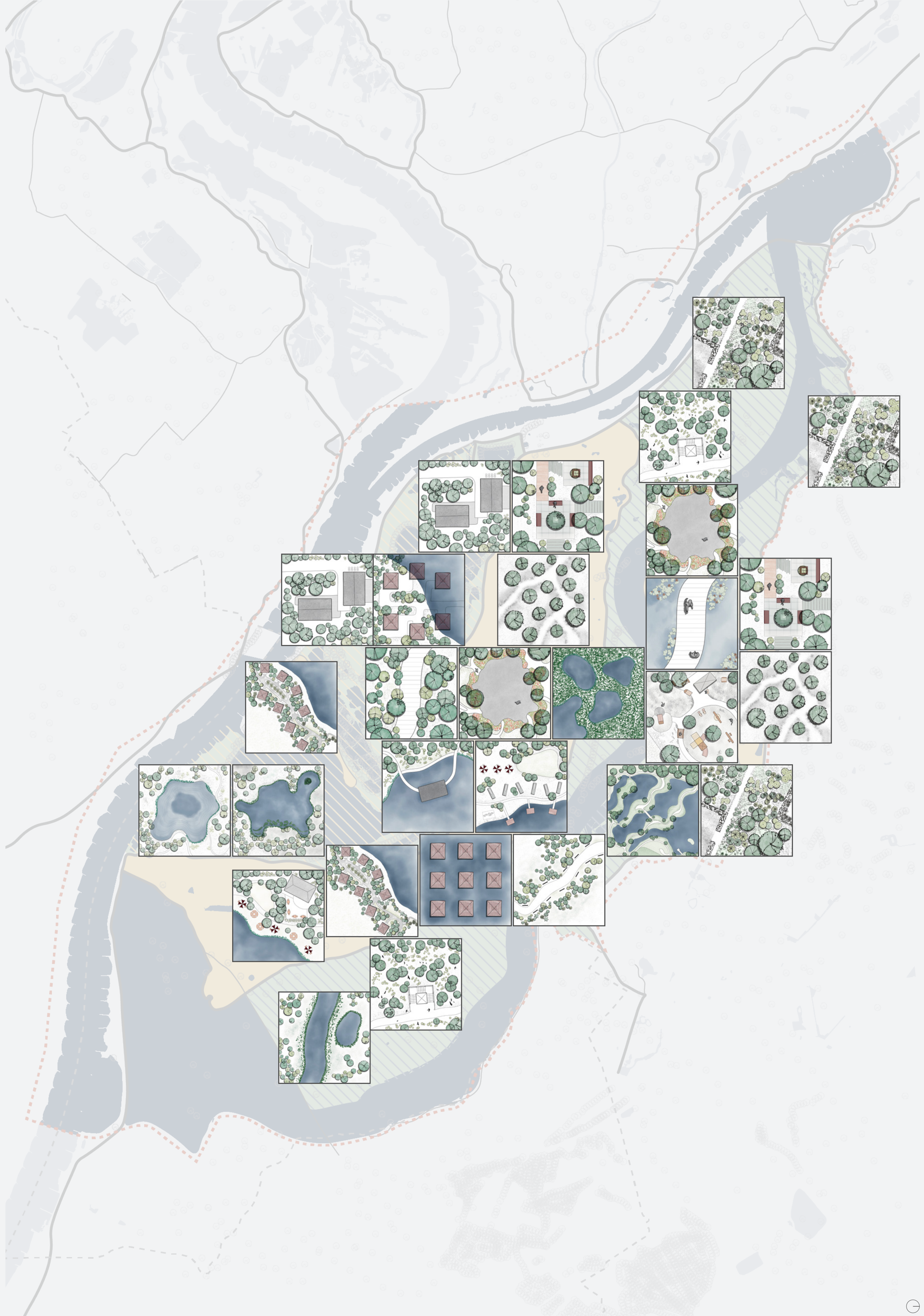

Restaurants


River front kitchen


Seasonal floodplains market


Seasonal pond


Tree courts



Map 25 | Design strategies
Source: Author

Ecological intensity mapping

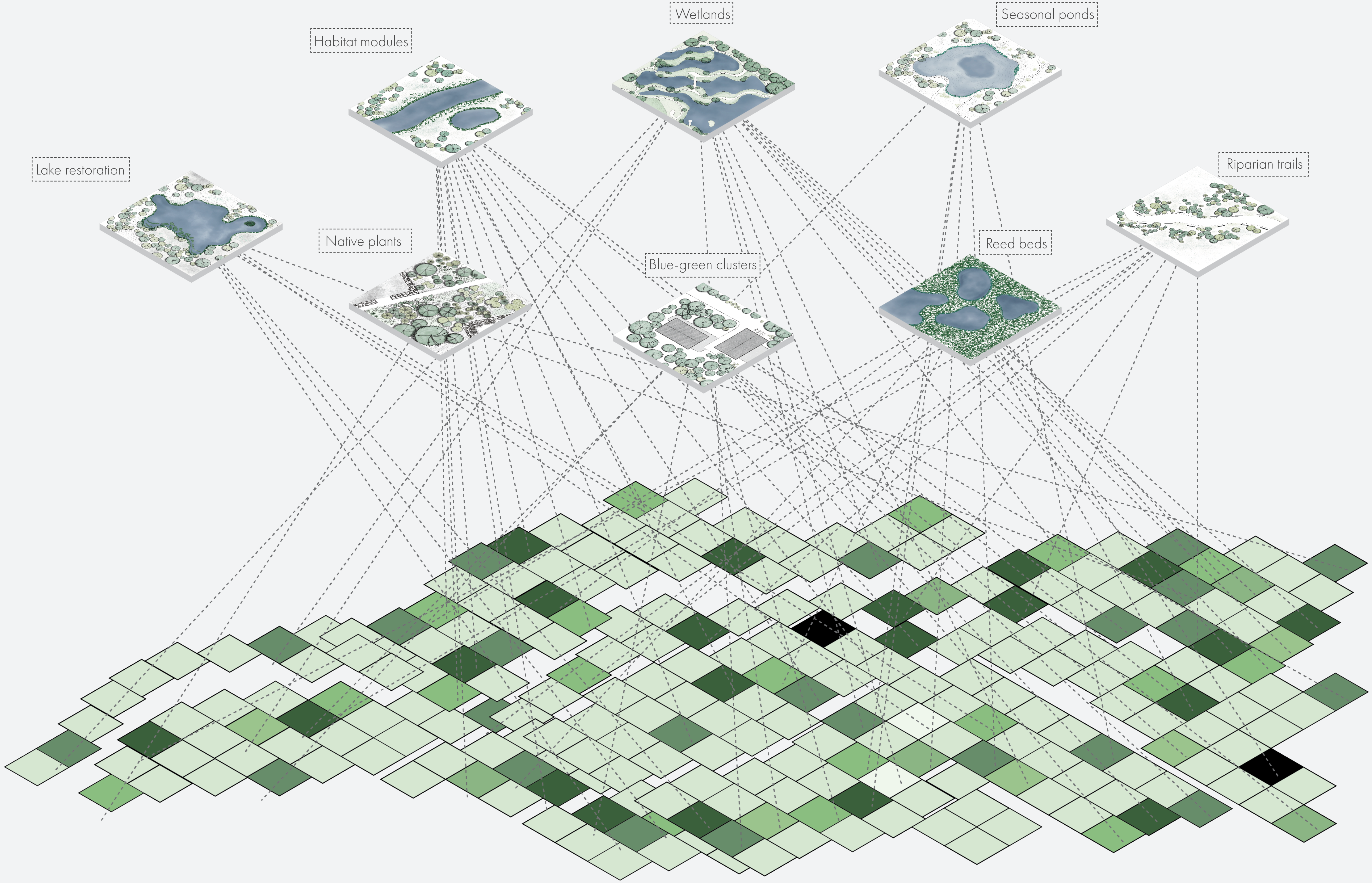


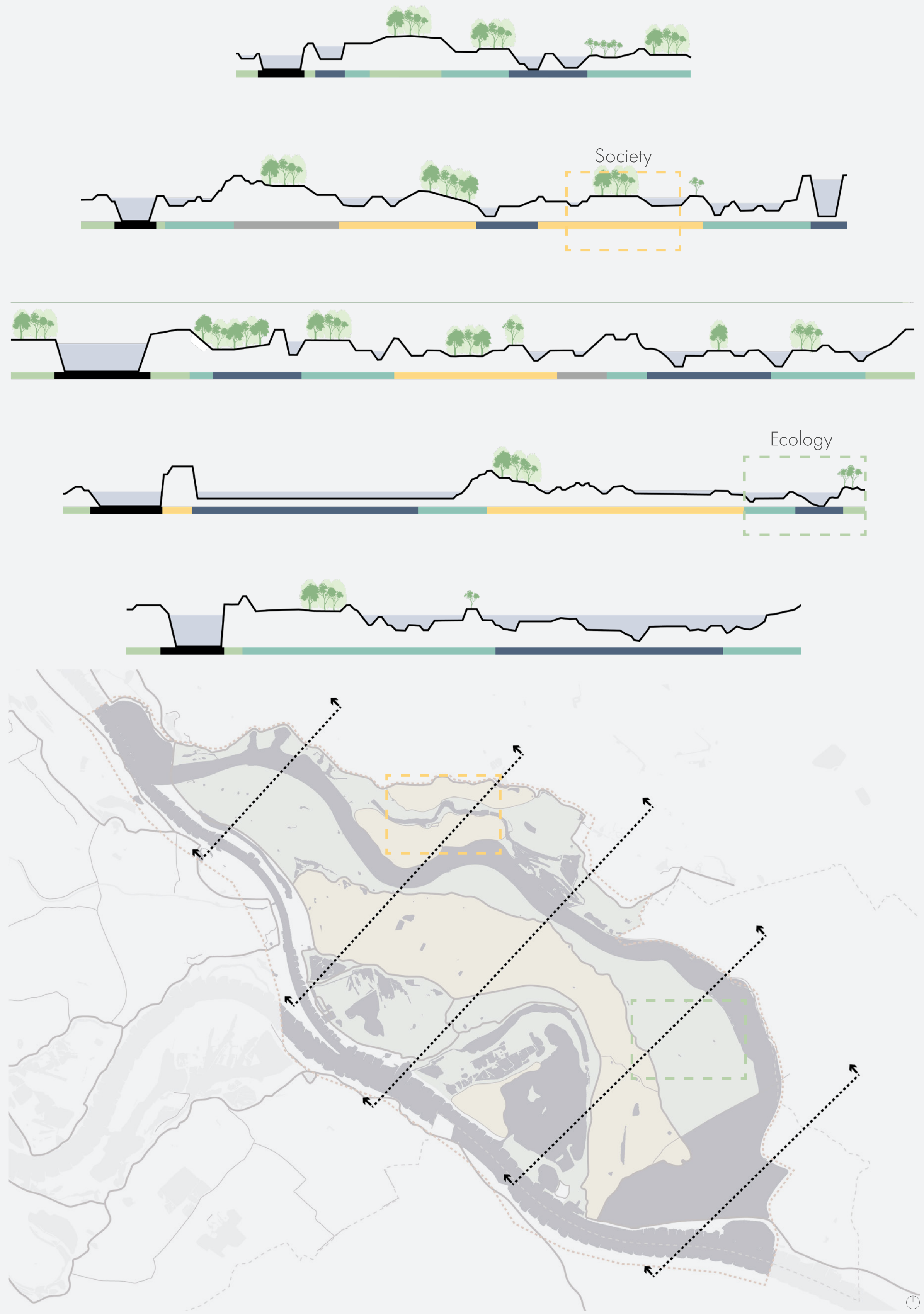
Illustration 27 | Design strategies
Source: Author

iSEEC

Site sections

In order to understand the spatial character, depth, and transformation potential of the Gelderse Poort area, a series of site sections were strategically cut across key zones. These sections were aligned with the proposed zoning system, allowing for a detailed examination of how water, ecology, and human activity interact across the landscape. The sectional studies offer insights into the ground profile, existing land use, vegetation, water edges, and infrastructure, helping to visualize how design strategies would be embedded within the site's topography. Alongside these drawings, a typology palette was developed, mapping specific design principles and spatial strategies such as flood-adaptive housing, wetland parks, ecological corridors, and economic nodes to their respective zones. This typology-to-section pairing makes it possible to visualize not only what interventions occur where, but how they perform spatially and experientially when viewed in vertical relation. The approach transforms abstract design logic into a physical narrative, illustrating how the area can evolve into a multi-functional, climate-responsive landscape that adapts to both hydrological shifts and community needs.

To deepen the spatial resolution of the design, smaller site stretches within the broader zoning framework were selected for detailed exploration. These focused segments allow for the translation of strategic principles into tangible spatial configurations, capturing how design interventions can respond to localized conditions, user needs, and fluctuating water dynamics. By zooming in further, the design process begins to articulate the materiality, scale, and experiential qualities of the proposed spaces bridging the gap between vision and implementation.



Legends

- Proposed water channel
- Dynamic zones
- Buffer area
- Society spaces
- Protected habitat area
- Lakes

Map 26 | Conceptual sections
Source: Author

Design exploration: Ecological Integration and Habitat Strategies

The ecological lens of this project explores how spatial and process-based strategies can be introduced within protected or untouched zones to support biodiversity, enhance resilience, and restore natural systems along the Rhine, particularly within the chosen area. These zones, often designated for conservation or restricted human access, offer unique opportunities to strengthen ecosystem services through subtle yet impactful design interventions.

The design exploration began with an inventory of existing ecological assets and the identification of sensitive zones where species regeneration and water retention are essential. Here, the focus was on rethinking the river's edge, its inner floodplains, and side channels as living laboratories of ecological innovation. Strategies like floating wetlands were envisioned to activate still water pockets and offer habitats for birds, amphibians, and aquatic species while also contributing to water filtration and cooling. Similarly, retention and detention basins were proposed not only for flood buffering but also as seasonal habitats where water levels support migratory birds in spring and nesting species in summer. Incorporating evapotranspiration fields through dense vegetation belts was another passive strategy to manage microclimate, regulate humidity, and contribute to the natural water cycle. These green layers designed to tolerate varying moisture levels help in capturing and gradually releasing water, reducing soil erosion, and creating cooling corridors.

All of these strategies were explored through hand-drawn sketches and conceptual sections, imagining how flora and fauna could thrive if given minimal but strategic spatial interventions. Rather than heavily engineered landscapes, the aim was to work with the rhythm of the ecosystem, introducing layered habitats, buffer zones, and water-interactive surfaces that respond dynamically to seasonal changes. This exploration not only supports biodiversity but also lays the foundation for ecological memory, where the landscape begins to regenerate itself, accommodating species listed under programs like Het Riversysteem 2050.

Conceptual sections

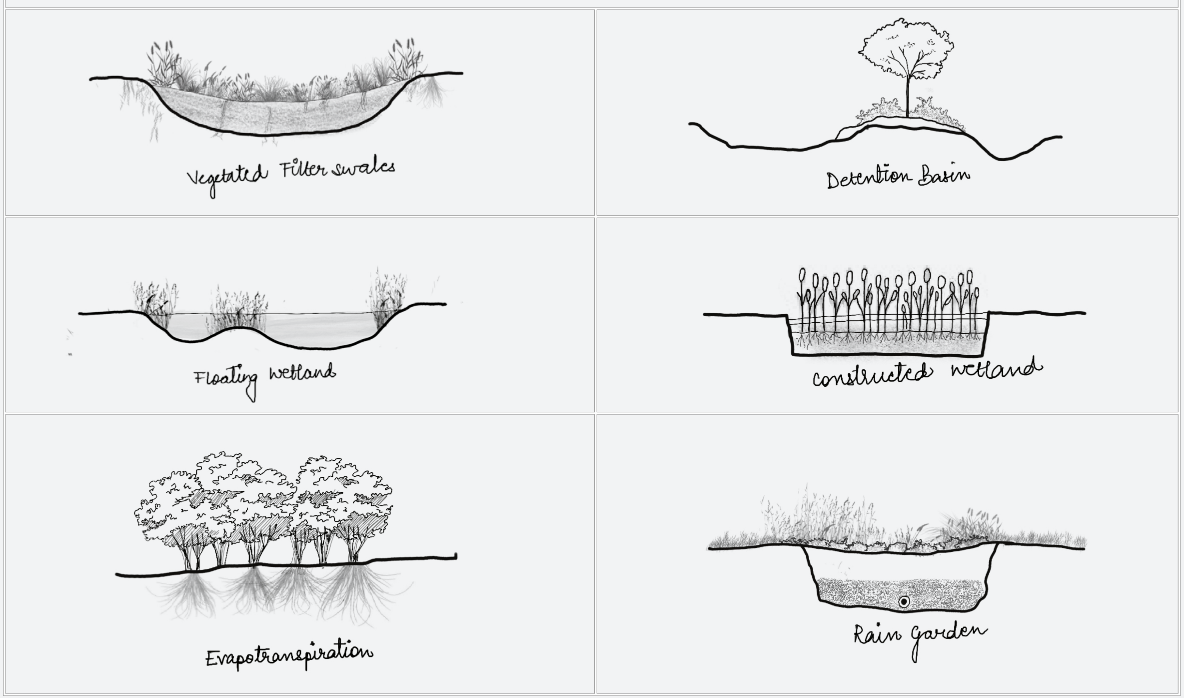
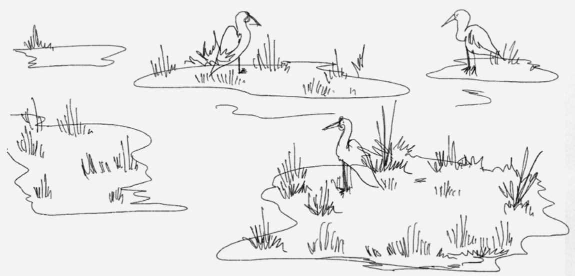


Illustration 28 | Conceptual sections
Source: Author

Layered nature with native plants

Shrubs maze



Wetlands with fauna

Water retention ponds with flora and fauna

Deck over pond

Avi flora zone attracting birds

Illustration 29 | Conceptual sketches
Source: Author

Design exploration: Ecological Habitat Strategies

Research on flora and fauna habitats was carried out to inform the creation of biodiverse ecological zones within one of the designated areas identified through the zoning strategy. Drawing on studies such as Het Riversysteem 2050, which outlines key species indicative of ecological health along the Rhine, several species were identified whose presence signals a thriving and resilient ecosystem. Areas that currently support or have the potential to support these species were mapped and prioritized. The design vision for this zone focuses on creating and enhancing suitable habitats that cater not only to these species but also to a broader range of ecological functions. Multiple habitat types ranging from wet meadows and riparian forests to submerged aquatic zones and edge ecologies were proposed. Species were then classified and matched based on their specific habitat needs, such as nesting grounds, water depth, vegetation type, and seasonality. This approach ensures that the design of each ecological pocket is functionally grounded, responsive to biodiversity goals, and contributes to a connected network of thriving, dynamic ecosystems across the site.

Refer factsheet 5 for further details on species and habitats

Protected species

Illustration 30 | Flora and Fauna classifications
Source: Author

Design exploration: Integrated multi species habitats

The design process then focused on merging multiple species-specific habitats into cohesive ecological environments through mapping out spatial overlaps and environmental synergies where different species could coexist, interact, and thrive.

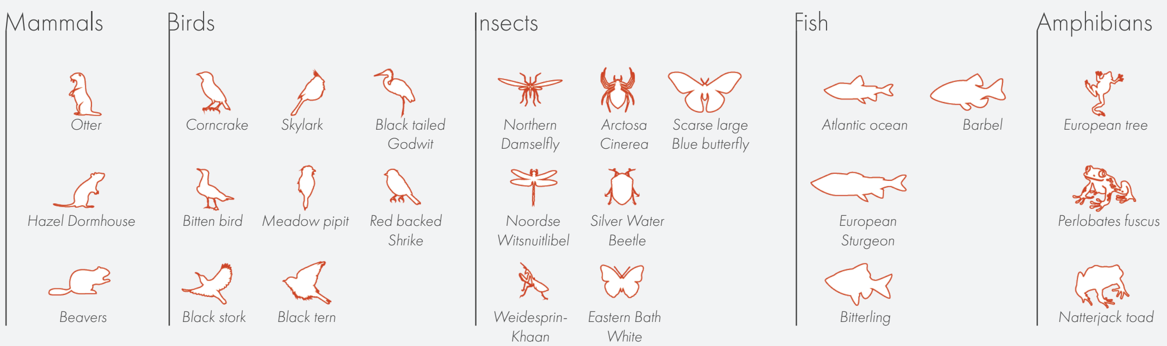
For instance, flowing river zones were designed not only to accommodate migratory fish like the Barbel and Atlantic salmon, but also to transition smoothly into riparian forests, which provide critical shelter for mammals like the Beaver and Otter, as well as nesting spaces for birds such as the Black Stork. These forested edges seamlessly transition into wetland pockets, offering suitable breeding grounds for sensitive species such as the Black Tern, Northern Damselfly, Silver Water Beetle, and European Tree Frog forming a gradient of water-dominated to forest-edge habitats.

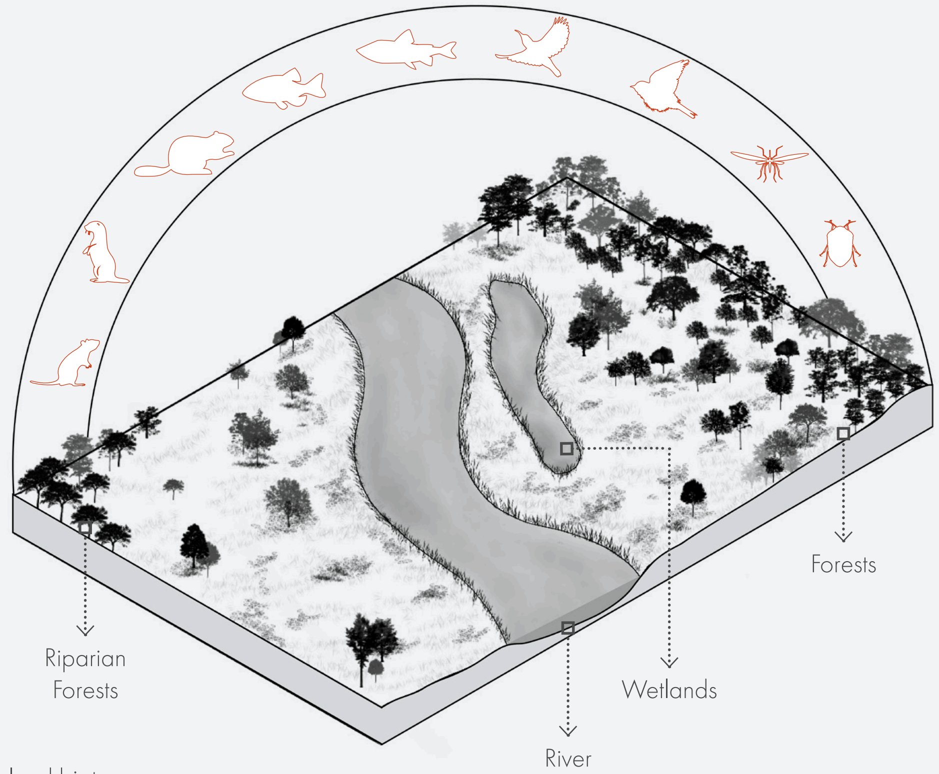
In another zone, floodplain meadows were conceptualized to support ground-nesting and wading birds like the Bittern, Skylark, Meadow Pipit, and Black-tailed Godwit. These meadows, periodically inundated during high water, offer seasonal richness that blends into scrublands and forest margins, which become critical for species such as the Hazel Dormouse, Red-backed Shrike, and again, the European Tree Frog.

By layering these habitats, not as isolated ecological patches but as interconnected tiles, the design achieves resilience through overlap where the decline or absence of one species doesn't collapse the system but instead is buffered by shared resources, varied terrain, and flexible zones.

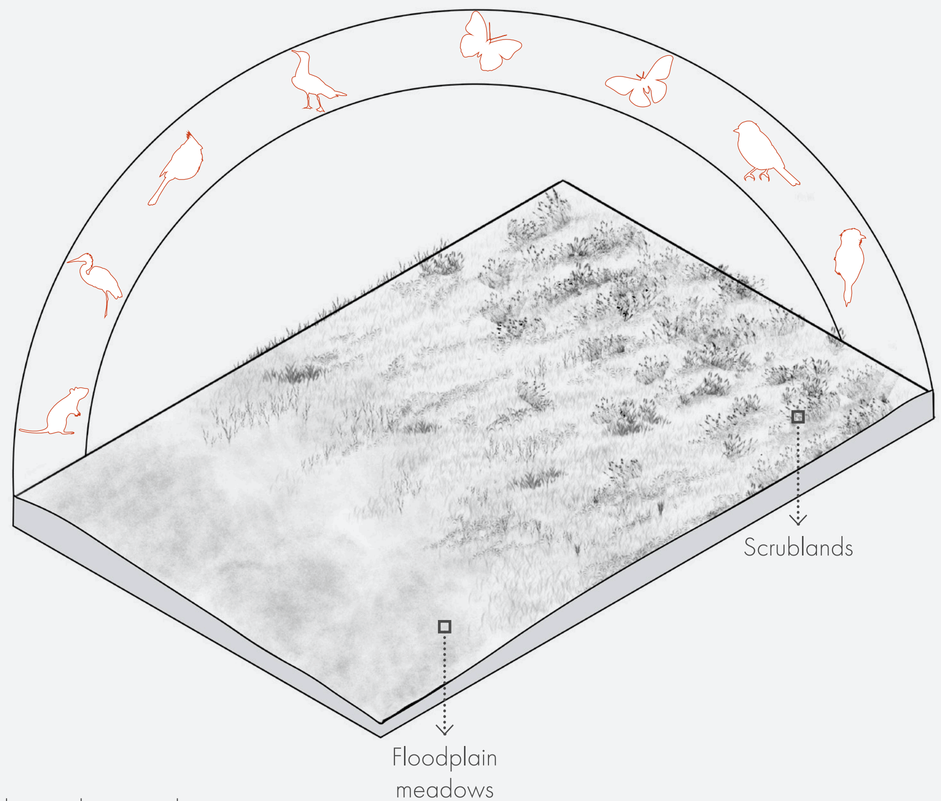
Vision: These zones are further envisioned in a collage on next page that how the specifies area might look like. It gives an idea or overview of how the area might transform with these strategies.

Key plan highlighting area of interest





Axon of Riverland biotope



Axon of Shrub-meadow corridor

Illustration 31 | Conceptual axonometric of clustered habitats Source: Author

Vision

Illustration 32 | Vision Ecology
Source: Author

Design exploration: Societal Integration Strategies

Within the societal design strategies, a series of experiential trails have been proposed to connect deeper engagement between people and the landscape. These trails are proposed not just as circulation paths, but as immersible spatial experiences that encourage users to connect with water, ecology, and seasonal rhythms. Features such as bird-watching points, deck seating along water edges, and canopy walks through riparian vegetation reflect the intent of various design principle cards tailored to the specific zones. These interventions are strategically placed to activate the landscape socially, offering spaces for reflection, learning, recreation, and collective memory. The aim is to cultivate a sense of belonging and stewardship by bringing people into dialogue with the river system, making the societal lens of the project both interactive and place-specific.

Together, these strategies offer a multi-layered social infrastructure that strengthens community resilience, supports inclusive access to nature, and acknowledges the river not just as a barrier or resource, but as a shared social partner, a living identity in the urban-rural continuum. The societal strategies bring water back into the public imagination, transforming risk into celebration and adaptation into a collective identity.

Key plan highlighting area of interest

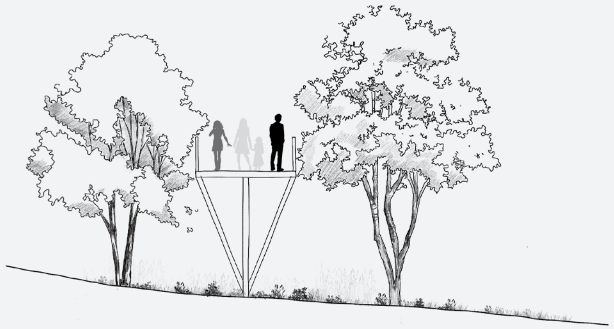


Illustration 35 | Area visualisation
Source: Author

Illustration 34 | Area visualisation
Source: Author

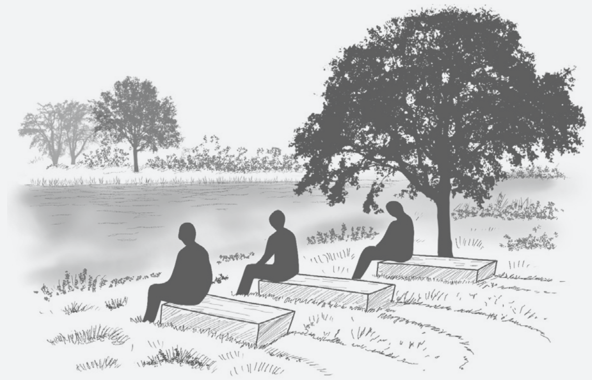
Illustration 33 | Experiential trail for society
Source: Author

Design exploration: Societal Integration Strategies

Bird watching tower

Canopy walk

Elevated pathways



Sitting decks along lake

Illustration 36 | Conceptualisation for societal parks
Source: Author

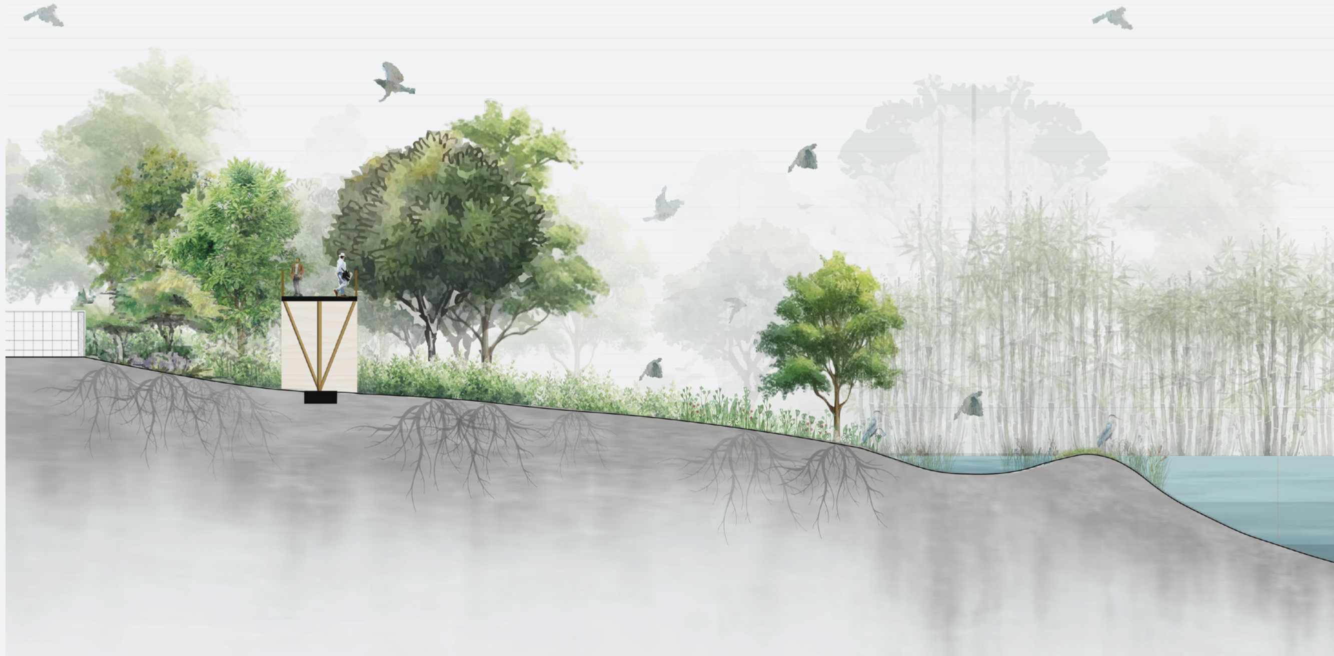


Illustration 39 | Canopy walk in Avi flora zone
Source: Author

Illustration 38 | Bird watching tower and water deck Source: Author

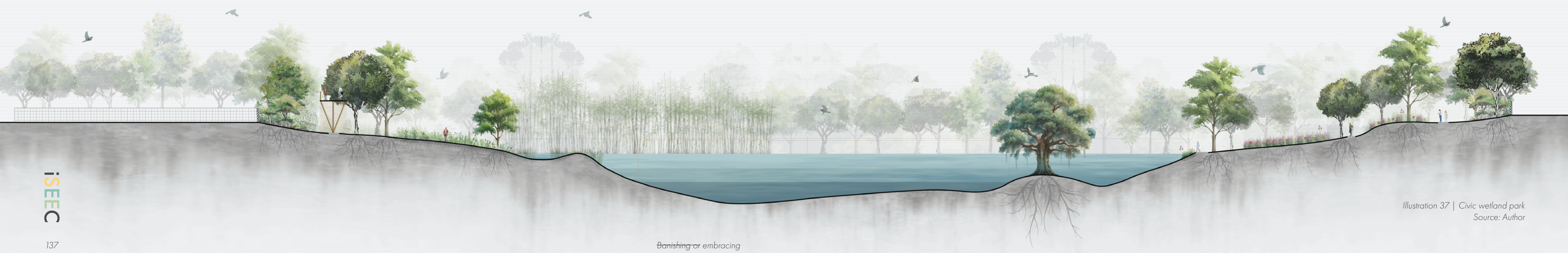


Illustration 37 | Civic wetland park
Source: Author

Vision

Illustration 40 | Vision society
Source: Author

Framework

To make the design principle cards more actionable and transferable, I developed a step-by-step framework that helps guide users through the process of selecting a site and applying relevant design strategies. This framework was especially useful during workshops and pilot evaluations, offering a structured yet flexible approach for vision-making.

1. Choosing a site based on analysis
   The first step involves identifying a site through quick yet insightful analysis. This includes reading the landscape through ecological, economic, and societal lenses, understanding hydrological patterns, urban growth, infrastructure pressures, or biodiversity hotspots. The selected site should reveal potential for transformation while also highlighting local vulnerabilities and opportunities.

2. Selecting appropriate design principles
   Once a site is chosen, the next step is to review the design principle cards and select the ones most suited to the specific challenges and potentials of that location.

3. Connecting principles to reveal connections
   The selected principles are then examined for their interrelations. This stage is about understanding synergy and conflict, how one intervention supports or challenges another. These connections help determine which clusters of principles work well together to create dynamic and integrated systems, ensuring that decisions are not made in isolation.

4. Identifying contextual design strategies
   With connected principles in place, the user can begin to translate them into tangible design strategies. This involves envisioning how each principle would manifest spatially and programmatically, what kind of infrastructure, land use, or social space might emerge from these ideas in the specific site context.

5. Designing the specified area
   Finally, the user designs the site based on the selected principles and strategies. This step is where abstract ideas take spatial form and translated into sections, plans, or axonometric diagrams. The design reflects a balance between water adaptability, ecological richness, economic utility, and societal engagement.

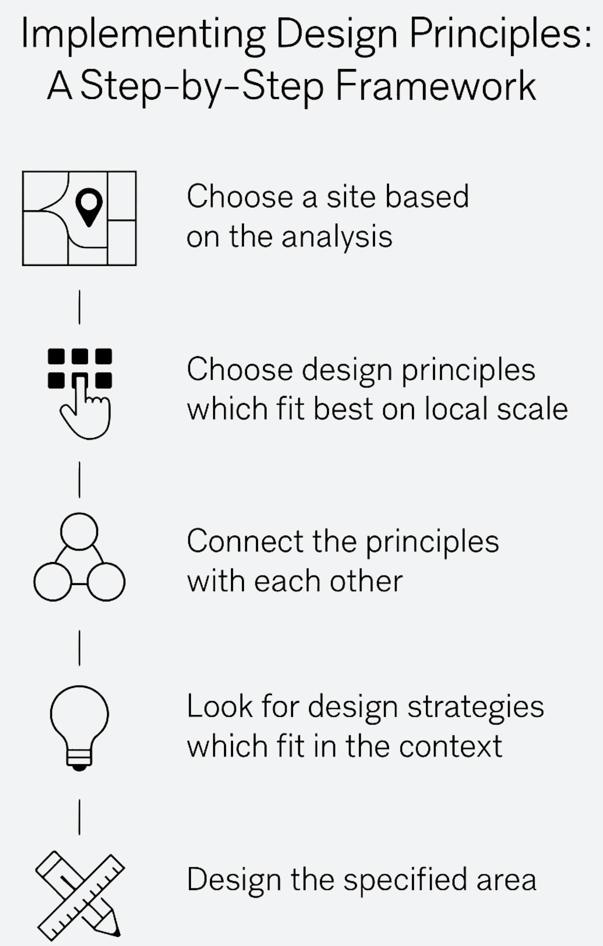


Illustration 41 | Framework
Source: Author

Evaluation

Transferable design principles

As part of evaluating the scalability, transferability and adaptability of my thesis framework, I organized a second workshop in collaboration with students from Tampere University, Finland. The intention behind this workshop was to test whether the design principles I developed could also be meaningfully applied to other areas along the Rhine River or similar river systems elsewhere. It was important for me to move beyond the localized pilot area and understand if the approach could hold value at a broader scale or be adapted to different environmental and cultural contexts.

To create an engaging and structured format, I designed a step-by-step framework for the participants. First, students were asked to perform a quick site analysis based on maps and climate data. They could choose any location along the Rhine and assess its ecological, economic, and societal potentials. Following this, they received a full set of design principle cards and were asked to place them on their chosen site. The aim was for them to imagine what kind of spatial vision could emerge from layering those cards and how multiple systems could intersect. The outcome of the workshop was both encouraging and insightful. Students found the card-based system intuitive and appreciated the clarity it brought to complex environmental challenges.

This exercise reaffirmed the core idea of the thesis: that achieving dynamic water equilibrium is not just a matter of design, but of translating adaptable strategies across regions and communities. For me, this workshop served as a crucial validation point, it proved that the principles I had developed were not bound to a single geography, but held broader relevance in shaping resilient, people-centred, and ecologically integrated river landscapes. Ultimately, the workshop deepened the collaborative and open-ended spirit of the thesis, making room for diverse voices and interpretations to shape shared futures along rivers like the Rhine.






Figure 24 | Workshop
Source: author

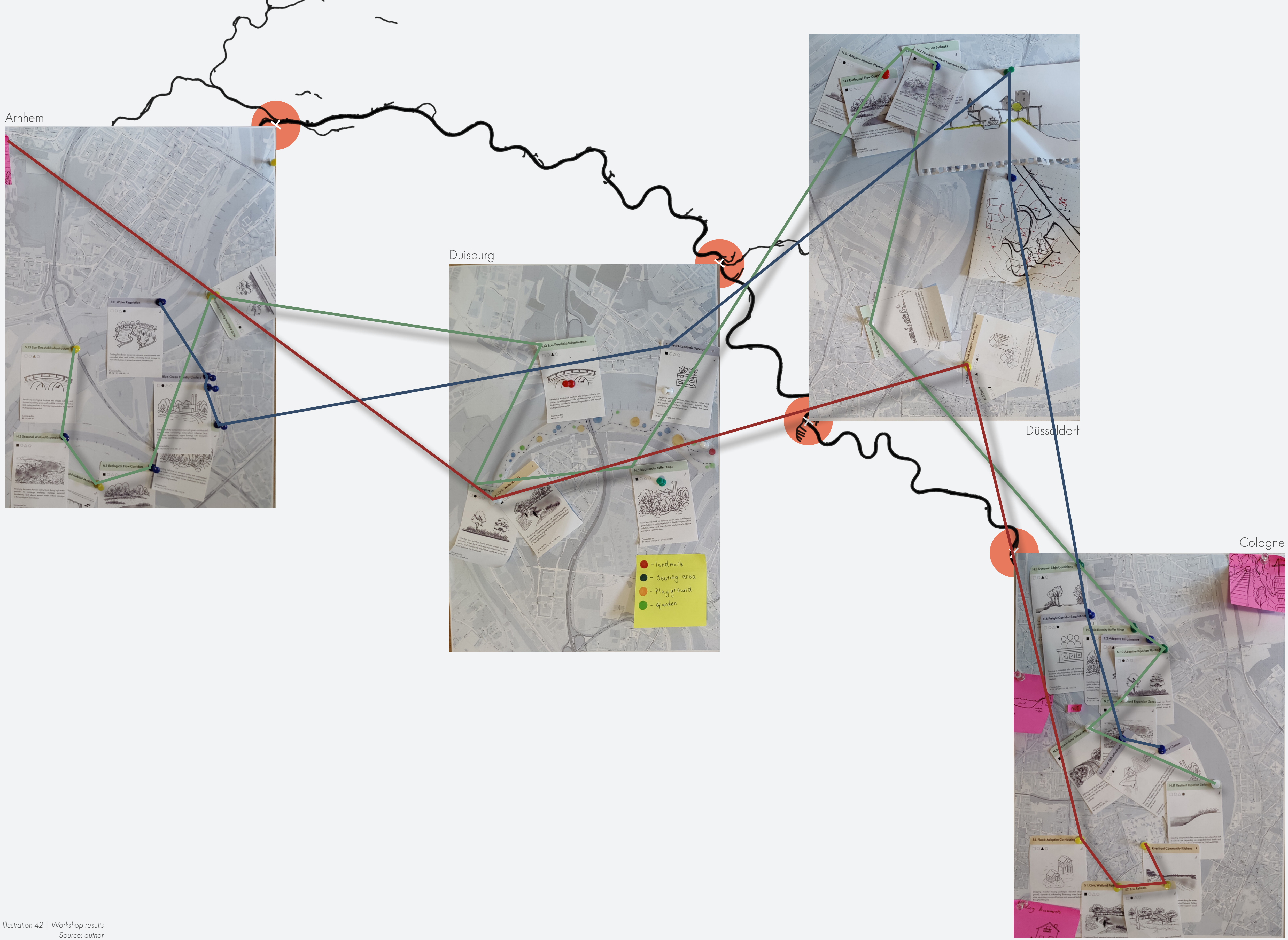


Illustration 42 | Workshop results
Source: author

Integration of SDG's

This research project is connected the sustainable development vision articulated in the "Rhine 2040" programme. This vision aligns closely with the 2030 UN Agenda for Sustainable Development, specifically targeting climate-resilient water systems, equitable governance, ecological conservation, and economic stability across borders. My work contributes to these goals in the following ways:

SDG 6: Clean Water and Sanitation
This project directly contributes to Target 6.3 (improving water quality by reducing pollution), 6.4 (increasing water-use efficiency), and 6.5 (implementing Integrated Water Resources Management), all of which are key targets under this goal. Through spatial zoning strategies, water retention landscapes, and bioremediation systems like bio-swales and wetlands, it addressed how to sustainably store, redirect, and purify water in both flood and drought conditions.

SDG 11: Sustainable Cities and Communities
By using site-specific zoning and flexible land-use design, the project enhances climate resilience in urban-rural fringes like the Gelderse Poort. It contribute to Target 11.5 (reducing the impact of water-related disasters) and 11b (adopting holistic urban disaster risk management strategies). The design cards, especially those dealing with flood-adaptive housing, community wetlands, and mobile infrastructure showcase integrated, locally grounded adaptation approaches.

SDG 12: Responsible Consumption and Production
The pattern language approach and seasonal economies promote 12.2 (sustainable management of natural resources). By transforming flood-prone zones into temporary markets or eco-retreats during droughts, this design demonstrates how space, water, and time can be cyclically and efficiently reused.

SDG 13: Climate Action
The core goal to design a dynamic water equilibrium that addresses 13.1 by proposing adaptive responses to climate-induced hazards. It links spatial design directly to climate adaptation, not only through zoning but also through programmatic interventions like seasonal economies and nature-based tourism.

SDG 14 & 15: Life Below Water and Life on Land
Through habitat restoration for riverine and floodplain species, it supports SDG 14.2 (protect marine ecosystems) and 15.1 (sustainable use of freshwater ecosystems). By strategising merged habitats like floodplain meadows, riparian forests, and flowing channels the project mirrors the goals of Rhine 2040 to increase biotope connectivity, species survival, and ecological continuity.

SDG 16: Peace, Justice, and Strong Institutions
The incorporation of cross-border governance frameworks (like hydro-political and polycentric governance theories) supports 16.7, ensuring inclusive and participatory decision-making. The participatory workshops with both professionals and students are practical reflections of transparency and inclusiveness in design governance.

SDG 17: Partnerships for the Goals
The collaborative nature of this research work done through mentor engagement, institutional input, office insights and workshops with international students strengthens 17.16 (multi-stakeholder partnerships). This reflects the belief in shared responsibility and knowledge transfer, especially for climate-vulnerable transboundary areas like the Rhine basin.

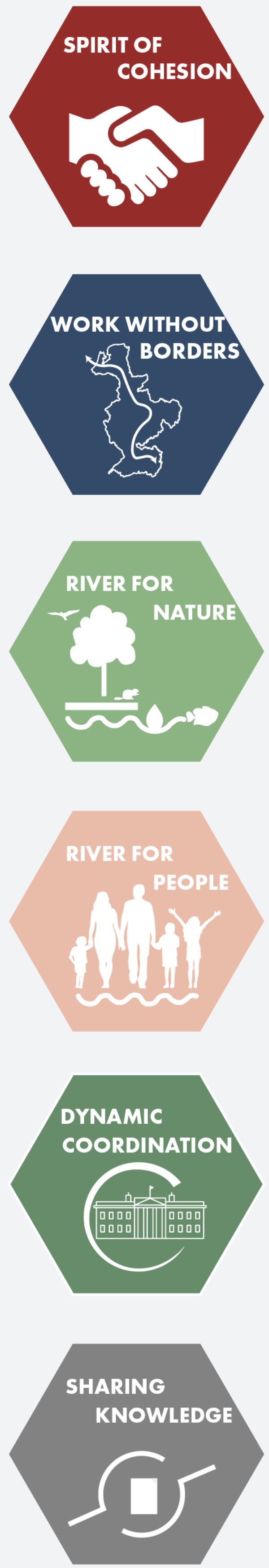
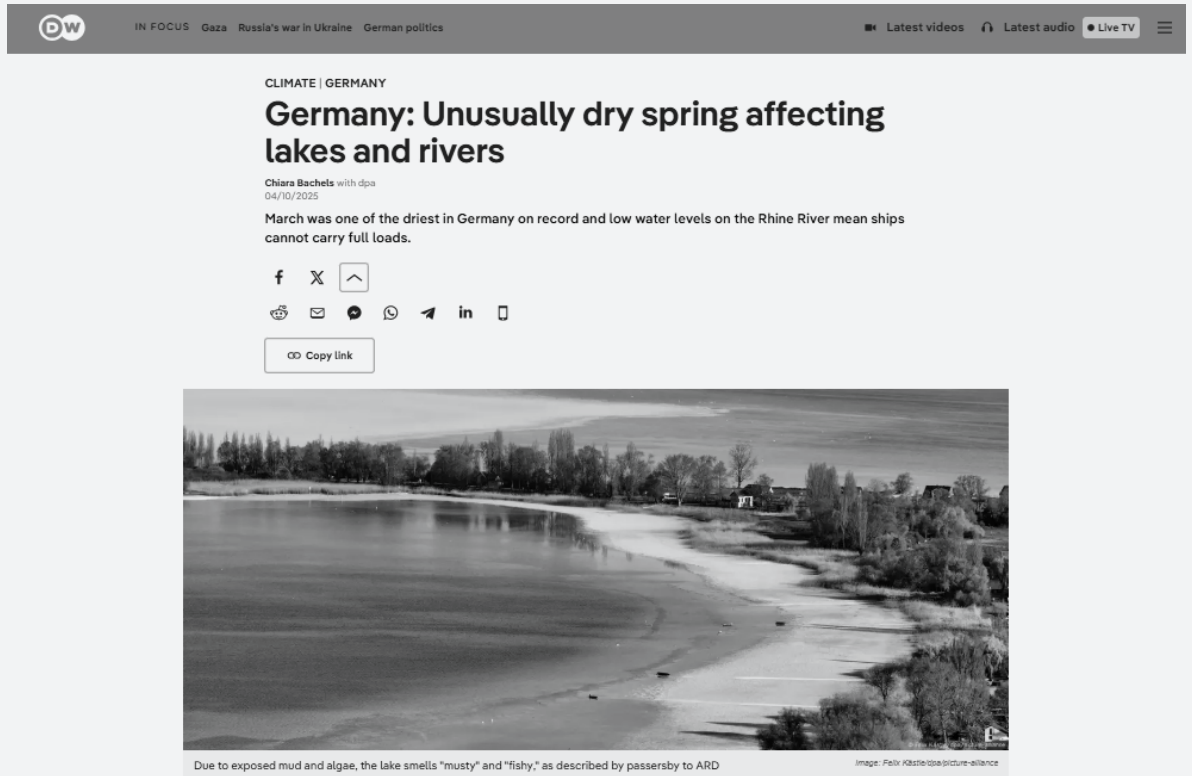


Illustration 43 | Sustainable development goals
Source: iksr | adapted by author

Validation

The urgency and relevance of this project lie in the increasingly visible and disruptive impacts of climate change on the Rhine River Basin. In recent years, extreme fluctuations in water levels have repeatedly disrupted navigation, trade, agriculture, and ecology. One significant evidence came during the course of this research when in 2025 *Deutsche Welle* reported that Germany experienced one of its driest springs in over 30 years, severely affecting rivers and lakes across the country. This event, unusual in frequency and intensity, is not an isolated anomaly but part of a growing trend confirmed by climate models that predict longer and more intense droughts in the future. Conversely, episodes of intense flooding such 2021, 20241 have also caused widespread damage, revealing the Rhine's vulnerability to both extremes.

These changing patterns expose the fragility of current water infrastructure, urban development practices, and governance frameworks in the region. Hence, this project positions itself at the centre of this challenge by acknowledging the risk and develop a research and design strategies.



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CLIMATE | GERMANY

Germany: Unusually dry spring affecting lakes and rivers

Chiara Bachels with dpa
04/10/2025

March was one of the driest in Germany on record and low water levels on the Rhine River mean ships cannot carry full loads.

Copy link

Due to exposed mud and algae, the lake smells "musty" and "fishy," as described by passersby to ARD

Image: Felix Kästle/dpa/picture-alliance

Figure 25 | 2025 Germany droughts in the spring for first time in 30 years
Source: Deutsche Welle

Conclusions and Reflection

Summary and Conclusions

This thesis set out to confront one of the most pressing challenges for Western Europe: how to sustainably adapt the Rhine River, a vital waterway for freight, ecology, and culture to intensifying climate-induced pressures. The research sought to achieve a dynamic water equilibrium, a condition in which fluctuating hydrological states like droughts and floods can be managed not by rigid control, but through adaptable, multi-scalar interventions that harmonize economic infrastructure, ecological systems, and socio-cultural landscapes.

What began with a macro-scale problem including Delta Scenario predictions of rising sea levels, prolonged droughts, and infrastructure vulnerabilities evolved into a nuanced inquiry grounded in research by design. By merging theory with territory, the project established a cross-disciplinary framework drawing from integrated water resource management (IWRM), socio-hydrology, and infrastructure economics. These frameworks allowed the project to move beyond isolated solutions, instead proposing resilient and responsive design strategies that are as spatial as they are systemic.

A key outcome of this approach is the set of 39 design principles, categorized by typology (spatial, infrastructural, policy, and programmatic) and scale (macro, meso, micro), and filtered through three critical lenses: economy, ecology, and society. These principles were developed into a pattern language, inspired by Christopher Alexander, and adapted to the complex realities of the Rhine. They were tested through cartographic overlays, stakeholder workshops, and conceptual design explorations in the Gelderse Poort region, a key site where flood water can be stored and reused strategically across seasons, allowing for climate-responsive transformation at a local scale.

Through site-specific mappings, pilot project simulations, and scenario-building for high and low water conditions, the thesis visualized how areas can shift between storage zones during floods and become productive, social, or ecological spaces during droughts. Participatory methods, including office-based and international workshops, ensured that these strategies were not only grounded in expert knowledge but also open to multiple visions for the Rhine's future.

What emerges from this body of work is not a fixed solution, but a flexible, replicable framework that can guide other transboundary river systems facing similar hydrological and infrastructural pressures. Whether it's through energy-transition logistics hubs, biodiversity-rich wetland corridors, or culturally rooted riparian trails, each strategy aims to negotiate the tensions between preservation and progress, making room not just for water, but for memory, identity, and future adaptability.

In conclusion, this research re-conceptualises the Rhine as a living infrastructure, one whose flow, function, and meaning can no longer be viewed through a single disciplinary lens of economy. Instead, it must be engaged as an evolving commons, shaped by cross-border cooperation, ecologically regenerative practices, and socially inclusive design. Through its comprehensive approach to design principles, stakeholder engagement, and theoretical synthesis, this thesis offers a scalable, transferable and grounded contribution to climate-responsive river basin design that aligns resilience with responsibility, and infrastructure with imagination.

Ethical reflection

Ethical considerations are integral to the research process, particularly when addressing issues of water management and climate adaptation. I am trying to prioritize a balanced approach towards environmental, social, and economic sustainability, through transport corridor lens to maintain the dynamic water equilibrium and ensuring that proposed solutions respect the ecological integrity of the river while addressing the needs of communities dependent on its resources. Cross-border collaboration emphasizes inclusivity and equitable sharing of knowledge and resources, avoiding potential biases or unequal burdens on specific regions or populations. Furthermore, the study recognizes the rights of more-than-human entities, such as rivers and ecosystems, advocating for their protection and long-term resilience in the face of climate change.

Limitations

The scope of this research is focused on addressing the challenges of transport disruptions caused by flooding and droughts within the Rhine River basin, as these disruptions threaten the trade heritage of Europe. While the impacts of these water extremes extend to dike breaches, subsidence, agricultural loss, industrial halts, biodiversity and wildlife loss, pile rot, wildfires, and social challenges, the study intentionally narrows its lens to transport disruptions and then analyse those disruptions from further three lenses i.e. economy, ecology and society.

The analysis spans the Rhine basin, but design interventions are localized to the Gelderse Poort area. Broader ecological or urban conditions beyond this selected pilot area are only referenced as context. The research develops spatial and strategic design principles, not detailed hydrological engineering, technical infrastructure designs (e.g., dike dimensioning, hydraulic modelling, real-time simulations) or stakeholder negotiation outcomes. Although societal impacts are conceptually explored, community participation methods and deep cultural ethnographies are beyond this scope and intended for future phases.

Avenues for future research

1. Hydrological Performance of Dynamic Water Systems - Future studies can quantitatively test how dynamic water interventions (e.g., seasonal retention zones, seepage channels) impact flood mitigation, drought resilience, and water balance at micro and regional scales.

2. Integration with Climate-Energy Transitions - synergies between dynamic water systems and renewable energy strategies (e.g., floating solar, hydro-microgrids) to align water resilience with energy neutrality goals.

3. Economic Valuation of Water-Based Landscapes - Develop methods to calculate the economic benefits of climate-adaptive design strategies—such as avoided flood damages, tourism gains, or ecosystem service provisioning.

4. Policy Testing and Governance Modelling - Model the effectiveness of polycentric governance frameworks in real-world administrative settings

Personal reflection

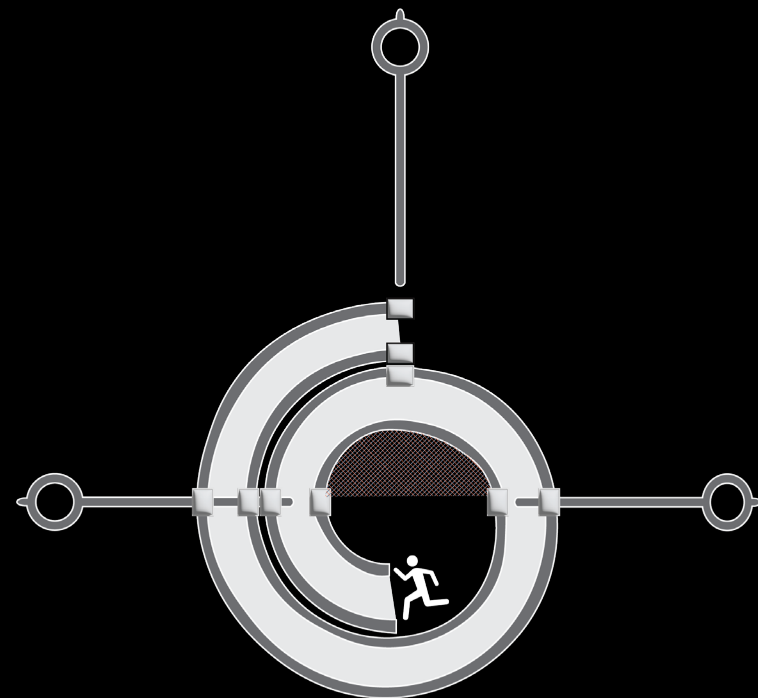
This thesis began with a pressing question: how can we manage the dual threats of flooding and droughts in the Rhine River Basin while preserving its vital economic, ecological, and societal roles? My personal fascination with the dynamics of water in urban and natural systems, especially following the 2018 drought that severely impacted transport on the Rhine, led me to investigate water as both a resource and a disruptor. The project evolved into a deep inquiry into how adaptable spatial and infrastructural strategies can create a dynamic water equilibrium that protects trade corridors while reinforcing ecological integrity and community well-being. The co-relation of my project and the studio topic "Altered Nature – Poetics of Change" have a shared focus on how human and natural systems interact, evolve, and adapt under the pressures of environmental and socio-economic challenges. My project highlights how climate-induced changes alter natural systems such as river flows, ecosystems, and hydrological cycles. This reflects the theme of altered nature, where human activities, urbanization, and resource exploitation reshape natural landscapes and processes.

My research encapsulates the principles of the Urbanism track by integrating urban design, spatial planning, and engineering, reflecting its multidisciplinary approach to sustainable development. Addressing the Rhine River basin's flooding and drought challenges, I integrate spatial planning, water governance, and infrastructure strategies to create adaptive solutions. By combining ecological insights with socio-economic and political considerations, my work reflects the track's emphasis on harmonizing natural and built environments to shape resilient and sustainable urban futures. The master's program gave me a platform to carry out this research, which has always fascinated me to deal with floods and droughts in the same location. This research combines the program's ethics of stimulating collaborative, integrated solutions for complex challenges in the built and natural environment.

My approach combined multi-scalar cartographic analysis, pattern language development, participatory methods, and scenario-based design. The iterative process of testing strategies through mapping, workshops, and ecological overlays not only validated the adaptability of my methods but revealed how interdependent the lenses of economy, ecology, and society truly are. The design principles I created emerged from this synthesis: 39 adaptable strategies that respond to fluctuating water conditions and integrate multiple stakeholders' needs. These cards became tools to communicate complex ideas, encourage participatory engagement, and create an actionable vision for the Gelderse Poort area, the Netherlands. Mentor feedback throughout the process pushed me to further clarify the scalability and coherence of my strategies. Initially, the wide scope of the thesis posed challenges in narrowing down the focus. But the guidance helped me to strengthen the link between macro-level vision and the micro-level pilot intervention. I incorporated this by framing a clear zoning logic based on water behaviour and testing design principles through fieldwork, mapping, and a site-specific prototype. This refinement reinforced my understanding of how to translate complex research into tangible design decisions.

The societal value of this thesis lies in its capacity to develops a new relationship between people and water. With over 60 million people dependent on the Rhine, and with increasing risks of both flooding and droughts, this research contributes tools and visions that address not only infrastructure resilience but also socio-cultural relevance. Ecological thinking and inclusive governance were key anchors in the project, ethically, it promotes strategies that are nature-based, participatory, and rooted in local realities. Academically, the thesis contributes to fields such as socio-hydrology, climate-responsive spatial design, and transboundary governance. Methodologically, it introduces a replicable framework that balances thoroughness, interactive design tools. Practically, it aligns with the goals of EU water directives and can be scaled to other river basins facing similar pressures. Furthermore it leaves to more questions: How can design principles remain flexible yet context-sensitive when applied across transboundary river systems with differing governance models?, Or, To what extent can participatory tools like design cards genuinely influence decision-making in institutional water governance frameworks?

In conclusion, my project does not present a fixed master plan but an adaptable, strategic vision. Through experimentation, mapping, prototyping, and stakeholder dialogue, I have re-imagined the Rhine not only as an infrastructure but as a shared, evolving cultural landscape. This reflection is not only a culmination of academic work, it is also a personal milestone in understanding how water, design, and people can move forward together.



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Factsheet

1. Climate data
2. Freight corridor data
3. Brede Welvaart en mobiliteit diagram
4. Design principles and their explanations
5. Species and habitat description

1

Climate data

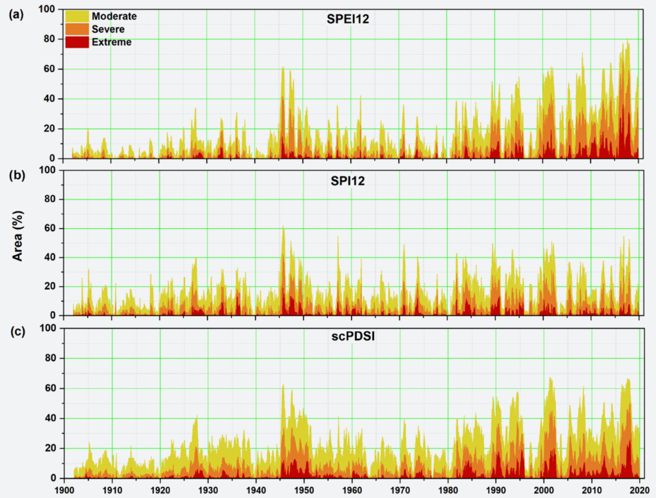


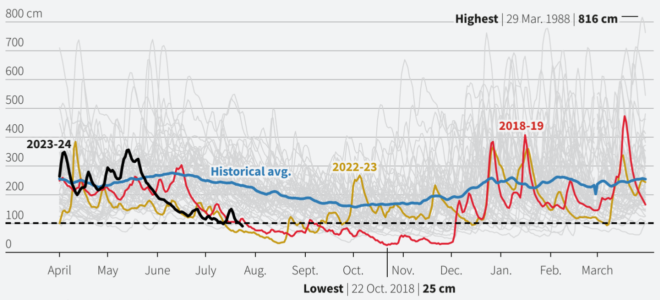
Figure 27 | Changes in drought features
Source: Federal water

	Kaub	Oestrich	Maxau	Cologne	Duisburg
2015	29	23	30	37	39
2016	19	18	27	26	35
2017	28	27	28	23	25
2018	107	78	80	121	128
2019	0	0	0	0	3
2020	0	0	0	11	14
2021	10	4	6	9	13
Average 2015-2021	28	21	24	32	37

Figure 28 | Water level below the equivalent water level Source: CCNR

Rhine above the line

Rhine water levels at the critical Kaub chokepoint on July 24 fell to their lowest level in 2023 so far. Low water levels have become a regular phenomenon in recent years, making it harder for barges to sail and impacting production at German companies.



Note: Data is from April to March.
Source: Federal Waterways and Shipping Agency (WSV), provided by the German Federal Institute of Hydrology (BfG)
Reuters, July 25, 2023 | By Kripa Jayaram

Figure 26 | Water levels at Kaub
Source: Federal water

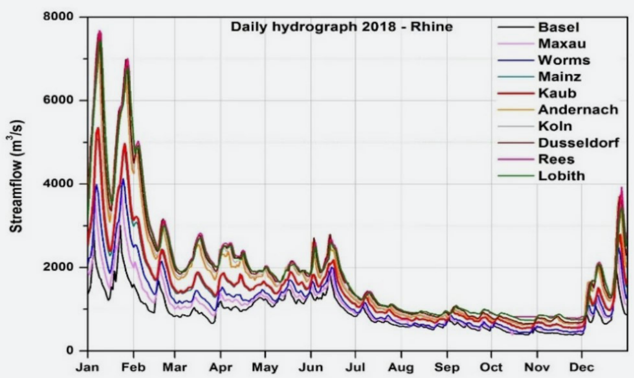


Figure 29 | Stream-flow in 2018
Source: CCNR

2

Freight Corridor

This earlier version of conceptual framework was more focused on the water management and governance which has been modified while delving deeper into the project.

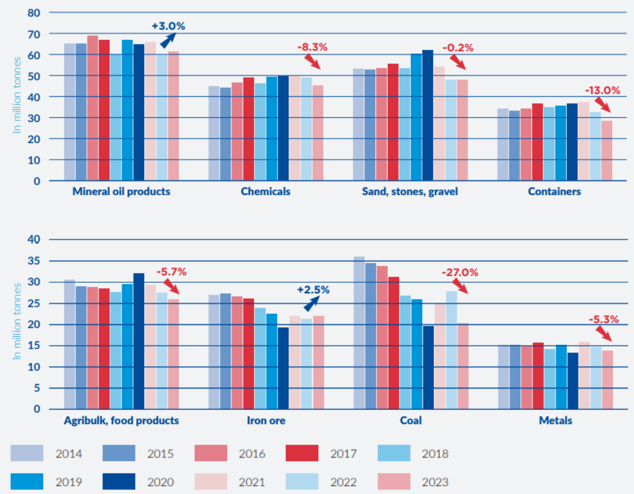


Figure 30 | Types of goods transported yearly (in million tonnes)
Source: CCNR

Rhine stretch or affluent	Measurement point	Name	Volume of transport (in million tonnes)			Number of cargo vessels passing		
			2021	2022	2023	2021	2022	2023
Lower Rhine *	Border DE/NL	Emmerich	134.5	124.9	117.9	106,497	105,886	105,809
Upper Rhine	Border DE/FR	Iffezheim	19.1	16.3	16.0	23,631	24,274	22,272
Wesel-Datteln Canal *	Junction with Rhine	Wesel-Friedrichsfeld	19.1	17.9	16.2	18,961	16,520	15,255
Rhein-Herne Canal *	Junction with Rhine	Duisburg-Meiderich	13.6	12.4	10.7	11,688	15,400	11,079
Main	Junction with Rhine	Mainz-Kostheim	12.1	11.1	11.5	15,213	14,309	13,707
Moselle	Junction with Rhine	Koblenz	9.2	8.8	7.7	8,459	9,106	5,073
Neckar	Junction with Rhine	Mannheim-Feudenheim	5.7	4.5	3.9	5,663	5,484	4,463

Figure 31 | Volume of transport
Source: CCNR

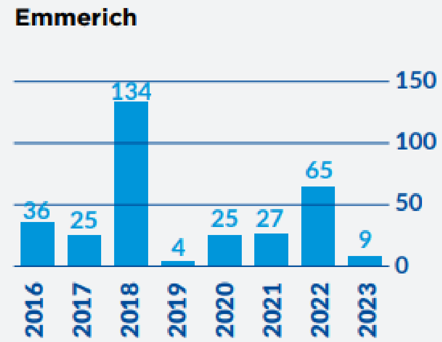


Figure 32 | Number of days below the equivalent water level
Source: CCNR

3

Brede Welvaart en Mobiliteit diagram

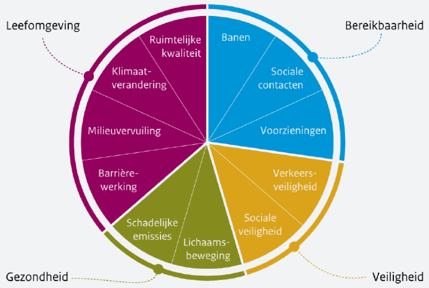


Figure 33 | Brede Welvaart en Mobiliteit diagram
Source: Netherlands Environmental Assessment Agency

Scenarios			
Cargos full capacity		No Cargos	
Accessibility			
More job opportunities in cargo transportation	+1	Will require a shift of jobs opportunities	-1
Reaches on time, no traffic jams		NA	
Safety			
More prone to accidents and specially in summers with narrow lanes and festivals in Nijmegen	-2	Completely safe from these accidents	+2
People in proximity will be at risk from explosions.		People are safe and sound without any risk.	
Health			
Harmful emissions as Germany has banned gas release.	-1	Issue might remain same in other type of transport	+2
NA		Have more time for self development.	
Environment			
Bridges need to be opened more frequently.	-2	Free flow movement	+2
Gases and noise pollution		Much greener environment	
More dikes and groynes needed for navigation due to climate		Nature driven solutions to cater climate change	
Degradation of spatial quality		Improves	

Figure 34 | Calculations in different categories
Source: Author

4

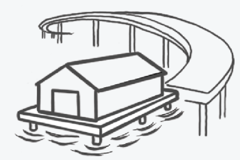
Design principles

E.1 Hydro-Economic Synergy

Designing seasonal retention zones, riparian buffers, and wetlands with low-impact economic activities (e.g., ecotourism, aquaculture, floating markets) that serve ecological and economic purposes.

Connected to:
SY - E9 | N2 | S1 | S2 ; **CO** - E8 | S5

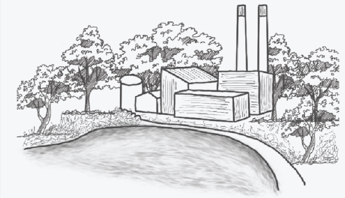
E.2 Adaptive Infrastructure



Introducing amphibious or floating infrastructure that adjusts to water levels with designed roads, warehouses, and public spaces with porous materials, raised foundations, or temporary uses during flood seasons.

Connected to:
SY - E5 | N3 | S5 ; **CO** - N9

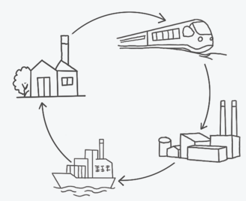
E.3 Blue-Green Industry Clusters



Creating industry zones interwoven with green corridors and canals, while co-locating water-reliant industries (e.g., bio-plastics, hydroponics, algae farming) with ecosystem services like reed filtration and natural cooling.

Connected to:
SY - E4| N4 | N7 | N16 ; **CO** - S7

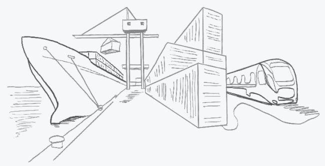
E.4 Local-Regional Economic Loops



Introducing decentralized economic zones that tie local production (food, energy, crafts) with regional distribution through waterways and slow mobility corridors and make economical loops.

Connected to:
SY - E3 | S2 | S6 ; **CO** - E6 | N11

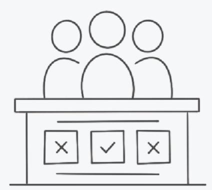
E.5 Modal Shift Infrastructure



Introducing inter-modal hubs near existing industrial zones (e.g., in Gelderse Poort) that allow flexible interchange between water-based and rail-based freight depending on water levels.

Connected to:
SY - E2 | E6 | E7 | E10 | S9 ; **CO** - N12

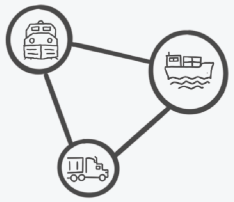
E.6 Freight Corridor Regulations



Forming a committee who will monitor and take real-time decisions about activating or deactivating freight routes on water, based on the water levels and severity of the goods needed.

Connected to:
SY - E5 | E7 | E7 | S11 ; **CO** - N1 | S10

E.7 Multi-Modal Logistics Nodes



Designing integrated logistics centers where inland ports, rail, and road systems intersect, allowing goods to move efficiently regardless of river usability.

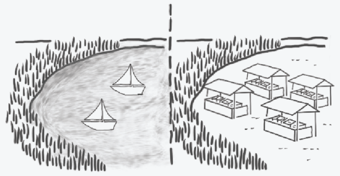
Connected to:
SY - E5 | E6 ; **CO** - N1 | N3 | N4 | N10 | N13 | S3 | S6 | S8 |

E.8 No-Dredge Economic Zone

Designate protected river sections as "no-dredge zones" with alternative transport investments and ecotourism potential instead of industrial dredging which causes erosion in the river bed.

Connected to:
SY - N1 | N5 | N6 | N9 ; **CO** - E10 | N16 | S9

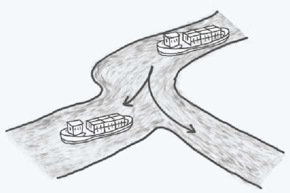
E.9 Economic Retention Basin Clusters



Designing retention basins near industrial belts that serve dual roles - temporary water storage and space for popup logistics or markets in dry seasons.

Connected to:
SY - E1 | N2 | S2 ; **CO** - S5

E.10 Parallel Water Channels



Constructing engineered water corridors parallel to the Rhine to reduce shipping pressure (eg. Gelderse Port area), bypass meandering sections, and allow energy-efficient flow and better logistical control.

Connected to:
SY - E5 | E6 ; **CO** - E8 | N2 | N7 | N7 | N9 | N15 | S1 | S4

E.11 Water Regulation

Dividing floodplain zones into dynamic compartments with controlled inlets and outlets, prioritizing flood storage in non-critical zones to protect economic infrastructure.

Connected to:
SY - N2 | S11 ; **CO** - S2 | S10

E.12 Tourism Hub

Develop riverside zones such as the chosen site in Gelderse Poort area with summer camps, boating circuits, floating platforms, and public gathering areas to stimulate local economies and attract seasonal activity.

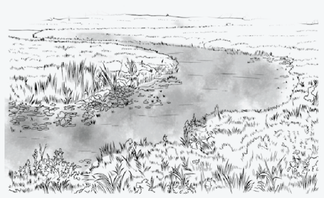
Connected to:
SY - S2 | S4 ; **CO** - N2 | | N5 | N8 | N14

N.1 Ecological Flow Corridors

Restoring riparian zones and reconnect side channels to support continuous riverine ecosystems, replacing artificial edges with soft, vegetated banks for unrestricted ecological flows.

Connected to:
SY - E8 | N2 | N5 ; **CO** - E6 | E7

N.2 Seasonal Wetland Expansion Zones



Reserving the areas that can safely flood during high-water periods to recharge wetlands, increase seasonal biodiversity, and absorb excess water without damage within ecological boundaries.

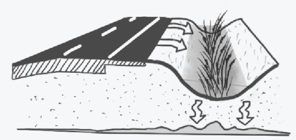
Connected to:
SY - E1 | E9 | E11 | N1 | N11 | N14 | S1 | S2 ; **CO** - E10 | E12

N.3 Dynamic Edge Conditions

Creating soft, responsive river edges that adapt with water level changes, such as graded banks, wetland shelves, and vegetated floodplains.

Connected to:
SY - E2 | N10 | S5 ; **CO** - E7

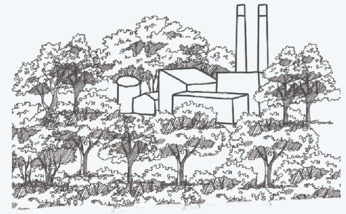
N.4 Water Purifying Bio-Filters



Integrating constructed wetlands, bioswales, and phytoremediation systems into industrial or urban runoff zones to passively clean water before it re-enters natural systems.

Connected to:
SY - E3 | N5 | N7 | S1 ; **CO** - E7

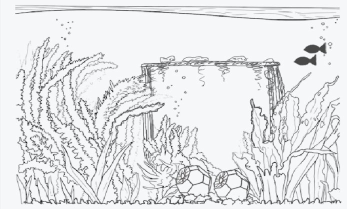
N.5 Biodiversity Buffer Rings



Encircling industrial or transport zones with multi-layered green buffers of native vegetation to shield ecosystems from pollution, noise, and direct human interference to reduce ecological fragmentation.

Connected to:
SY - E8 | N1 | N4 | N13 | S7 ; **CO** - E12 | S9

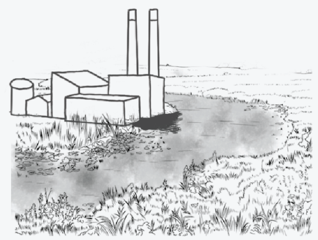
N.6 Submerged Habitat Modules



Creating modular structures such as rock beds, fish shelters, submerged wood in calm water areas in and around wetlands to create underwater ecosystems to create a bio-diverse environment.

Connected to:
SY - E8 | N12 ; **CO** - E10

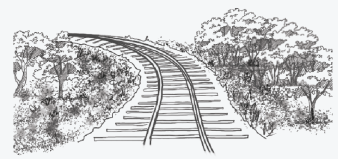
N.7 Pollution-Responsive Zones



Introducing ecological buffer zones that are activated during pollution spikes - such as temporary wetland basins or bio-reactive filtration beds to neutralise pollutants before they spread to natural systems.

Connected to:
SY - E3 | N4 | S3 ; **CO** - E10

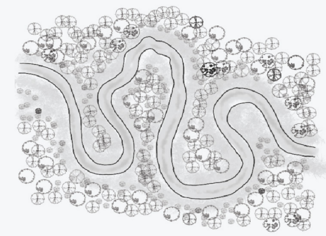
N.8 Micro-Habitat Interstices



Utilizing marginal urban spaces like canal edges, between rail lines, or road buffers as dense micro-habitat pockets using native species and habitat features for ecological continuity.

Connected to:
SY - N10 | S10 ; **CO** - E12

N.9 Reviving Dredged Canals



Transforming abandoned or heavily dredged canals into natural blue-green corridors by softening banks, reducing channelization, reintroducing meanders, and native wetland vegetation.

Connected to:
SY - E8 | N15 | S8 ; **CO** - E2 | E10

N.10 Adaptive Riparian Planting

Selecting and planting native species based on flood tolerance, water depth, and seasonal variation to support resilient and ecologically productive vegetated zones to build resilience into landscapes

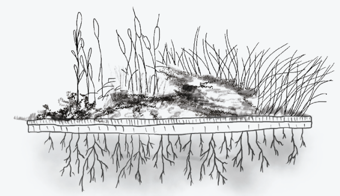
Connected to:
SY - N3 | N8 | S5 ; **CO** - E7

N.11 Resilient Riparian Setbacks

Creating adaptable buffer zones along river edges that shift in size or use depending on projected flood levels and long-term climate patterns predicted for 2100 and 2200.

Connected to:
SY - N2 ; **CO** - E4

N.12 Floating Wetlands



Using floating vegetated structures placed in calm waters or canals to absorb nutrients, provide cooling, and support aquatic micro habitats for habitat regeneration.

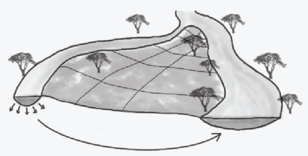
Connected to:
SY - N6 | S1 ; **CO** - E5

N.13 Eco-Threshold Infrastructure

Introducing ecological functions into bridges, culverts, and barriers by adding green walls, wildlife crossings, and bat or bird nesting modules to minimize fragmentation and support multi-species interaction.

Connected to:
SY - N5 ; **CO** - E7

N.14 River Seepage Channels



Introducing controlled seepage channels along riverbanks to slowly infiltrate excess water into the soil, supporting underground recharge while reducing surface runoff intensity.

Connected to:
SY - N2 ; **CO** - E12

N.15 Flowing Side Channels

Reactivating historical or artificial side channels that flow parallel to the main river, creating secondary habitats and distributing seasonal floodwaters more gradually.

Connected to:
SY - N9 ; **CO** - E10

N.16 Energy Transition

Incorporate renewable energy infrastructure like solar arrays on wetlands or low-impact hydro systems or wind mills that coexist with ecological zones and require minimal spatial intrusion.

Connected to:
SY - E3 ; **CO** - E8

S1. Civic Wetland Parks

Combining flood retention basins with multi-functional public spaces by integrating walkways, ecological features, and cooling zones to engage people with the water landscape in the neighborhood.

Connected to:
SY - E1 | N2 | N4 | N12 | S7 ; **CO** - E10

S2. Seasonal Market Floodplains

Activating floodplains during dry months as flexible-use community markets for local farmers, artisans, or events, using lightweight structures and adaptive layouts.

Connected to:
SY - E4 | E9 | N2 | S6 ; **CO** - E11

S3. Eco-Monitoring Platforms

Installing observation decks such as bird watching tower to engage people with the nature and also help in eco-data monitoring to create participatory environmental engagement.

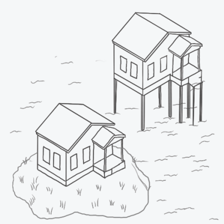
Connected to:
SY - N7 | S10 ; **CO** - E7

S4. Cultural Riparian Trails

Developing storytelling-based walking and cycling trails along riverscapes such as oude Rhine or Rijnstrangen, embedding interpretive signage, public art, and oral history markers to share river heritage.

Connected to:
SY - E12 | | S8 | S9 ; **CO** - E10

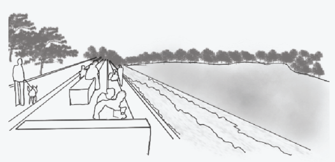
S5. Flood-Adaptive Co-Housing



Designing modular housing prototypes elevated above ground, capable of withstanding fluctuating water levels, while supporting communal functions and seasonal flexibility throughout the year.

Connected to:
SY - E2 | N3 | N10 ; **CO** - E1 | E9

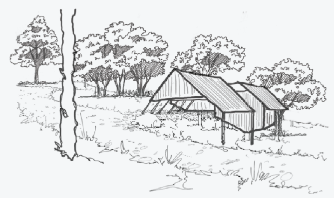
S6. Riverfront Community Kitchens



Building shared cooking and dining spaces along the water channels or wetlands, linked to seasonal harvests, fishing activities, and food sharing traditions that support social cohesion.

Connected to:
SY - E4 | S2 ; **CO** - E7

S7. Eco-Retreats



Creating accessible seasonal shelters and nature-based retreats and lodges providing cooling, rest, and wellness infrastructure in natural settings for the peace and capture nature.

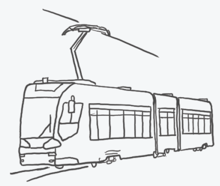
Connected to:
SY - N5 | S1 ; **CO** - E3

S8. Memory Island

Transforming overlooked river islands into memorial landscapes that archive flood histories, local stories, and cultural rituals through symbolic planting, signage, and public spaces (main Island protected by dikes in the chosen area).

Connected to:
SY - N9 | S4 ; **CO** - E7

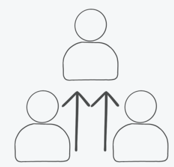
S9. Connecting Arnhem & Nijmegen



Strengthening public transport, bike trails, and walkable green corridors from Arnhem and Nijmegen towards the chosen location to activate regional collaboration and environmental continuity.

Connected to:
SY - E5 | S4 ; **CO** - E8 | N8

S10. Bottom-Up Neighbourhood Design



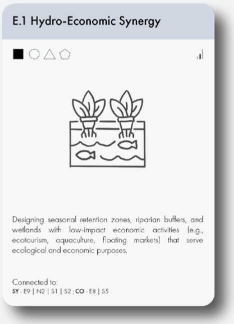
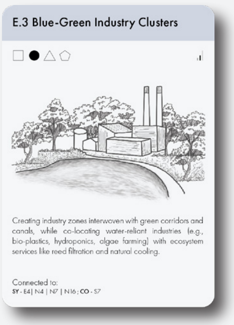
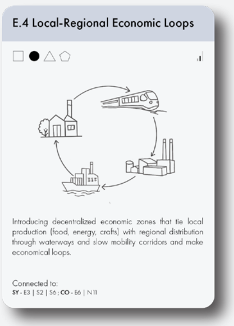
Applying participatory design methods by co-creating public spaces based on community visions, needs, and feedback through workshops, mapping, and model prototyping.

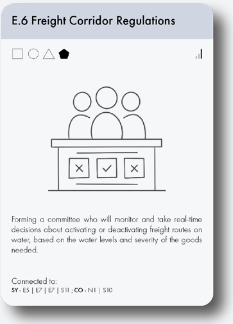
Connected to:
SY - N8 | S3 ; **CO** - E6 | E11

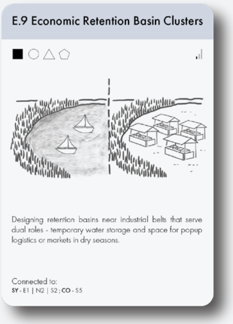
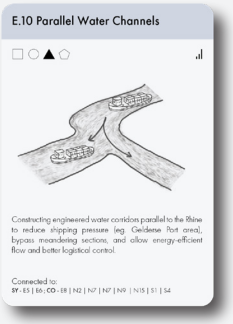
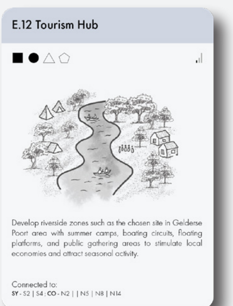
S11. Transboundary Government

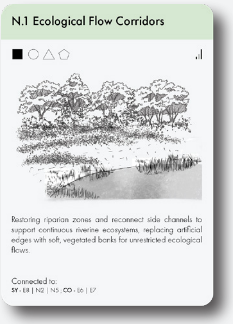
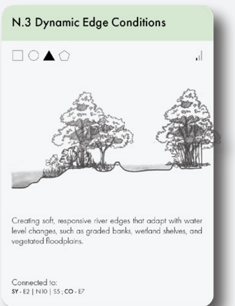
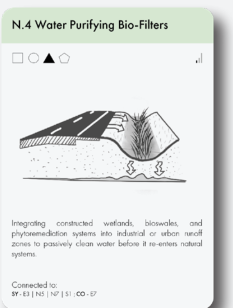
A government body which helps in governing the River in collaboration and find solutions collectively in the interest of all the parties involved.

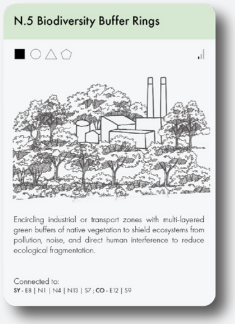
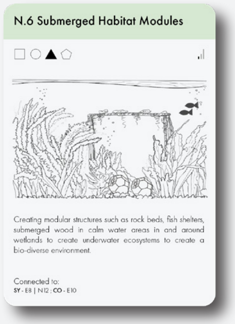
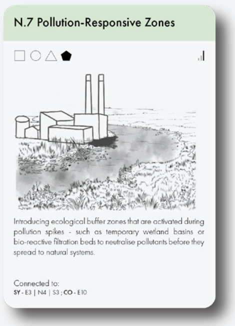
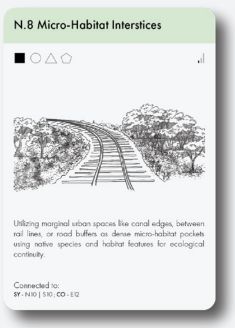
Connected to:
SY - E6 | E11

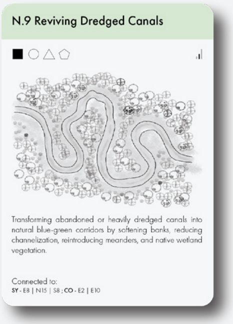
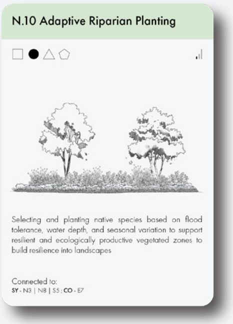
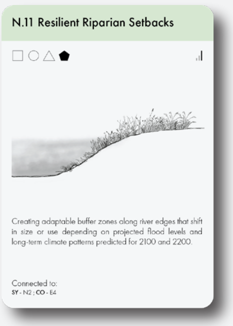
Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
E.1 Hydro-Economic Synergy 	Design multi-functional water landscapes integrating retention zones, reed buffers, and wetlands with low-impact economic uses like eco-tourism, aquaculture, and seasonal recreation spaces.	Supports micro-economies (fishing, tourism, aquaculture) while minimizing climate-related risks. Landscapes act as economic engines and resilience buffers.	**Meso** Applies to regional zones integrating water, ecology, and local economy.	**E9**: Promotes flexible water use and economic growth. **N2**: Seasonal wetland floods support floodplain economies. **S1**: Offers direct economic benefits through eco-tourism integration. **S2**: Economic and social activities align with seasonal floods.	**E8**: Restrictive zoning may limit economic activities like aquaculture or floating markets. **S5**: Housing developments may conflict spatially with economic zones if mismanaged.	**Spatial** It shapes multi-functional landscapes blending water retention, ecology, and micro-economies.
E.2 Adaptive Infrastructure 	Implement amphibious, modular, or floating structures like raised warehouses, elevated roads, and flood-resilient logistics to accommodate fluctuating water levels.	Prevents economic losses during flood events, enables uninterrupted operation of critical industries, and builds investor confidence in climate-adaptive infrastructure zones.	**Micro** Implemented at neighbourhood scale for roads and floating structures.	**E5**: Both focus on adaptable, resilient infrastructure solutions. **N3**: Compatible flexible design to address fluctuating water levels. **S5**: Housing and infrastructure share similar adaptation strategies.	**N9**:Adaptive structures might restrict opportunities for complete ecological restoration.	**Infrastructural** Adaptive construction responds to water fluctuation and climate extremes.
E.3 Blue-Green Industry Clusters 	Create mixed industrial zones with ecological corridors and canals to co-locate water-based industries with low-energy cooling, reuse systems, and reedbed filtration.	Reduces resource intensity, fosters water recycling, and supports green job creation while ensuring regulatory compliance with future sustainability frameworks.	**Meso** Applies to regional industry zones using sustainable water processes.	**E4**: Co-location of sustainable production and local economies strengthens regional resilience. **N4**: Industry clusters naturally align with pollution control and water purification. **N7**: Industrial pollution needs responsive ecological countermeasures **N16**: Blue-green industries offer platforms for renewable integration.	**S7**: Industrial activities could negatively impact tranquil retreat spaces.	**Programmatic** Encourages clean-tech clusters aligned with blue-green industrial innovation.
E.4 Local-to-Regional Economic Loops 	Link local production and distribution nodes with small-scale transport corridors via canals, greenways, and energy-positive networks to foster circular regional economies.	Improves supply chain resilience, fosters rural employment, and builds adaptive economies less vulnerable to global disruptions or fossil fuel logistics.	**Meso** Encourages regional loops of food and product distribution.	**E3**: Co-location of sustainable production and local economies strengthens regional resilience. **S2**: Supports local Production circulation through tourism integration. **S6:** Encourages locally sourced food and shared cultural practices.	**E6**: Local economic loops may conflict with larger-scale dynamic freight management. **N11**: Regional economic loops may seek access to now-restricted land.	**Programmatic** Links local production loops with decentralized slow mobility and trade.

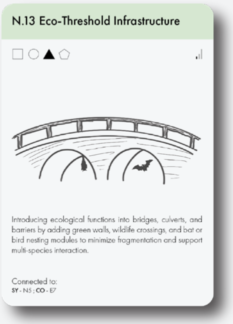
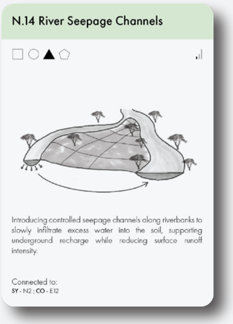
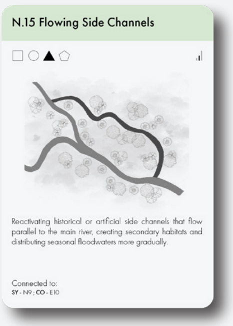
Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
E.5 Modal Shift Infrastructure 	Develop inter-modal hubs that switch between river, rail, and road freight depending on water levels, ensuring continuity of logistics under drought or flood conditions.	Reduces downtime in critical industries, improves energy efficiency, and diversifies logistical resilience in climate-stressed transport corridors.	**Meso** Targets regional logistics shift hubs at river-train intersections.	**E2**: Both focus on adaptable, resilient infrastructure solutions. **E6**: Enhances logistical adaptability. **E7**: Both directly encourage diversified, resilient transport solutions. **E10**: An additional channel or system for multi-path transport. **S9:** Infrastructure enhances sustainable public connectivity within the trade corridor.	**N12**: Spatial overlap could limit installation of floating wetland habitats.	**Infrastructural** Provides flexible freight switch points between water and rail modes.
E.6 Dynamic Freight Corridor Regulation 	Forming a committee who will monitor and take real-time decisions about activating or deactivating freight routes on water, based on the water levels and severity of the goods needed.	Optimizes freight movement, lowers fuel costs, reduces dredging, and ensures economic continuity with fewer delays and unnecessary operational waste.	**Macro** Policy-driven regulation across entire Rhine transport corridor.	**E5**: Complements flexible transport strategies. **E7**: Dynamic routing complements inter-modal logistics. **E10**: Governance is needed for parallel water channels. **S11:** Collaboration for the freight regulation committee and the governance is required for holistic approach.	**N1**: Real-time freight corridors may override ecological priorities in key stretches. **S10**: Local preferences could conflict with centralized freight decisions.	**Policy** Regulates freight activity based on water levels and river health data.
E.7 Multi-Modal Logistics Nodes 	Design centralized freight hubs combining inland port, rail, and road access that adapt to seasonal water conditions for continuous, multi-modal transport flow.	Attracts investment in logistics technology, supports local employment, and minimizes disruptions from climate-induced low river navigability.	**Macro** Requires systemic integration across Rhine-wide transport networks.	**E5**: Co-location of industries mutually supportive for transport resilience. **E6**: Dynamic routing complements inter-modal logistics.	**N1**: Dense infrastructure in multi-modal nodes can fragment vital ecological paths. **N3**: Fixed logistics platforms challenge dynamic, fluid edge spaces. **N4**: Heavy traffic and pollution can overwhelm purification systems. **N10**: Infrastructure limits space for layered plant zones. **N13**: Industrial design often lacks biodiversity components. **S3**: Logistics nodes might reduce environmental observation quality. **S6:** Kitchens and logistics need distinct spatial zones due to functional incompatibility. **S8**: In Historical and cultural islands might be negatively impacted by nearby logistics.	**Infrastructural** Connects multiple transport systems with logistic flexibility.
E.8 No-Dredge Economic Zone 	Allocate ecologically sensitive zones where dredging is restricted, redirecting shipping routes and encouraging green mobility and passive-use alternatives.	Saves long-term maintenance costs, enhances landscape value for tourism, and supports sustainable economies without degrading riverbed ecology.	**Macro** Designation of protected zones across the entire river system.	**N1**: Direct support for maintaining ecological integrity. **N5**: Ecological zones gain permanence and function from protected status. **N6**: Undisturbed zones foster aquatic life through long-term ecological stability. **N9**: Complements ecological restoration efforts.	**E10**: Could restrict alternative shipping routes or require careful planning. **N16**: Protected river zones may limit infrastructure expansion. **S9:** Transportation links might fragment or intrude upon preserved natural corridors.	**Policy** Bans dredging in protected economic-ecological zones.

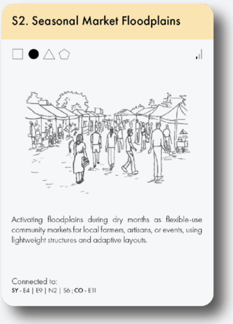
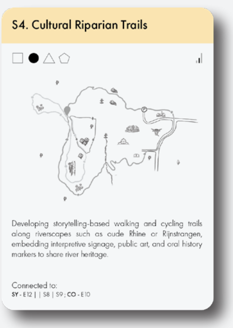
Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
E.9 Economic Retention Basin Clusters 	Create retention basins that double as seasonal economic spaces—hosting markets, logistics activities, or recreational uses during dry periods.	Converts potential flood zones into flexible income-generating assets, creating dual-purpose infrastructure that is both protective and productive.	**Micro** Site-based adaptive reuse of seasonal land areas.	**E1**: Both promote multi-functional water management and economic opportunity. **N2**: Shared basin zones offer dual functionality of flood management and habitat. **S2**: Economic basins activate and provide spaces for markets.	**S5**: Residential uses may conflict spatially.	**Spatial** Designs water basins as temporary economic or civic spaces.
E.10 Parallel water Channels 	Construct alternative water routes beside the main Rhine channel to reduce congestion, shorten distances, and distribute shipping loads across engineered corridors.	Improves transport efficiency, reduces navigational risks, and extends operational days during droughts, supporting regional trade stability and fuel savings.	**Macro** Involves restructuring navigation corridors at Rhine scale.	**E5**: An additional channel or system for multi-path transport. **E6**: Aligns with flexible freight strategy.	**E8**: Could restrict alternative shipping routes or require careful planning. **N2**: Parallel channelling reduces natural expansion areas for wetlands. **N6**: Active navigation routes threaten submerged habitats. **N7**: Excess sediment from navigation may trigger frequent ecological shutdowns. **N9**: Could disrupt ecological restoration if misaligned. **N15**: May spatially compete with engineered transport channels. **S1**: Additional channels may compromise space needed for civic parks. **S4:** Channel construction may disrupt continuous trail networks.	**Infrastructural** Builds secondary navigation to reduce stress on main river.
E.11 Water regulation 	Divide spaces into flood compartments with prioritization protocols, enabling early overflow into lower-value areas to protect economic assets by governing body (eg: Waterschap Issel en Rijn for Gelderse Poort).	Prevents high-value damage, improves emergency planning, and reduces insurance costs for industries and logistics in vulnerable zones.	**Meso** Applies compartmentalization at regional water control zones.	**N2**: Direct compatibility in flood management. **S11**: All the water directory needs to go under the supervision of the transboundary governance.	**S2**: Regulatory compartmentalization may limit market flexibility. **S10**: Public wishes may conflict with compartment flooding decisions.	**Policy** Implements compartmental water zoning to manage regional floods.
E.12 Tourism adventures 	Develop riverside spaces for boating, seasonal events, and nature experiences that transform floodplains into recreational and cultural economic engines.	Diversifies income sources, stimulates local service industries, and increases the attractiveness of the region for investment and visitation.	**Micro** Designs place-based tourism infrastructure and activities.	**S2**: Tourism complements local markets. **S4**: Enhances visitor experiences.	**N2**: Tourism may require hardened infrastructure which disrupts seasonally fluid landscapes. **N8**: Local economic loops may harm micro-habitats by visitor's pressure. **N5**: Increased recreational use can breach buffer sanctity. **N14**: Urban tourism development may block seepage paths.	**Programmatic** Promotes recreational economic activity like boating, events, and eco-tourism.

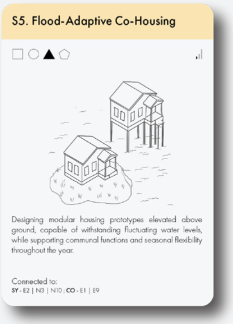
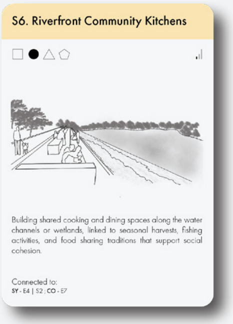
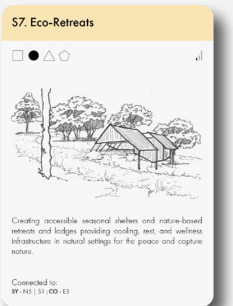
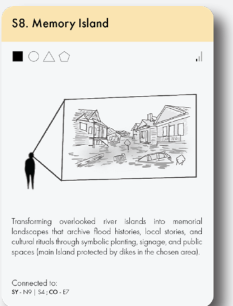
Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
N.1 Ecological Flow Corridors 	Restore riparian zones and reconnect side channels to support continuous riverine ecosystems, replacing artificial edges with soft, vegetated banks for unrestricted ecological flows.	Enables species migration, sediment transport, and habitat diversity while reconnecting aquatic and terrestrial systems disrupted by past engineering and infrastructure interventions.	**Macro** Supports long ecological continuity along the Rhine.	**E8**: Avoidance of dredging maintains natural sediment and flow continuity crucial for ecological networks. **N5**: Buffer zones strengthen corridor performance by reducing external ecological disturbance. **N2**: Enhances continuous habitat connectivity through seasonal wetland support.	**E6**: Real-time freight corridors may override ecological priorities in key stretches. **E7**: Dense infrastructure in multi-modal nodes can fragment vital ecological paths.	**Spatial** Restores continuous riparian corridors to support migration and flow.
N.2 Seasonal Wetland Expansion Zones 	Identify and restore areas that can safely flood during high-water periods to recharge wetlands, increase seasonal biodiversity, and absorb excess water without damage.	Enhances groundwater recharge, supports migratory species, reduces flood risk downstream, and strengthens the ecological functioning of natural floodplains and moist habitats.	**Meso** Applies to regional wetland ecosystems expanding seasonally.	**E1**: Seasonal wetland floods support floodplain economies. **E9**: Shared basin zones offer dual functionality of flood management. **E11**: Direct compatibility in flood management. **N1**: Contributes vital seasonal habitat expansion along ecological flows. **N11**: Wetland expansion benefits from protected floodplain zoning. **N14**: Support seasonal recharge and groundwater buffering. **S1**: Civic parks benefit from dynamic wetland habitat exposure. **S2**: Complements ecological cycles with human activity.	**E10**: Parallel channelling reduces natural expansion areas for wetlands. **E12**: Tourism may require hardened infrastructure which disrupts seasonally fluid landscapes.	**Spatial** Allows wetlands to expand seasonally, boosting biodiversity..
N.3 Dynamic Edge Conditions 	Construct adaptive embankments with floodable terraces and vegetation layers that expand or contract based on changing water levels and seasonal flows.	Stabilizes riverbanks, supports native plant growth, buffers infrastructure from flood impacts, and encourages a dynamic interface between urban and natural environments.	**Micro** Constructed edges and embankments respond to site-scale water shifts.	**E2**: Adaptive infrastructure can incorporate edge adaptation principles. **N10**: Flood-resilient plant palettes improve flexibility and edge stabilisation. **S5**: Elevated housing can work in tandem with morphing embankments.	**E7**: Fixed logistics platforms challenge dynamic, fluid edge spaces.	**Infrastructural** Constructs adaptable river edges to absorb and guide floodwaters.
N.4 Water Purifying Bio-Filters 	Integrate constructed wetlands, bioswales, and filtering vegetation into industrial or urban runoff zones to passively clean water before it re-enters natural systems.	Improves downstream water quality by removing pollutants and heavy metals while providing habitats for aquatic plants, insects, and small vertebrate species.	**Micro** Installed near localized port and runoff sites.	**E3**: Water-reliant industries benefit from cleaner ecosystems, forming closed-loop systems. **N5**: Buffers increase filtering capacity and habitat layers. **N7**: Complement filtration goals through adaptive control. **S1**: Public interaction with filtration systems promotes stewardship.	**E7**: Heavy traffic and pollution can overwhelm purification systems.	**Infrastructural** Uses bio-filtering wetlands near pollution zones.

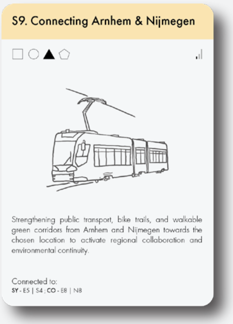
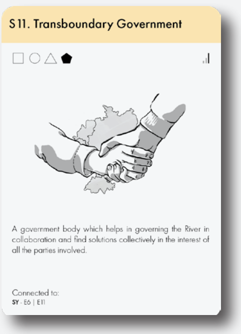
Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
N.5 Biodiversity Buffer Rings  	Surround industrial or transport zones with multi-layered green buffers of native vegetation to shield ecosystems from pollution, noise, and direct human interference.	Reduces ecological fragmentation, protects sensitive habitats from edge effects, and forms corridors for pollinators, birds, and small mammals across fragmented zones.	**Meso** Surrounds industrial zones at regional buffer scale.	**E8**: Ecological zones gain permanence and function from protected status. **N1**: Corridors gain security and reduced human pressure with buffers. **N4**: Pollution buffers and biodiversity buffers perform mutually reinforcing roles **N13**: Buffers gain additional function through integrated green infrastructure. **S7:** Carefully placed retreats support buffer functions with regulated human presence.	**E12**: Increased recreational use can breach buffer sanctity. **S9**: Infrastructural links could dissect continuous ecological buffers.	**Spatial** Creates buffers around infrastructure to reduce ecological stress.
N.6 Submerged Habitat Modules  	Introduce modular underwater structures in low-flow areas that increase aquatic complexity and provide fish breeding grounds, resting niches, and oxygenation points.	Enhances aquatic biodiversity by offering secure habitats, enriching spawning grounds, and improving underwater ecological structures in disturbed or canalized rivers.	**Micro** Built in low-traffic urban river sections.	**E8**: Undisturbed zones foster aquatic life through long-term ecological stability. **N12**: Floating wetlands add habitat complexity in same water zones.	**E10**: Active navigation routes threaten submerged habitats.	**Infrastructural** Introduces submerged habitats to diversify aquatic life.
N.7 Pollution-Responsive Zones  	Establish wetland or buffer areas that are activated during pollution peaks, designed to isolate and process contaminated runoff before reaching sensitive ecosystems.	Protects aquatic habitats by containing sudden contaminant surges, promoting nutrient filtration, and reducing chemical and sediment load in natural watercourses.	**Macro** Applies to river basin-level pollution monitoring and zoning.	**E3**: Industrial pollution needs responsive ecological countermeasures **N4**: Complement filtration goals through adaptive control. **S3**: Directly supports seasonal shelters and nature based retreats..	**E10**: Excess sediment from navigation may trigger frequent ecological shutdowns.	**Policy** Ecological areas respond dynamically to pollution events.
N.8 Micro-Habitat Interstices  	Transform narrow and residual urban edges—such as rail lines or canal margins—into diverse micro-habitats using native plantings and ecological layering.	Encourages urban biodiversity by creating habitat pockets for insects, amphibians, and small mammals in underused and ecologically fragmented cityscapes.	**Micro** Targets scattered leftover micro-lands in urban areas.	**N10**: Local planting supports scattered micro-ecosystems. **S10**: Community inclusion makes use of neglected or marginal spaces.	**E12**: High footfall can destroy small, delicate ecologies.	**Spatial** Reuses leftover urban lands to create mini-habitats.

Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
N.9 Reviving Dredged Canals 	Re-naturalize abandoned or heavily dredged canals by softening edges, reducing channelization, and reintroducing meanders and native wetland vegetation.	Restores natural channel processes, attracts native species, enhances landscape permeability, and revitalises lost ecological functions.	**Meso** Reclaims regional canal systems as ecological networks.	**E8**: Restoration zones benefit from non-intervention policy. **N15**: Side channels support flow, expand restored blue-green corridors. **S8:** Shared interest in recovering historical waterways and morphologies.	**E2**: Heavy infrastructure limits restoration flexibility. **E10**: Active channels may cut through revival efforts.	**Spatial** Revives old canal systems as hybrid ecological corridors.
N.10 Water-Responsive Plant Palettes 	Apply hydro-zoned planting using species selected for different water levels, flood tolerance, and seasonal variation to support resilient plant-based systems.	Provides erosion control, pollinator support, and flood resilience while improving microclimate regulation and soil stability during water-level fluctuations.	**Micro** Planting interventions at plot, park, and roadside scale.	**N3**: Dynamic edges need planting strategies that follow water levels. **N8**: Local planting supports scattered micro-ecosystems. **S5**: Housing landscape buffers benefit from well-zoned plant palettes	**E7**: Infrastructure limits space for layered plant zones.	**Programmatic** Applies flood-resilient vegetation to vulnerable sites.
N.11 Resilient Riparian Setbacks 	Define flexible zoning buffers from river edges that shift in size or use depending on projected flood levels and long-term climate patterns.	Ensures room for habitat migration, prevents ecosystem compression, and maintains ecological continuity during increasing climatic and hydrological variability.	**Macro** Sets regulatory riparian boundaries across Rhine floodplain.	**N2**: Wetland expansion benefits from protected floodplain zoning.	**E4**: Regional economic loops may seek access to now-restricted land.	**Policy** Sets climate-based zoning regulations near rivers.
N.12 Floating Wetlands 	Use buoyant vegetated structures placed in calm waters or canals to absorb nutrients, provide cooling, and support aquatic microhabitats in urban contexts.	Improves surface water quality, reduces algal blooms, provides bird nesting sites, and contributes to aquatic temperature regulation and habitat regeneration.	**Micro** Floating units used in ports or calm water pockets.	**N6**: Works together to enrich aquatic ecosystems. **S1**: Civic parks gain shade and educational features.	**E5**: Transport navigation may be hindered by floating structures.	**Infrastructural** Creates floating wetland systems on calm water bodies.

Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
N.13 Eco-Threshold Infrastructure 	Integrate ecological functions into bridges, culverts, and barriers by adding green walls, wildlife crossings, and bat or bird nesting modules.	Minimizes fragmentation, reconnects habitats across transportation corridors, and supports multispecies interaction within heavily developed or urbanized areas.	**Micro** Inserted into bridges, sound barriers and street systems.	**N5**: Buffers gain additional function through integrated green infrastructure.	**E7**: Industrial design often lacks biodiversity components.	**Infrastructural** Adds ecological niches to urban and transit structures.
N.14 River seepage channels 	Introduce controlled seepage channels along riverbanks to slowly infiltrate excess water into the soil, supporting groundwater recharge and buffering runoff intensity.	Enhances soil moisture, sustains vegetation in dry seasons, regulates base flow, and stabilizes the ecological balance in floodplain environments.	**Micro** Built near specific riverbanks to recharge groundwater.	**N2**: Support seasonal recharge and groundwater buffering.	**E12**: Urban tourism development may block seepage paths.	**Infrastructural** Implements seepage channels for groundwater recharge.
N.15 Flowing side channels 	Reactivate historical or artificial side channels that flow parallel to the river, allowing seasonal water spread and improved lateral ecological connectivity.	Diversifies aquatic environments, reduces flood risk in main channels, and supports unique sedimentation patterns and wildlife niches in secondary water bodies.	**Meso** Constructed alongside main river channel across regions.	**N9**: Channel revival depends on natural side flow.	**E10**: May spatially compete with engineered transport channels.	**Infrastructural** Constructs side channels for ecological flow during floods.
N.16 Energy Transition 	Integrate low-impact renewable energy systems—such as solar or hydro modules—into ecological zones without fragmenting landscapes or displacing habitats.	Enables de-carbonization while preserving ecosystem integrity, reducing emissions from water-based industries, and promoting energy-landscape cohabitation.	**Meso** Targets industrial transition across multiple clustered areas.	**E3**: Blue-green industries offer platforms for renewable integration.	**E8**: Protected river zones may limit infrastructure expansion.	**Policy** Supports transition to renewable energy near water-based industries.

Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
S.1 Civic Wetland Parks 	Combine flood retention basins with multi-functional public spaces by integrating walkways, ecological features, and cooling zones to engage people with the water landscape.	Encourages water literacy, creates inclusive recreational areas, improves public health, and offers spaces for education and social interaction in climate-responsive environments.	**Micro** Civic parks built into flood-adapted neighbourhoods.	**E1:** Offers direct economic benefits through eco-tourism integration. **N2**: Wetland parks rely on seasonal flooding benefits. **N4:** Enhances water purification, improving visitor experience. **N12**: Civic parks gain shade and educational features. **S7:** Retreats can be embedded into park systems, offering low-impact accommodation.	**E10**: Additional channels may compromise space needed for civic parks.	**Spatial** Public parks designed as floodplains that host wetland functions.
S.2 Seasonal Market Floodplains 	Activate floodplains during dry months as flexible-use community markets for local farmers, artisans, or events, using lightweight structures and adaptive layouts.	Boosts local economies, supports seasonal livelihoods, promotes social resilience, and turns water-prone land into a productive and celebrated communal asset.	**Micro** Floodplain reused seasonally for local markets.	**E4**: Supports regional economy and local resilience. **E9**: Economic basins activate and provide spaces for markets. **N2**: Complements ecological cycles with human activity. **S6:** Activates community spaces aligned with seasonal rhythms and agricultural cycles.	**E11**: Regulatory compartmentalization may limit market flexibility.	**Programmatic** Markets align with seasonal flooding and local economies.
S.3 Eco-Monitoring Platforms 	Install public platforms equipped with citizen science tools like biodiversity counters, rainfall gauges, and digital dashboards to foster participatory environmental engagement.	Empowers communities to monitor their landscape, increases environmental awareness, and encourages long-term stewardship through locally driven water and ecology data collection.	**Micro** Installed at specific locations for community engagement.	**N7**: Directly supports monitoring pollution zones. **S10:** Encourages participatory neighbourhood environmental stewardship.	**E7**: Logistics nodes might reduce environmental observation quality.	**Programmatic** Interactive platforms invite citizen science and eco-monitoring.
S.4 Cultural Riparian Trails 	Develop storytelling-based walking and cycling trails along riverscapes, embedding interpretive signage, public art, and oral history markers to share river heritage.	Revitalises cultural identity, enhances tourism potential, deepens sense of place, and reconnects residents with ecological and historical narratives of the Rhine corridor.	**Meso** Cultural trails connect city-scale or regional narratives.	**E12:** Trails directly support tourism and heritage initiatives. **S8:** Linked cultural pathways reinforce narratives of flood history and ecological change. **S9:** Connectivity strengthens regional trail networks.	**E10:** Channel construction may disrupt continuous trail networks.	**Programmatic** Trails integrate stories, education, and heritage of rivers.

Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
S.5 Flood- adaptive Co- Housing 	Design modular housing prototypes elevated above ground, capable of withstanding fluctuating water levels, while supporting communal functions and seasonal flexibility.	Demonstrates forward-looking housing solutions for vulnerable zones, improves adaptive capacity, and supports dignified, collective living amid flood-prone environments.	**Micro** Housing clusters designed at neighbourhood level.	**E2:** Both promote resilient forms of living and mobility under fluctuating water conditions. **N3:** These support housing built into flexible, water-responsive landforms. **N10**: Housing landscape buffers benefit from well-zoned plant palettes	**E1**: Housing developments may conflict spatially with economic zones if mismanaged. **E9:** Shared land may become contested between water retention and residential use.	**Infrastructural** Elevated or floating housing protects against seasonal floods.
S.6 Riverfront Community Kitchens 	Build shared cooking and dining spaces along rivers, linked to seasonal harvests, fishing activities, and food sharing traditions that support social cohesion.	Strengthens neighbourhood ties, encourages food sustainability, revives traditional knowledge, and turns riverfronts into inclusive spaces of nourishment and gathering.	**Micro** Riverfront kitchens support hyper-local food activity.	**E4:** Encourages locally sourced food and shared cultural practices. **S2:** Activates community spaces aligned with seasonal rhythms and agricultural cycles.	**E7:** Kitchens and logistics need distinct spatial zones due to functional incompatibility.	**Programmatic** Community kitchens linked to seasonal food systems and rivers.
S.7 Eco-Retreats 	Create accessible seasonal shelters and nature-based retreats for children, elderly, or marginalized groups, providing cooling, rest, and wellness infrastructure in natural settings.	Supports equitable access to safe, healthy environments, enhances physical and mental well-being, and offers climate-adaptive community-oriented healing spaces.	**Micro** Retreats designed for specific population groups and microclimates.	**N5:** Carefully placed retreats support buffer functions with regulated human presence. **S1:** Retreats can be embedded into park systems, offering low-impact accommodation.	**E3:** Industrial proximity may disturb the retreat environment's tranquillity and health benefits.	**Programmatic** Seasonal eco-retreats offer respite during climate extremes.
S.8 Memory Island 	Transform overlooked river islands into memorial landscapes that archive flood histories, local stories, and cultural rituals through symbolic planting, signage, and public spaces.	Preserves intangible heritage, reinforces collective memory, honours past adaptations, and invites reflection on climate, loss, and transformation within riverine societies.	**Meso** Islands often span regional identities and cultural ecologies.	**N9:** Shared interest in recovering historical waterways and morphologies. **S4:** Linked cultural pathways reinforce narratives of flood history and ecological change.	**E7:** Industrial access may degrade historic or symbolic island areas.	**Spatial** Islands reimagined as memory-rich ecological storytelling spaces.

Design Principle	Design strategy	Impact	Scale	Synergy	Conflict	Type
S.9 Connecting Arnhem & Nijmegen 	Strengthen public transport, bike trails, and walkable green corridors between Arnhem and Nijmegen to activate regional collaboration and environmental continuity.	Encourages daily exchange between cities, supports equitable mobility, reduces emissions, and builds stronger social and economic integration across the river zone.	**Meso** Transit connections designed between cities or regional corridors.	**E5:** Infrastructure enhances sustainable public connectivity within the trade corridor. **S4:** Mobility links enhance cross-city cultural trails.	**E8:** Transportation links might fragment or intrude upon preserved natural corridors. **N5**: Infrastructural links could dissect continuous ecological buffers.	**Infrastructural** Transport links boost cross-city cohesion and access.
S.10 Bottom-up Neighbourhood design 	Apply participatory design methods by co-creating public spaces based on community visions, needs, and feedback through workshops, mapping, and model prototyping.	Builds ownership, ensures cultural relevance, enhances inclusion, and results in spaces that reflect real needs, identities, and lived experiences of residents.	**Micro** Neighbourhood-driven design applied locally with direct community input.	**N8:** Residents can shape forgotten spaces into ecological assets. **S3:** Shared public engagement tools foster participatory planning and community-driven decisions.	**E6:** Local needs may conflict with centralized freight decisions and sensor networks. **E11**: Public wishes may conflict with compartment flooding decisions.	**Policy** Enables neighbourhood-driven planning with ecological and social focus.
S.11 Transboundary Government 	A government body which helps in governing the River in collaboration and find solutions collectively in the interest of all the parties involved.	A river has no administrative boundary, so this transboundary governance will help in identifying the issues and works as an advocate for the river and it's needs.	**Micro** Neighbourhood-driven design applied locally with direct community input.	**E6:** Collaboration for the freight regulation committee and the governance is required for holistic approach. **E11**: All the water directory needs to go under the supervision of the transboundary governance.		**Policy** Enables neighbourhood-driven planning with ecological and social focus.

5

Species and habitats description

HABITATS	DESCRIPTION	MAMMALS	BIRDS	INSECTS	FISHES	REPTILES / AMPHIBIANS
Riparian / Floodplain Forests	Tree-dominated ecosystems along rivers or in low-lying areas that are seasonally or permanently flooded	Beavers Otters	Black Stork			
Reed and Vegetated Marshes	Wetlands dominated by dense, water-tolerant plants like reeds, grasses, and sedges	Beavers Otters	Bittern Black Stork Black Tern			European Tree Frog
Scrublands	Transitional zones with low-growing vegetation dominated by shrubs, bushes, and hardy plants	Hazel Dormhouse	Red-Backed Shrike			European Tree Frog
Dense Forests	Tightly packed tree stands forming shaded, multi-layered ecosystems	Hazel Dormhouse				
River Dikes	Embankments along river channels, often vegetated and stabilized over time		Red-Backed Shrike	Eastern Bath White		
Grasslands	Sunlit open habitats dominated by grasses and wildflowers, often tree-less.		Corncrake Red-Backed Shrike Skylark Meadow Pipit	Weidesprinkhaan Eastern Bath White		Natterjack toad
Shallow vegetated wetlands	Wetlands with standing shallow water and dense aquatic or semi-aquatic vegetation		Black Tern	Northern Damselfly Silver Water Beetle		European Tree Frog
Low Shoreline Vegetation	Low-growing plants (grasses, sedges, rushes) along water edges, stabilizing banks			Noordse Witsnuitlibel Arctosa cinerea		Natterjack toad
Floodplain Meadows	Seasonally inundated grasslands along river valleys		Bittern Skylark Meadow Pipit Black-tailed Godwit	Eastern Bath White Scarce Large Blue Butterfly		
Shallow and Deep Water Body	Depth-varying habitats from productive shallows to deep-water zones				European Sturgeon Bitterling	
Oxygen-Rich River Habitat	Fast-flowing, well-aerated sections of river				Atlantic Salmon Barbel	
Sandy Soil Zones	Areas dominated by loose, well-drained sandy substrates					Pelobates fuscus

FISHES	HABITAT	NOTES
European Sturgeon	• deep freshwater rivers • **Large, Free-Flowing Rivers**	Once a **flagship species of the Rhine**
Atlantic Salmon	• **Cold, Oxygen-Rich Rivers**	
Bitterling	• **slow-moving, vegetated waters** • **Floodplain Pools** • **Canals & Ditches**	
Barbel	• **fast-flowing, well-oxygenated river channels** • **Main Channels of the Rhine**	

MAMMALS	HABITAT	NOTES
Otter	• **Floodplain Wetlands**: Shallow, vegetated waters • **Riparian Forests** • **Marshes** (Slow moving water)	
Beaver	• Floodplain woodlands and riverbanks • Lowland rivers • Ponds and marshes	broad, slow-moving or stagnant water bodies
Hazel Dormouse	• species-rich hedgerows and scrublands • **Dense Deciduous Forests** • Old river dikes and wooded floodplain banks	Connected Canopy Isolated woodlands hinder movement

REPTILES / AMPHIBIANS	HABITAT	NOTES
European Tree Frog	• warm, sunny wetlands with abundant vegetation • **dynamic, sun-exposed wetlands** with **Shallow, Vegetated Ponds, Reed Beds & Marsh Edges, Connected Scrubland**	Spends time in **tall herbaceous vegetation**, **shrubs**, or **low branches** of trees and hedgerows. Summer Habitat (Terrestrial)
Natterjack Toad	• **warm, shallow, sunlit temporary ponds** and **open, sparsely vegetated terrain**	Prefers **ephemeral (temporary) shallow pools** **Dynamic Floodplain Areas**: Sandy riverbanks and dunes **Heathland Edges**: Transition zones between dunes and wet meadows
Pelobates fuscus	• **Sandy soils** for burrowing • **Low-lying, temporary ponds** for breeding, those that are **fish-free** and have **gentle shorelines** and **sparse aquatic vegetation** • Open Landscapes	

BIRDS	HABITAT	NOTES
Bittern	• Extensive reed marshes • Shallow freshwater wetlands • Seasonally flooded meadows	depend almost entirely on dense, tall reed beds for nesting, roosting, and feeding
Corncrake	• **tall, dense grassland** • grasslands • Marshy margins	Corncrakes are more often heard than seen—their rasping call ("crex-crex") echoes at night! Red listed Species
Black Stork	• **forested wetlands** • **Shallow Marshes** • marshy grasslands	Prefers **oaks or pines** **Clear, Slow-Moving Water** **flagship species** for healthy, connected landscapes combining **wetlands and mature forests**.
Red-backed Shrike	• **Thorny scrub and scattered bushes** (transitional zones between grassland and woodland) • **Open meadows** with tall herbs and grasses • River dike edges • **semi-open, shrub-rich landscapes**	**semi-open, mosaic landscapes** **Hedgerow Restoration**
Black Tern	• Shallow freshwater marshes • Over open water bodies • **shallow, vegetated wetlands**	**Floating Vegetation Mats**
Black-tailed Godwit	• wet meadows - **open, flat grasslands** with **high groundwater tables** • Shallow wet areas, mudflat	Nesting typically occurs in **tall, undisturbed grass** meadows
Skylark	• Open, dry to moderately moist grasslands and floodplain meadows • Mosaic landscapes with variation in vegetation height • **open, treeless landscapes with - Extensive Grasslands i.e.** both farmlands and natural meadows	Skylarks build their nests directly on the ground, in **sparsely vegetated areas** with **short to medium-height grasses**. **Sparse, Low Vegetation**
Meadow Pipit	• **open, undisturbed grasslands** and **lightly grazed floodplains** • grasslands and marshy patches • **open, moist grasslands** and **lowland moors**	

INSECTS	HABITAT	NOTES
Weidesprinkhaan	species-rich grasslands	Needs **high groundwater tables** and **patchy vegetation** with both **grassy cover** and **bare patches** for basking. Indicator of **high-quality wet grasslands.**
Noordse Witsnuitlibel	• Shallow wetlands • Rewetted zones • low vegetation along shorelines • **peat-based wetlands**	
Northern Damselfly	• Shallow wetlands • floating-leaved plants • **Edges of wetlands with open, sunny conditions**	
Eastern Bath White	• **dry grasslands, floodplain meadows**, and **river dikes**	open, sunny habitats **flower-rich landscapes**
Scarce Large Blue Butterfly	• Wet, Species-Rich Floodplain Meadows	
Silver Water Beetle	• **shallow, nutrient-rich wetlands** with abundant **submerged and floating vegetation** • Prefers **permanent, shallow, water bodies**	especially in **rewetted floodplain zones**.
Arctosa cinerea	• sparsely vegetated floodplain • **riverine landscapes with** Floodplains	Designated "spider reserves" in key areas

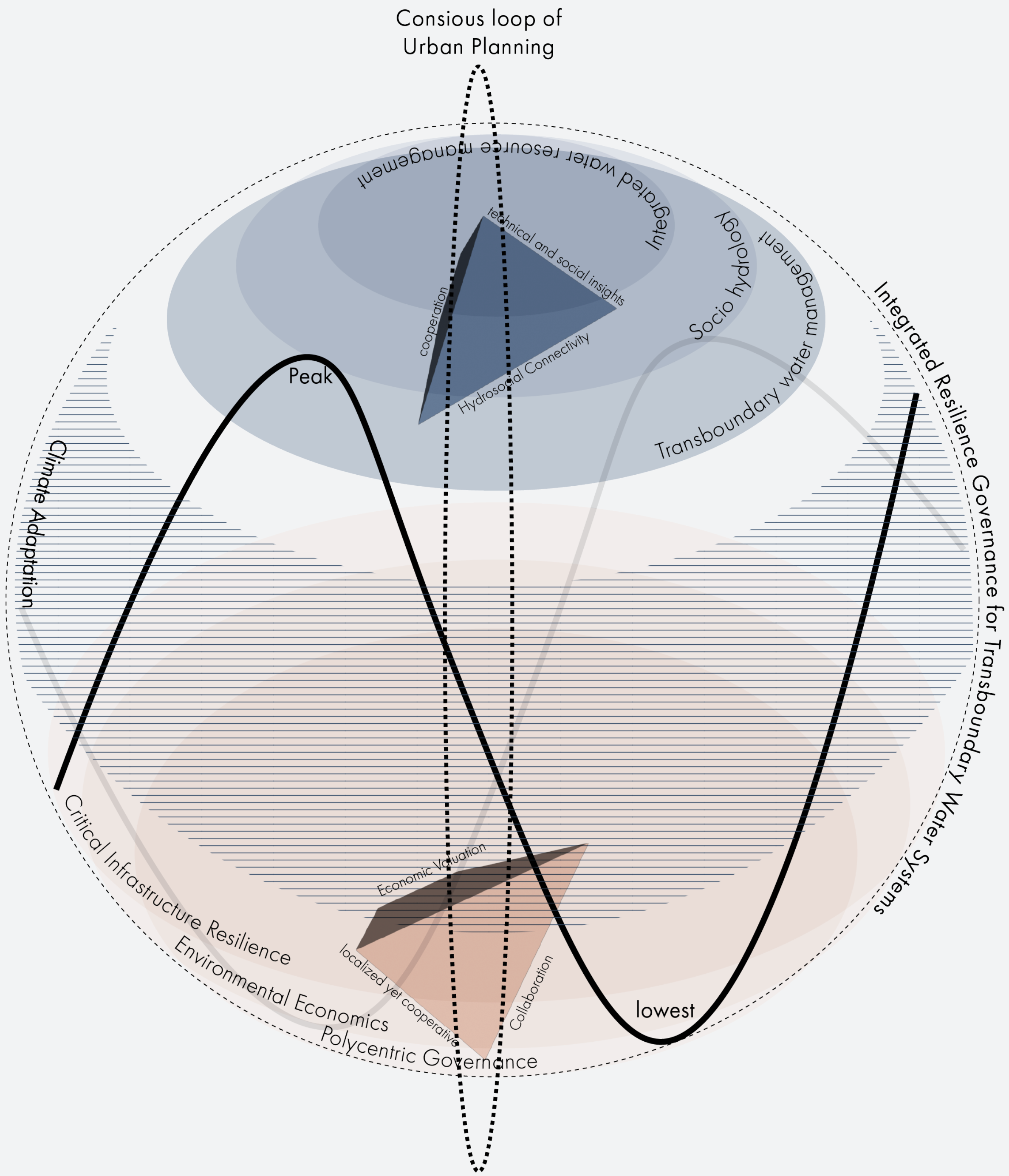
Appendix

1. Conceptual framework
2. Methodological framework
3. Major companies along the Rhine
4. Impact chain of climate change on freight transport
5. Interviews with experts

1

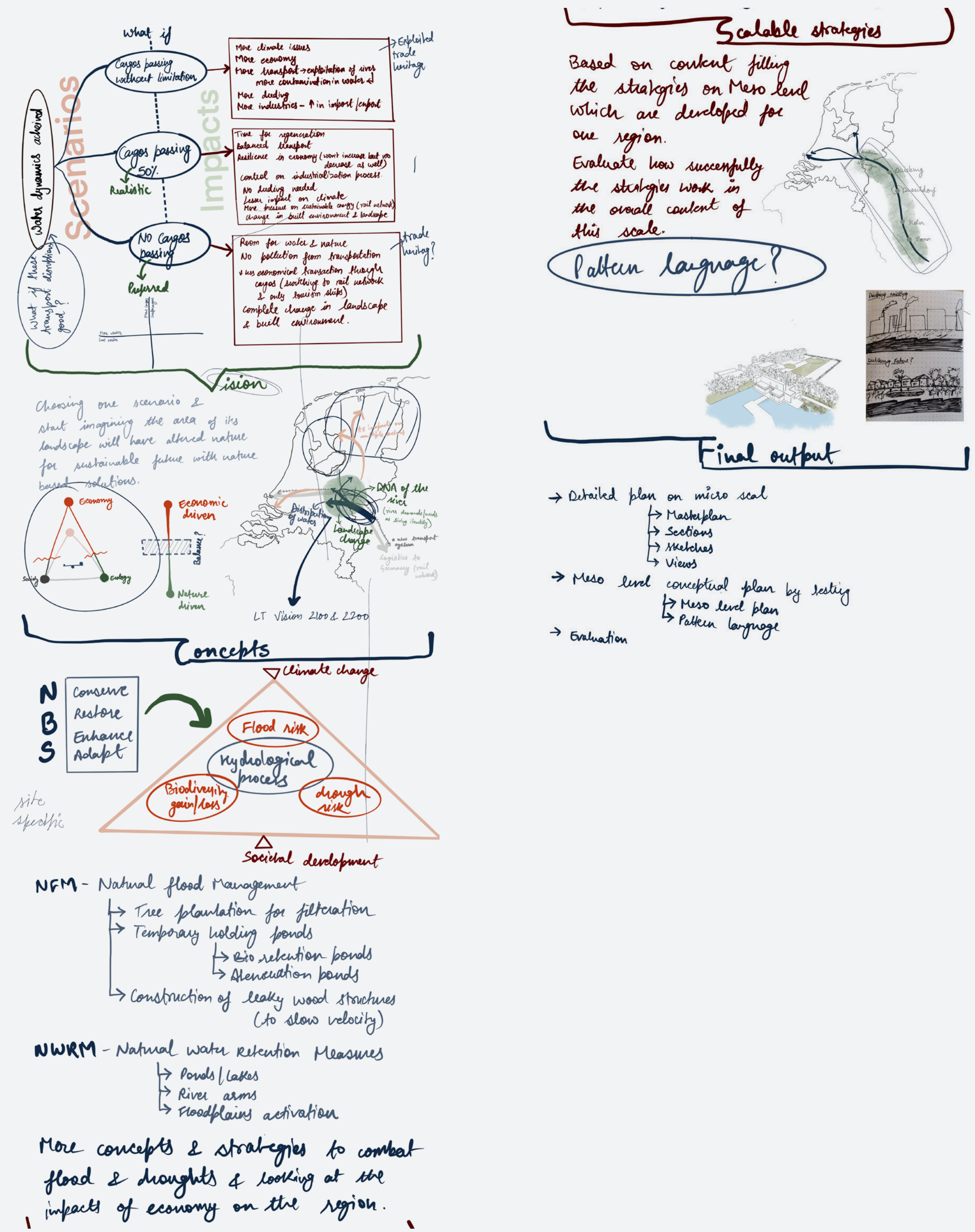
Conceptual Framework

This earlier version of conceptual framework was more focused on the water management and governance which has been modified while delving deeper into the project.



2

Methodological framework



3

Major Companies along Rhine - Shell plc

Out of major oil companies, Shell plc is one of the leading companies and has largest crude oil refinery in Pernis with 20 million tones capacity and 17 million tones capacity refinery in Rhineland being the biggest in Germany. Shared infrastructure is used such as depots, pipelines RRP and RMR connecting the Pernis and Rhineland refineries, rail, road and barge transfers optimizes the flow between the sites.

Contargo

With an annual throughput of more than 2 million TEU, Contargo is one of Europe's leading container hinterland logistics networks. It integrates container transport between the western sea ports, Germany's North Sea ports and the European hinterland. It is a trimodal system with barges, rail transport and road transport.

Legends

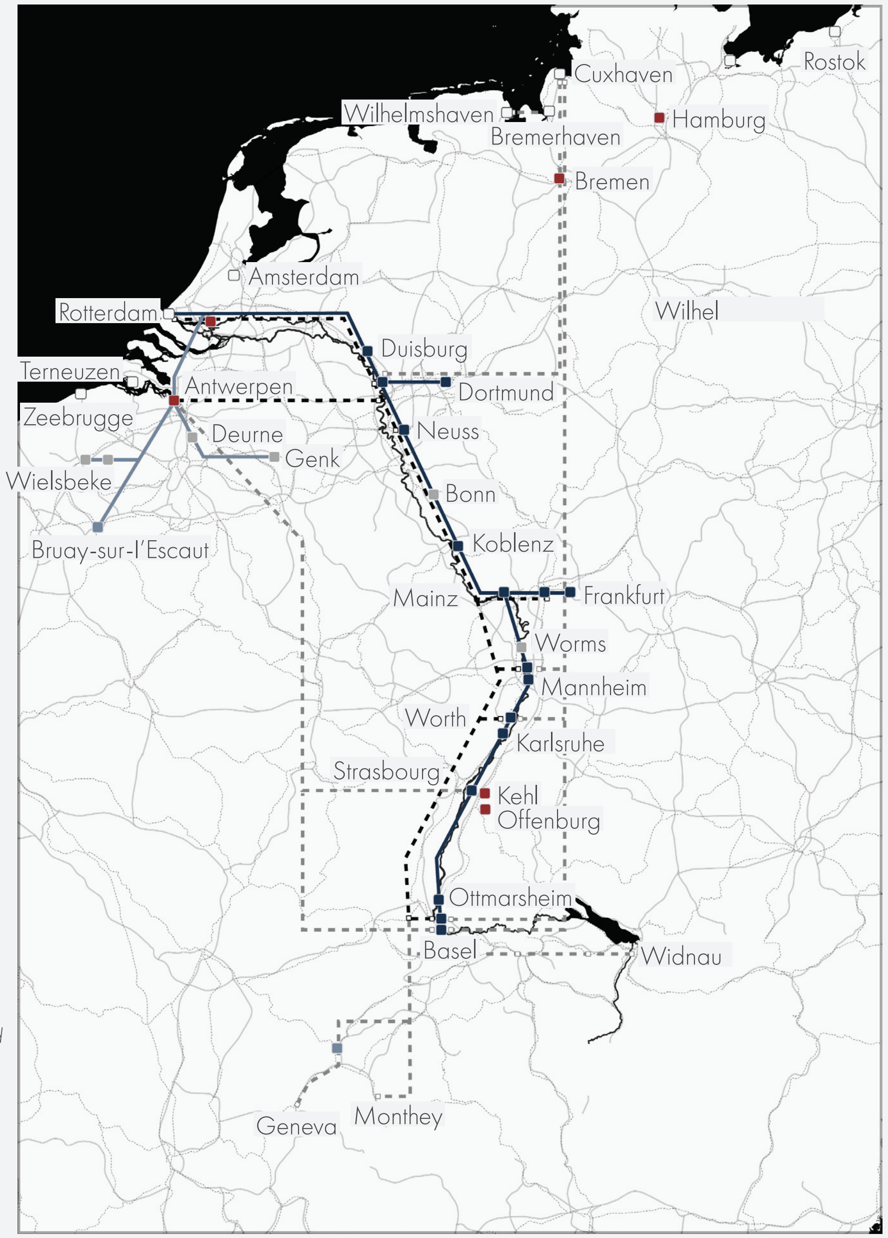
- Railway network
- Road network
- Shell Storage depot
- Joint storage depot
- Chemical plants
- Shell refineries
- Shell refineries
- Other refineries
- RRP
- RMR
- Industrial area

Figure 35 | Shell network
Source: Shell | adapted by author

Legends

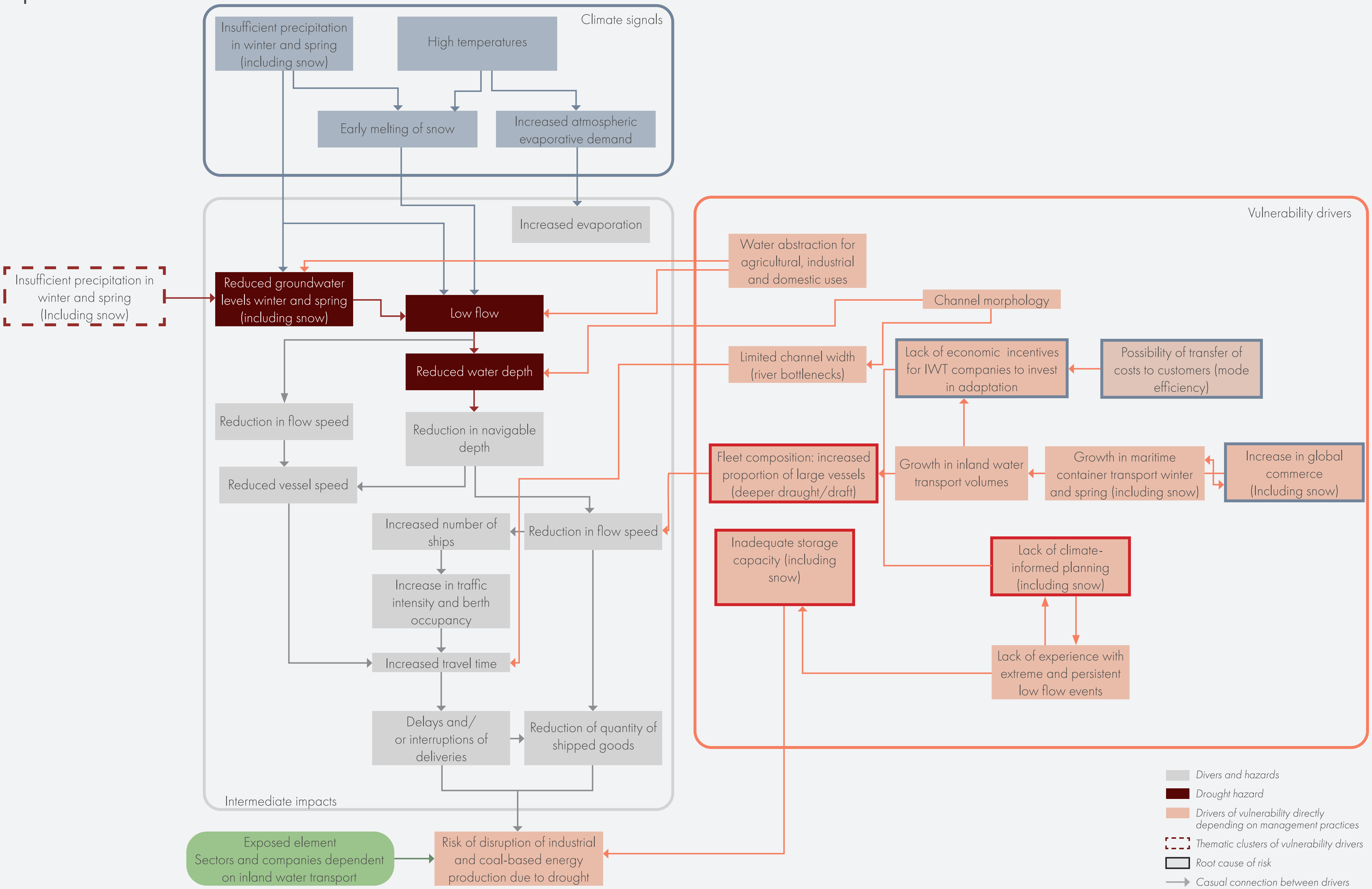
- Railway network
- Road network
- Contargo container terminals
- Contargo offices
- Corporation partners seaport
- Corporation partners hinterland
- Barge transport
- Own railway lines
- Corporation railway lines

Figure 36 | Contargo network
Source: Shell | adapted by author



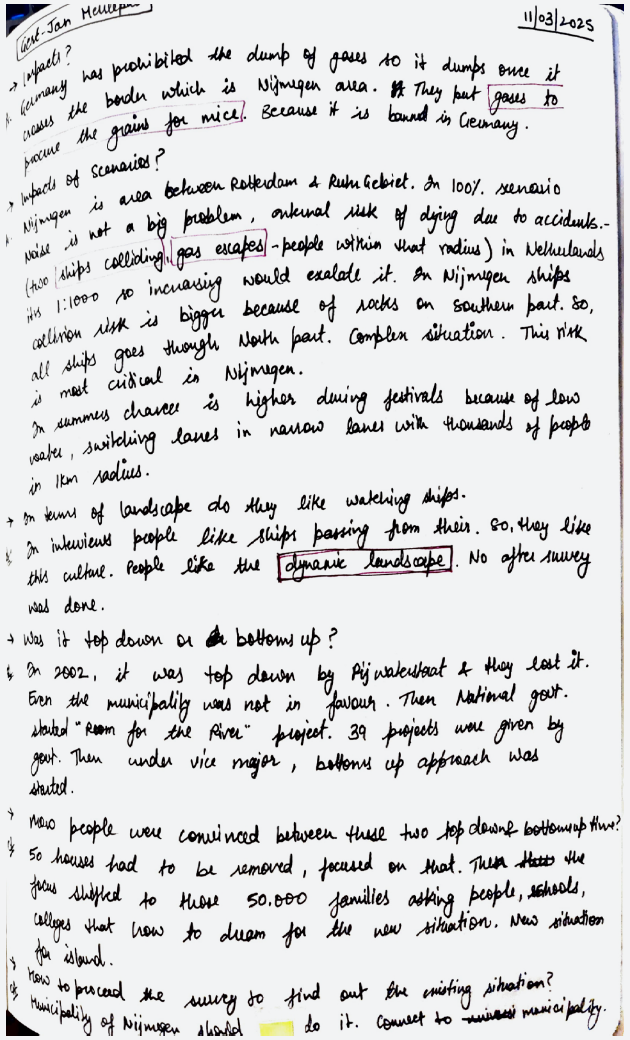
4

Impact chain

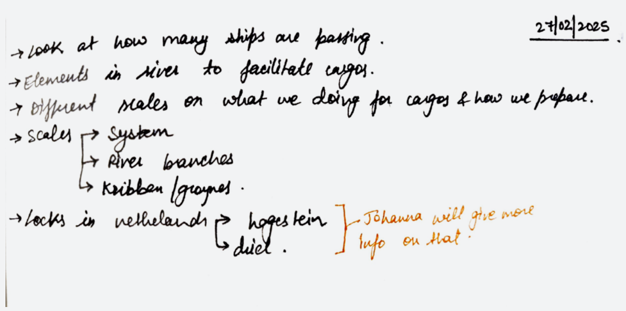


5

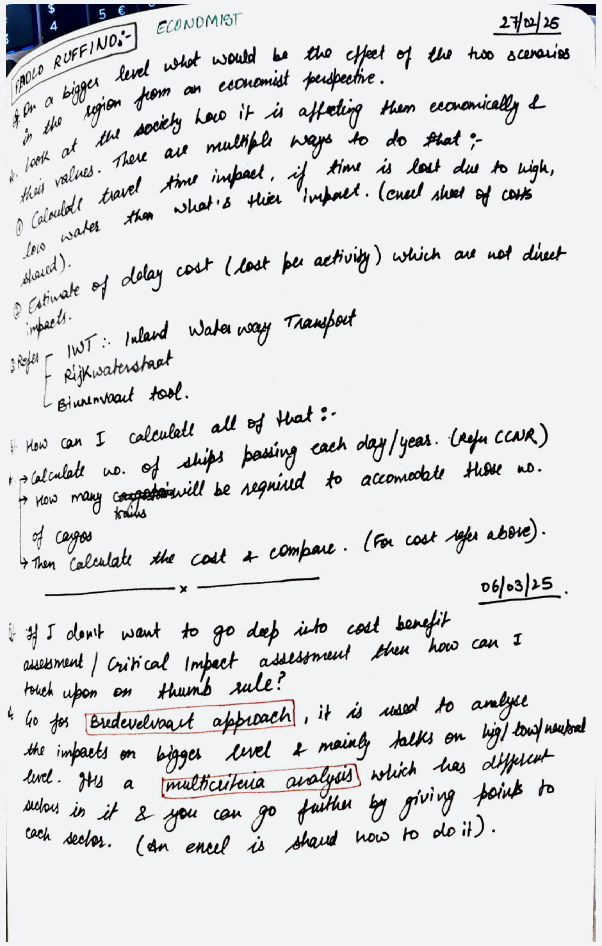
Interviews with experts


Gert-Jan Hellegers 11/03/2025

→ Impacts?
→ Germany was prohibited the dump of gases so it dumps once it crosses the border which is Nijmegen area. They put gases to procure the grains for mice. Because it is banned in Germany.
→ Impacts of Scenarios?
→ Nijmegen is area between Rotterdam & Ruhr Gebiet. In 100% scenario noise is not a big problem, external risk of dying due to accidents (two ships colliding) gas escapes - people within that radius) in Netherlands its 1:1000 so increasing would exalate it. In Nijmegen ships collision risk is bigger because of rocks on southern part. So, all ships goes through North part. Complex situation. This risk is most critical in Nijmegen.
→ In summers chances is higher during festivals because of low water, switching lanes in narrow lanes with thousands of people in 1km radius.
→ In terms of landscape do they like watching ships.
→ In interviews people like ships passing from their. So, they like this culture. People like the dynamic landscape. No other survey was done.
→ Was it top down or bottoms up?
→ In 2002, it was top down by Rijkwaterstaat & they lost it. Even the municipality was not in favour. Then National govt. started "Room for the River" project. 39 projects were given by govt. Then under vice major, bottoms up approach was started.
→ How people were convinced between these two top down/bottom up thus?
→ 50 houses had to be removed, focused on that. Then the focus shifted to these 50,000 families asking people, colleges that how to dream for the new situation. New situation for island.
→ How to proceed the survey to find out the existing situation?
→ Municipality of Nijmegen should do it. Connect to municipality.


27/02/2025

→ Look at how many ships are passing.
→ Elements in river to facilitate cargos.
→ Different scales on what we doing for cargos & how we prepare.
→ Scales → System
→ River branches
→ Kribben /groynes.
→ Locks in netherlands → hogestein
→ driel.
] - Johanna will give more info on that.

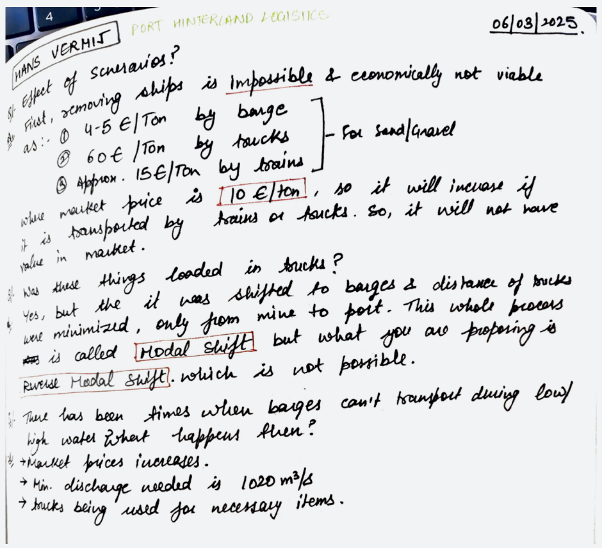

PAOLO RUFFINO:- ECONOMIST 27/02/25

Q. On a bigger level what would be the effect of the two scenarios in the region from an economist perspective.
A. Look at the society how it is affecting them economically & their values. There are multiple ways to do that :-
① Calculate travel time impact, if time is lost due to high, low water then what's their impact. (excel sheet of costs shared).
② Estimate of delay cost (lost per activity) which are not direct impacts.
③ Refer [IWT :- Inland Waterway Transport
Rijkwaterstaat
Binnenvaart tool.
Q. How can I calculate all of that :-
A. → Calculate no. of ships passing each day/year. (Refer CCNR)
→ How many ~~cargo~~ trains will be required to accomodate those no. of cargos
→ Then Calculate the cost & compare. (For cost refer above).

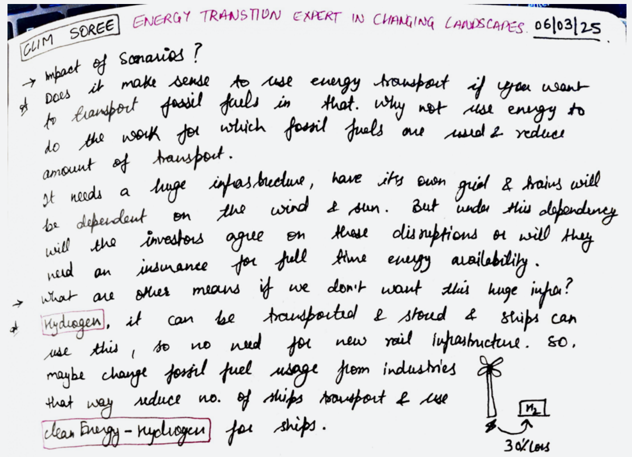
———— × ————

06/03/25.

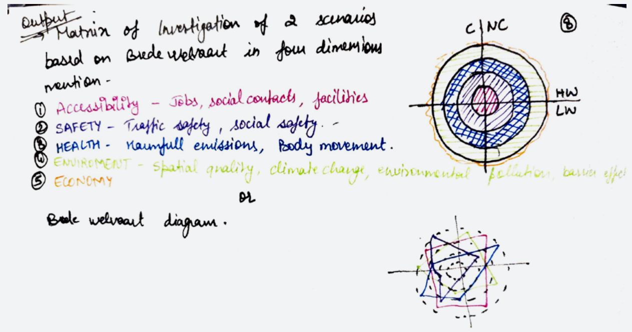
Q. If I don't want to go deep into cost benefit assessment / Critical Impact assessment then how can I touch upon on thumb rule?
A. Go for Bredewelvaart approach, it is used to analyse the impacts on bigger level & mainly talks on high/low/neutral level. Its a multicriteria analysis which has different sectors in it & you can go further by giving points to each sector. (An excel is shared how to do it).


HANS VERMIJ PORT HINTERLAND LOGISTICS 06/03/2025.

Q. Effect of scenarios?
A. First, removing ships is Impossible & economically not viable as :- ① 4-5 €/Ton by barge
② 60 € /Ton by trucks
③ Approx. 15€/Ton by trains] - For sand/Gravel
where market price is 10 €/ton, so it will increase if it is transported by trains or trucks. So, it will not have value in market.
Q. Was these things loaded in trucks?
A. Yes, but the it was shifted to barges & distance of trucks were minimized, only from mine to port. This whole process is called Modal Shift but what you are proposing is Reverse Modal Shift. which is not possible.
Q. There has been times when barges can't transport during low/high water What happens then?
A. → Market prices increases.
→ Min. discharge needed is 1020 m^3/s
→ trucks being used for necessary items.


GIJM SOREE ENERGY TRANSITION EXPERT IN CHANGING LANDSCAPES 06/03/25.

→ Impact of Scenarios?
A. Does it make sense to use energy transport if you want to transport fossil fuels in that. Why not use energy to do the work for which fossil fuels are used & reduce amount of transport.
It needs a huge infrastructure, have its own grid & trains will be dependent on the wind & sun. But under this dependency will the investors agree on these disruptions or will they need an insurance for full time energy availability.
→ What are other means if we don't want this huge infra?
A. Hydrogen, it can be transported & stored & ships can use this, so no need for new rail infrastructure. So, maybe change fossil fuel usage from industries that way reduce no. of ships transport & use clean Energy - hydrogen for ships.
H_2
30% loss

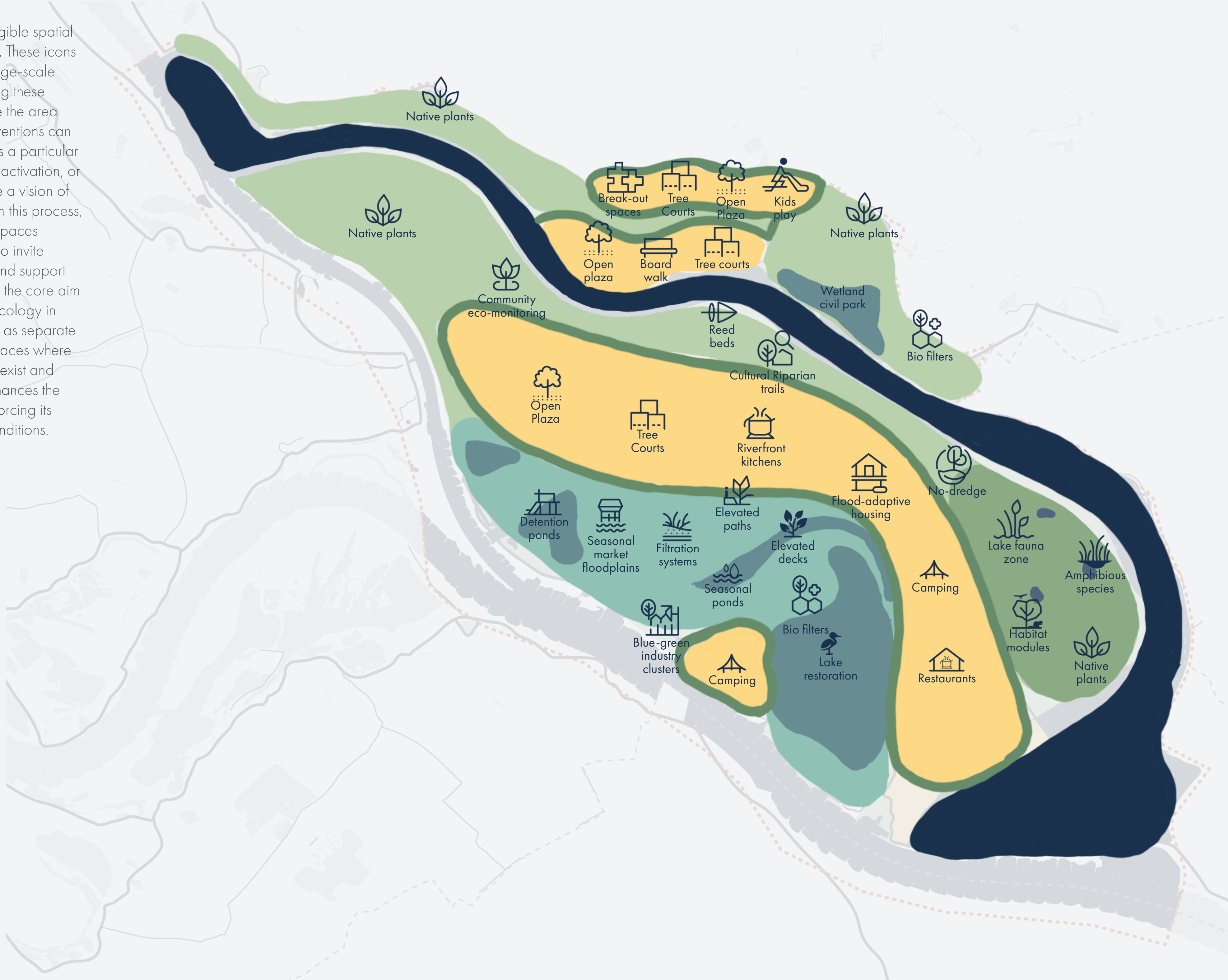

Output :- → Matrix of Investigation of 2 scenarios based on Brede welvaart in four dimensions mention -
① Accessibility - Jobs, social contacts, facilities
② SAFETY - Traffic safety, social safety. -
③ HEALTH - Harmfull emissions, Body movement.
④ ENVIROMENT - Spatial quality, climate change, environmental pollution, barrier effect
⑤ ECONOMY
or
Brede welvaart diagram.
C | NC
HW
LW
⑧

6

Problem statement

Design strategies

To better translate abstract design principles into tangible spatial interventions, a set of strategic icons was developed. These icons serve as visual tools that bridge the gap between large-scale strategies and localized spatial responses. By placing these icons across the plan, it became possible to visualize the area at multiple scales, particularly focusing on how interventions can manifest at point-specific levels. Each icon represents a particular design intent, be it ecological restoration, economic activation, or social interaction and collectively they help articulate a vision of the area as a dynamic, adaptive landscape. Through this process, a network of multi-functional zones created, where spaces are not only resilient to changing water levels but also invite public life, promote small-scale economic systems, and support ecological processes. These spatial strategies reflect the core aim of the project: to intertwine people, economy, and ecology in meaningful ways. Rather than treating these domains as separate layers, the design integrates them, creating hybrid spaces where cultural identity, biodiversity, and productivity can coexist and reinforce each other. This visualization approach enhances the clarity and communicability of the design while reinforcing its flexibility across different scenarios and seasonal conditions.



Legends
- *Proposed water channel*
- *Dynamic zones*
- *Buffer area*
- *Society spaces*
- *Protected habitat area*
- *Lakes*

Figure 37 | Testing of design principles Source: Author