EVERY DROP COUNTS

How to keep the Rhine functional in times of drought

Metropolitan Ecologies of Place
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26/06/2023

Dürre-sommer 2022

“Vater Rhein” verlässt sein Bett: Deutschlands längster Strom fällt trocken

“Father Rhine” leaves his streambed: Germany’s longest river falls dry (Stern, 2022)

Water level difference of the Rhine (Offern, 2022)

De Rijn is te droog voor binnenvaart, die juist cruciaal is voor de Duitse economie

The Rhine is too dry for inland navigation, which is crucial for the German economy (Bekkum, 2022)

Rette sich, werr kann - Wie Deutschland sich für die Klimakrise wappnet

Save yourself if you can - How Germany is arming itself for the climate crisis (Duhm et al., 2022)

Niet eerder sinds begin metingen zoveel ijsverlies in de Alpen

Not before since the beginning of measurements so much ice loss in the Alps (Kersten & Ekker, 2023)

Glaciers melting between 2006 and 2018 (Huss & GLAMOS, 2018)

Waterpeil in de Rijn zakt tot ‘kritiek niveau’ door extreme droogte

Water level in the Rhine drops to ‘critical level’ due to extreme drought (Brandsma, 2022)

Low water levels near Emmerich (Offern, 2022)

Gletsjers smelten sneller dan verwacht: zelfs in beste scenario verdwijnt helft deze eeuw

Glaciers melt faster than expected: even in best-case scenario half will disappear this century (NOS Nieuws, 2023)

The Netherlands

Arnhem

North sea

Rotterdam

Nijmegen

Duisburg

Düsseldorf

Germany

Cologne

Bonn

Belguim

Koblenz

Luxemburg

Bad
Kreuznach

Mainz

Mannheim

Strasbourg

Basel

France

Austria

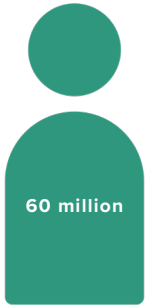
Switzerland

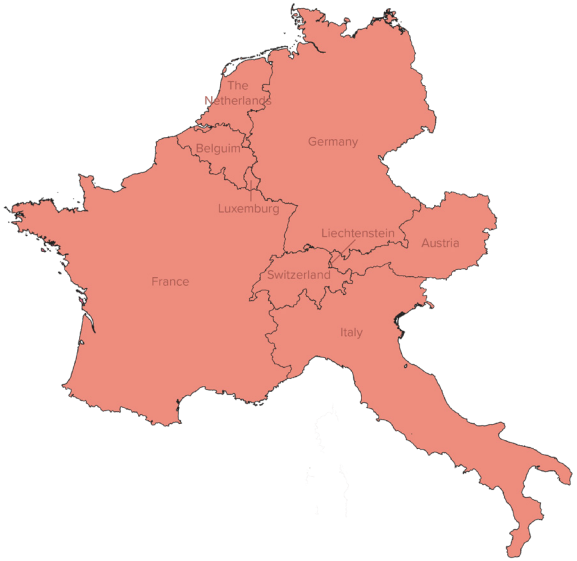
Tomasee

Paradies Glacier

Italy


185.000 km²


60 million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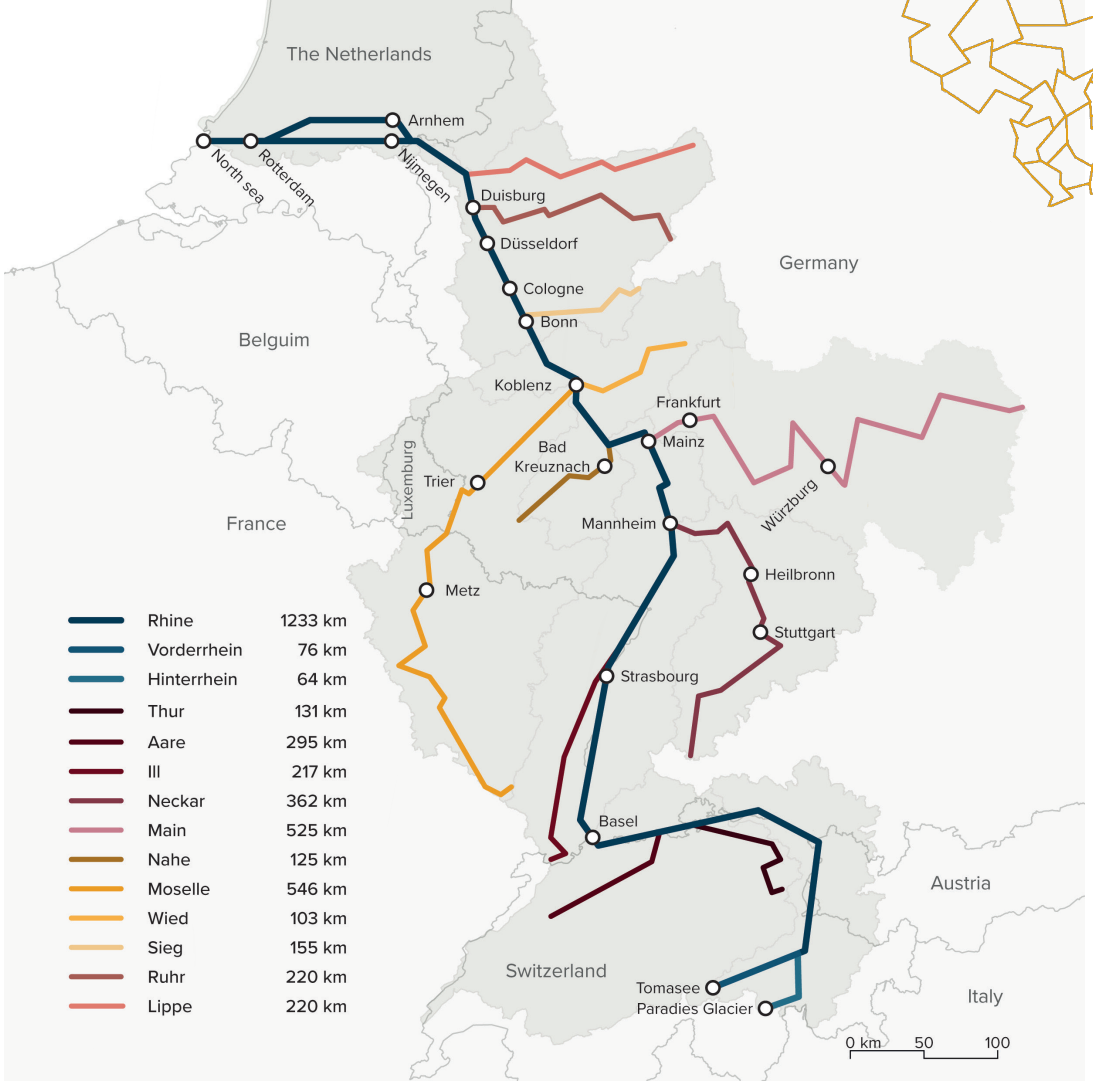
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Mannheim
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Strasbourg
Basel
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Switzerland
Tomasee
Paradies Glacier
Italy
0 km
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100
Rhine 1233 km
Vorderrhein 76 km
Hinterrhein 64 km
Thur 131 km
Aare 295 km
Ill 217 km
Neckar 362 km
Main 525 km
Nahe 125 km
Moselle 546 km
Wied 103 km
Sieg 155 km
Ruhr 220 km
Lippe 220 km

Goals and aims

Show how the surrounding landscape of the Rhine River can contribute to mitigating drought-related problems and keep the riverscape functional.

The Middle Rhine valley (ALAMY, 2021)

Personal motivation

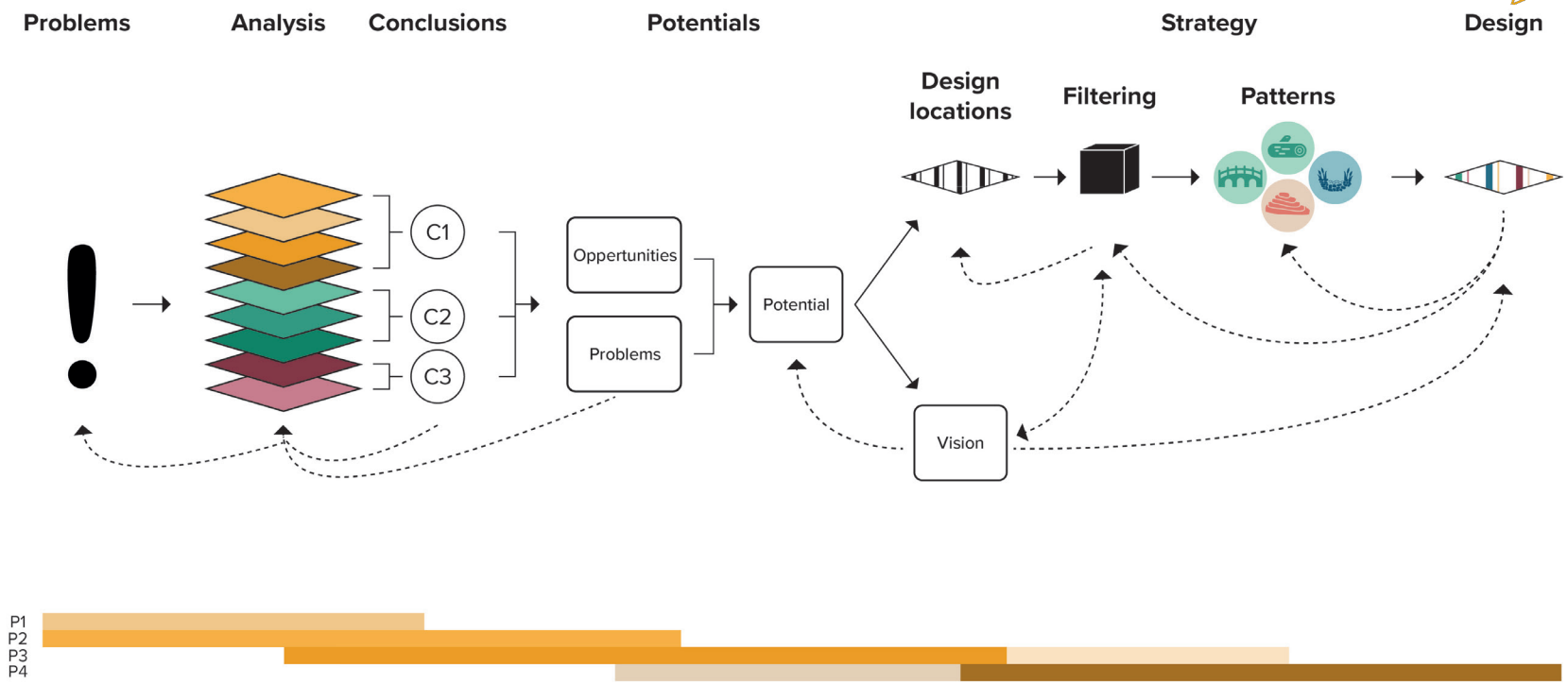
Explore drought

Expand knowledge on climate adaptation

Scale

Outside of Netherlands

Schiffe bei Mainz, Philipp Zeltner, 1865 (Rhein-Museum Koblenz)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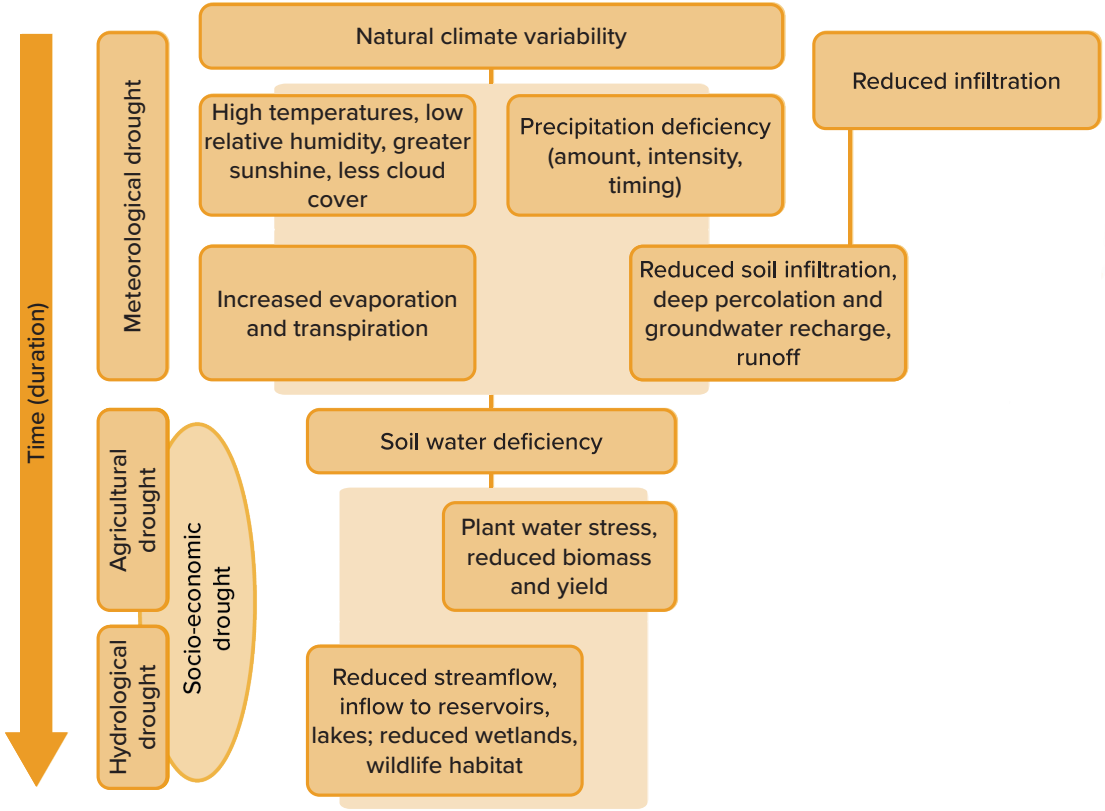
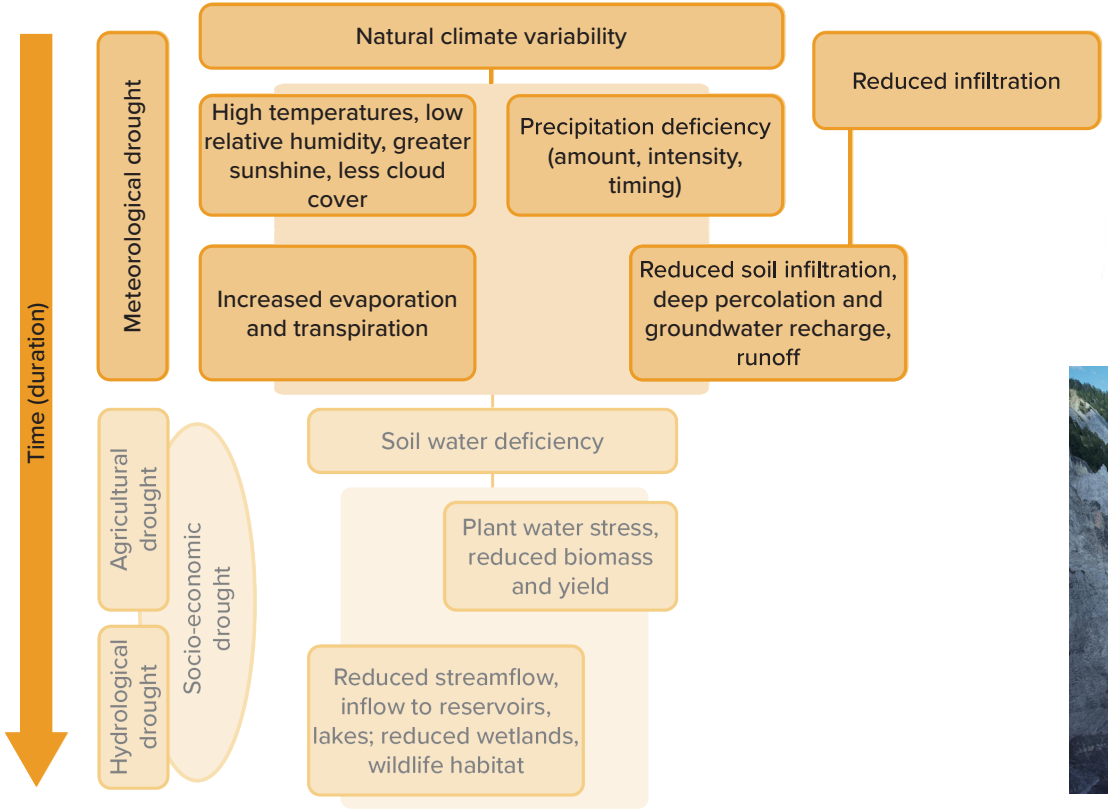
Drought explained



Lack of precipitation in combination with high evaporation rates

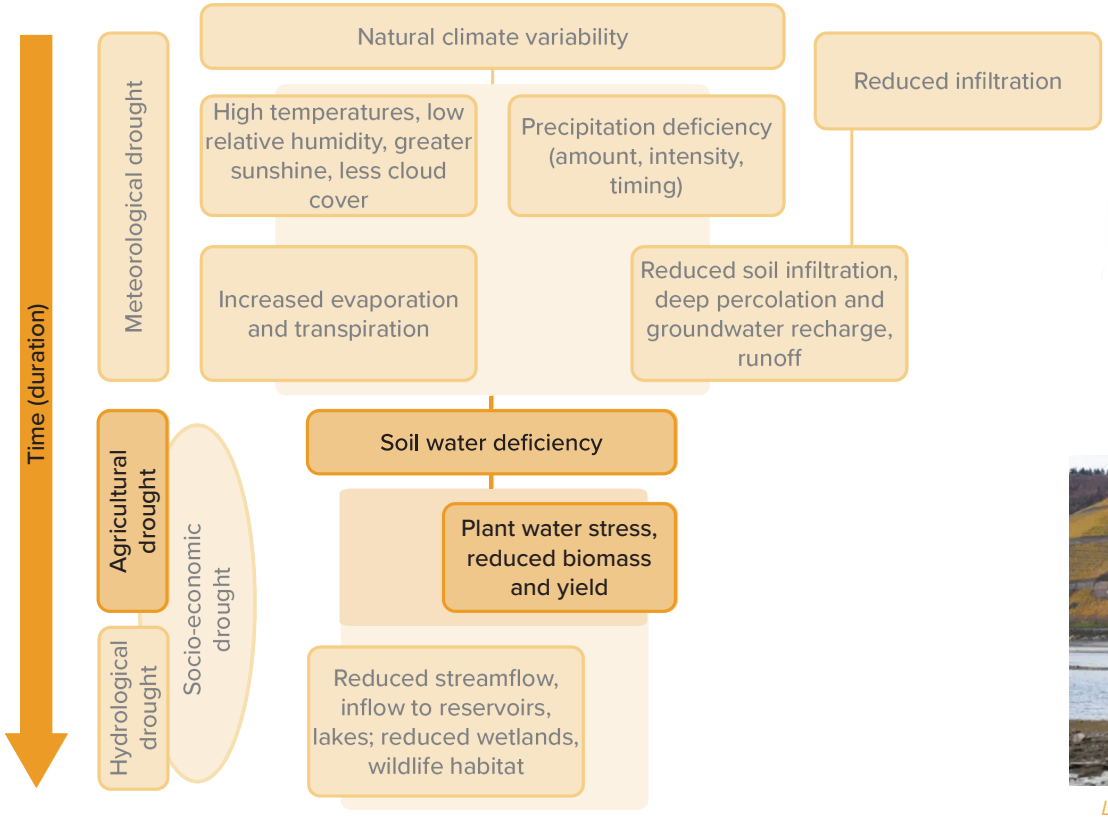
Drought explained



Below average precipitation

Alpine Rhine (Flimslaax, n.d.)

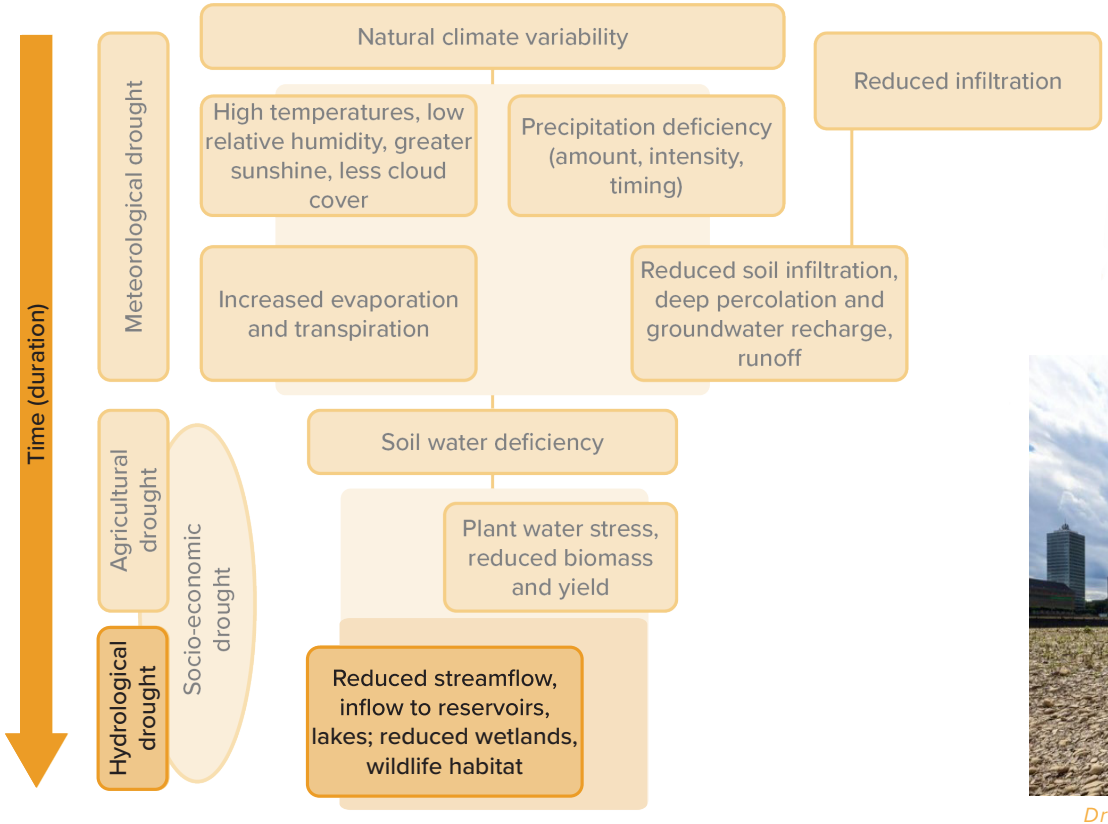
Drought explained



Lack of soil moisture

Low precipitation leads to agricultural drought along the Rhine (Rentz, 2019)

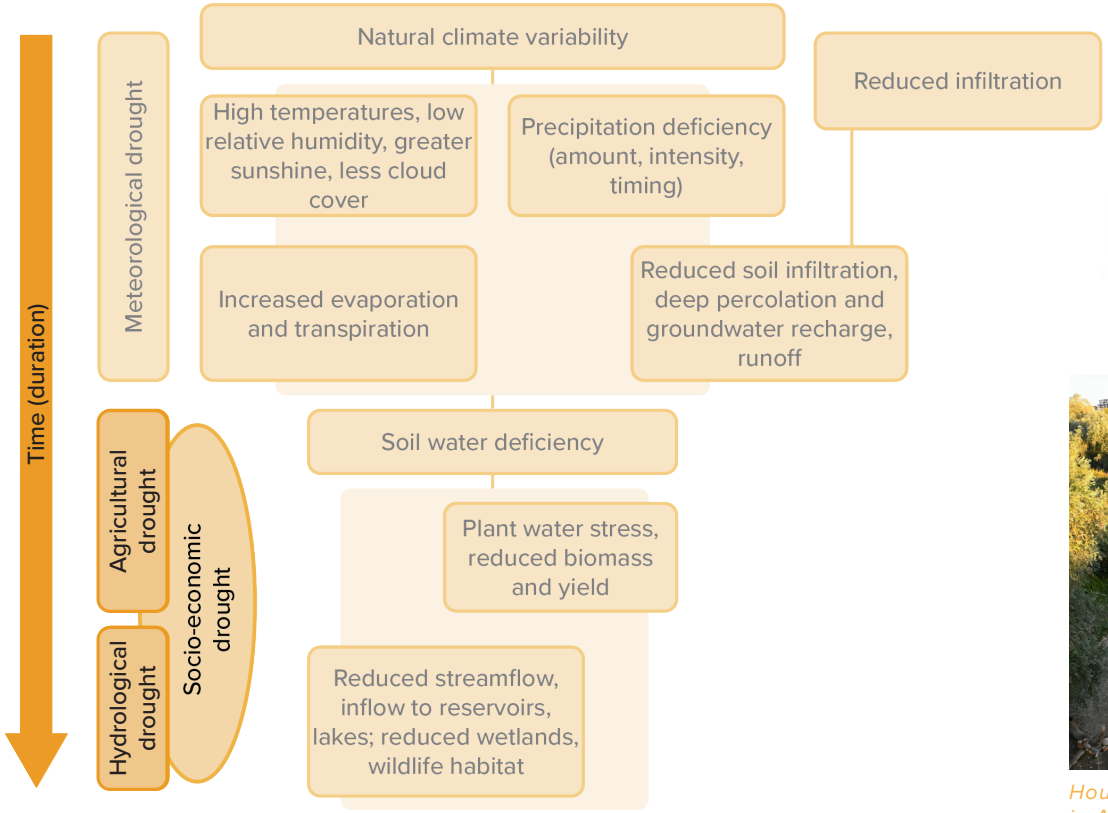
Drought explained



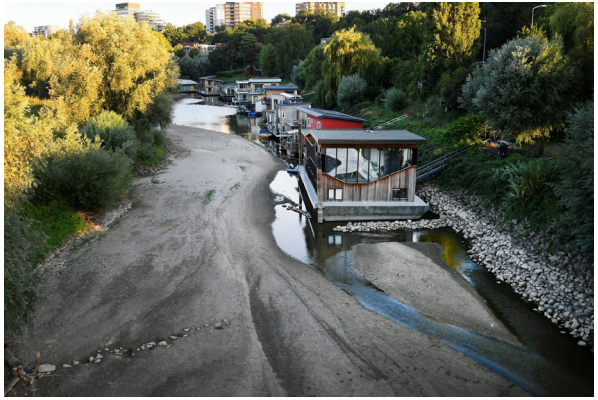
Streamflows, lakes and groundwater see a significant reduction in the amount of water

Drought in Düsseldorf, the Rheinkniebridge spans only dry ground (Oberhäuser, 2022)

Drought explained

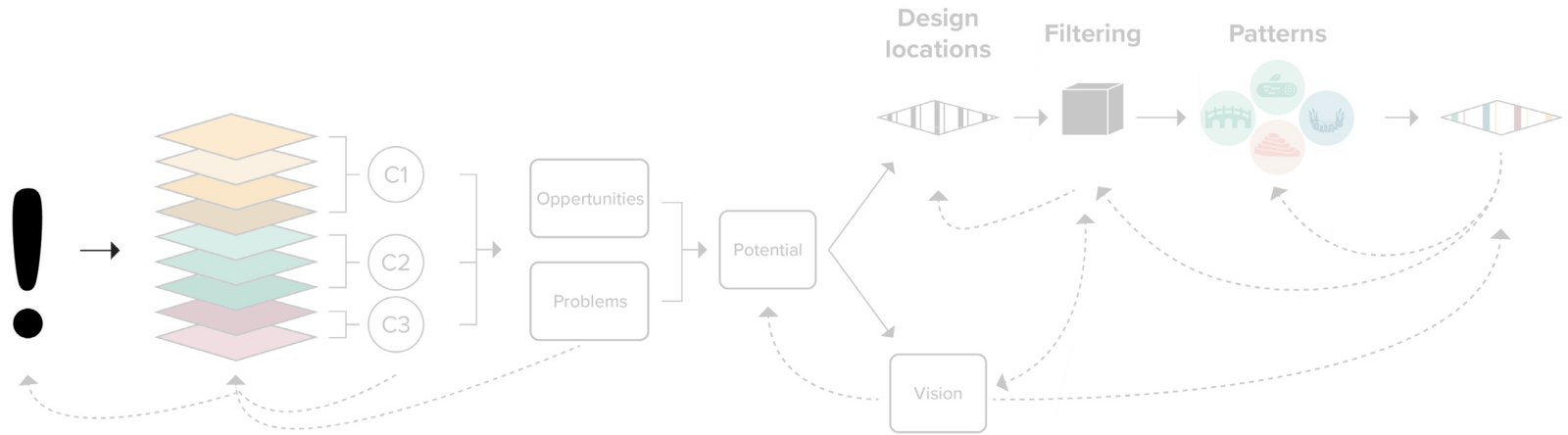


During different phases of drought.
The lack of water effecting the economy and well-being of people.



Houseboats are on dry land in the Waal near Nijmegen in August 2022 (Wouw, 2022)

Problems Analysis Conclusions Potentials Strategy Design



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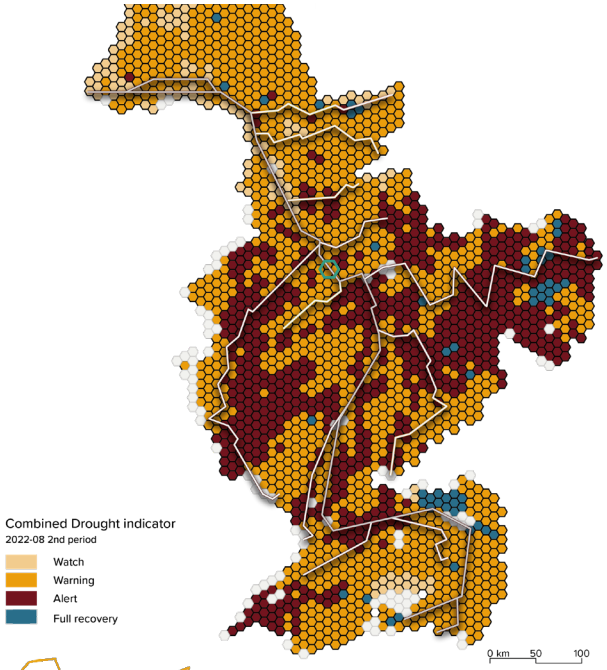
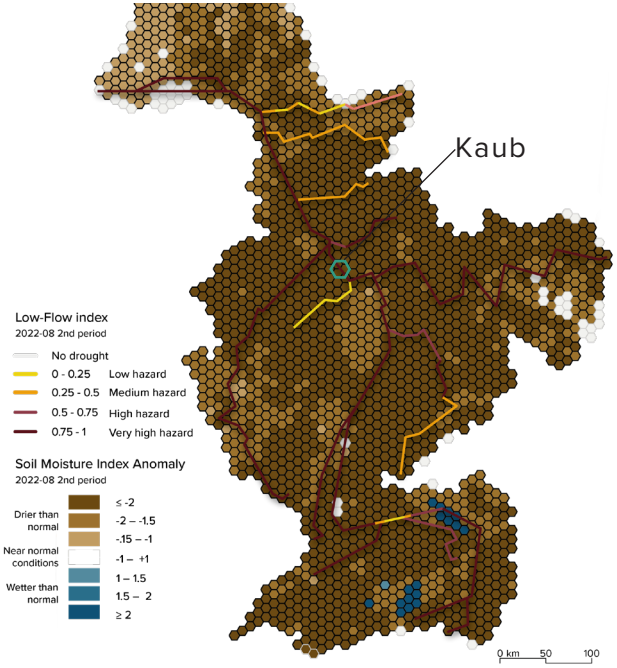
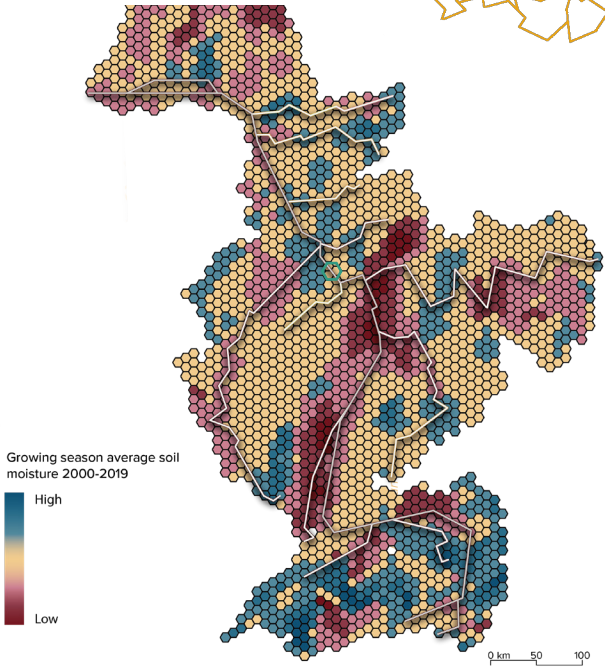
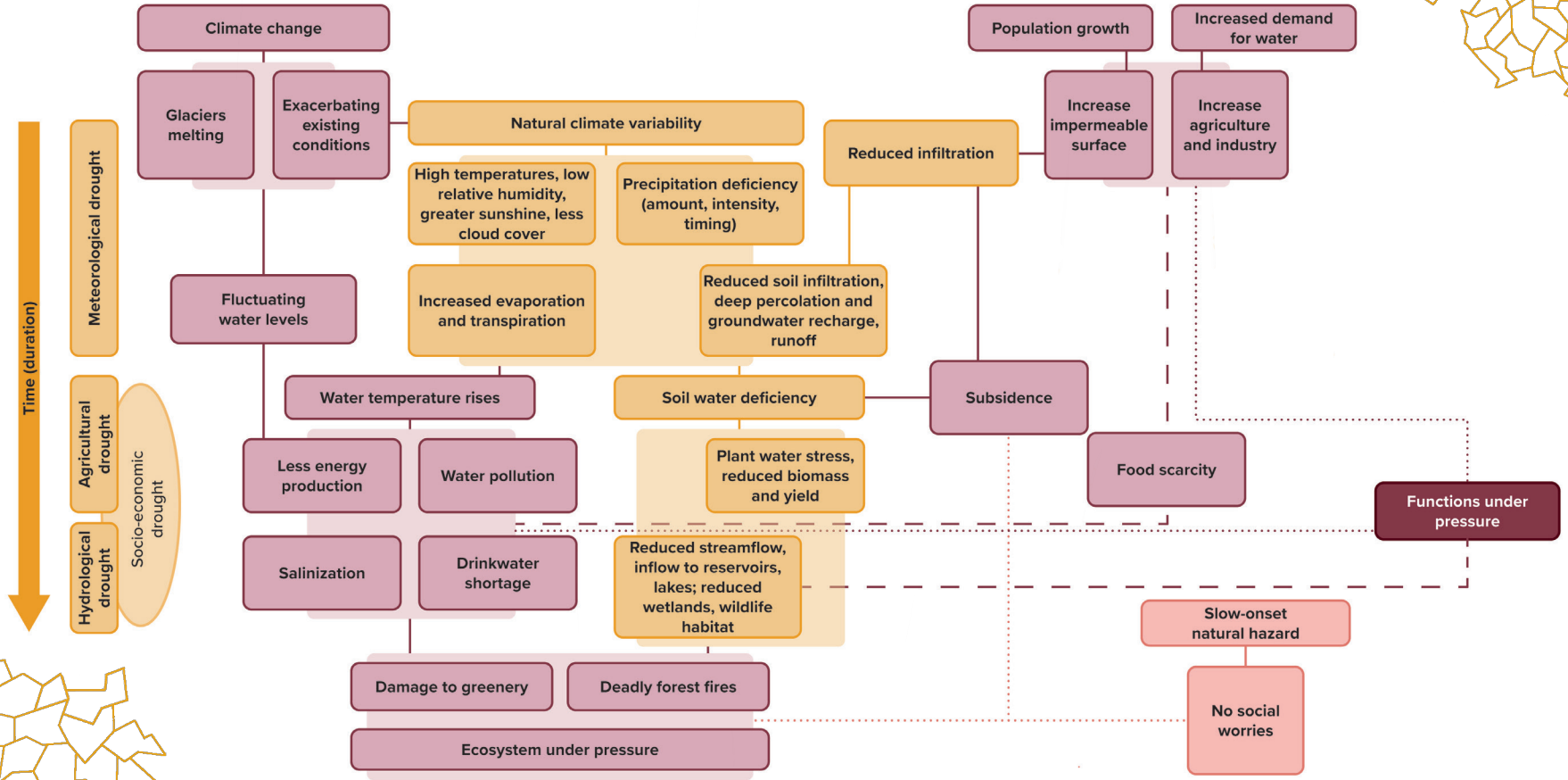
Problem field







Problem statement



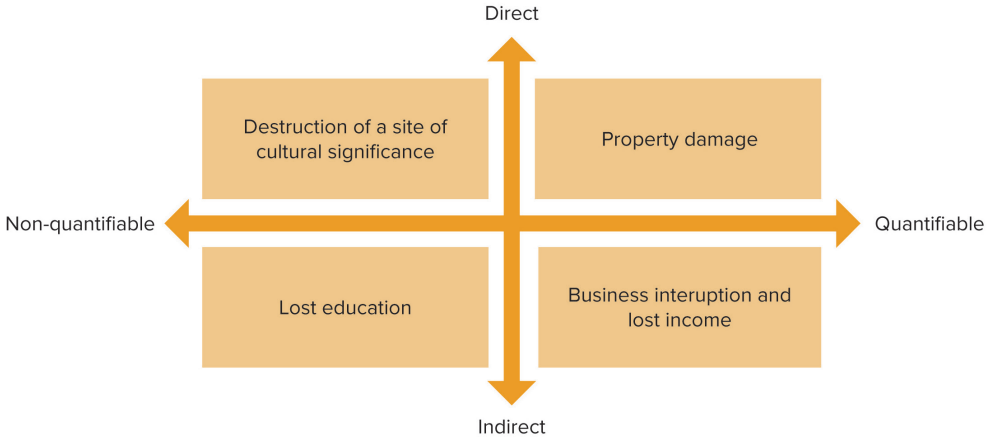
Problem statement

Het waterpeil van de Rijn ter hoogte van Kaub dusdanig laag dat het voor het meeste scheepvaartverkeer onmogelijk is om te bevaren (Gennip, 2022)

Problem statement

In 2018, water levels in the Rhine dropped to lows unseen along the river, hugely impacting thousands of businesses (Gerten et al., 2018)

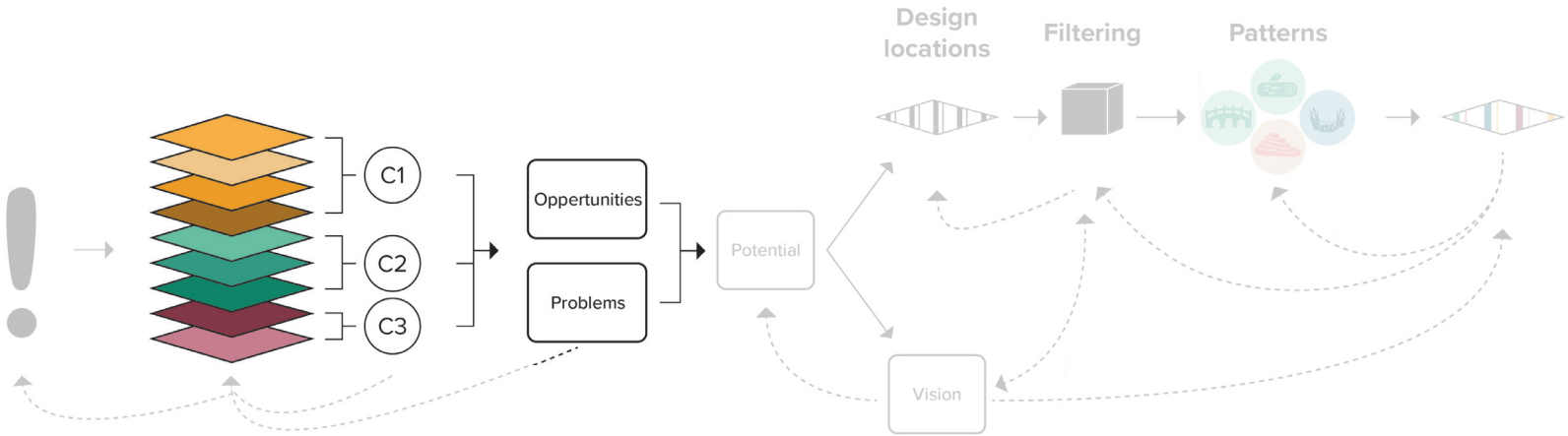
Problem statement



Indirect and intangible losses. Based on PreventionWeb (n.d.)

How can the river Rhine stay a functional riverscape by creating a synergy between urban and rural areas while using the green-blue infrastructure approach to mitigate drought-related problems?

Problems **Analysis** **Conclusions** **Potentials** Strategy Design



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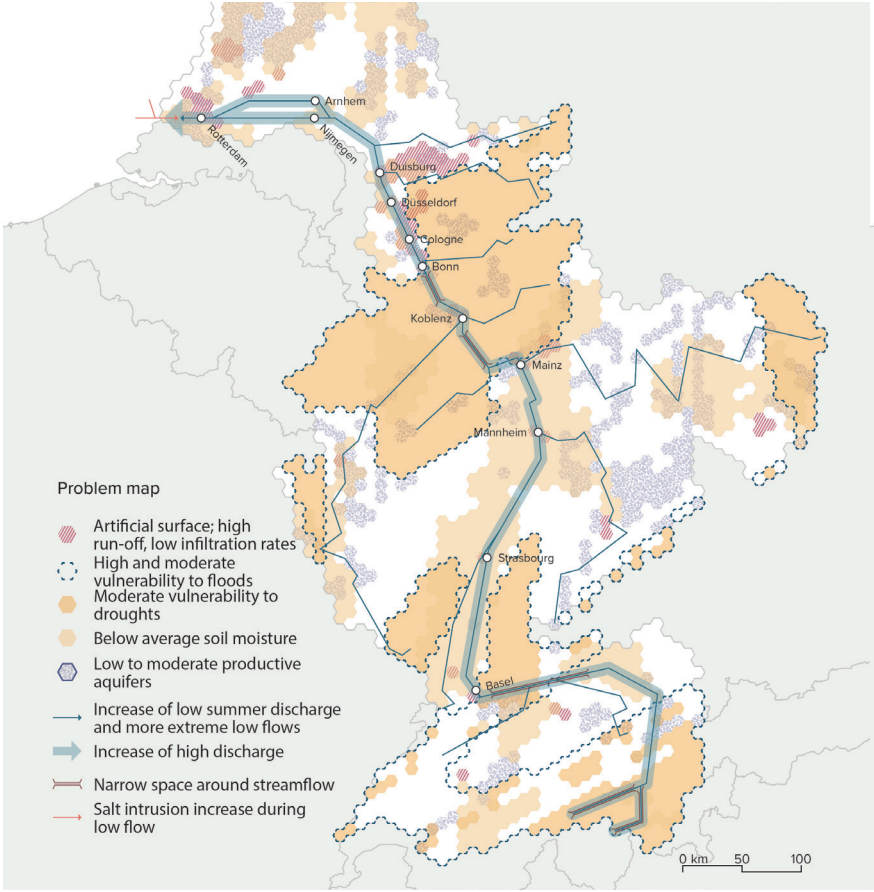
Potentials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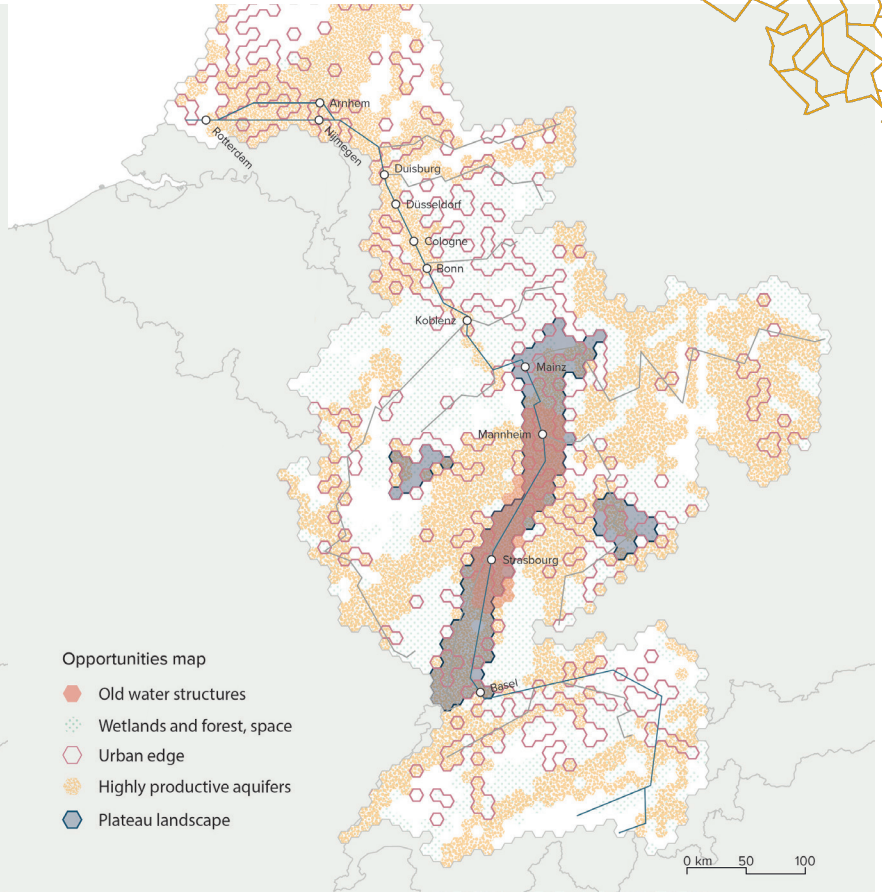
Strasbourg
Basel
Problem map
Artificial surface; high run-off, low infiltration rates
High and moderate vulnerability to floods
Moderate vulnerability to droughts
Below average soil moisture
Low to moderate productive aquifers
Increase of low summer discharge and more extreme low flows
Increase of high discharge
Narrow space around streamflow
Salt intrusion increase during low flow
0 km 50 100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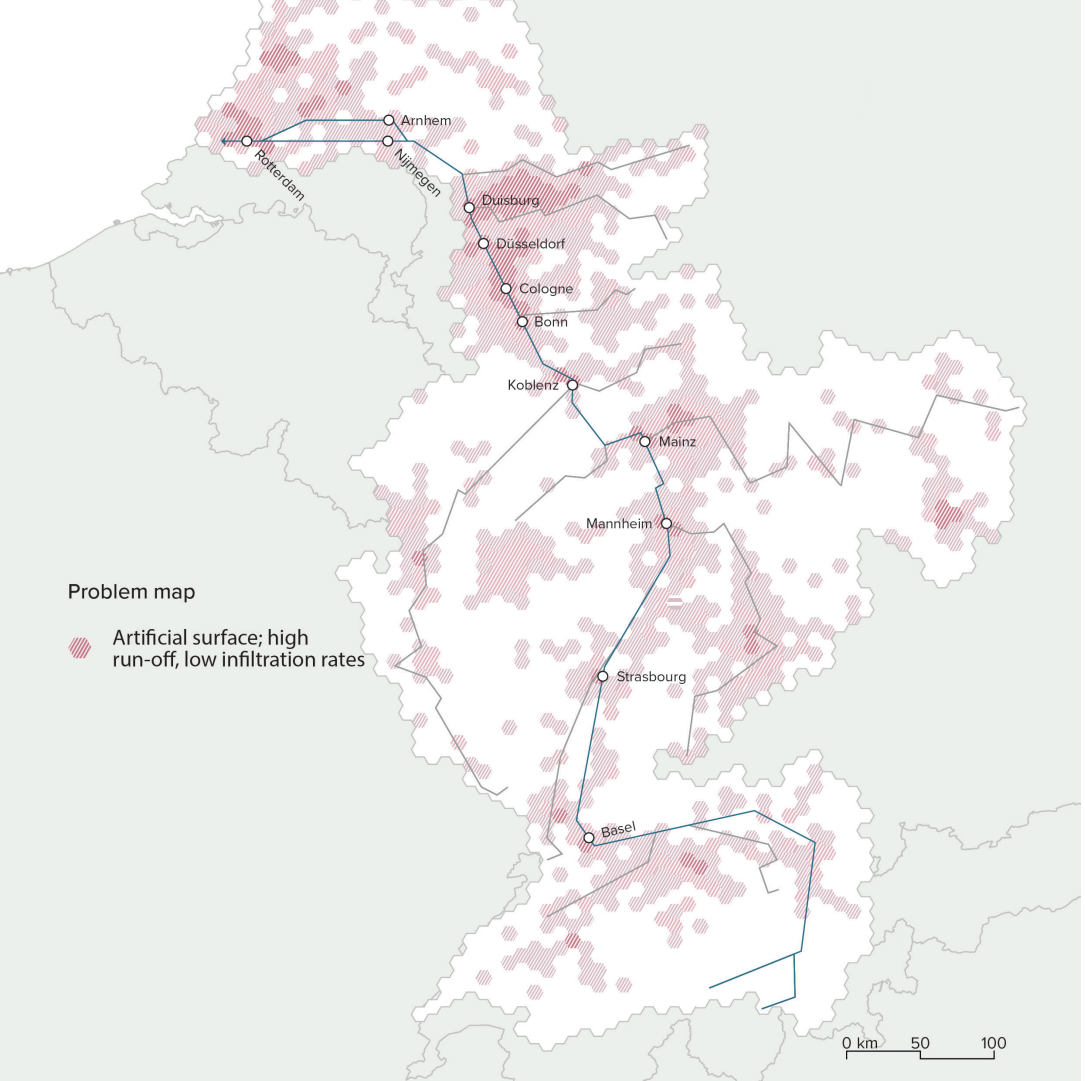
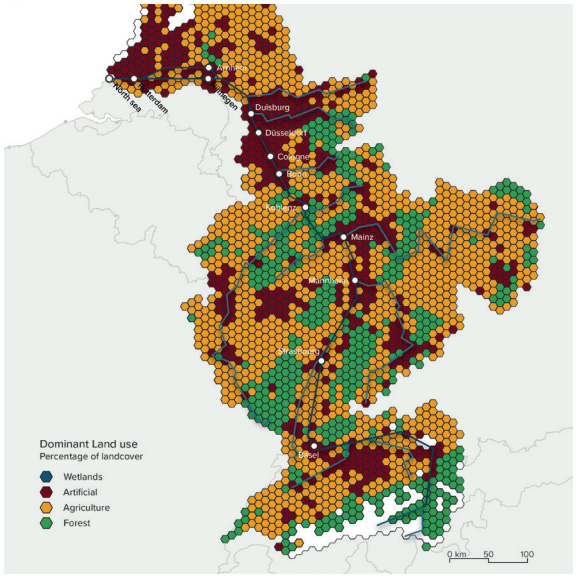
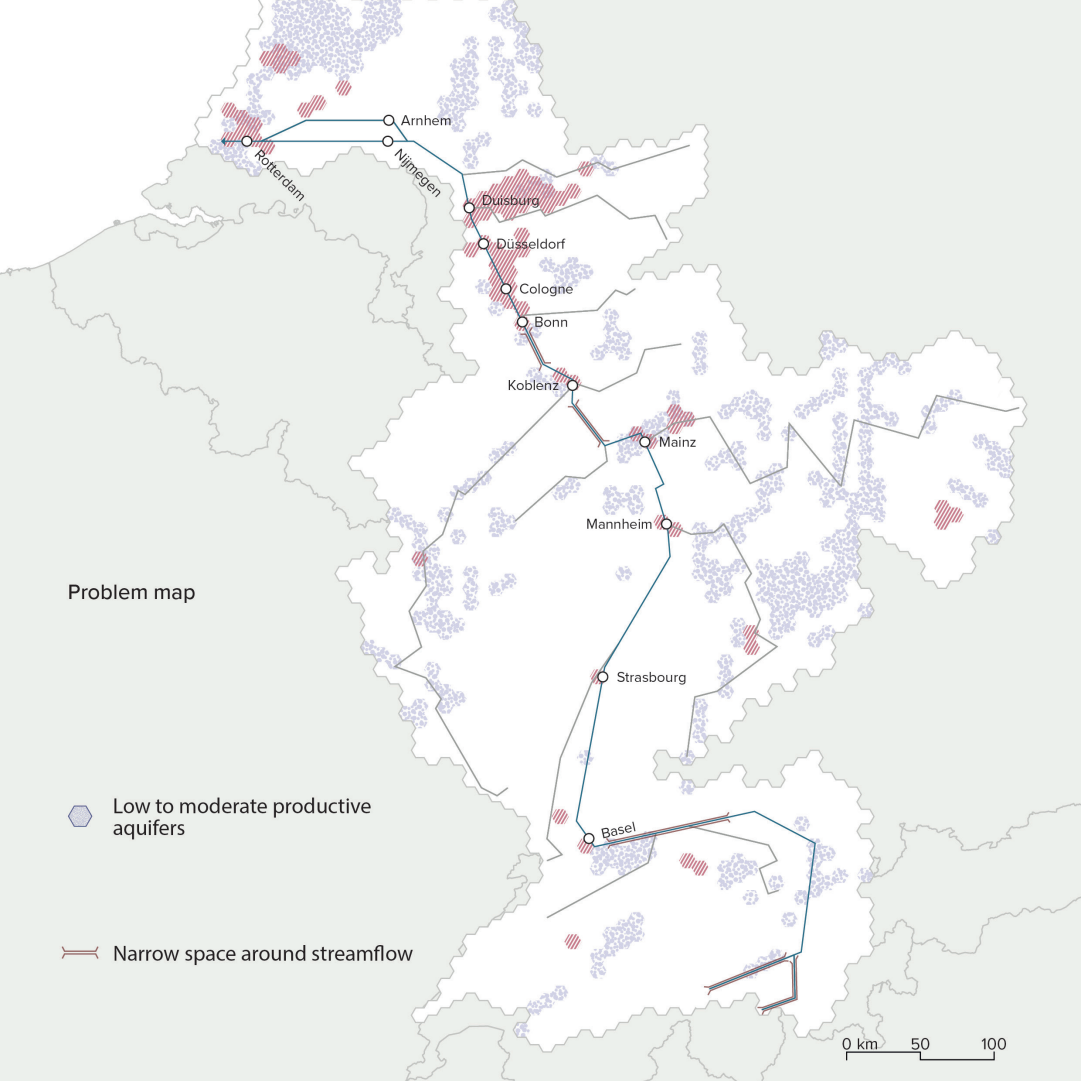
Opportunities map
Old water structures
Wetlands and forest, space
Urban edge
Highly productive aquifers
Plateau landscape
0 km 50 100

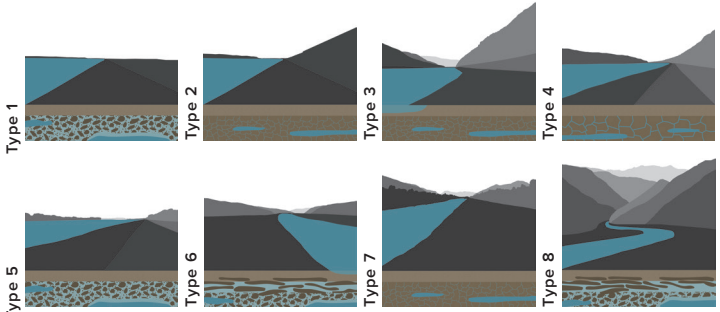
Problem map - Land use

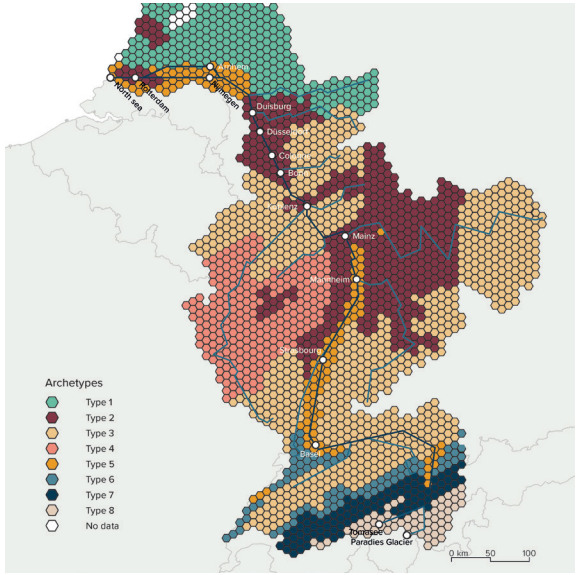




Problem map - Geomorphology

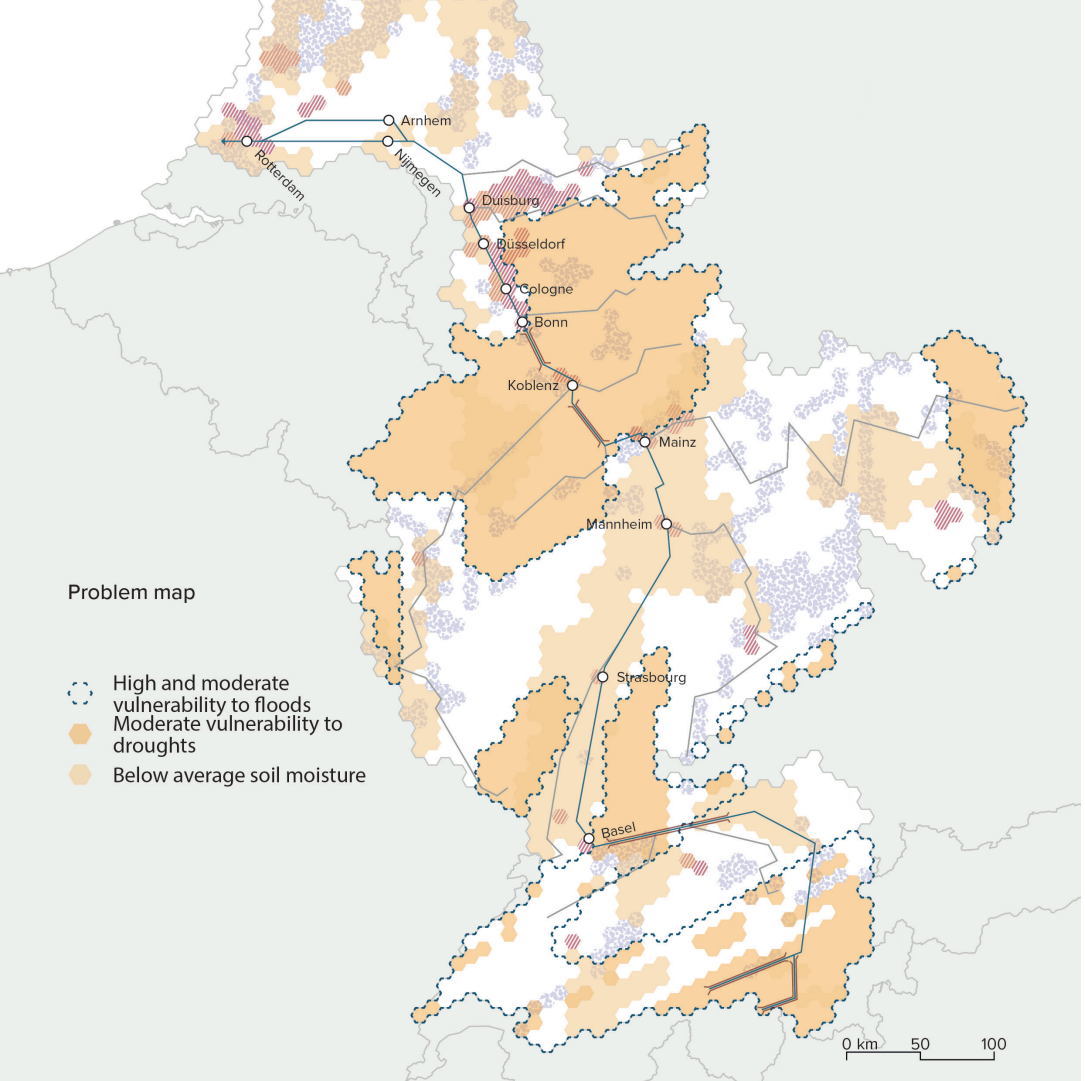


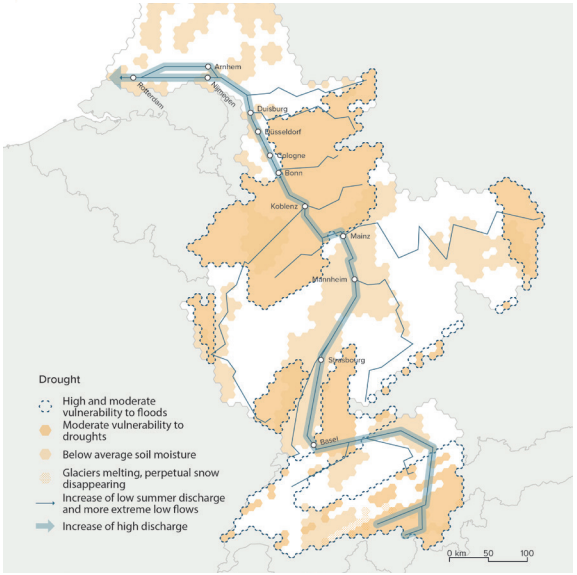




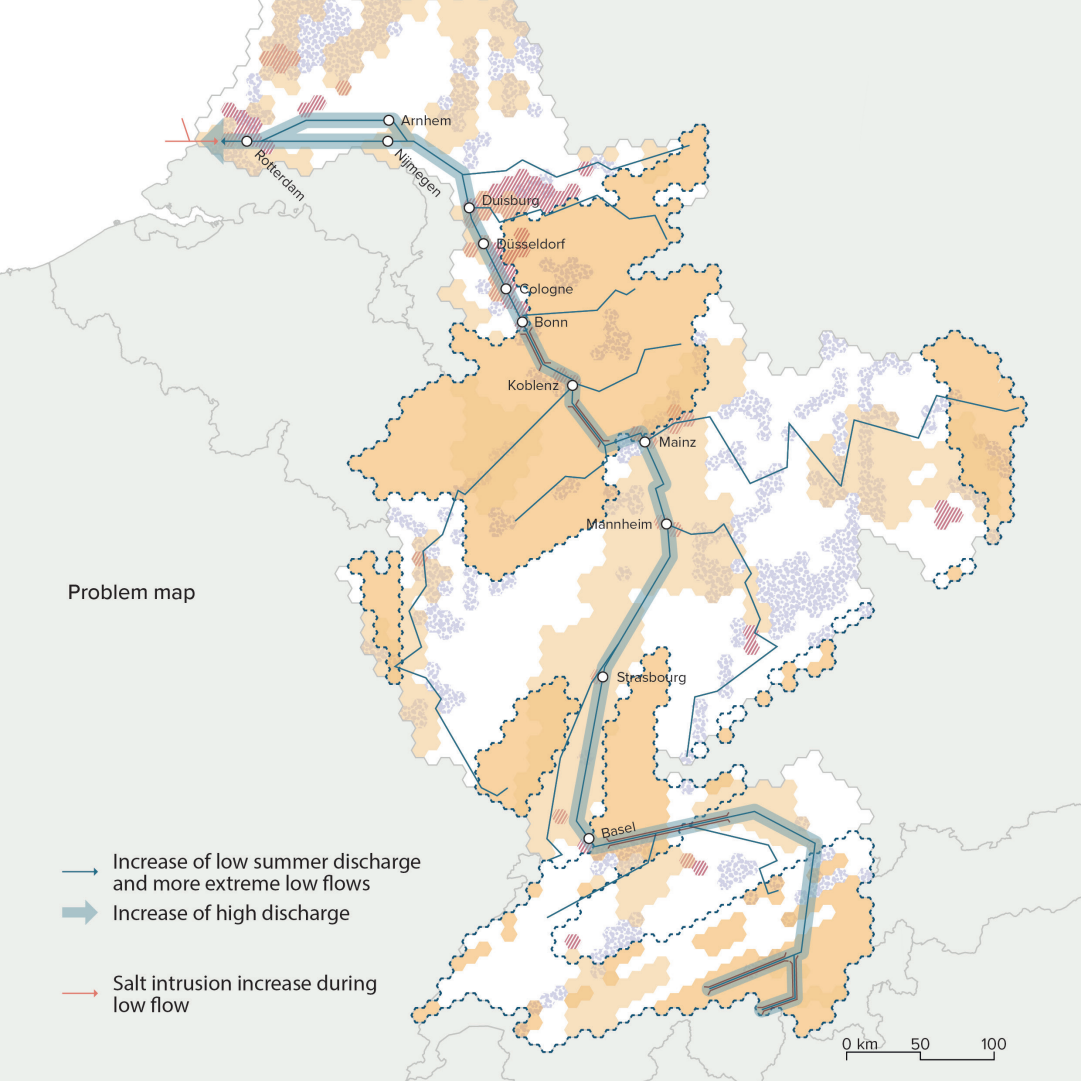
Problem map - Drougth

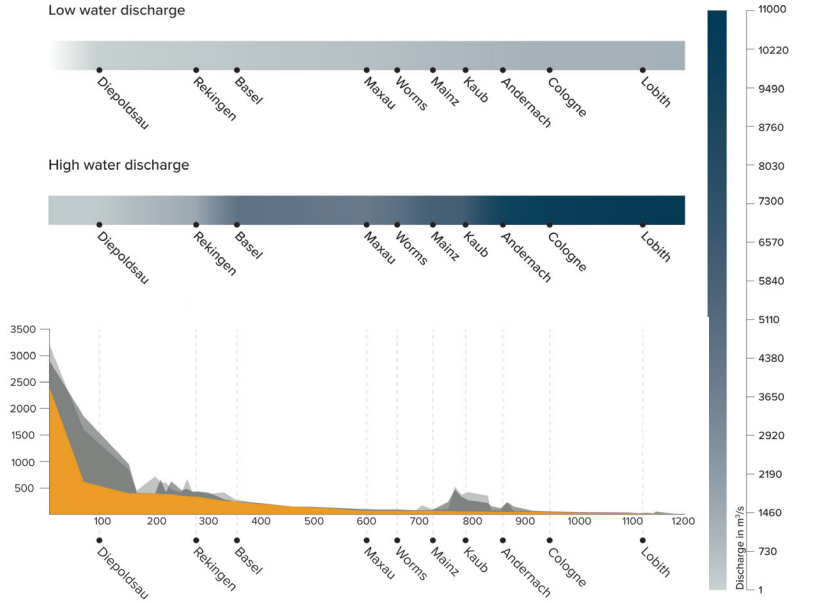
- Low flow index
- Combined drought indicator
- Soil moisture index anomaly
- Groundwater vulnerability
- Growing season average soil moisture





Problem map - Discharge





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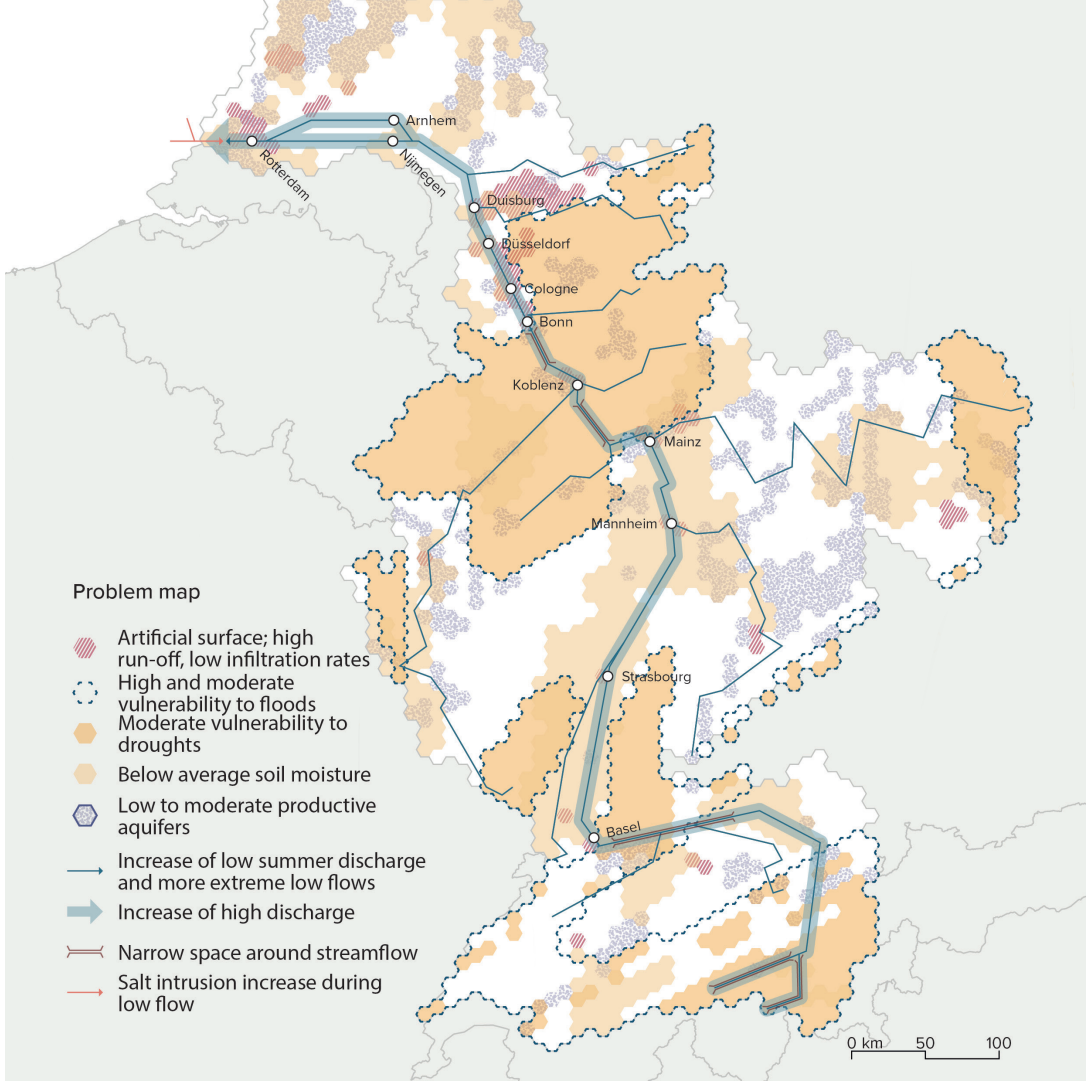
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50
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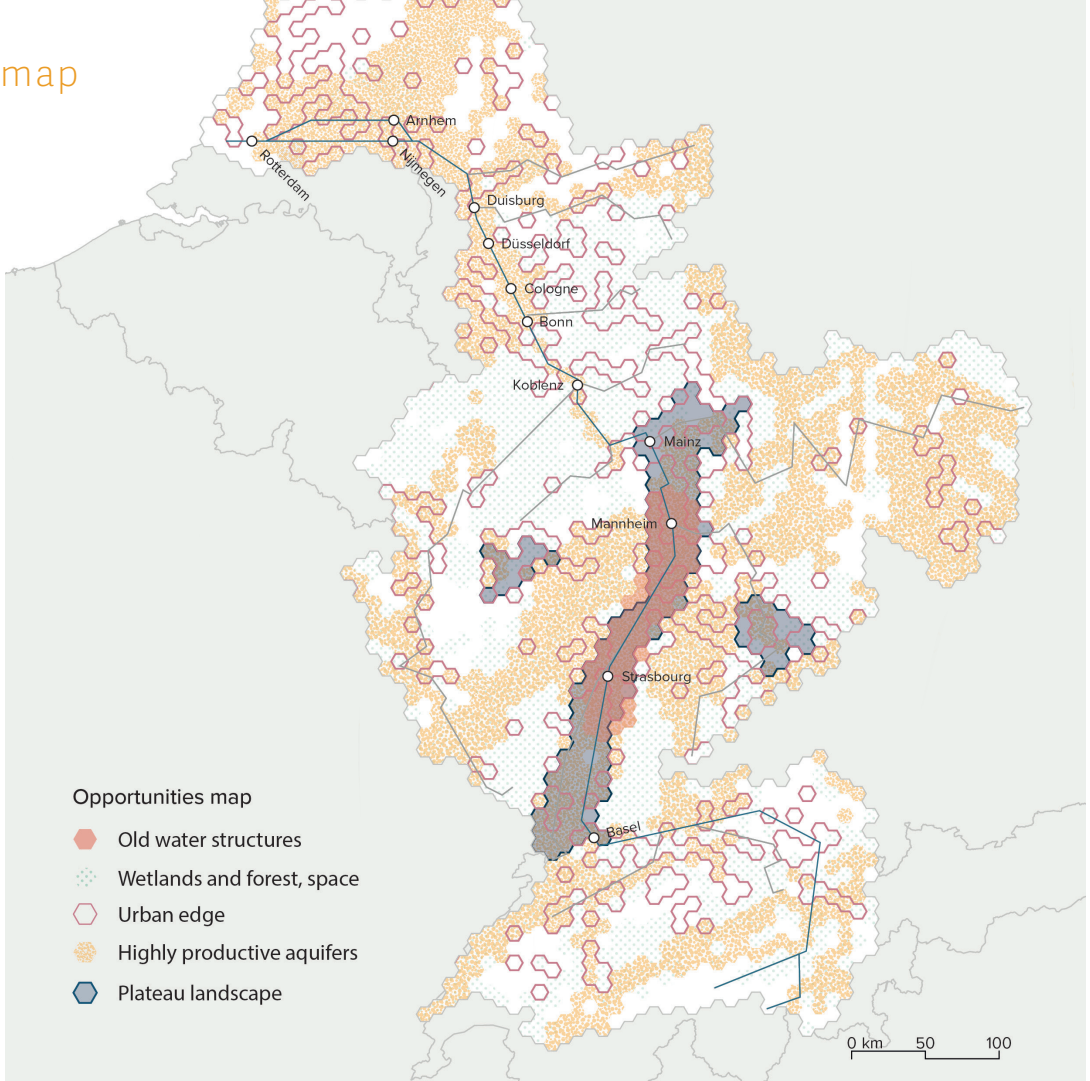
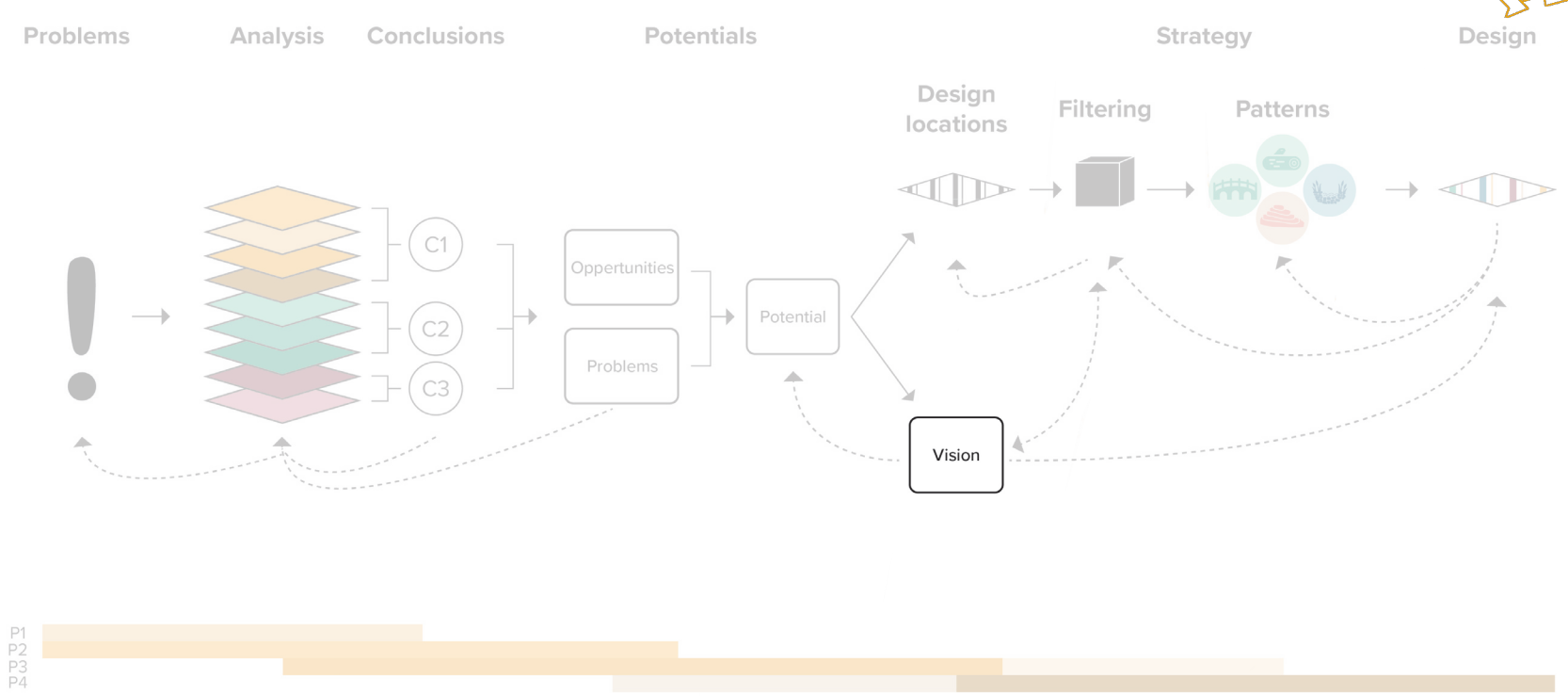
Opportunities map

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Vision statement

Backbone

Blue infrastructure

Supproted by green implementations

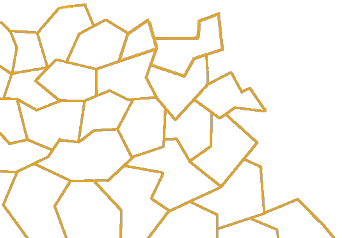
Beyond borders

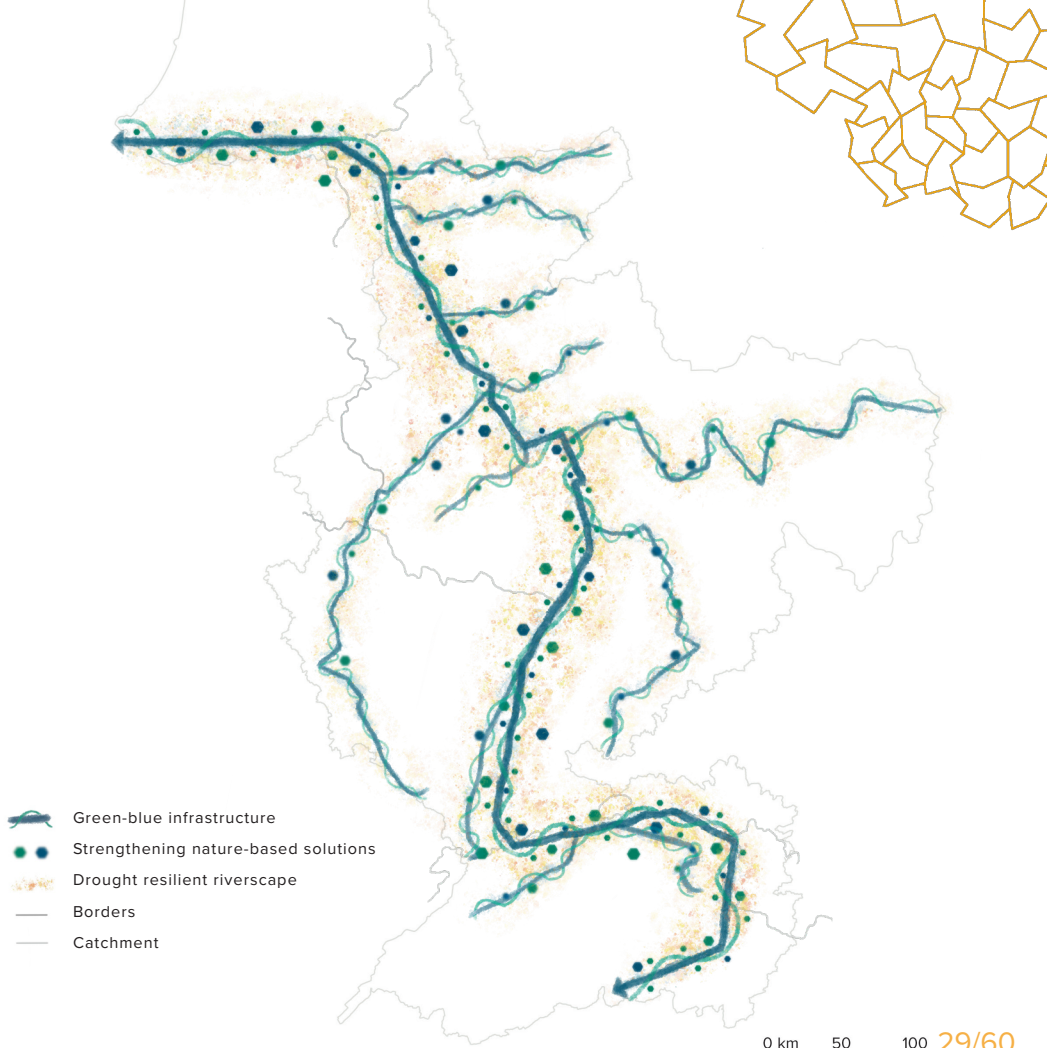
Tributaries

Strengthening

Nature-based solutions

Drought-mitigating strategy





Green-blue infrastructure

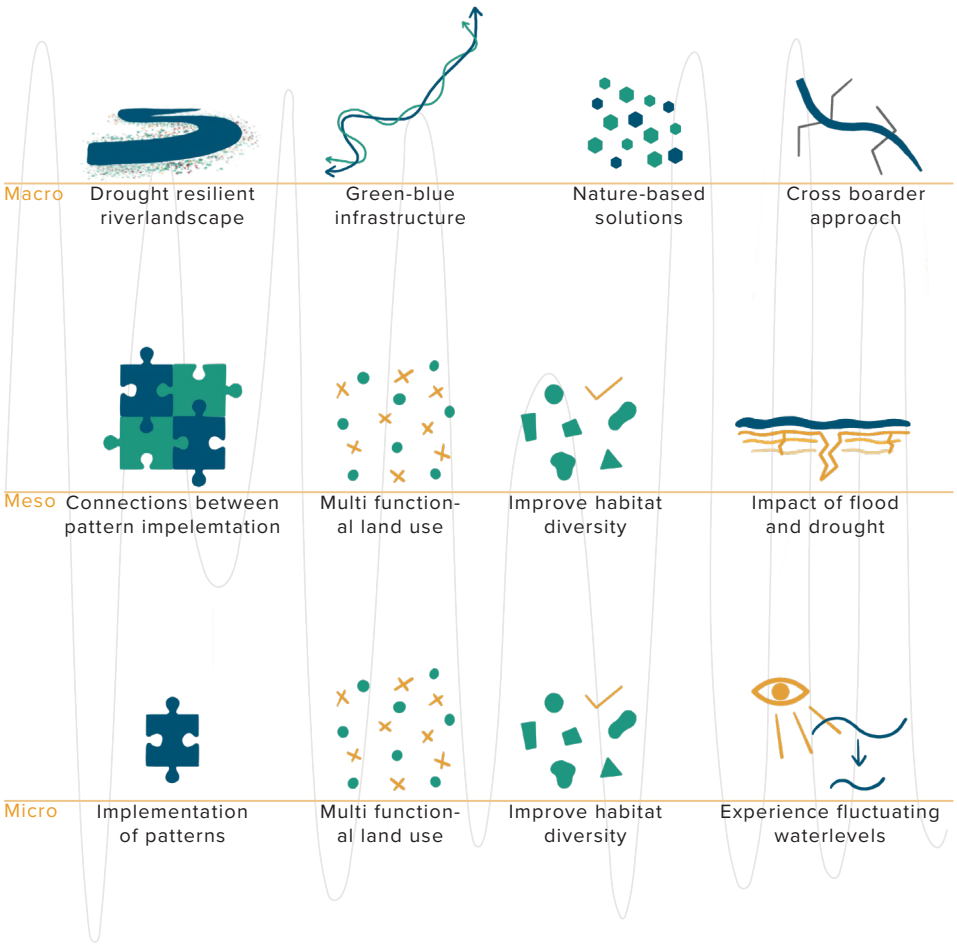
Network of ecosystems
Crossscale relationships

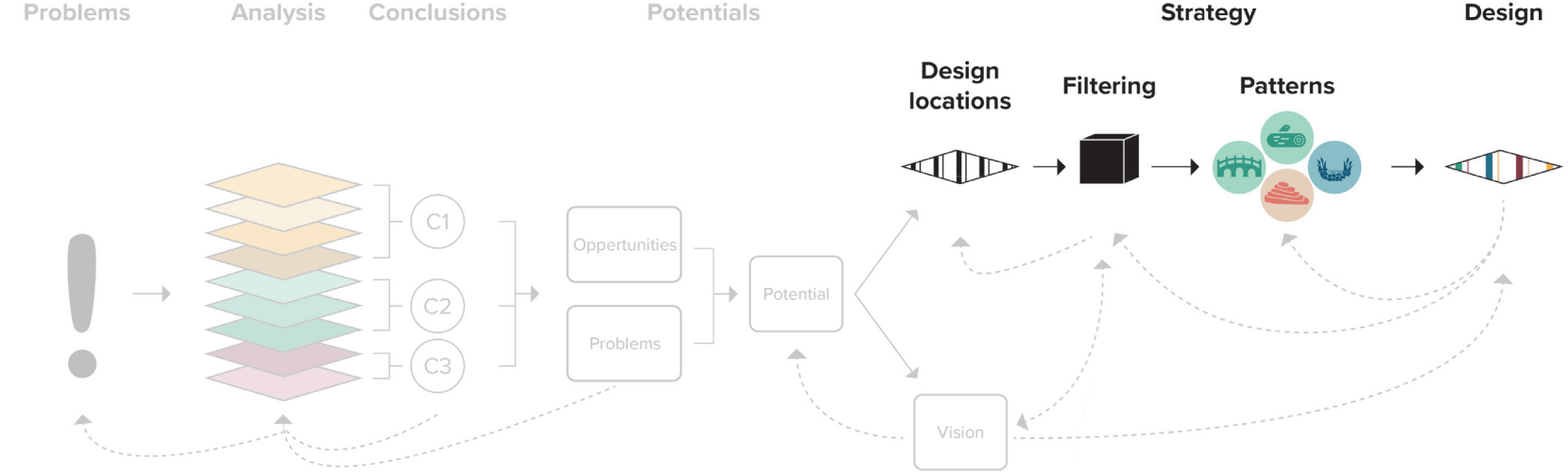
Nature-based solutions

Working with nature and ecosystem
Connection with smaller scale

Blick vom Isteiner Klotz Rheinaufwärts gegen Basel
(Peter Birmann, 1844)

Vision concepts

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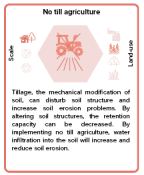
Patterns

Buffer strips and hedges

Buffer strips provide effective water infiltration, and they slow surface run-off. Permanent vegetation along buffer strips promotes the natural retention of water. By implementing hedges alongside buffer strips, soil erosion can be reduced and slow surface run-off, especially along sloped areas.

No till agriculture



Tillage, the mechanical modification of soil, can disturb soil structure and increase soil erosion problems. By altering soil structures, the retention capacity can be decreased. By implementing no till agriculture, water infiltration into the soil will increase and reduce soil erosion.

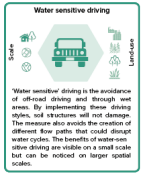
Reduced stocking density

Livestock can have a severely destructive impact on the soil structure. By reducing the density of livestock, the negative effects on the soil are reduced. Water infiltration into the soil gets less impacted, leading to better groundwater recharge and less flood risk.

Intercropping

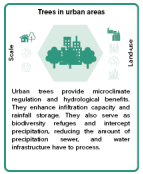
Intercropping is the practice of growing two or more crops next to each other. By intercropping, greater yield can be produced, and land can be more productively utilised. By using a combination of deep-rooted and shallow-rooted crops, infiltration rates of soil can be improved. By using intercropping, space can be created for other water retention measures.

Water sensitive driving



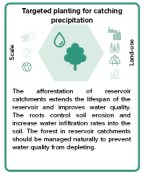
'Water sensitive' driving is the avoidance of off-road driving and through wet areas. By implementing these driving styles, soil structures will not damage. The measure also avoids the creation of different flow paths that could disrupt water cycles. The benefits of water-sensitive driving are visible on a small scale but can be noticed on larger spatial scales.

Trees in urban areas



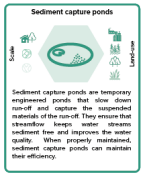
Urban trees provide microclimate regulation and hydrological benefits. They enhance infiltration capacity and rainfall storage. They also serve as biodiversity refugees and intercept precipitation, reducing the amount of precipitation sewer, and water infrastructure have to process.

Targeted planting for catching precipitation



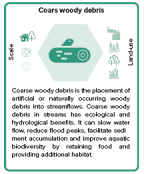
The afforestation of reservoir catchments extends the lifespan of the reservoir and improves water quality. The roots control soil erosion and increase water infiltration rates into the soil. The forest in reservoir catchments should be managed naturally to prevent water quality from depleting.

Sediment capture ponds



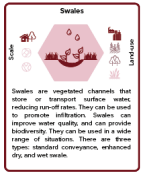
Sediment capture ponds are temporary engineered ponds that slow down run-off and capture the suspended materials of the run-off. They ensure that streamflow keeps water streams sediment free and improves the water quality. When properly maintained, sediment capture ponds can maintain their efficiency.

Coars woody debris



Coarse woody debris is the placement of artificial or naturally occurring woody debris into streamflows. Coarse woody debris in streams has ecological and hydrological benefits. It can slow water flow, reduce flood peaks, facilitate sediment accumulation and improve aquatic biodiversity by retaining food and providing additional habitat.

Swales

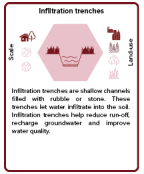


Swales are vegetated channels that store or transport surface water, reducing run-off rates. They can be used to promote infiltration. Swales can improve water quality, and can provide biodiversity. They can be used in a wide range of situations. There are three types: standard conveyance, enhanced dry, and wet swale.

Rainwater harvesting

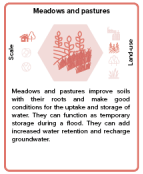
Rainwater harvesting is collecting and storing rainwater using water butts or larger tanks. Water butts are primarily for small-scale use in households, while tanks can manage stormwater volumes. However, rainwater harvesting is limited during wet periods and should be considered part of a sustainable water management system in combination with other measures.

Infiltration trenches



Infiltration trenches are shallow channels filled with rubble or stone. These trenches let water infiltrate into the soil. Infiltration trenches help reduce run-off, recharge groundwater and improve water quality.

Meadows and pastures



Meadows and pastures improve soils with their roots and make good conditions for the uptake and storage of water. They can function as temporary storage during a flood. They can add increased water retention and recharge groundwater.

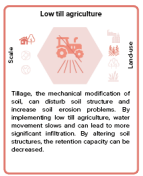
Mulching

Mulching is the application of adding material to the surface of the existing soil. Preferably the mulch is an organic material. Mulching can improve the capacity of the soil to store water.

Green cover

Green cover is the planting of crops in the late summer or autumn. Green cover protects the soil against erosion. Green cover can also improve soil structures and improve the infiltration of soil.

Low till agriculture

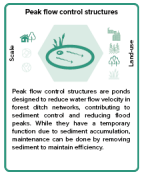


Tillage, the mechanical modification of soil, can disturb soil structure and increase soil erosion problems. By implementing low till agriculture, water movement slows and can lead to more significant infiltration. By altering soil structures, the retention capacity can be decreased.

Urban forest parks

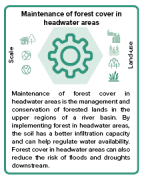
Urban forest parks provide various ecosystem and hydrology-related benefits. They enhance air quality, biodiversity, and recreation and mitigate climate change while improving local microclimates. Forest soil has a higher infiltration capacity than other urban land covers, considerably impacting aquifer recharge.

Peak flow control structures



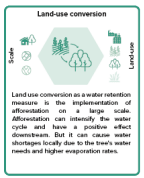
Peak flow control structures are ponds designed to reduce water flow velocity in forest ditch networks, contributing to sediment control and reducing flood peaks. While they have a temporary function due to sediment accumulation, maintenance can be done by removing sediment to maintain efficiency.

Maintenance of forest cover in headwater areas



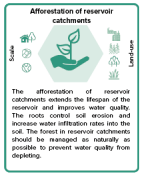
Maintenance of forest cover in headwater areas is the management and conservation of forested lands in the upper regions of a river basin. By implementing forest in headwater areas the soil has a better infiltration capacity and can help regulate water availability. Forest cover in headwater areas can also reduce the risk of floods and droughts downstream.

Land-use conversion



Land use conversion as a water retention measure is the implementation of afforestation on a large scale. Afforestation can intensify the water cycle and have a positive effect downstream. But it can cause water shortages locally due to the tree's water needs and higher evaporation rates.

Afforestation of reservoir catchments

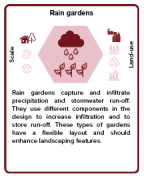


The afforestation of reservoir catchments extends the lifespan of the reservoir and improves water quality. The roots control soil erosion and increase water infiltration rates into the soil. The forest in reservoir catchments should be managed as naturally as possible to prevent water quality from depleting.

Soakaways

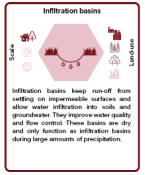
Soakaways are underground storage that store and allow surface water to soak into the ground. They provide stormwater treatment, recharge groundwater, and have the potential to mitigate low river flows. Soakaways are easy to integrate into sites and do not take up land. They do not have any additional benefits for biodiversity.

Rain gardens



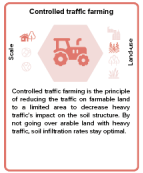
Rain gardens capture and infiltrate precipitation and stormwater run-off. They use different components in the design to increase infiltration and to store run-off. These types of gardens have a flexible layout and should enhance landscaping features.

Infiltration basins



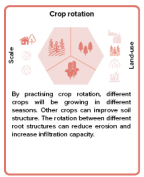
Infiltration basins keep run-off from settling on impermeable surfaces and allow water infiltration into soils and groundwater. They improve water quality and flow control. These basins are dry and only function as infiltration basins during large amounts of precipitation.

Controlled traffic farming



Controlled traffic farming is the principle of reducing the traffic on farmable land to a limited area to decrease heavy traffic's impact on the soil structure. By not going over arable land with heavy traffic, soil infiltration rates stay optimal.

Crop rotation

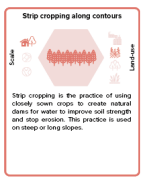


By practising crop rotation, different crops will be growing in different seasons. Other crops can improve soil structure. The rotation between different root structures can reduce erosion and increase infiltration capacity.

Early sowing

By implementing early sowing, usually up to six weeks earlier than the typical sowing season, winter crops can root and create a more robust green cover for the winter. This green cover protects the soil against erosion. It can also improve soil structures and infiltration rates. Early sowing can also help with the impact of drought during summer, as plants are already rooted.

Strip cropping along contours

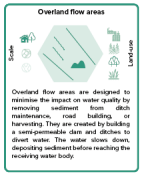


Strip cropping is the practice of using closely sown crops to create natural dams for water to improve soil strength and stop erosion. This practice is used on steep or long slopes.

Traditional terracing

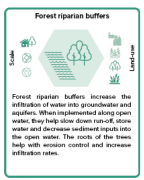
Traditional terracing is implemented along slopes. These platforms, created in sloped areas, can be sustained by stone walls and support farming. The structure of terracing can reduce soil erosion and slow down surface run-off. Because of the horizontal layout, infiltration is also improved.

Overland flow areas



Overland flow areas are designed to minimise the impact on water quality by removing sediment from ditch maintenance, road building, or harvesting. They are created by building a semi-permeable dam and ditches to divert water. The water slows down, depositing sediment before reaching the receiving water body.

Forest riparian buffers

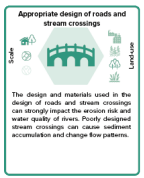


Forest riparian buffers increase the infiltration of water into groundwater and aquifers. When implemented along open water, they help slow down run-off, store water and decrease sediment inputs into the open water. The roots of the trees help with erosion control and increase infiltration rates.

Continuous cover forestry

Continuous cover forestry combines a range of forest management practices. The main principle is the protection of the soil and the creation of a continuous cover. This strategy includes a natural forest hydrological cycle with beneficial hydrological effects. Continuous cover forestry also reduces the impact of run-off.

Appropriate design of roads and stream crossings

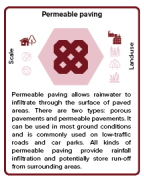


The design and materials used in the design of roads and stream crossings can strongly impact the erosion risk and water quality of rivers. Poorly designed stream crossings can cause sediment accumulation and change flow patterns.

Retention ponds

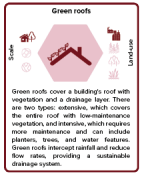
Retention ponds are designed to hold excess run-off and release this water slowly to prevent flooding. They can improve water quality and are shallow zones for ecology. Retention ponds have ecological benefits and can be incorporated into public open spaces.

Permeable paving



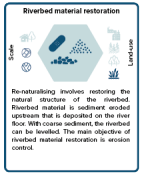
Permeable paving allows rainwater to infiltrate through the surface of paved areas. There are two types: porous pavements and permeable pavements. It can be used in most ground conditions and is commonly used on low-traffic roads and car parks. All kinds of permeable paving provide rainfall infiltration and potentially store run-off from surrounding areas.

Green roofs



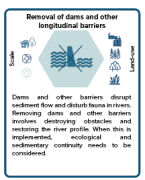
Green roofs cover a building's roof with vegetation and a drainage layer. There are two types: extensive, which covers the entire roof with low-maintenance vegetation, and intensive, which requires more maintenance and can include planters, trees, and water features. Green roofs intercept rainfall and reduce flow rates, providing a sustainable drainage system.

Riverbed material restoration



Re-naturalising involves restoring the natural structure of the riverbed. Riverbed material is sediment eroded upstream that is deposited on the river floor. With coarse sediment, the riverbed can be levelled. The main objective of riverbed material restoration is erosion control.

Removal of dams and other longitudinal barriers

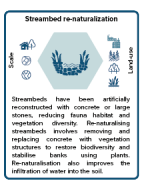


Dams and other barriers disrupt sediment flow and disturb fauna in rivers. Removing dams and other barriers involves destroying obstacles and restoring the river profile. When this is implemented, ecological and sedimentary continuity needs to be considered.

Re-meandering

A river meander is a U-form that slows water velocity. Many rivers in Europe have been straightened and channelised for various reasons. River re-meandering creates new flow structures, gives more space for water, and improves sedimentation and biodiversity. By creating new meandering courses, new habitats for various plant and animal species can be provided.

Streambed re-naturalization



Streambeds have been artificially reconstructed with concrete or large stones, reducing fauna habitat and vegetation diversity. Re-naturalising streambeds involves removing and replacing concrete with vegetation structures to restore biodiversity and stabilise banks using plants. Re-naturalisation also improves the infiltration of water into the soil.

Restoration and reconnection of seasonal streams

Seasonal streams are rivers that dry up during dry periods in the year but are essential for supporting biodiversity. They provide ecosystem services such as flood control and irrigation. Restoring and reconnecting seasonal streams can improve the overall functioning of the river by altering flows, improving infiltration and improving water retention during floods.

Re-naturalization of polder areas

A polder is a piece of land surrounded by dikes with its own hydrological system. The re-naturalisation of polder areas involves providing more water storage and increasing biodiversity.

Wetland restoration and management

Wetlands can contribute to flooding prevention, water quality improvement, store water and enhance biodiversity. Wetlands provide water retention, enhance biodiversity and can improve water quality. Wetlands can be restored on a large scale or implemented as a small-scale measure.

Restoration of natural infiltration to groundwater

Groundwater is a vital water resource for human activities, but landscape modifications have reduced the infiltration capacity of many European soils. Restoring the natural infiltration enhances the quality and availability of water, lowers run-off on land and improves groundwater aquifers.

Reconnection of oxbow lakes and similar features

An oxbow lake is a river meander that has been cut off from the main river to straighten the river flow. Reconnecting it to the river involves removing land between the two water bodies, which improves the river's overall functioning by restoring river flow, more potential for infiltration and enhancing water retention during floods.

Channels and rills

Channels and rills are shallow channels with open surface water that capture and slow run-off. They can collect and store debris, treat pollution, and guide water downstream. They can be designed in different varieties, and the planting can improve water quality.

Detention basins

Detention basins are vegetated impressions in the landscape that holds run-off. They allow pollutants and sediments to settle. Detention basins do not allow infiltration, and water is drained into nearby water structures.

Filter strips

Filter strips are gently sloping strips that treat run-off through vegetative filtering. They intercept sedimentation and let water infiltrate. Filter strips can be used as a pre-treatment technique in small drainage areas. They can serve as buffers between conflicting land uses and help with groundwater recharge.

Floodplain restoration and management

Floodplains are designed to retain flood and rainwater. However, human activities like urbanisation and land drainage have separated floodplains from the river, losing their retention capacity and ecosystem functions. Restoring floodplains requires removing sediment, modifying channels, creating wetlands and lakes and afforestation.

Detention basins and ponds

Detention basins and ponds are designed to store surface run-off. When soil conditions are good, the water can infiltrate into the ground. During dry seasons detention basins are dry and store water during periods of precipitation. Ponds contain water during dry periods.

Lake restoration

Lakes are water retention facilities with multiple uses, including flood control and water storage, to provide water for different functions. They also provide habitats for many species. Priority to agricultural services and lack of maintenance have led to siltation or drainage of lakes. Lake restoration aims to enhance old structures and functions where drainage once occurred.

Elimination of riverbank protection

Removing riverbank protection enhances the connection of the river. When removed, it can diversify flows and habitats and lessen floods in mainstreams. The elimination of riverbank protection is a prerequisite for many other measures.

Natural bank stabilisation

Riverbanks can be natural or artificial. Artificial riverbanks often have adverse effects like erosion, increased water flow and decreased biodiversity. Renaturation of riverbanks involves restoring ecological aspects to stabilise banks and allow rivers to flow more freely. Renaturing can reverse damages done to the river structure.

Filtering patterns

Step 1 Geomorphology
- Type 1
- Type 2
- Type 3
- Type 4
- Type 5
- Type 6
- Type 7
- Type 8

Step 2 Branch
- Main branch
- Tributaries

Step 3 Placement
- Delta
- Middle
- Headwater

Step 4 Land use
- Agriculture
- Wetlands
- Forest
- Artificial

Step 5 Scale
- Small
- Medium
- Large

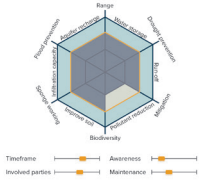
Extensive patterns

Wetland restoration and management

(Peters, n.d.)

A wetland is an area of marsh, fen, peatland, or water. It can be a natural or artificial made structure and occur permanently or temporarily. The water in the area can be static as well as flowing. A wetland provides water retention, biodiversity enhancement and water quality improvement. They can be implemented in a wide range of locations but need flat areas or topographic depressions. Restoration and management of wetlands is the practice of rehabilitating and preserving wetland ecosystems. Due to human activities, wetlands have been degraded or lost. Restoring and maintaining them can provide numerous positive benefits, like water purification, flood control, shoreline stabilisation, and habitat diversity.

(European Commission & Office International de l'Eau, 2014a)

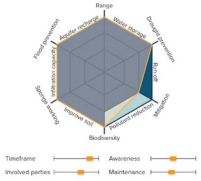


Floodplain restoration and management

(Bebanic, n.d.)

A floodplain is a relatively flat area next to a river or stream. These watercourses can experience periodic flooding. Floodplains are mainly naturally occurring structures shaped by the river's flow and sediment deposition. Because of periodic flooding, the floodplains are often composed of fertile soils. These floodplains have a crucial role in maintaining river ecosystems and often provide habitats for plants and animals adapted to periodic flooding.
Floodplains have often been altered due to human interference. These modifications disrupt the natural functions of the floodplains. The original function can be kept by restoring and maintaining floodplains, and floods are kept in the designated areas.

(European Commission & Office International de l'Eau, 2014a)

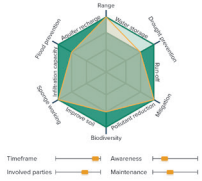


Afforestation of reservoir Catchments

(Mann-Kremer Architects, 1999)

The afforestation of reservoir catchments is the practice of planting trees in a reservoir catchment. Afforestation extends the life of the reservoir and improves water quality. This can help control the erosion of soil. The roots of the trees help hold the soil together and prevent erosion. Water quality improvement is achieved by precipitation infiltration the reservoir's surrounding soil, where tree roots help improve soil structure and infiltration rates and in turn improve water quality. When implementing afforestation of reservoir catchments it is essential that enough precipitation still reaches the reservoir to recharge it. Forests in reservoir catchments should be managed as naturally as possible to prevent water quality from depleting. Using afforestation on steep areas can benefit sediment retention and erosion prevention.

(European Commission & Office International de l'Eau, 2014a)

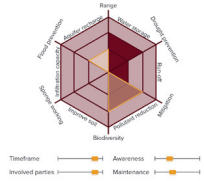


Retention ponds

(Hessing, 2020)

Retention ponds are ponds designed to hold excess run-off. These permanent ponds support the surrounding area during heavy rainfall and flooding by providing additional storage capacity. The ponds then release water at a controlled rate. Through sedimentation and vegetation, the water quality of the water can be improved before releasing it back into the streamflow. Retention ponds consist of a pre-treatment area and a permanent pool that remains wet throughout the year. Most ponds will also contain temporary storage volume and a shallow edge to provide space for wetland vegetation. Ponds cannot be too small, because they will run the risk of drying out during period of drought. Because of the design of these ponds, they are applicable in the urban landscape.

(European Commission & Office International de l'Eau, 2014a)

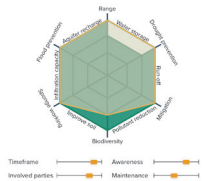


Maintenance of forest cover in headwater areas

(Mammen, 2006)

Maintenance of forest cover in headwater areas is the management and conservation of forested lands in the upper regions of a river basin. Maintaining these areas is crucial for downstream ecosystems by regulating the quantity and quality of water resources downstream. By implementing forest in headwater areas, the soil has a better infiltration capacity and can help regulate water availability. Forest cover in headwater areas can also reduce the risk of floods and droughts downstream. Maintaining these forest areas is critical to ensure the quality and quantity of water resources. Forest cover in headwater areas is most effective in areas where flood risk reduction or improvements in water quality are needed.

(European Commission & Office International de l'Eau, 2014a; The Food and Agriculture Organization of the United Nations et al., 2021)

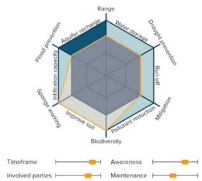


Re-meandering

(Ilias, 2022)

Many rivers in Europe have been straightened and channeled. This has been done due to human activities such as agriculture, urbanisation, or to shorten transport time and problems. A meandering river slows down water velocity due to its U-from. Straightening these meanders can cause various environmental issues such as erosion, the fragmentation of habitats, loss of biodiversity, and reduced water quality. Re-meandering a river is restoring its natural course, which creates more diverse habits and improves biodiversity. Because of the slowed velocity of the water, re-meandering also helps with erosion prevention. The slowed watercourse then improves water quality as sediments and pollutants are reduced. Next to that, the water has more room, which helps prevent floods. There is increased storage for run-off, especially when combined with afforestation patterns. This pattern is mainly implemented in flat or lowland areas.

(European Commission & Office International de l'Eau, 2014a)

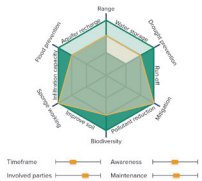


Urban forest park

(Vecka 42)

Urban forest parks are forests in urban areas that contribute to various ecosystems and the hydrological system. These parks have a recreational function but also improve urban biodiversity. Urban forest parks generally have greater infiltration capacity than other urban parks. The root structures of the forest improves the infiltration rate and at the same time prevents soil erosion. This contributes then to aquifer recharge. This measure has local benefits on the surrounding urban developments.

(European Commission & Office International de l'Eau, 2014a)

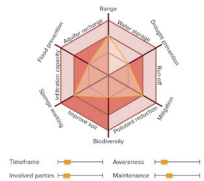


Crop rotation

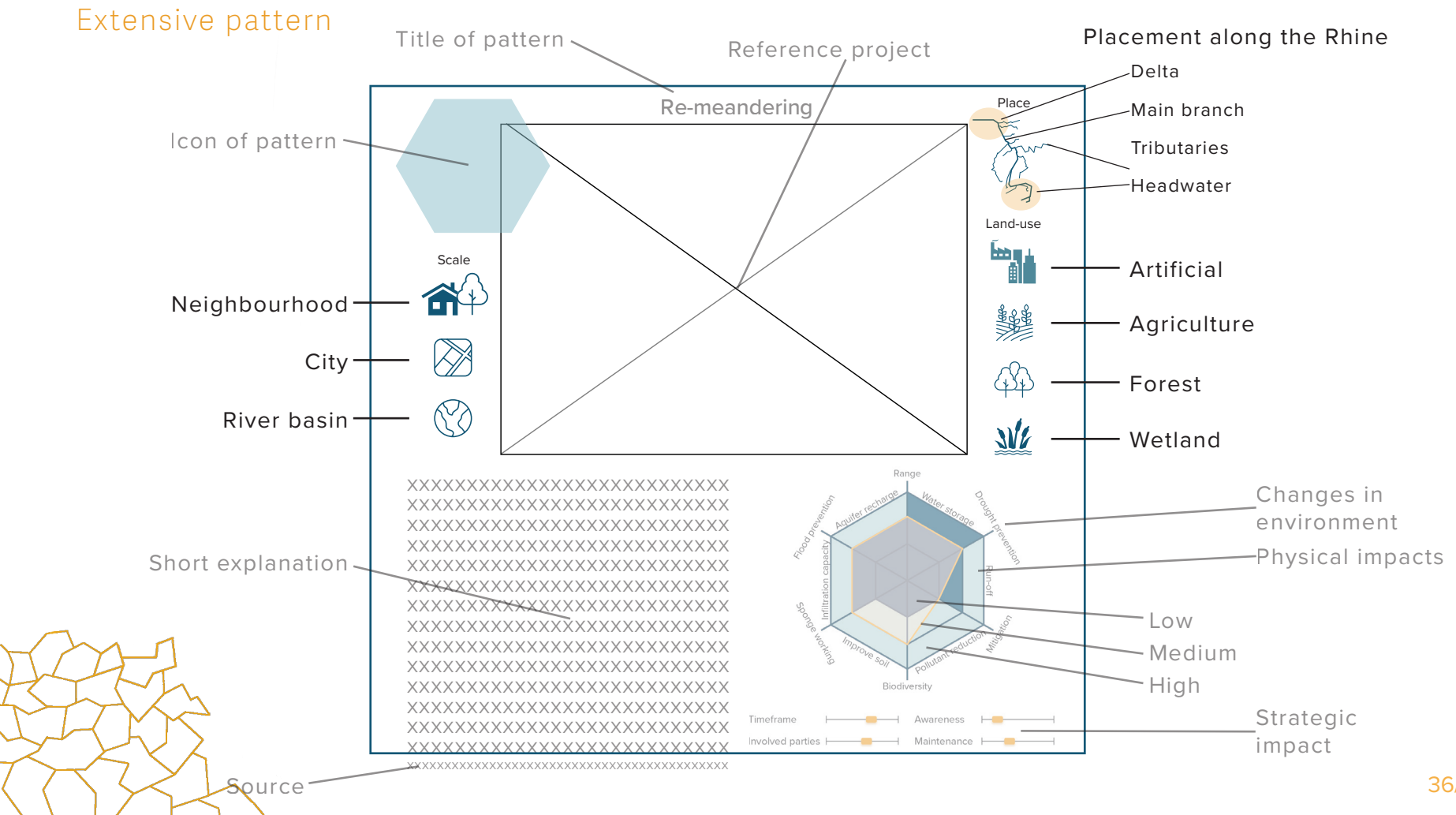
(Mammen, 2006)

Crop rotation is an agricultural practice that enhances soil fertility, promotes sustainable farming and mitigates the risk of crop diseases. The practices involve changing the crop types in a field over a defined period. With the rotation, yields are optimised, and chemical fertilisers and pesticides are unnecessary. By creating a rotation pattern in the implementation of crops, the soil will not be depleted of specific nutrients. In between different crops, the soil has time to recover. When implementing crop rotation, crops with different root lengths can be implemented. This improves the natural infiltration of the soil.

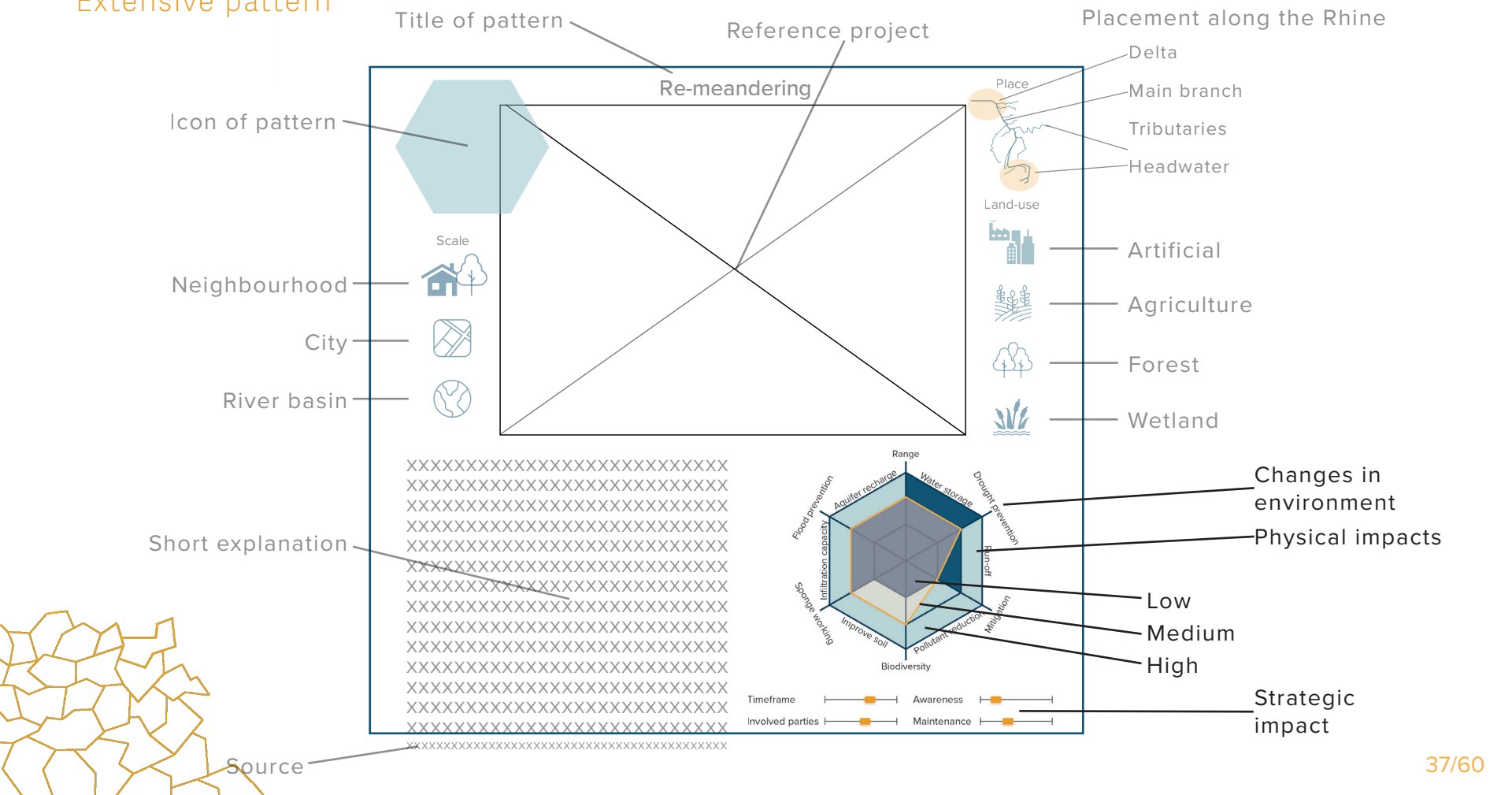
(European Commission & Office International de l'Eau, 2014a)



Extensive pattern

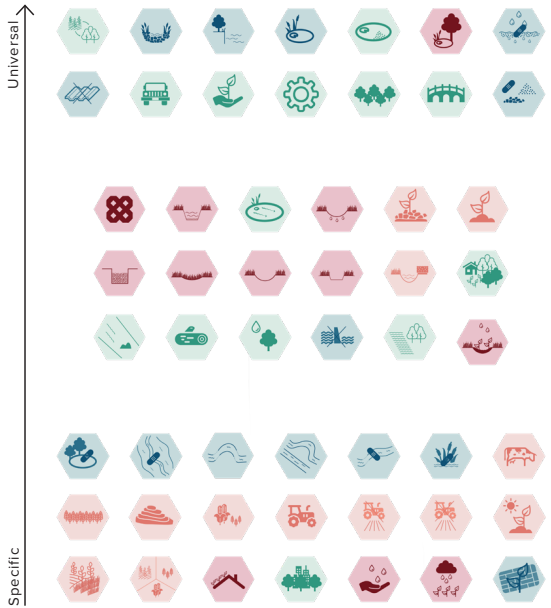


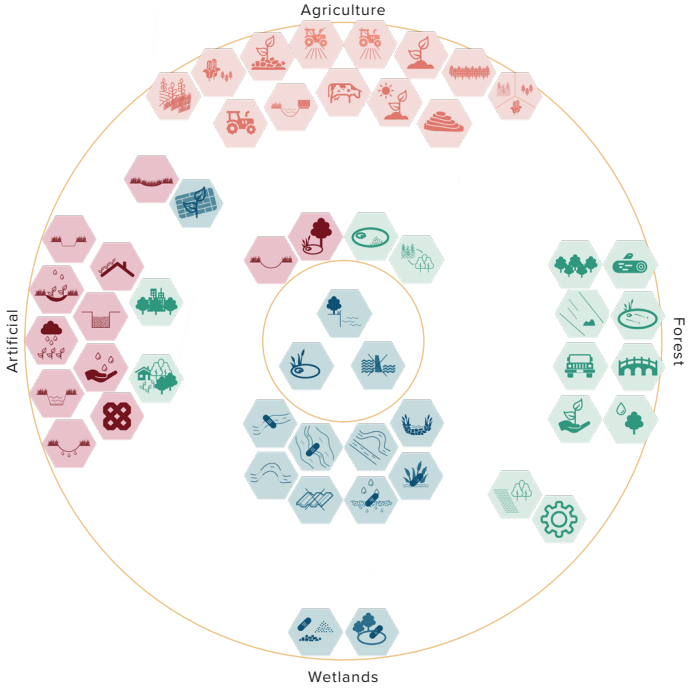
Extensive pattern



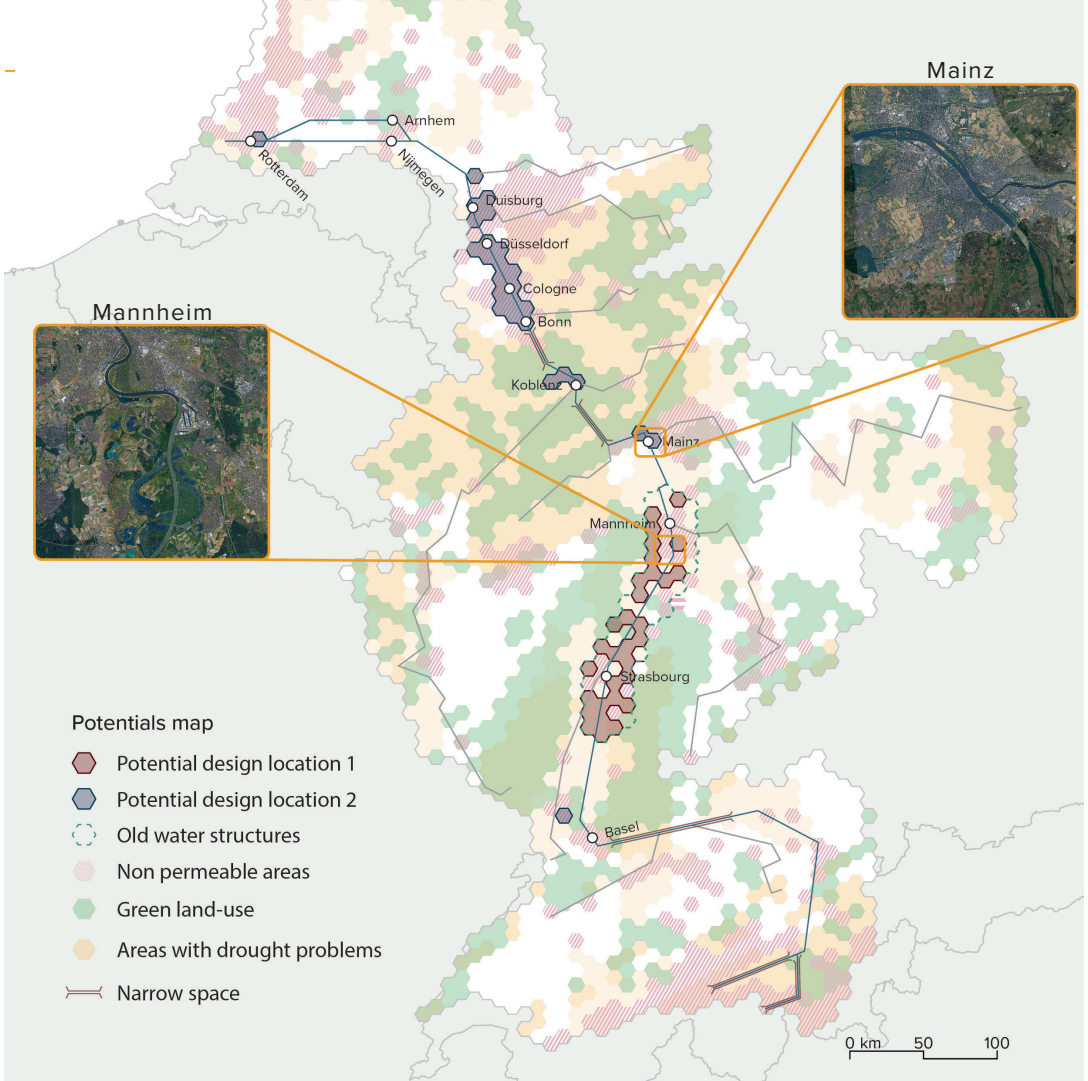
Pattern field

- Restoration of natural infiltration to groundwater
- Detention basins and ponds
- Retention ponds
- Sediment capture ponds
- Natural bank stabilisation
- Streambed re-naturalisation
- Land use conversion

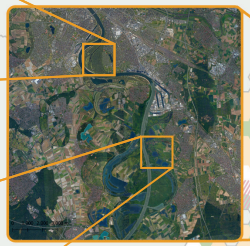


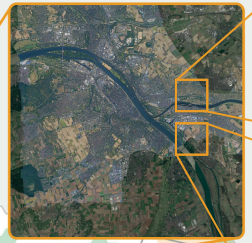


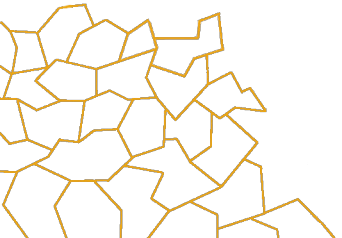
Design locations - Meso-scale



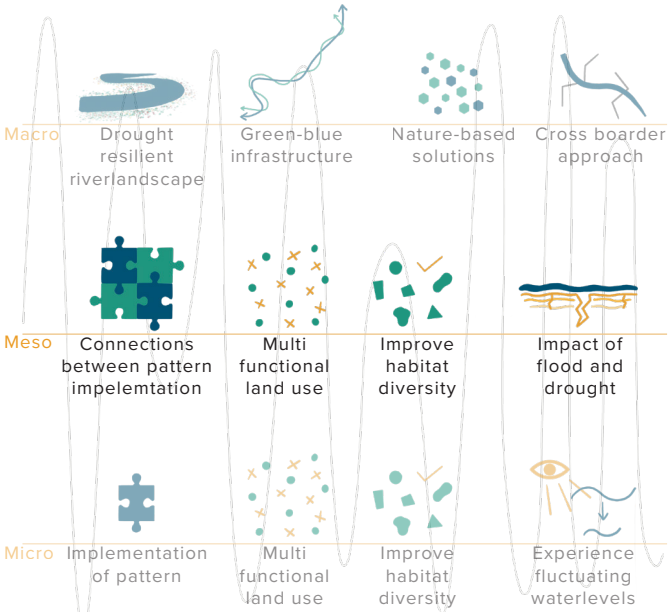
Design locations - Micro-scale

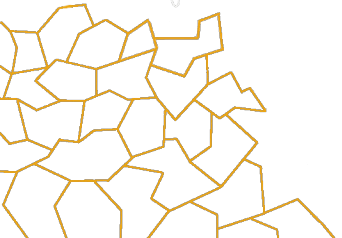




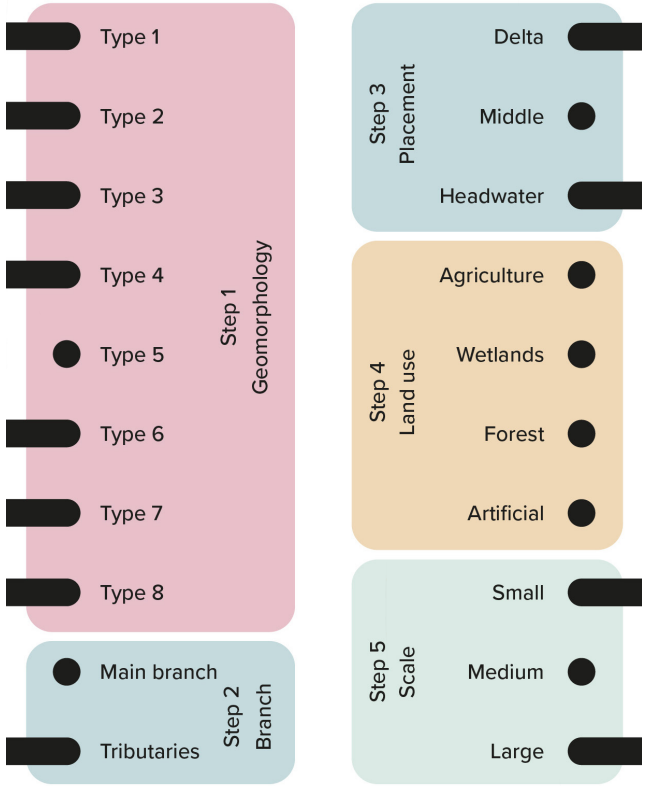


Mannheim design Meso-scale

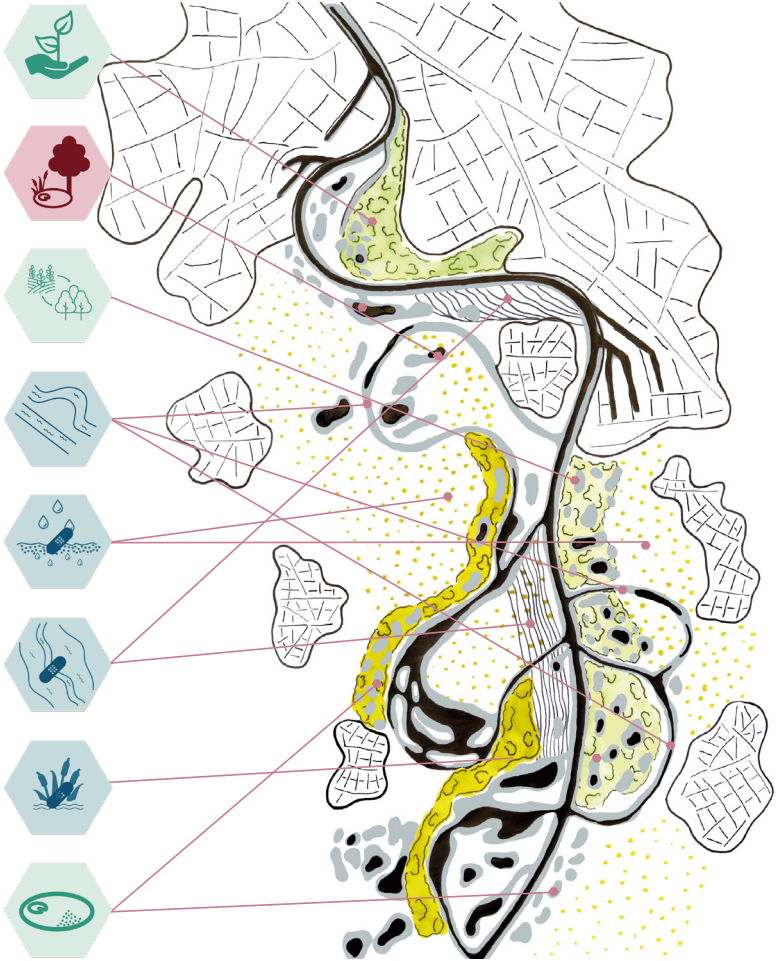




Patterns for Mannheim Meso-scale



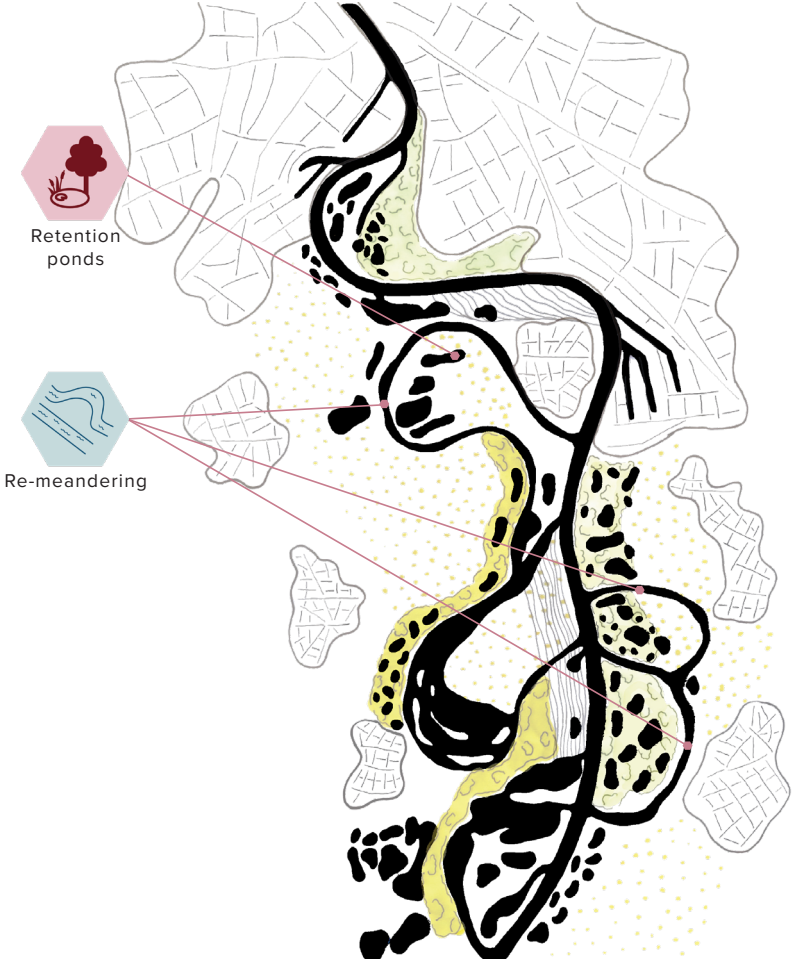
Mannheim



- Water drought
- Water
- Artificial surfaces
- Footpath
- Forest
- Urban forest
- Fluvial forest
- Agriculture; improved soil
- Vineyard
- Floodplain
- Buffer strips
- Strip cropping
- Point of attention

0 km 1 2

Mannheim



- Water drought
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0 km 1 2

Mannheim

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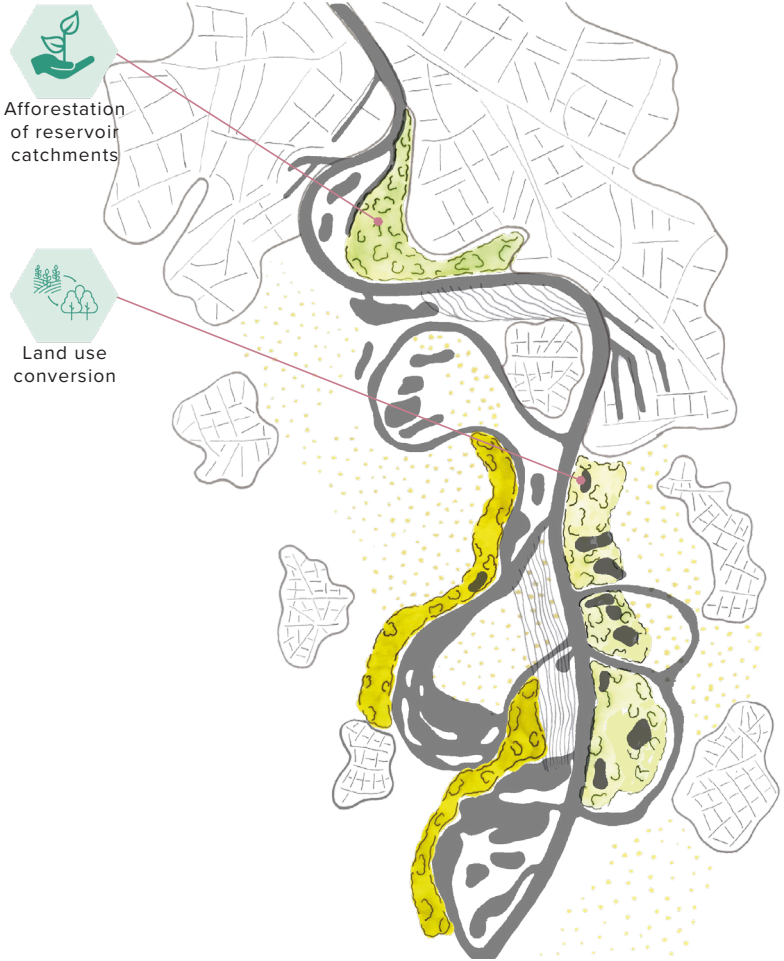
0 km 1 2

Mannheim



- Water drought
- Water
- Artificial surfaces
- Footpath
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- Buffer strips
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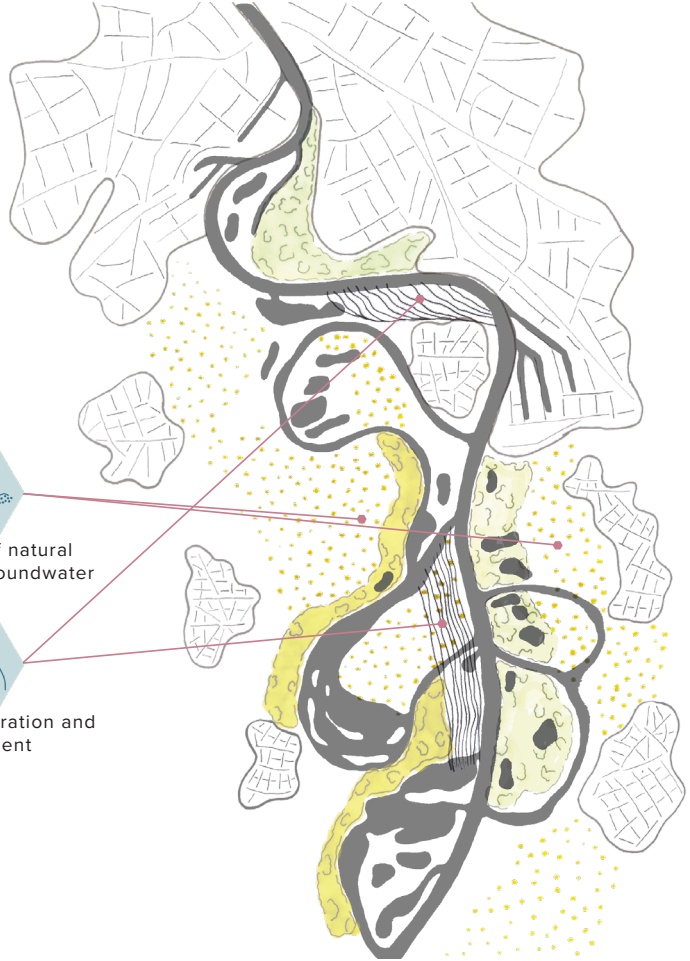
0 km 1 2

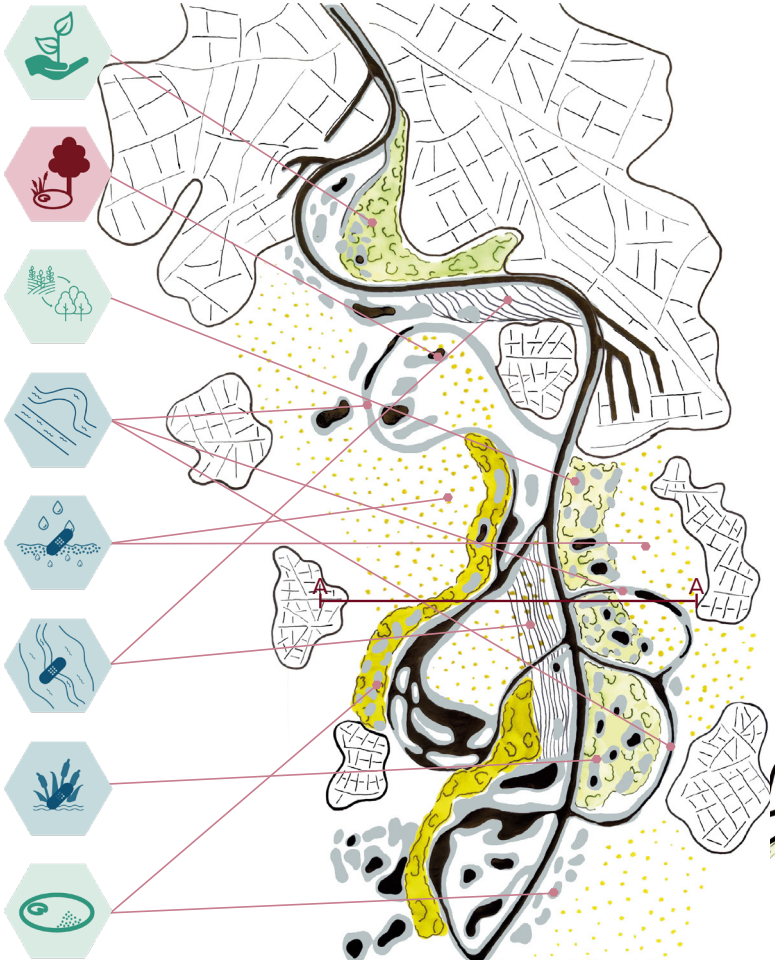
Mannheim

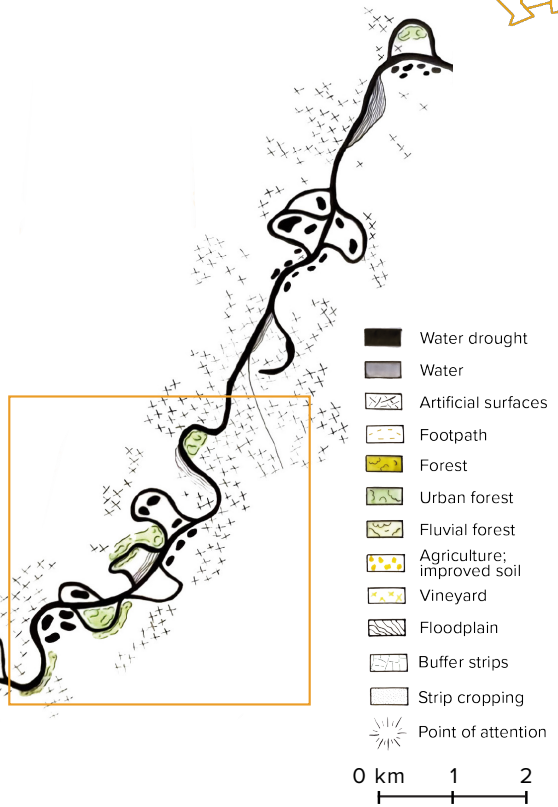


Water drought
Water
Artificial surfaces
Footpath
Forest
Urban forest
Fluvial forest
Agriculture; improved soil
Vineyard
Floodplain
Buffer strips
Strip cropping
Point of attention

0 km 1 2

Flooding

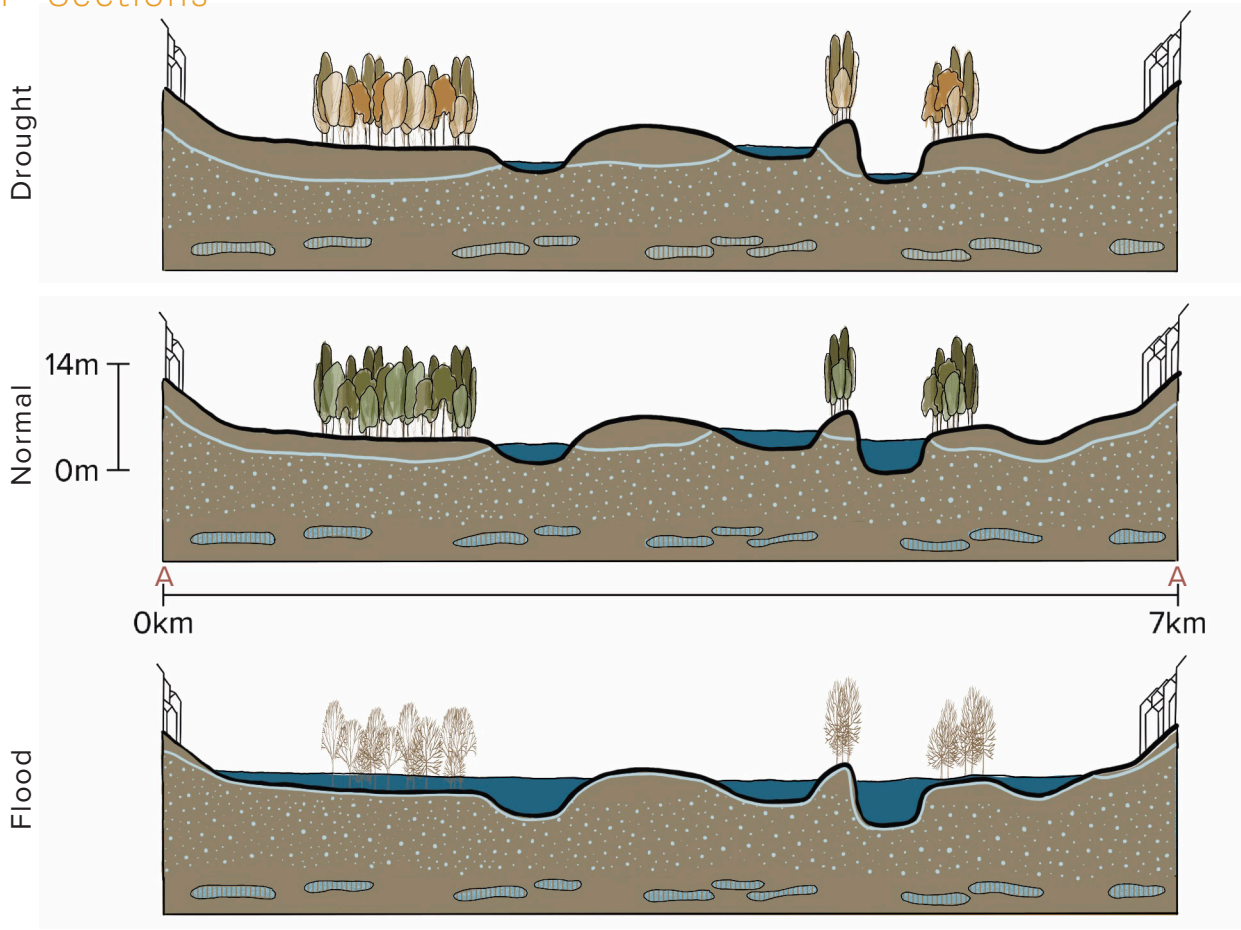


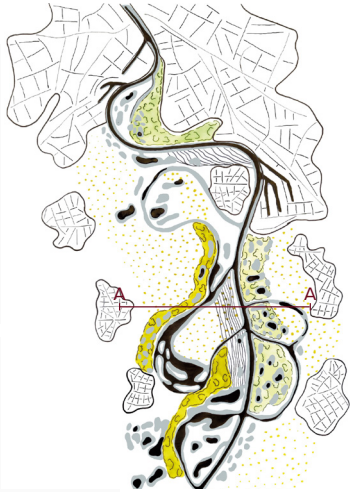


Water drought
Water
Artificial surfaces
Footpath
Forest
Urban forest
Fluvial forest
Agriculture; improved soil
Vineyard
Floodplain
Buffer strips
Strip cropping
Point of attention

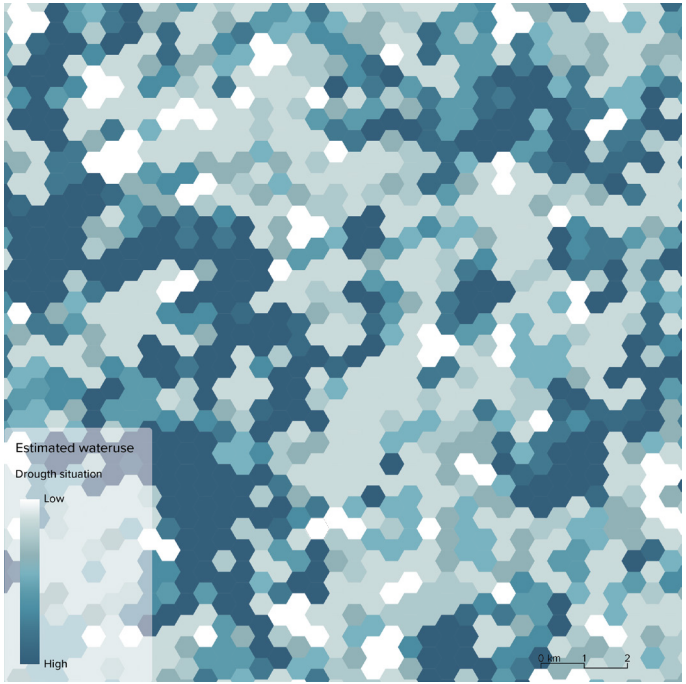
0 km 1 2

Mannheim - Sections





Mannheim - Wateruse

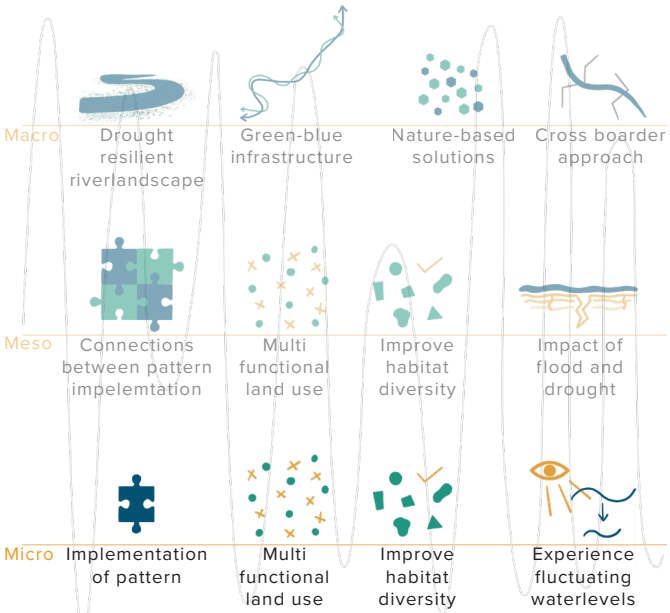


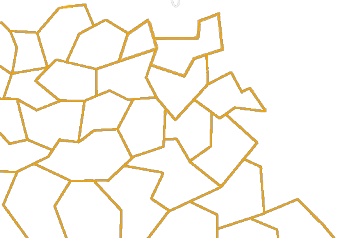
Estimated wateruse during current drought situations

Estimated wateruse after design implementation, during drought situation

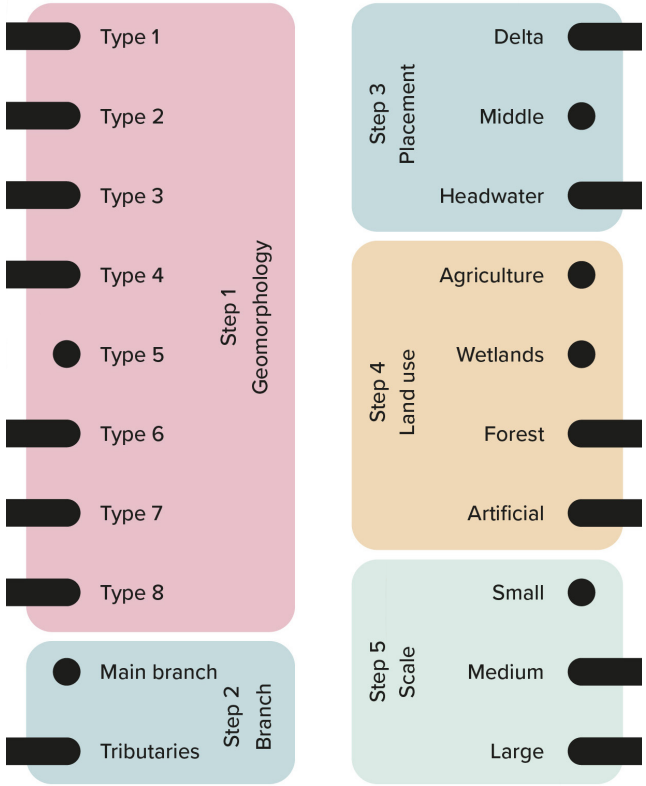
Design locations

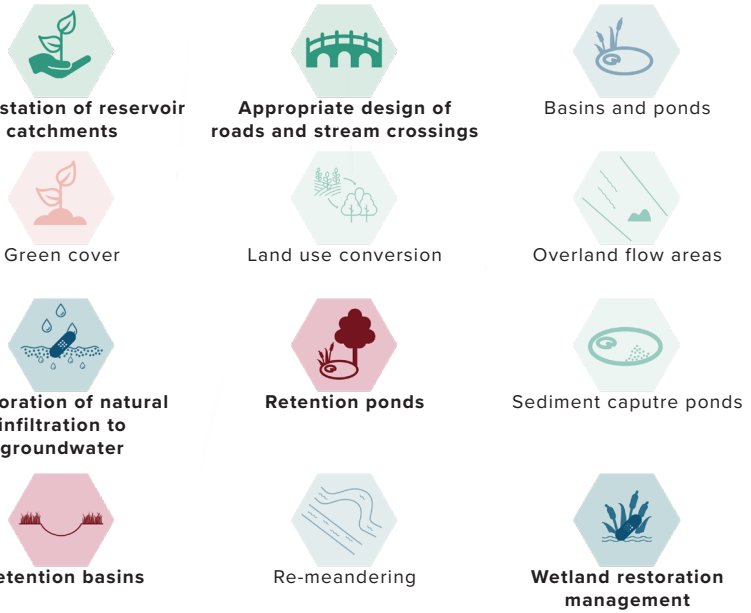
Mannheim design Micro-scale





Patterns for Mannheim Micro-scale



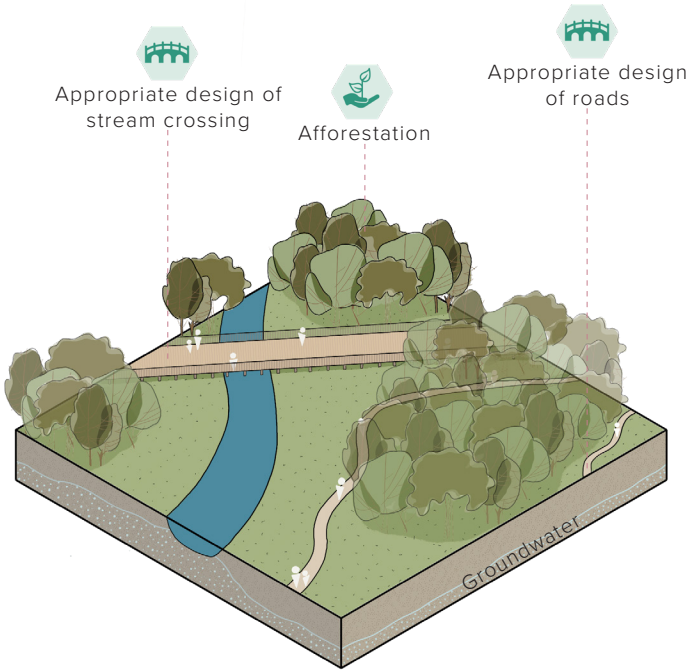


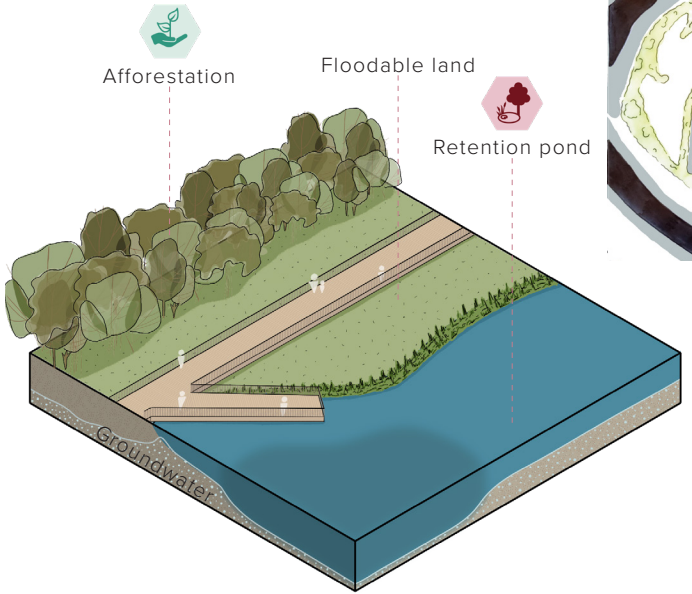
Flooding

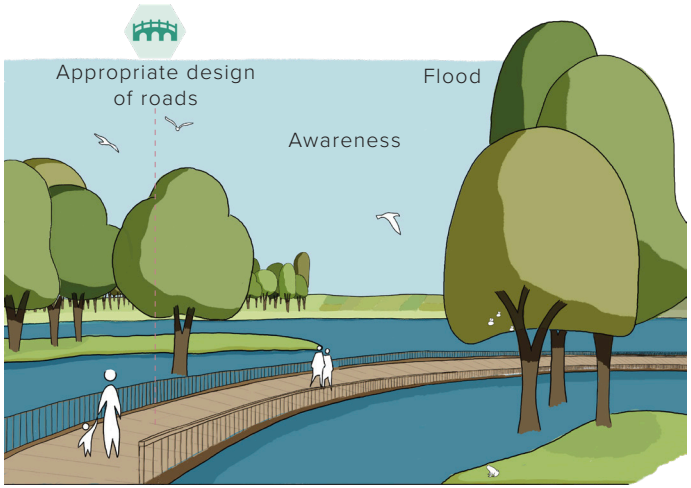
Water drought
Water
Artificial surfaces
Footpath
Forest
Urban forest
Fluvial forest
Agriculture; improved soil
Vineyard
Floodplain
Buffer strips
Strip cropping
Point of attention

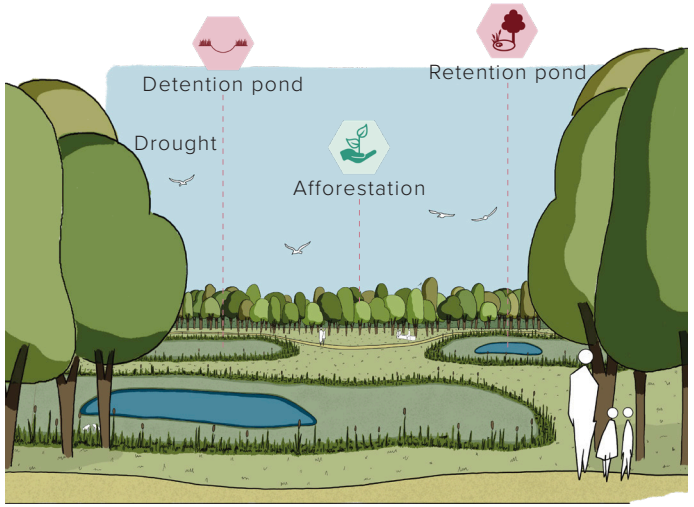
0 m 250 m 500 m

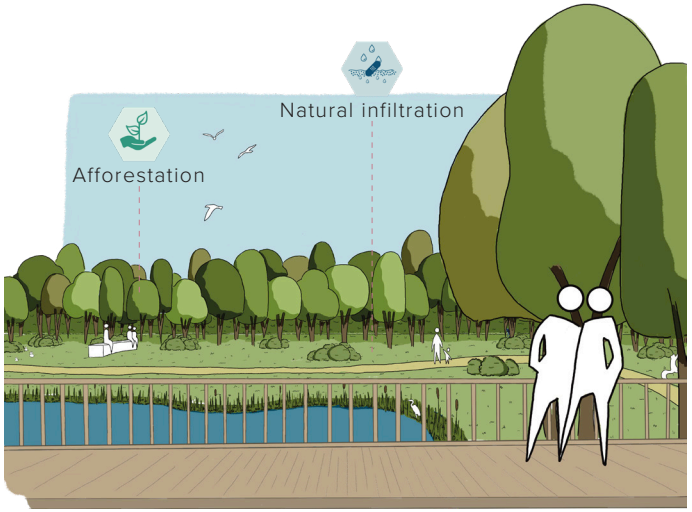
Mannheim


Appropriate design of stream crossing
Afforestation
Appropriate design of roads
Groundwater

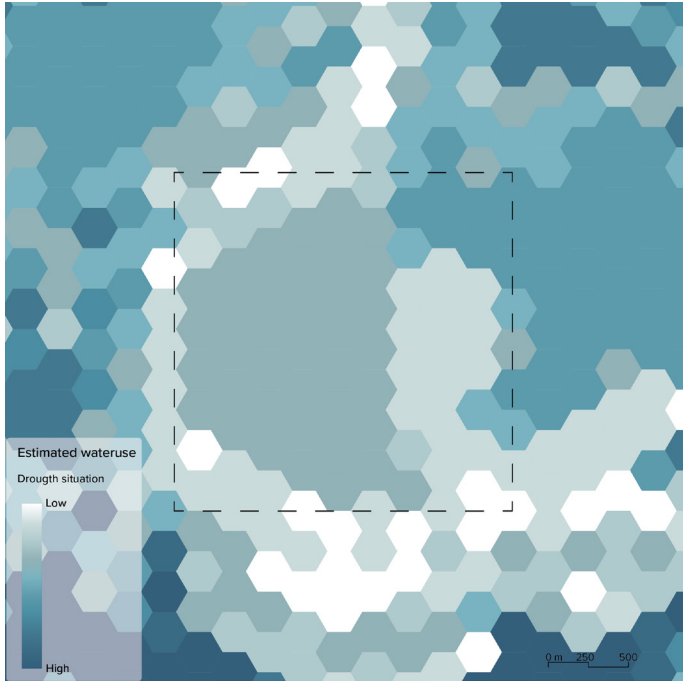

Afforestation
Floodable land
Retention pond
Groundwater


Appropriate design
of roads
Flood
Awareness

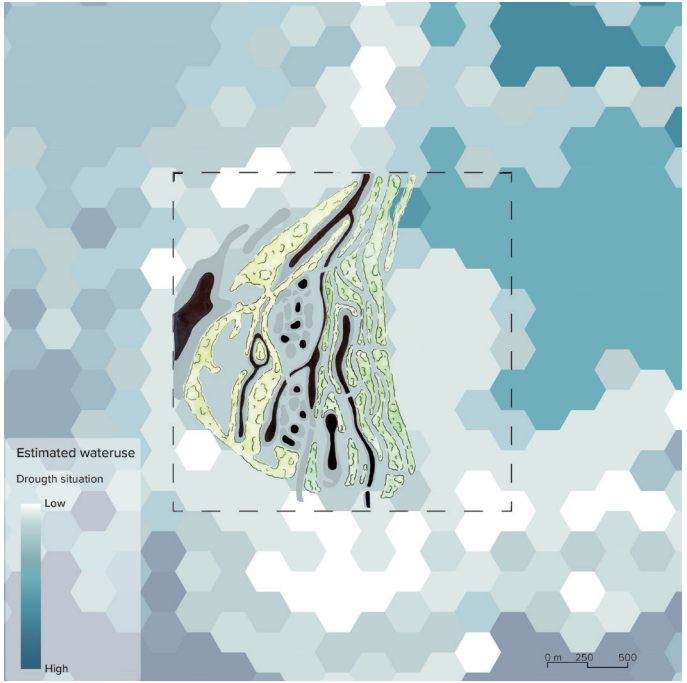

Detention pond
Retention pond
Drought
Afforestation


Natural infiltration
Afforestation

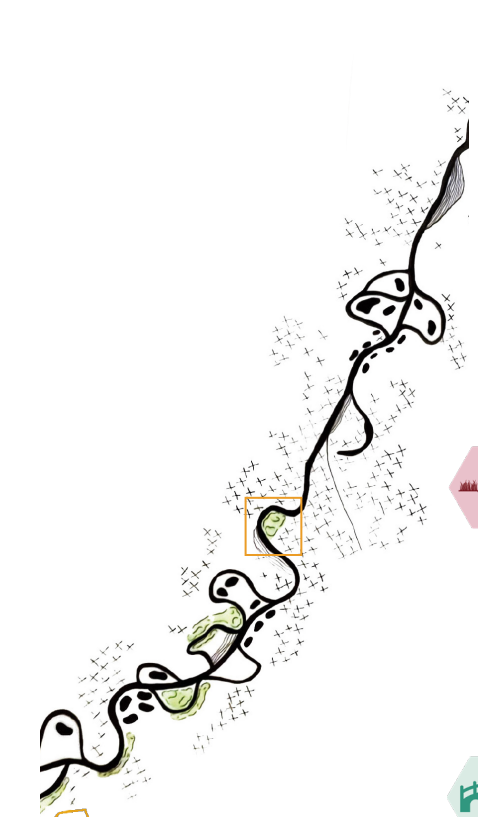
Mannheim - Wateruse

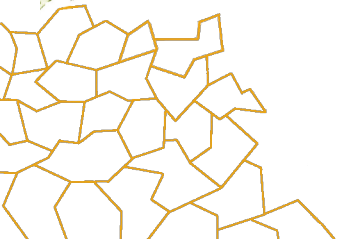


Estimated wateruse during current drought situations



Estimated wateruse after design implementation, during drought situation





- Water drought
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- Strip cropping
- Point of attention

0 m 250 m 500 m

Conclusions and further research

Patterns in different environments

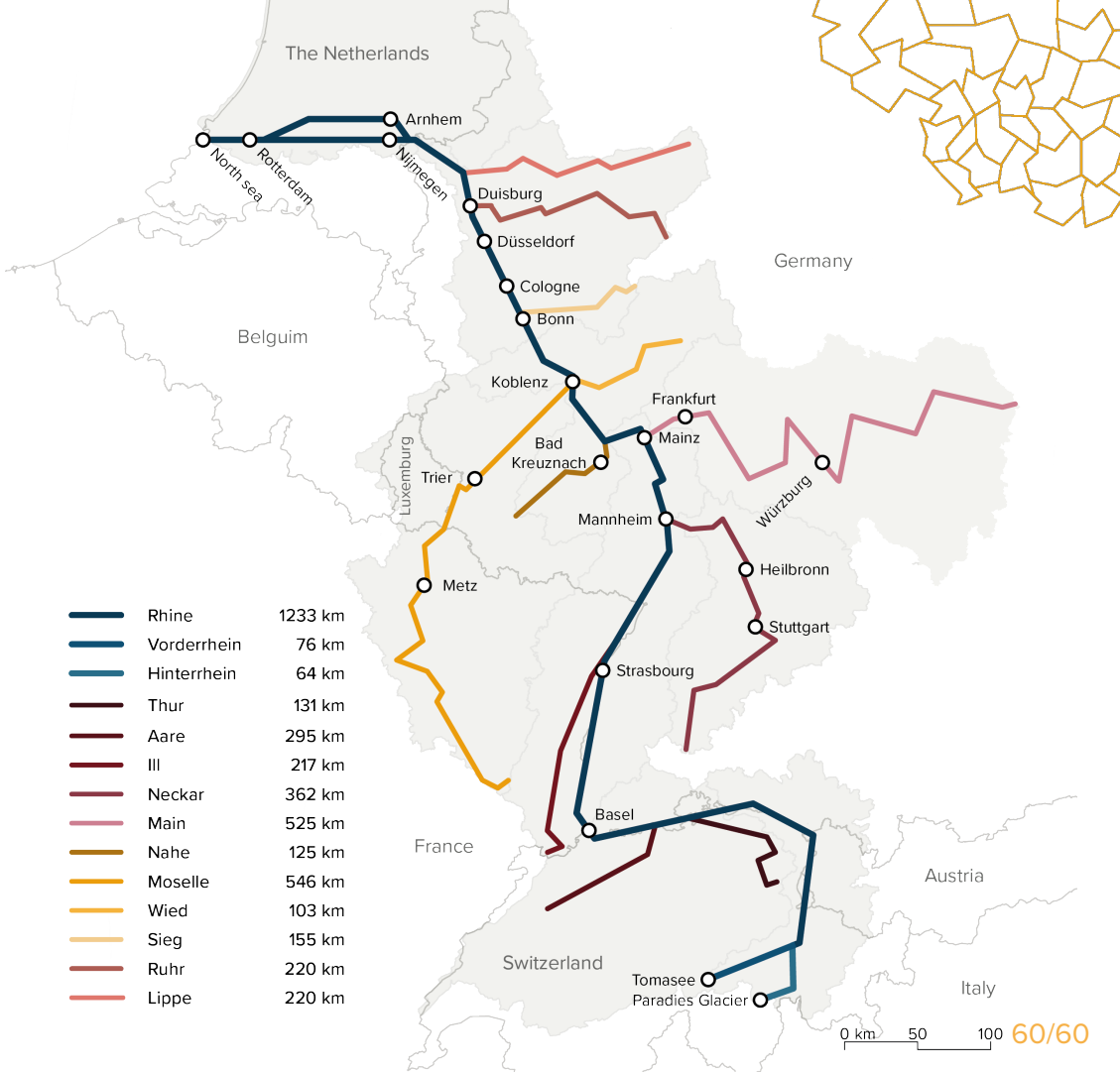
Filtering for new desirable choices for designing

Transferable drought-mitigating pattern catalogue

Figures and cattle in a mountain landscape with the Rhine (Barend Cornelis Koekkoek, 1862)

Thank you for listening

Questions?



EVERY DROP COUNTS

How to keep the Rhine functional in times of drought

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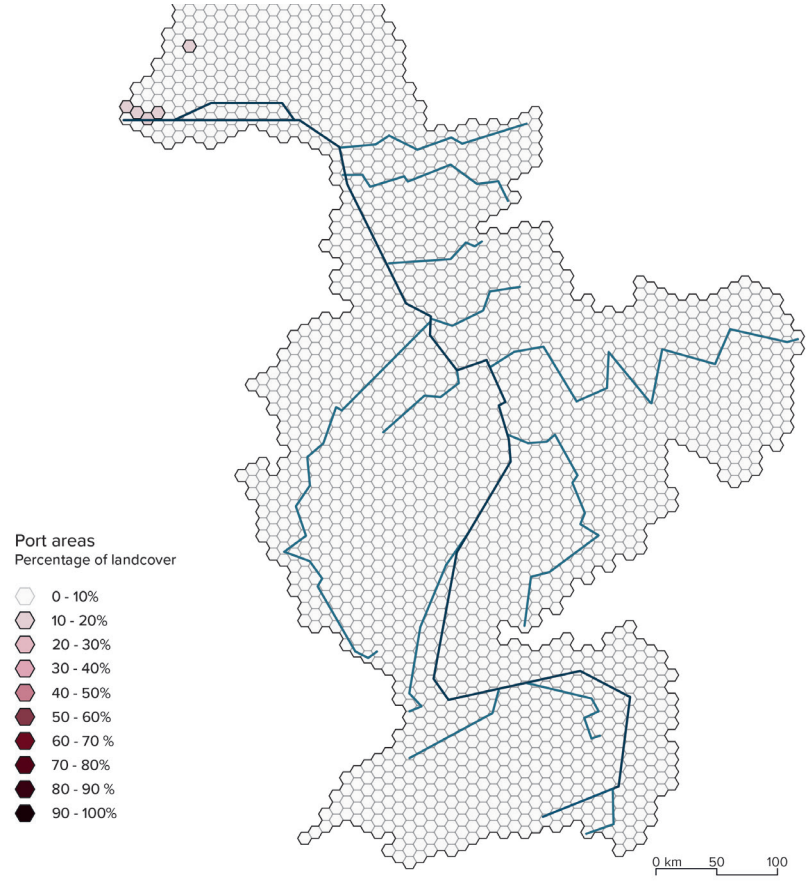
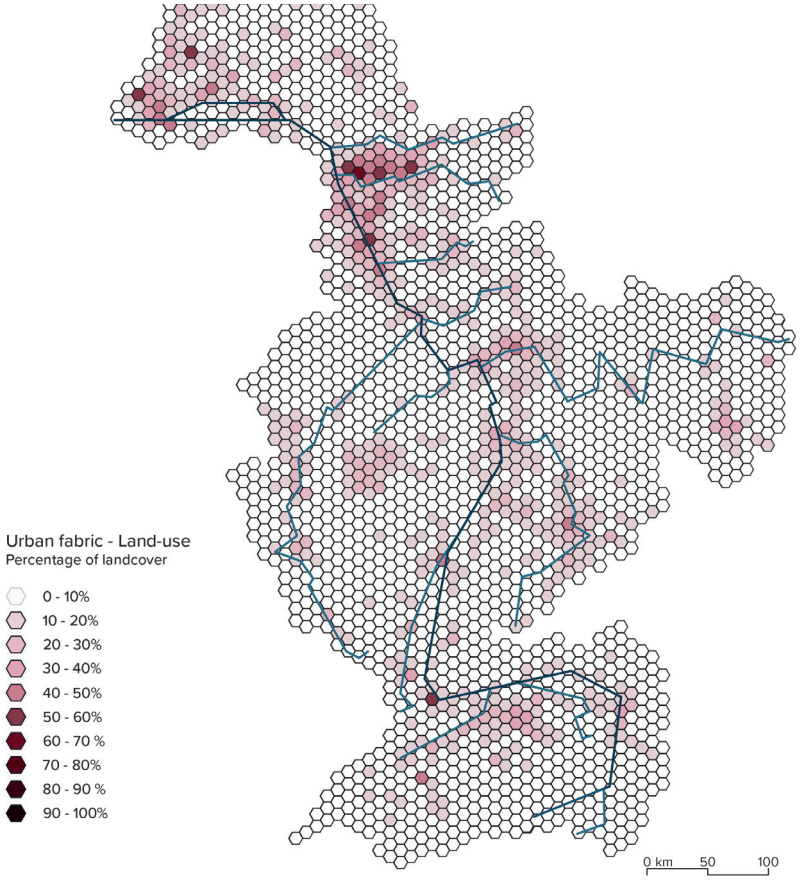
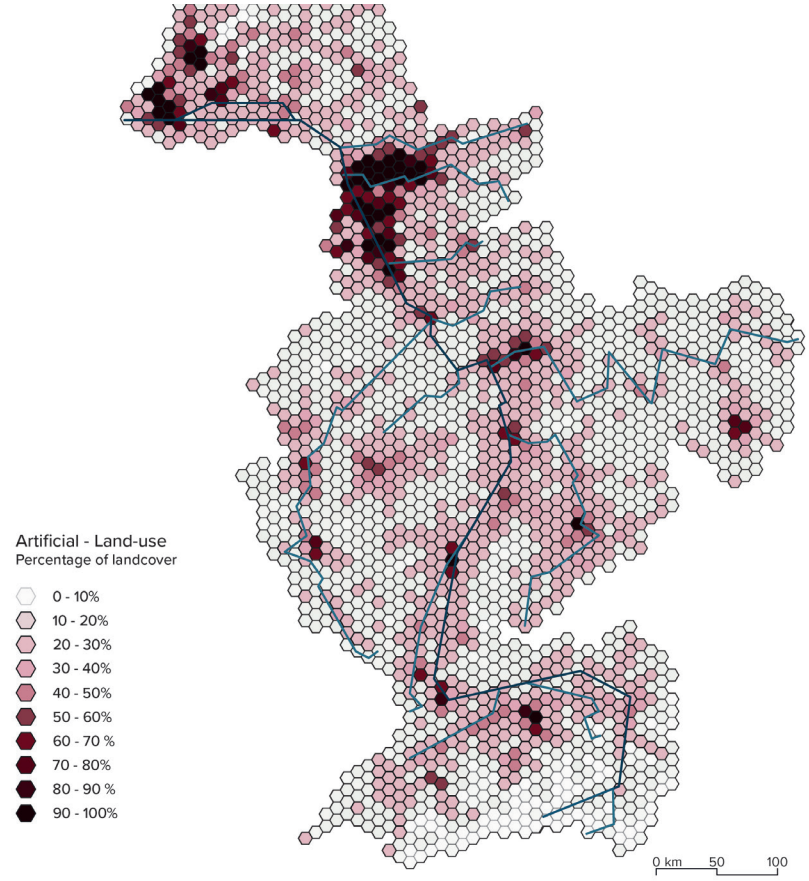
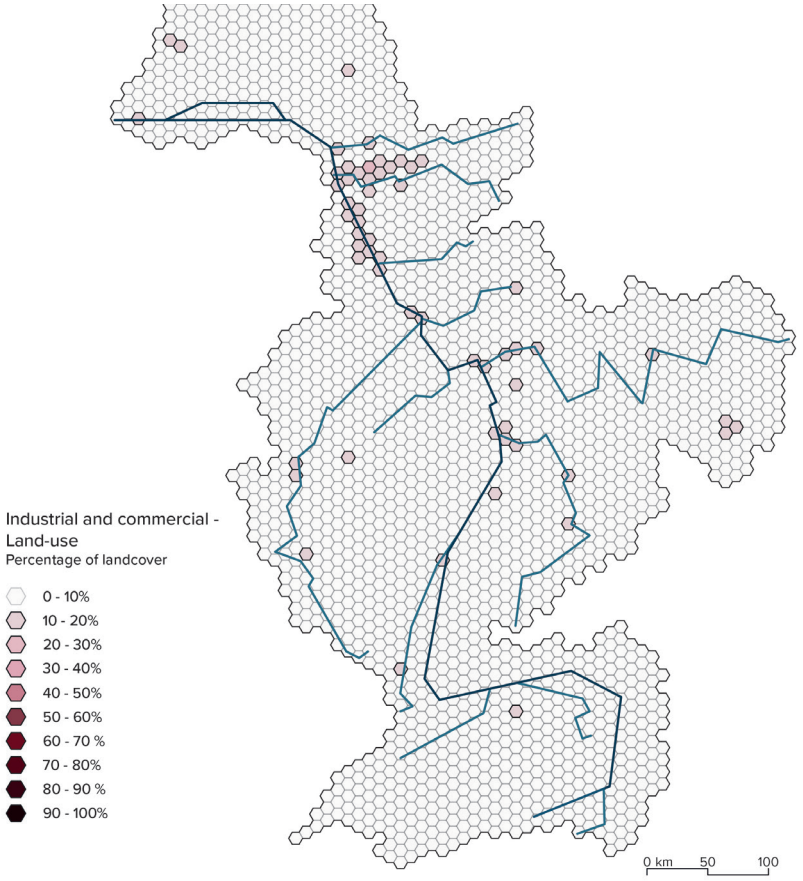
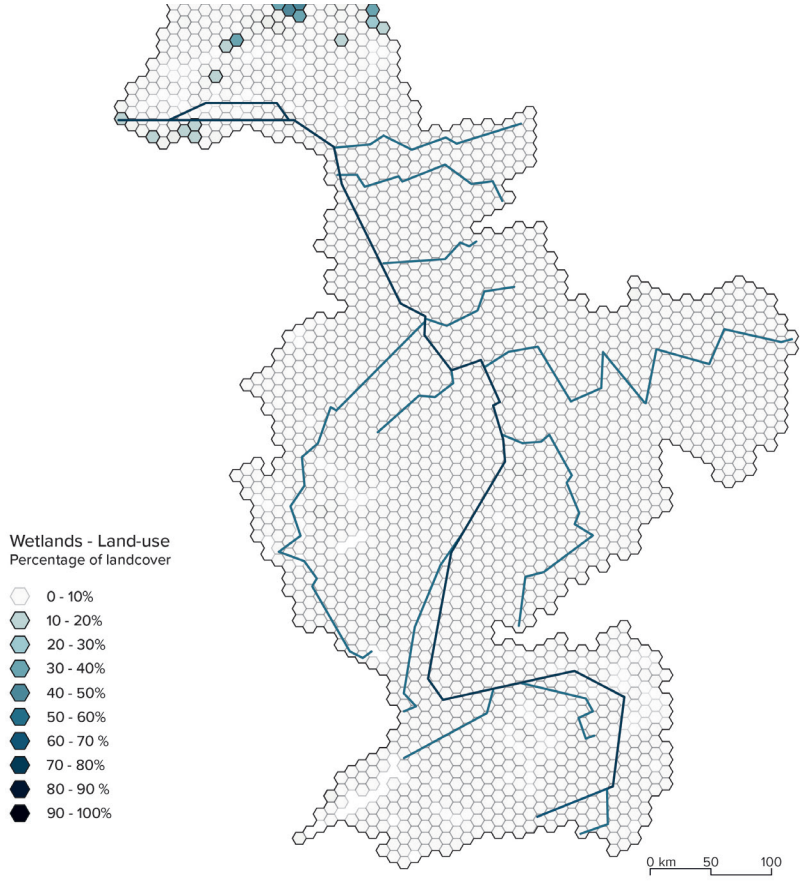
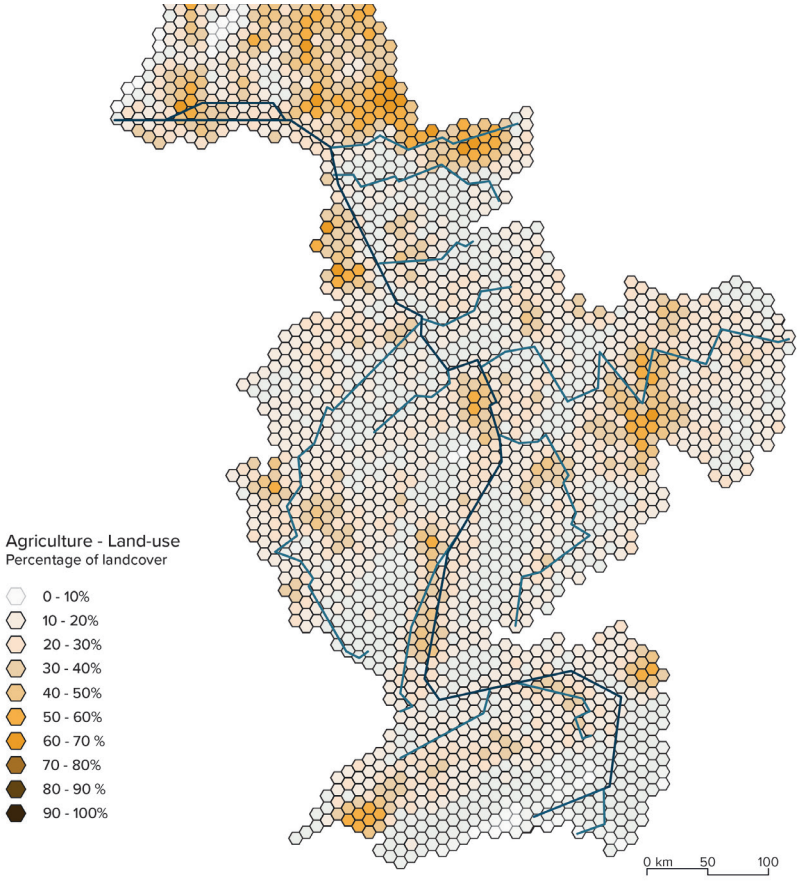

Port areas
Percentage of landcover
0 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70 %
70 - 80%
80 - 90 %
90 - 100%
0 km 50 100

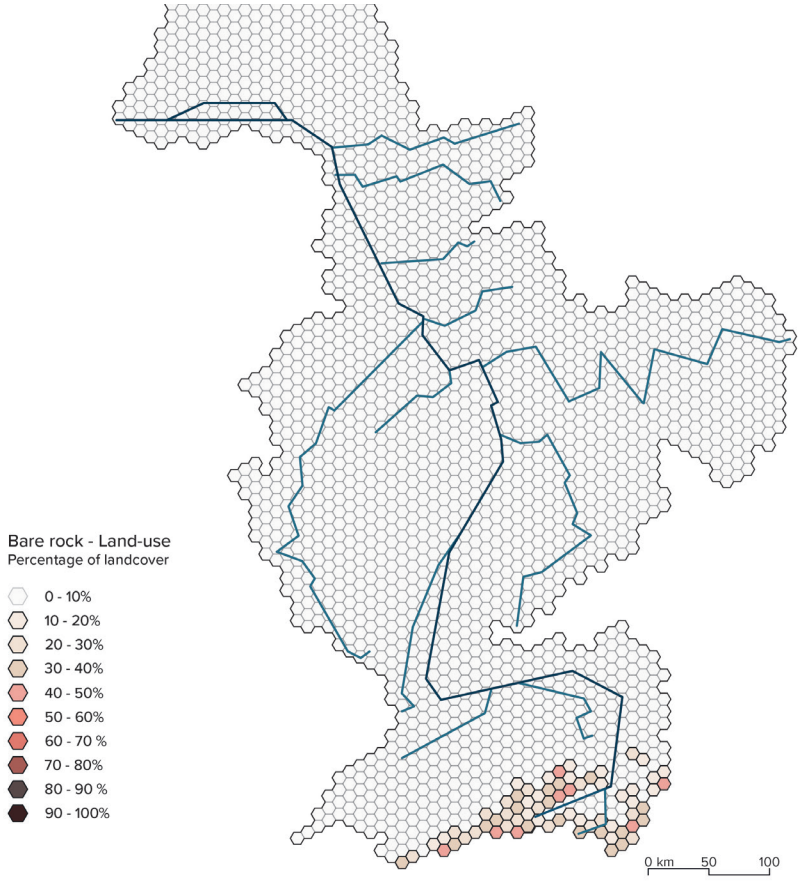

Urban fabric - Land-use
Percentage of landcover
0 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70 %
70 - 80%
80 - 90 %
90 - 100%
0 km 50 100

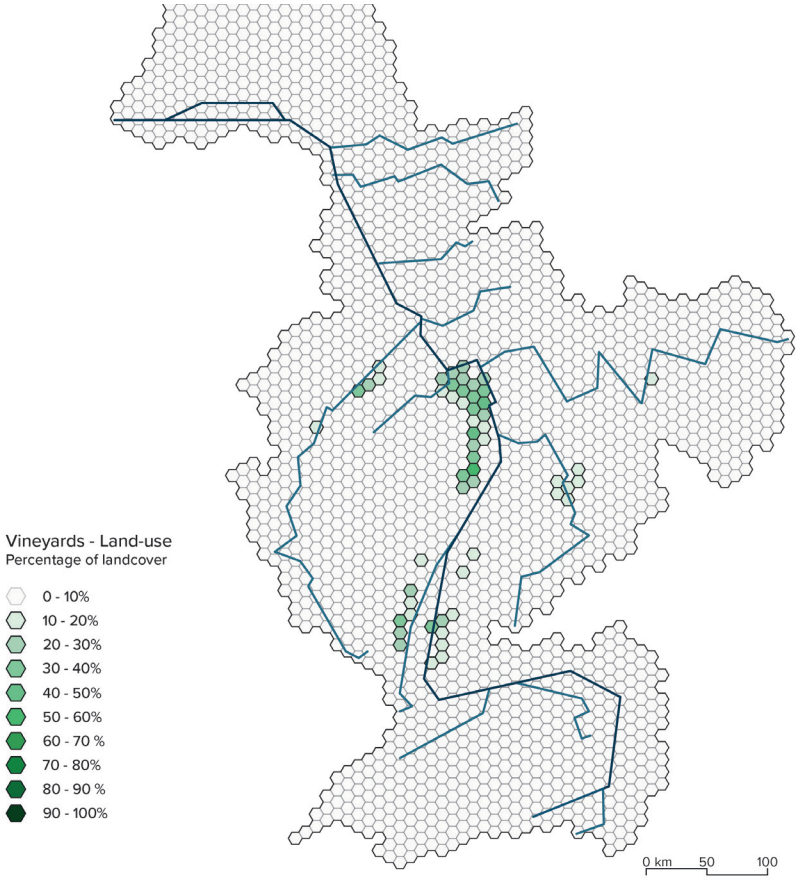

Artificial - Land-use
Percentage of landcover
0 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70 %
70 - 80%
80 - 90 %
90 - 100%
0 km 50 100

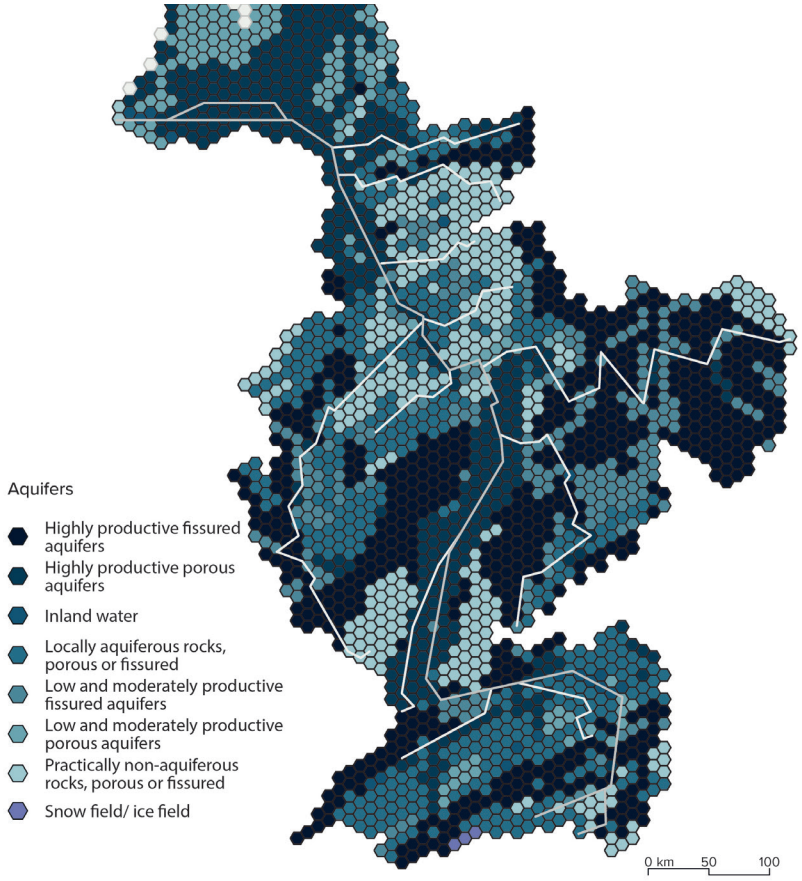

Industrial and commercial - Land-use
Percentage of landcover
0 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70 %
70 - 80%
80 - 90 %
90 - 100%
0 km 50 100

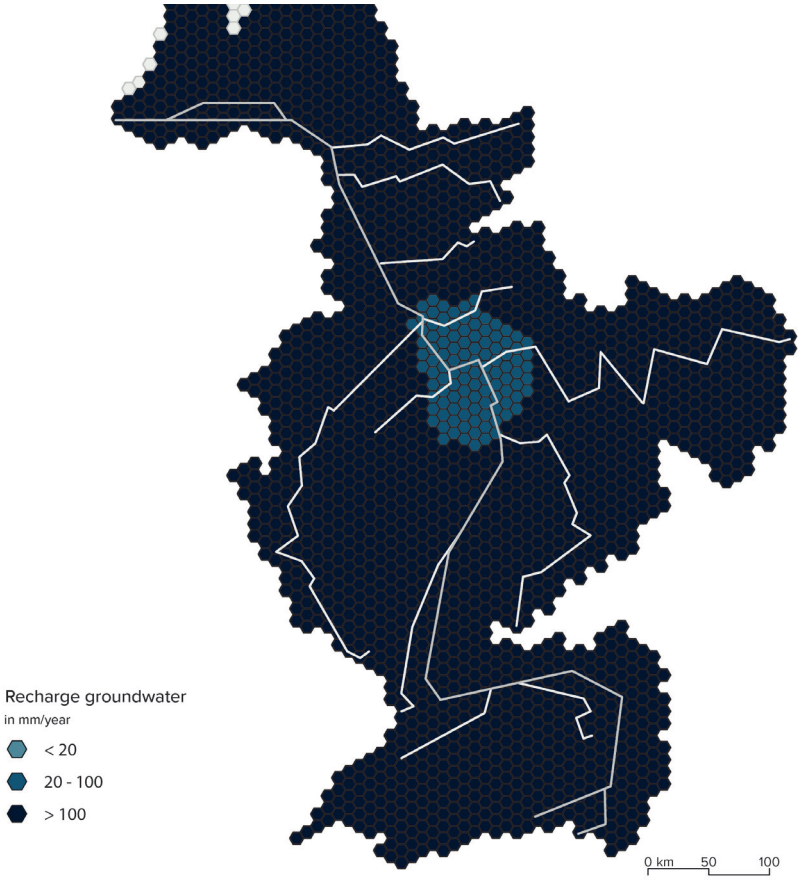

Wetlands - Land-use
Percentage of landcover
0 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70 %
70 - 80%
80 - 90 %
90 - 100%
0 km 50 100

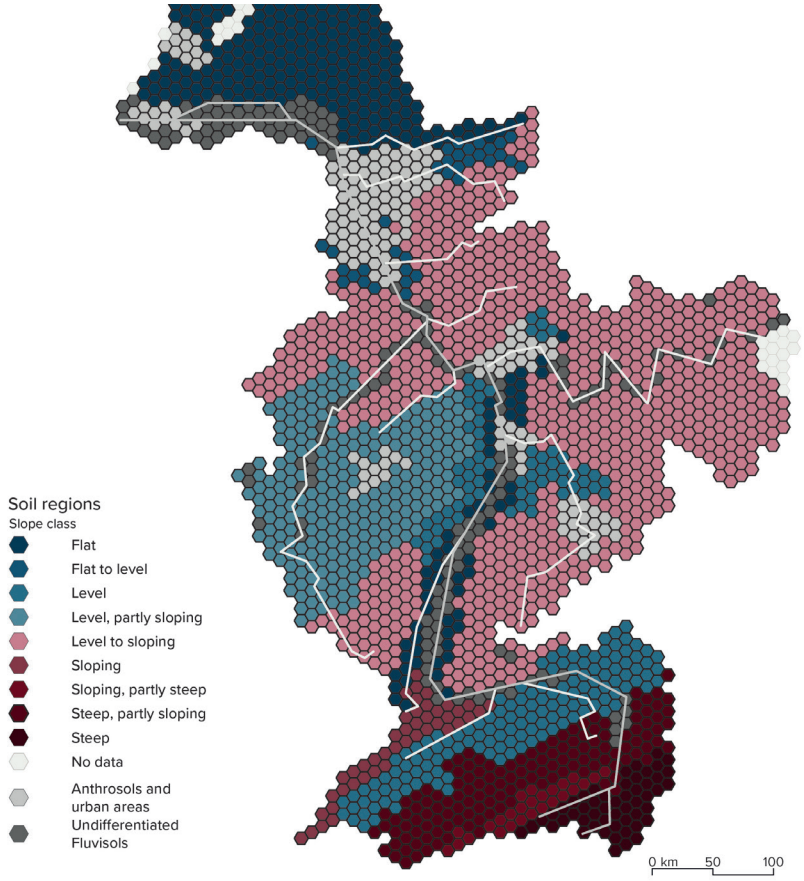

Agriculture - Land-use
Percentage of landcover
0 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70 %
70 - 80%
80 - 90 %
90 - 100%
0 km 50 100

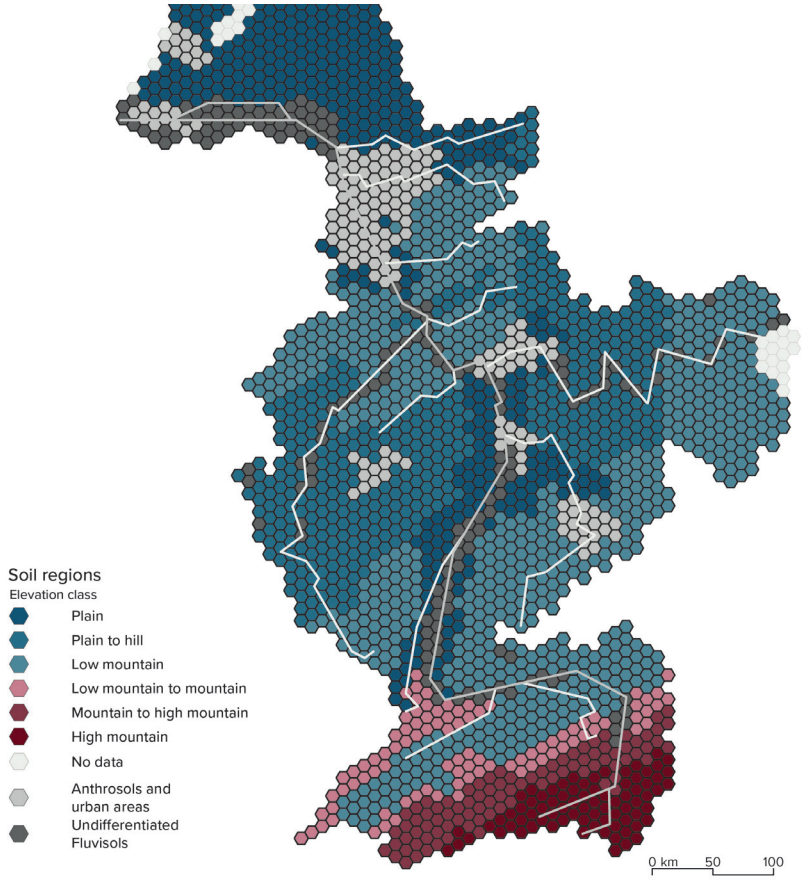

Bare rock - Land-use
Percentage of landcover
0 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70 %
70 - 80%
80 - 90 %
90 - 100%
0 km
50
100

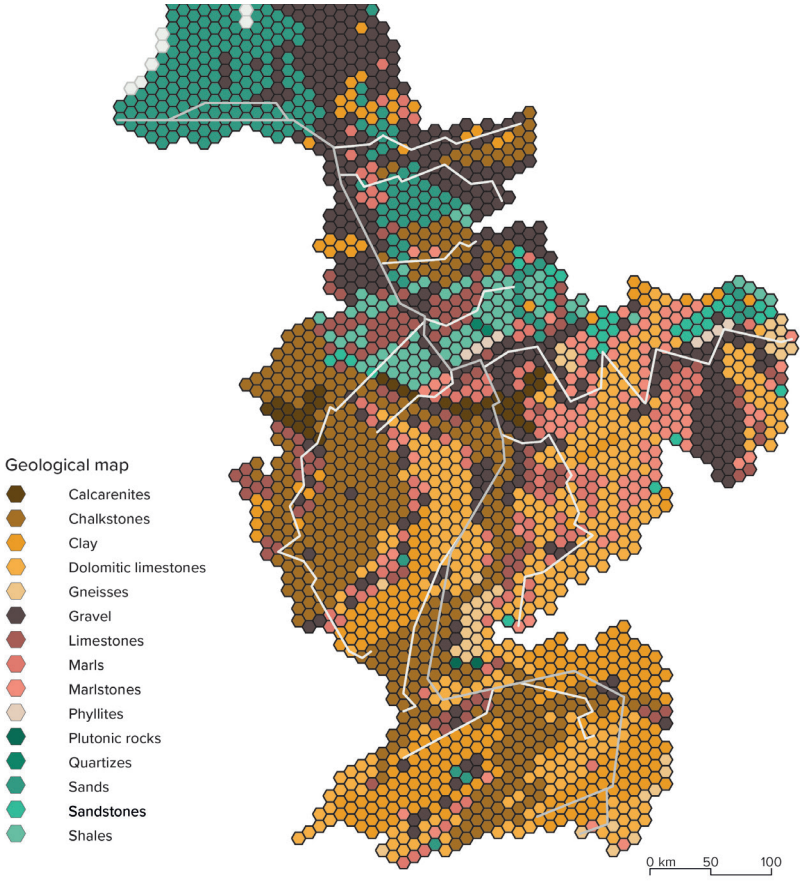

Vineyards - Land-use
Percentage of landcover
0 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70 %
70 - 80%
80 - 90 %
90 - 100%
0 km
50
100

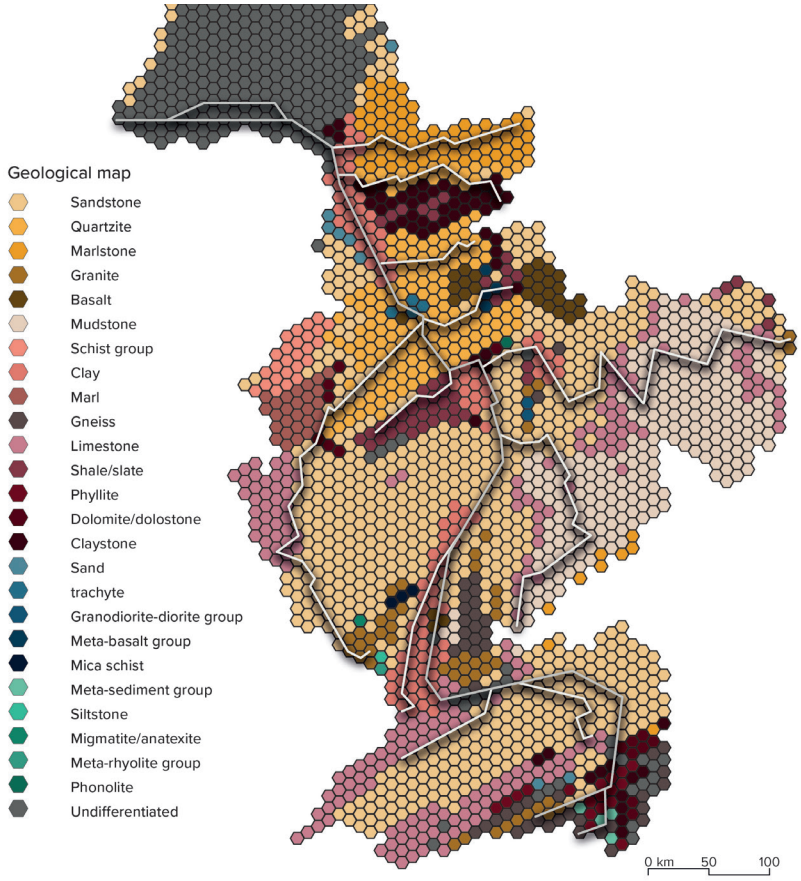

Aquifers
Highly productive fissured aquifers
Highly productive porous aquifers
Inland water
Locally aquiferous rocks, porous or fissured
Low and moderately productive fissured aquifers
Low and moderately productive porous aquifers
Practically non-aquiferous rocks, porous or fissured
Snow field/ ice field
0 km 50 100

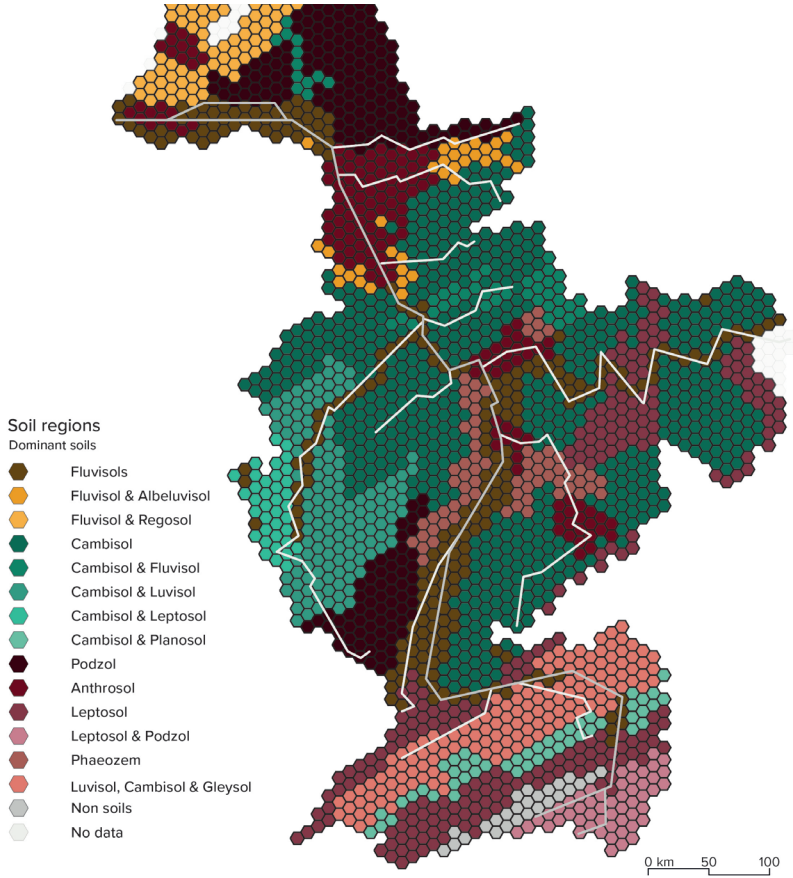

Recharge groundwater
in mm/year
< 20
20 - 100
> 100
0 km 50 100

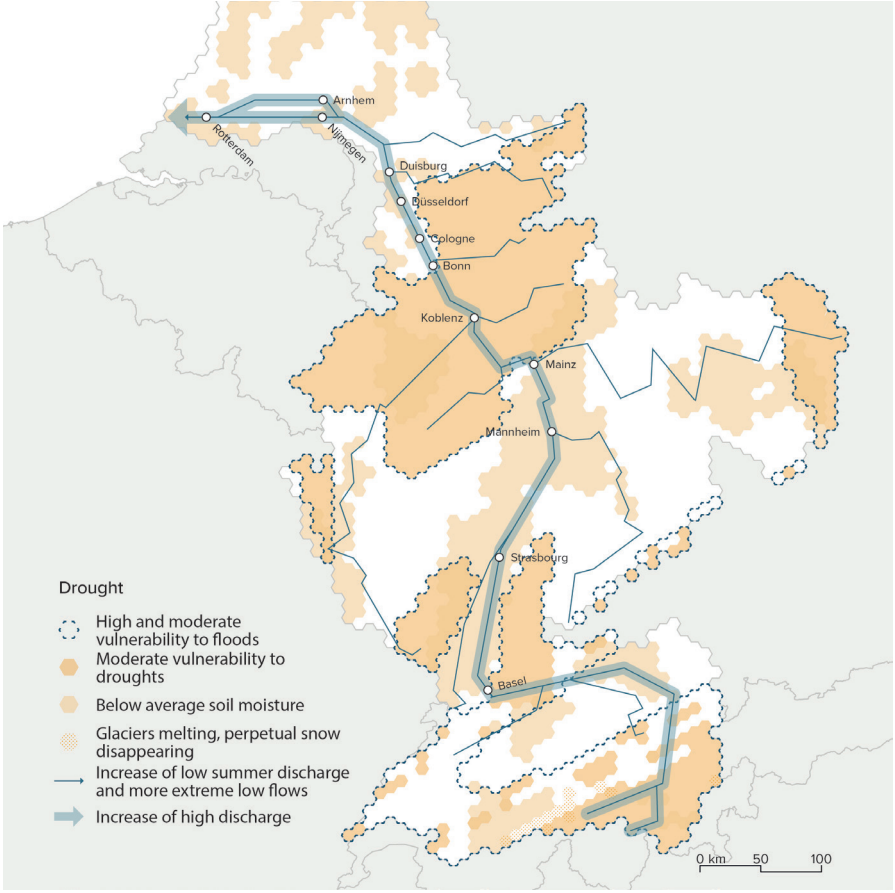

Soil regions
Slope class
Flat
Flat to level
Level
Level, partly sloping
Level to sloping
Sloping
Sloping, partly steep
Steep, partly sloping
Steep
No data
Anthrosols and urban areas
Undifferentiated Fluvisols
0 km 50 100


Soil regions
Elevation class
Plain
Plain to hill
Low mountain
Low mountain to mountain
Mountain to high mountain
High mountain
No data
Anthrosols and urban areas
Undifferentiated Fluvisols
0 km 50 100


Geological map
Calcarenites
Chalkstones
Clay
Dolomitic limestones
Gneisses
Gravel
Limestones
Marls
Marlstones
Phyllites
Plutonic rocks
Quartizes
Sands
Sandstones
Shales
0 km 50 100


Geological map
Sandstone
Quartzite
Marlstone
Granite
Basalt
Mudstone
Schist group
Clay
Marl
Gneiss
Limestone
Shale/slate
Phyllite
Dolomite/dolostone
Claystone
Sand
trachyte
Granodiorite-diorite group
Meta-basalt group
Mica schist
Meta-sediment group
Siltstone
Migmatite/anatexite
Meta-rhyolite group
Phonolite
Undifferentiated
0 km 50 100

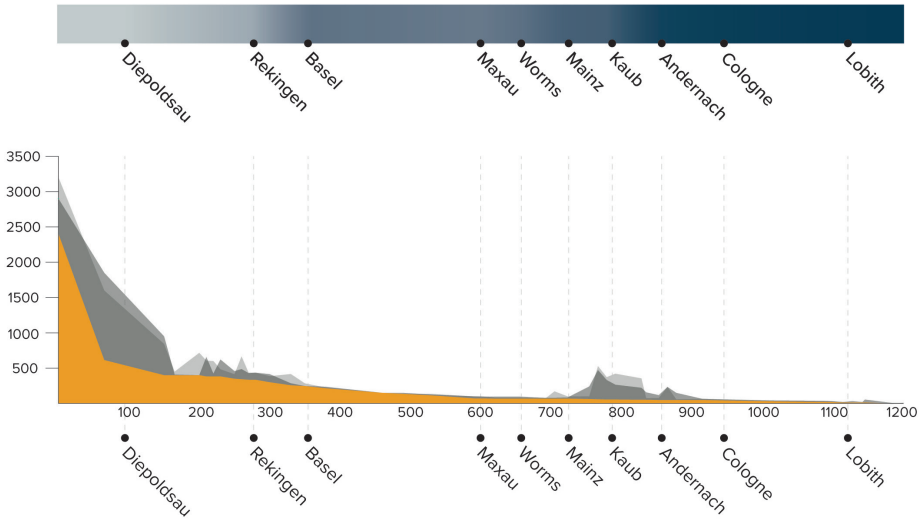

Soil regions
Dominant soils
Fluvisols
Fluvisol & Albeluvisol
Fluvisol & Regosol
Cambisol
Cambisol & Fluvisol
Cambisol & Luvisol
Cambisol & Leptosol
Cambisol & Planosol
Podzol
Anthrosol
Leptosol
Leptosol & Podzol
Phaeozem
Luvisol, Cambisol & Gleysol
Non soils
No data
0 km 50 100

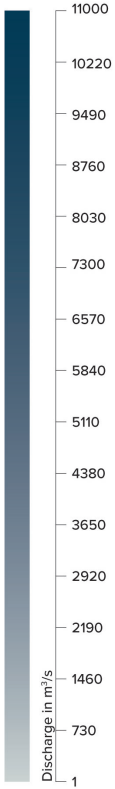

Arnhem
Nijmegen
Rotterdam
Duisburg
Düsseldorf
Cologne
Bonn
Koblenz
Mainz
Mannheim
Strasbourg
Basel
Drought
High and moderate vulnerability to floods
Moderate vulnerability to droughts
Below average soil moisture
Glaciers melting, perpetual snow disappearing
Increase of low summer discharge and more extreme low flows
Increase of high discharge
0 km 50 100

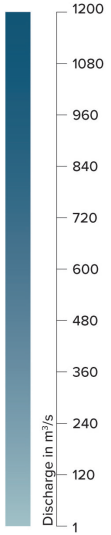
Low water discharge

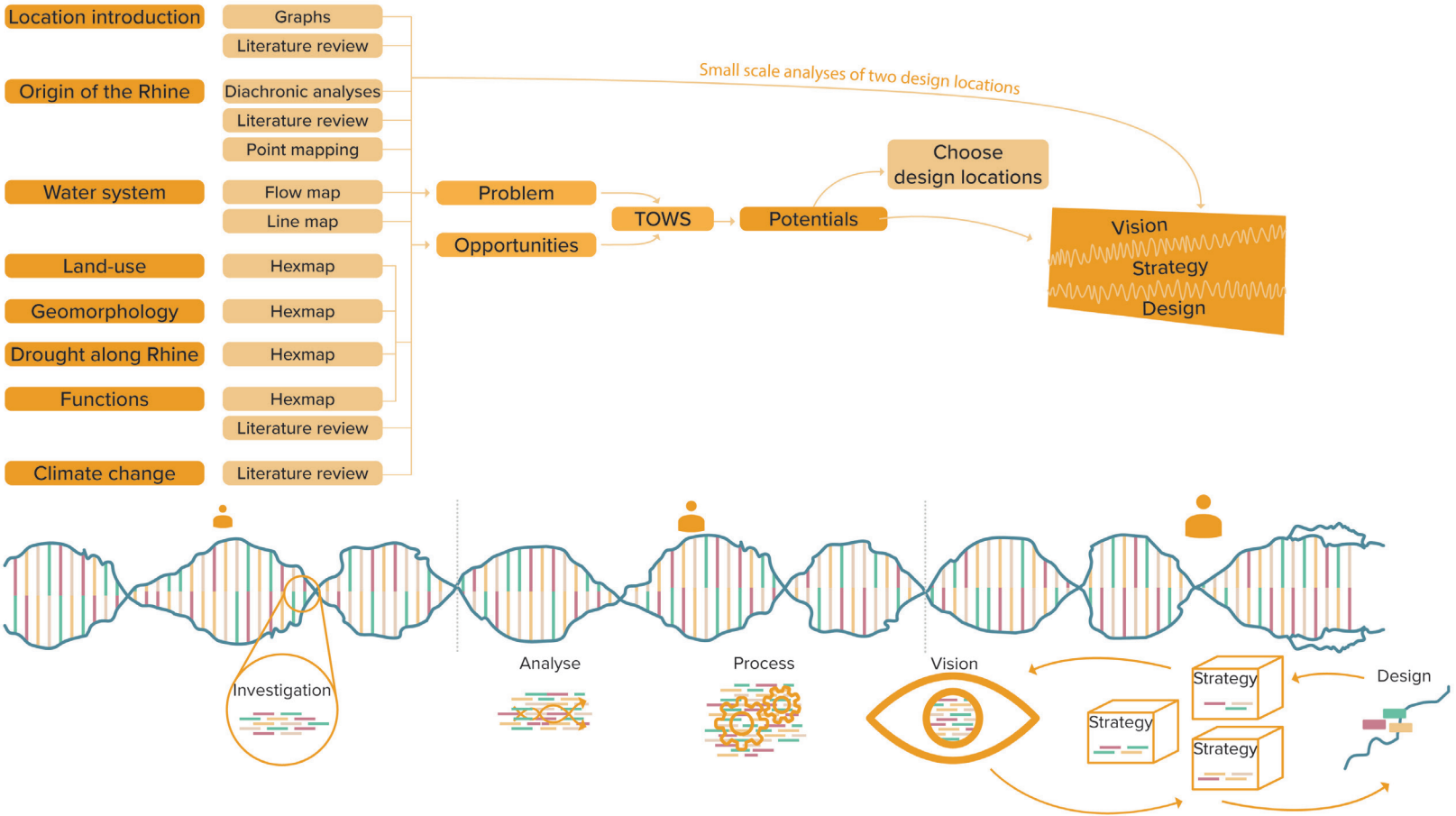
Low water discharge

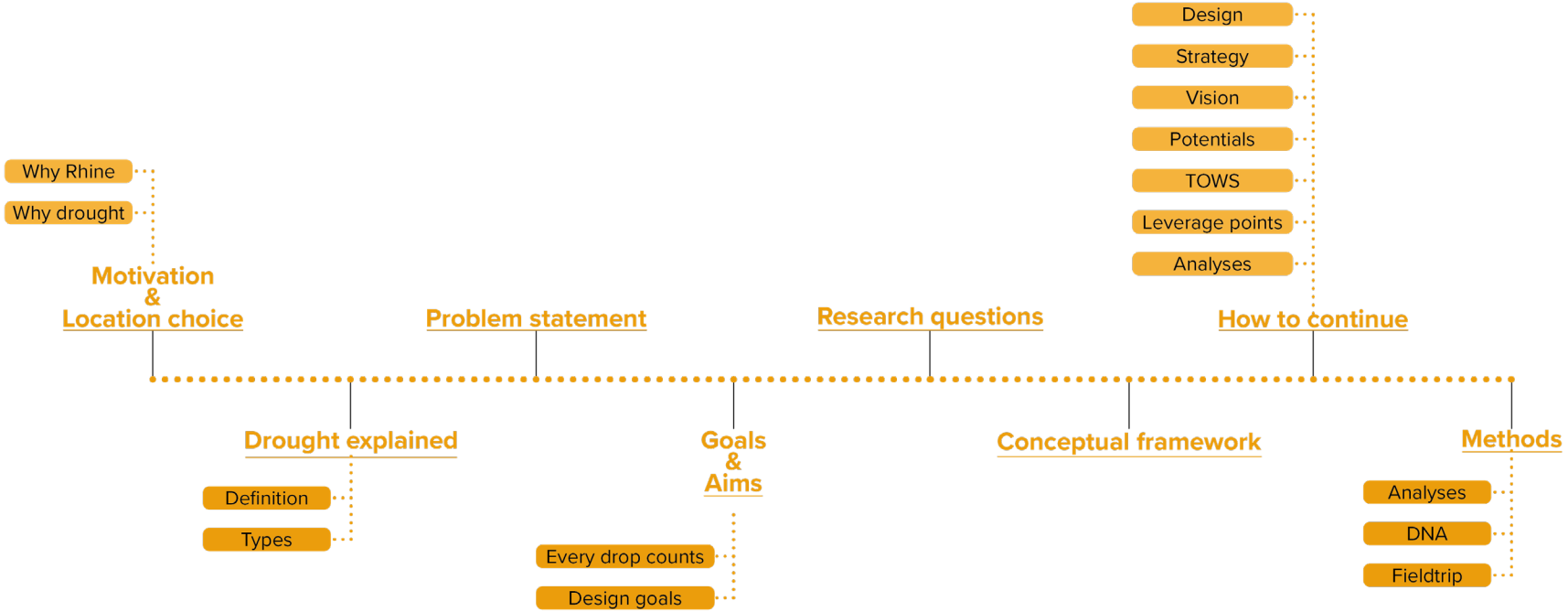
High water discharge








Location introduction
Graphs
Literature review
Origin of the Rhine
Diachronic analyses
Literature review
Point mapping
Water system
Flow map
Line map
Land-use
Hexmap
Geomorphology
Hexmap
Drought along Rhine
Hexmap
Functions
Hexmap
Literature review
Climate change
Literature review
Small scale analyses of two design locations
Problem
Opportunities
TOWS
Potentials
Choose design locations
Vision
Strategy
Design
Investigation
Analyse
Process
Vision
Strategy
Strategy
Strategy
Design


Why Rhine
Why drought
Motivation & Location choice
Problem statement
Research questions
Design
Strategy
Vision
Potentials
TOWS
Leverage points
Analyses
How to continue
Drought explained
Definition
Types
Goals & Aims
Every drop counts
Design goals
Conceptual framework
Methods
Analyses
DNA
Fieldtrip

Research questions

How can the river Rhine stay a vibrant and functional riverscape by creating a synergy between urban and rural areas while using the green infrastructure approach to prevent drought-related problems?

Analyses

To understand the environmental impact of drought on functions of the Rhine.

How does streamflow drought impact the Rhine and the surrounding landscape?

To understand the social impact of drought on functions of the Rhine.

How are the functions of and on the Rhine affected by drought?

To find solutions to combat the impact of drought on functions of the Rhine

Vision

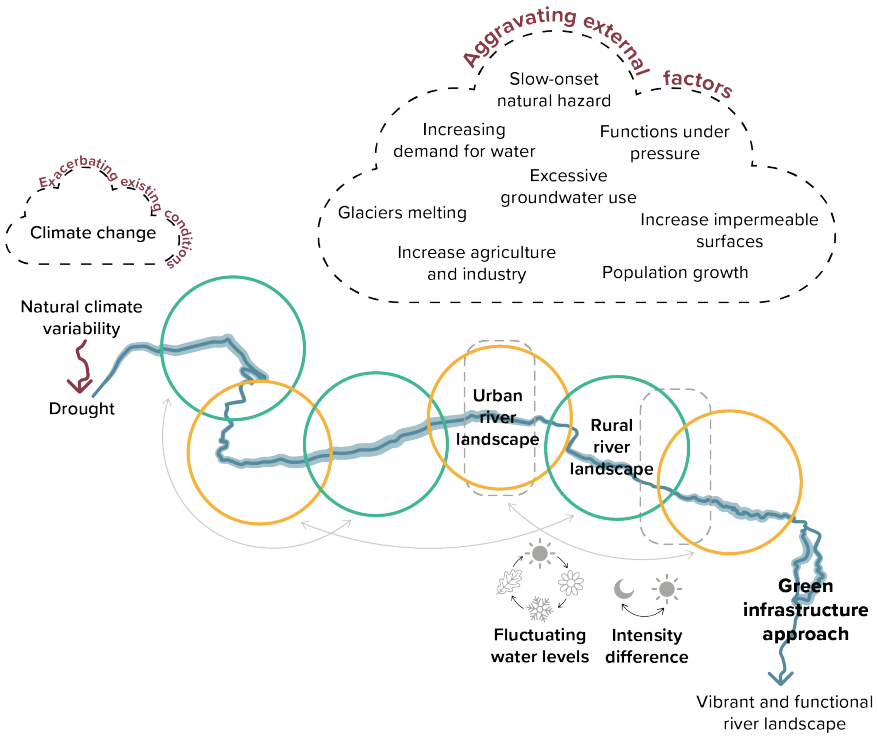
How can urban and rural river landscapes form a synergy in drought prevention?

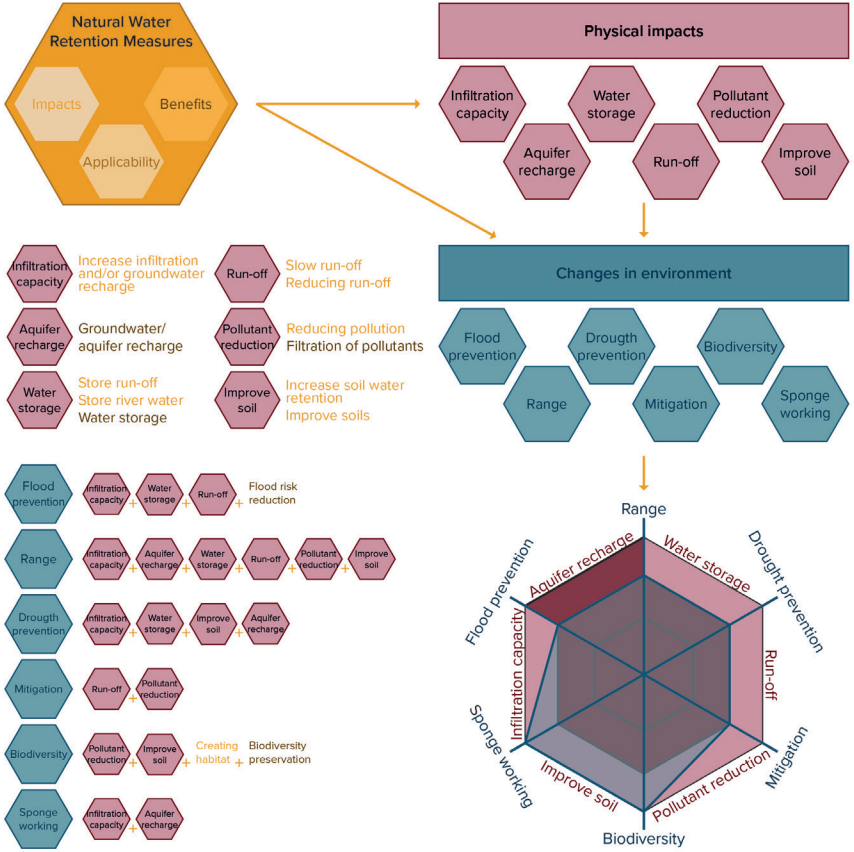
Strategy

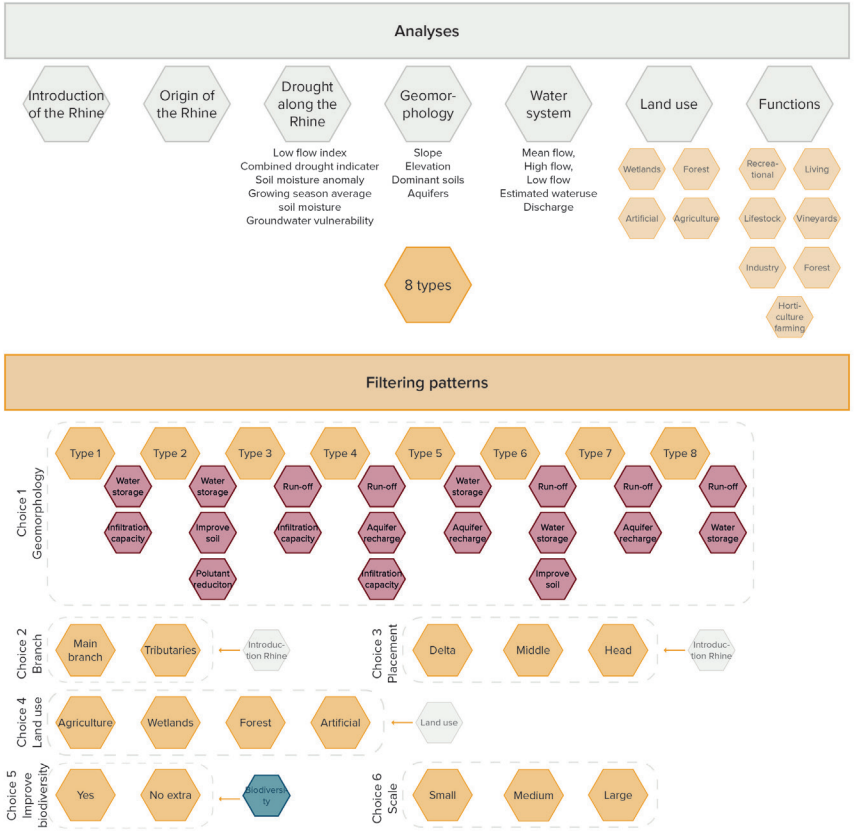
How can the green infrastructure approach be used for drought prevention strategies along the Rhine?

Design

How can the desired drought prevention strategies be implemented along the Rhine?


Aggravating external factors
Slow-onset natural hazard
Increasing demand for water
Functions under pressure
Excessive groundwater use
Glaciers melting
Increase impermeable surfaces
Increase agriculture and industry
Population growth
Exacerbating existing conditions
Climate change
Natural climate variability
Drought
Urban river landscape
Rural river landscape
Fluctuating water levels
Intensity difference
Green infrastructure approach
Vibrant and functional river landscape


Natural Water Retention Measures
Impacts
Benefits
Applicability
Physical impacts
Infiltration capacity
Water storage
Pollutant reduction
Aquifer recharge
Run-off
Improve soil
Changes in environment
Flood prevention
Drougth prevention
Biodiversity
Range
Mitigation
Sponge working
Infiltration capacity
Increase infiltration and/or groundwater recharge
Aquifer recharge
Groundwater/ aquifer recharge
Water storage
Store run-off
Store river water
Water storage
Run-off
Slow run-off
Reducing run-off
Pollutant reduction
Reducing pollution
Filtration of pollutants
Improve soil
Increase soil water retention
Improve soils
Flood prevention
Infiltration capacity
Water storage
Run-off
Flood risk reduction
Range
Infiltration capacity
Aquifer recharge
Water storage
Run-off
Pollutant reduction
Improve soil
Drougth prevention
Infiltration capacity
Water storage
Improve soil
Aquifer recharge
Mitigation
Run-off
Pollutant reduction
Biodiversity
Pollutant reduction
Improve soil
Creating habitat
Biodiversity preservation
Sponge working
Infiltration capacity
Aquifer recharge
Range
Water storage
Drought prevention
Run-off
Mitigation
Pollutant reduction
Biodiversity
Improve soil
Sponge working
Infiltration capacity
Flood prevention
Aquifer recharge


Analyses
Introduction of the Rhine
Origin of the Rhine
Drought along the Rhine
Low flow index
Combined drought indicater
Soil moisture anomaly
Growing season average soil moisture
Groundwater vulnerability
Geomor-phology
Slope
Elevation
Dominant soils
Aquifers
8 types
Water system
Mean flow,
High flow,
Low flow
Estimated wateruse
Discharge
Land use
Wetlands
Forest
Artificial
Agriculture
Functions
Recrea-tional
Living
Lifestock
Vineyards
Industry
Forest
Horti-culture farming
Filtering patterns
Choice 1 Geomorphology
Type 1
Water storage
Infiltration capacity
Type 2
Water storage
Improve soil
Pollutant reducitory
Type 3
Run-off
Infiltration capacity
Type 4
Run-off
Aquifer recharge
Infiltration capacity
Type 5
Water storage
Aquifer recharge
Type 6
Run-off
Water storage
Improve soil
Type 7
Run-off
Aquifer recharge
Type 8
Run-off
Water storage
Choice 2 Branch
Main branch
Tributaries
Introduc-tion Rhine
Choice 3 Placement
Delta
Middle
Head
Introduc-tion Rhine
Choice 4 Land use
Agriculture
Wetlands
Forest
Artificial
Land use
Choice 5 Improve biodiversity
Yes
No extra
Biodiversity
Choice 6 Scale
Small
Medium
Large