PATTERN CATALOGUE

Every Drop Counts

How to keep the Rhine functional in times of drought

Anna van den Berg
19/06/2023

COLOPHON

Master Thesis - P5 Report

Faculty of Architecture and the Built Environment
MSc Architecture, Urbanism and Building Sciences - Track Urbanism
Delft University of Technology
Graduation Lab: Metropolitan Ecologies of Place

Pattern Catalogue
Every Drop Counts
How to keep the Rhine functional in times of drought

2022-2023

Author

Name:	Anna van den Berg
Student number:	5438888

Supervisors

First Mentor:	Ir. K.P.M. (Kristel) Aalbers - Environmental Technology & Design
Second Mentor:	Dr. ir. C. (Claudiu) Forgaci - Urban Design
Delegate of the board:	Ir. W. (Wouter) Willers
	Drs. D.J. (Dirk) Dubbeling

* Cover image made by author

CONTENT

INTRODUCTION

1.

1.1 PATTERN LANGUAGE AND THE PROJECT

Patterns are flexible principles that can be adapted to various situations and locations. In this strategy, the patterns are based on the book by Alexander et al. (1977) that explores the concept of patterns. The patterns are essential guidelines that can be used to solve specific design problems in a distinct context. A pattern gives information about the crucial guidelines and where and how these design principles could be implemented. The patterns inform in which context they would be most effective.

The patterns are a design tool to distil design solutions into a set of underlying principles (patterns) that can be applied across various situations. Some patterns can be combined to enhance one another. The patterns are flexible and adaptable to the situation, creating a functional result. The patterns are a starting point for designing, giving the designer the best-suited solutions for the location. These patterns can then be tailored and combined with a site's needs.

Patterns are also used as communication tools towards all stakeholders and designers. These design solutions are made digestible for all stakeholders with a short overview of information and a clear explanation. They help stakeholders work together and ensure that everyone involved in a project works towards the same goals.

Every Drop Counts uses a green-blue infrastructure approach. With this, patterns are cross-border applicable and aim to connect. The overall aim of the patterns for Every Drop Counts is to create an overview of design measures that can be implemented along the Rhine to mitigate drought problems. The patterns are focused on their ability to alleviate drought and flood. Because of many possibilities, these patterns contain a filtering system considering the need for infiltration or placement along the streamflow. These patterns will be implemented in a design strategy to show how they can be used.

1.2 PATTERN SETUP

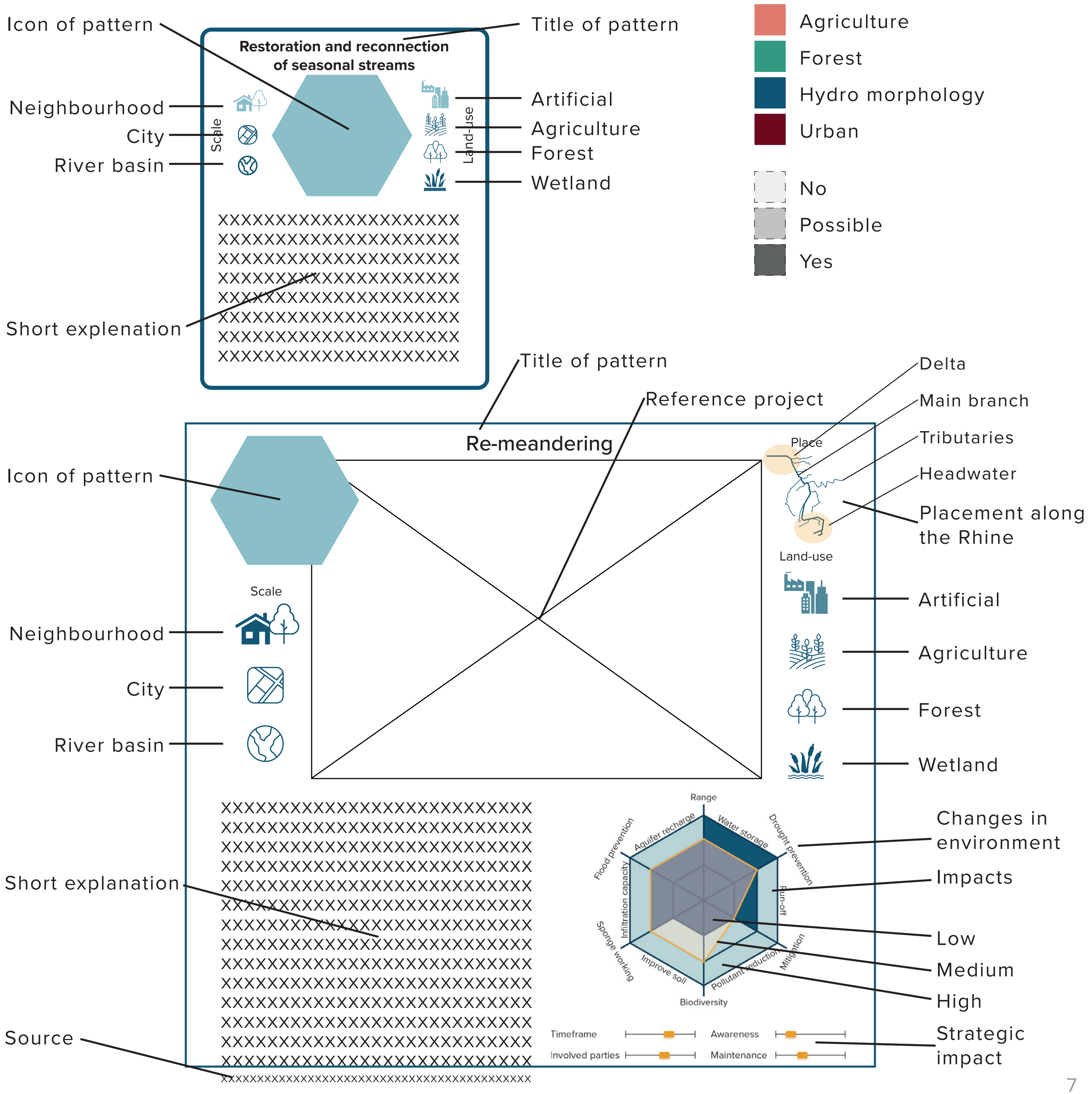
For this project, two types of patterns are created. A small pattern card is used to give an overview of all patterns included in this catalogue. Then there are larger patterns that contain background information for the patterns on the small cards. Only the patterns used for the project Every Drop Counts are elaborated for the large patterns.

Small patterns contain a title that describes the pattern, an icon indicating the use of the pattern and a small text with a short explanation. The scale and land use where this pattern can be implemented is shown. The cards can have four different colours, each corresponding to a different theme; agriculture, forest, hydro morphology, and urban.

The large pattern gives more background information on the measure. It also contains the describing title, icon, scale, and land use icons. Furthermore, this pattern shows the possible placement of the pattern along the Rhine. The main image shows a reference project of the pattern, giving an example of how this pattern could be implemented. There is a longer explanation of the measure. The last part is a multi-level radar chart. This chart shows the impact the measure can have when implemented on a low to high-impact scale. The effects are infiltration, run-off, flood prevention, water storage, biodiversity, and groundwater recharge. The second layer shows environmental impacts.

In this layer, the following aspects are detailed:

- Time frame: This shows the amount of time it takes to complete this pattern. This can be completed in months to years to decades.
- Involved parties: This gives an idea of the number of parties that could be involved in setting up this pattern. The more parties involved, the more complicated it can be to introduce a pattern successfully.
- Impact: Gives an idea of the pattern's impact is a local or regional scale or if a measure upstream can have an effect downstream.
- Water velocity: The impact on the water velocity from minimal to significant.
- Awareness: The impact this pattern has on the general public to inform on drought and floods. Does it create some awareness from no noticeable differences to very educational.
- Relief: The relief of the landscape from only impactful on one type of relief to multipurpose to possible to implement on all kinds of reliefs.



Icon of pattern
Title of pattern
Restoration and reconnection of seasonal streams
Neighbourhood
City
River basin
Scale
Land-use
Artificial
Agriculture
Forest
Wetland
Short explenation
Agriculture
Forest
Hydro morphology
Urban
No
Possible
Yes
Title of pattern
Reference project
Re-meandering
Delta
Main branch
Tributaries
Headwater
Place
Placement along the Rhine
Land-use
Icon of pattern
Scale
Neighbourhood
City
River basin
Artificial
Agriculture
Forest
Wetland
Short explanation
Source
Range
Water storage
Drought prevention
Run-off
Mitigation
Pollutant reduction
Biodiversity
Improve soil
Sponge working
Infiltration capacity
Flood prevention
Aquifer recharge
Changes in environment
Impacts
Low
Medium
High
Timeframe
Awareness
Involved parties
Maintenance
Strategic impact

CATALOGUE OF NWRM

2.

2.1 METHODOLOGY

This Pattern Catalogue is based on the European Natural Water Retention Measures catalogue from the EU Directorate General Environment. They advocate for using nature-based green infrastructure solutions, *"Natural Water Retention Measures (NWRM) support Green Infrastructure by contributing to integrated goals dealing with nature and biodiversity conservation and restoration, landscaping, etc."*. They collected different NWRM to support the green infrastructure in a catalogue, where the biophysical impacts of these measures are indicated.

Natural Water Retention Measures are multifunctional measures that aspire to preserve water resources. They are based on the principle of restoring or maintaining ecosystems and natural features and characteristics. The main focus of these measures is to enhance the retention capacity of aquifers, soil, and aquatic and water-dependent ecosystems. pi

The NWRM have an excellent basis for a pattern structure and already includes many measures suitable for mitigating drought along the Rhine. Patterns have been created using the information provided by the European Commission and Office International de l'Eau (2014a). Using the NWRM as patterns makes information more accessible and allows for connecting different patterns. These patterns can be found on page 20 to 33.

The patterns are divided into the categories used for the NWRM. These are as follows:

- Agriculture
- Forest
- Hydro morphology
- Urban

Besides the NWRM, some different patterns have been added that can help to reduce the drought problems around the Rhine.

This booklet contains a pattern catalogue and not a pattern language. This pattern catalogue will probably never be fully complete, either because new measures are discovered or the sheer amount of possibilities for actions. It will not be fully completed and is a starting point for a pattern language.

Not all Natural Water Retention Measures are as crucial for Every Drop Counts. Thus, the most influential and adjustable patterns for the circumstances have been selected for different scale sizes. With the help of pattern fields, a selection can be made. There are different types of pattern fields. The pattern fields can be viewed on page 12 to 19.

In this report, the following will be implemented:

- Organised by theme; it gives a short overview of the patterns per category.
- Organised by land use; it shows what pattern can perform on what land use.
- Organised by scale and abstractness; it gives an overview of the scale of each pattern and how concrete they are when implemented.
- Relatedness; it shows what patterns can be implemented together. This creates a hierarchy in the implementation of patterns.
- The impact on drought; shows what patterns are most effective for drought problems.

2.2 PATTERN FIELDS

Pattern fields are fundamental for understanding and creating meaningful design solutions. The pattern fields represent challenges commonly encountered in the built environment. By categorising the patterns, connections can be spotted, and a shared way of communicating and addressing issues can be created. The pattern fields are used to show how the patterns relate to each other. With these pattern fields, a better understanding of the filtering of the patterns can be achieved, and an overview of the patterns can be achieved. When designing with the patterns, the pattern fields can help to identify suitable implementations.

The first pattern field is **organised by theme.** This gives an overview of the used patterns and their general theme in this report.

The second pattern field is **organised by scale and abstractness**. With this pattern field, the difference between themes is very noticeable. The artificial patterns are noticeably more small-scale and concrete than any other theme, while the wetland and forest patterns tend to lean more towards large-scale and abstract forms.

The third pattern field is **organised by land use**. This is a circular field because some patterns apply to multiple land uses. In the inner circle, three patterns are found. These patterns apply to every land use type. In the layer beyond this, two clusters are found. These patterns apply to three land use types. One group applies to artificial, agricultural & forest. The second group applies to artificial wetlands and forests. Then there are two groups of both patterns. They apply to either artificial & agriculture or forest and wetlands. The groups left are only implementable on one specific land use type.

Noticeable is the lack of connection between wetlands and agriculture. These two land uses do not work well together in the design and create an extra challenge by using two different sets of patterns. Another exciting discovery is that patterns with the theme forest only apply to artificial land uses. Urban forest parks and trees in urban areas are both patterns that are indeed forest themed but targeted explicitly for urbanised areas, making them fit for artificial land use.

The fourth pattern field is **organised by scale**. Here the patterns are categorised by their ability to be implemented on different scales. Every Drop Counts assesses each pattern on three scales. This pattern field gives an overview of the flexibility of the pattern in adjusting to a different scale. The top ones apply to all scale types, while the bottom ones only apply to one scale. In this field, it is very noticeable that patterns with an artificial agricultural theme are pretty rigid in their ability to adjust to different scales. These patterns are thought out for a specific scale and cannot be easily adjusted to other scales. At the same time, forest and hydro morphological patterns are more commonly adjustable to different scales.

The fifth pattern field is **organised by flexibility**. In this pattern field, the ability of the patterns to adjust to different scales and to apply to different land uses is tested. The top ones are patterns that can be implemented on different scales and different types of land uses. While the bottom patterns apply to one land use type and one scale. Here is again a noticeable difference between artificial and agricultural patterns and forest and hydro morphological patterns. The first two are again rigid, while the last two are more flexible in application.

The sixth pattern field is **organised by applicability.** Here patterns that are universally implementable are on the top. These patterns often don't need specific land typologies or structures to be able to be applied. Patterns on the bottom have specific elements that must appear in the landscape to implement these patterns.

The seventh pattern field is **organised by applicability, land use, & flexibility.** This field gives an extensive overview of the patterns. Here the patterns can be judged per land use type and see which ones are rigid or flexible and which are universal or specific.

The patterns are **organised by type** for the eighth and final pattern field. Here, eight types of patterns are shown: large water structures, holding water, guiding water, improving soil structure, improving urban areas, adding or maintaining greenery, changing built structures, and improving agricultural practices. This can help compare patterns that have similarities but differ in effectiveness and implementation. By using this pattern field and adding other pattern fields for information, choices can be made more accessible.

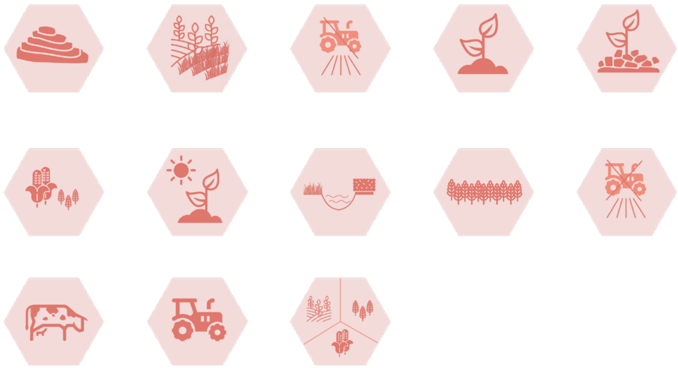
When looking at every pattern field, a few patterns jump out as applicable to various situations. These patterns are flexible, universal, and applicable to multiple land uses and scales. The patterns that come back a lot are:

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

These patterns are a good starting point when wanting to design with patterns and finding out what patterns will suit the design location and its needs most.

Organised by theme

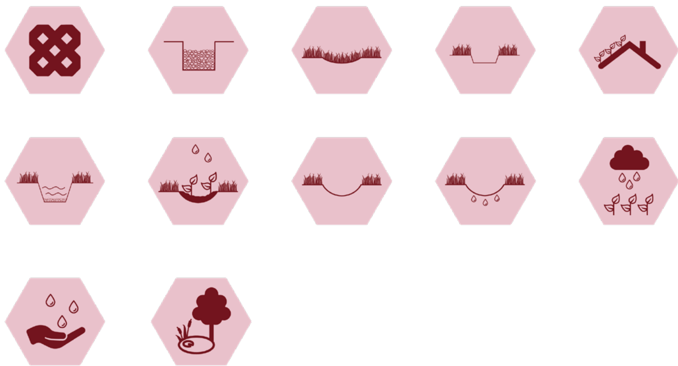
Agriculture



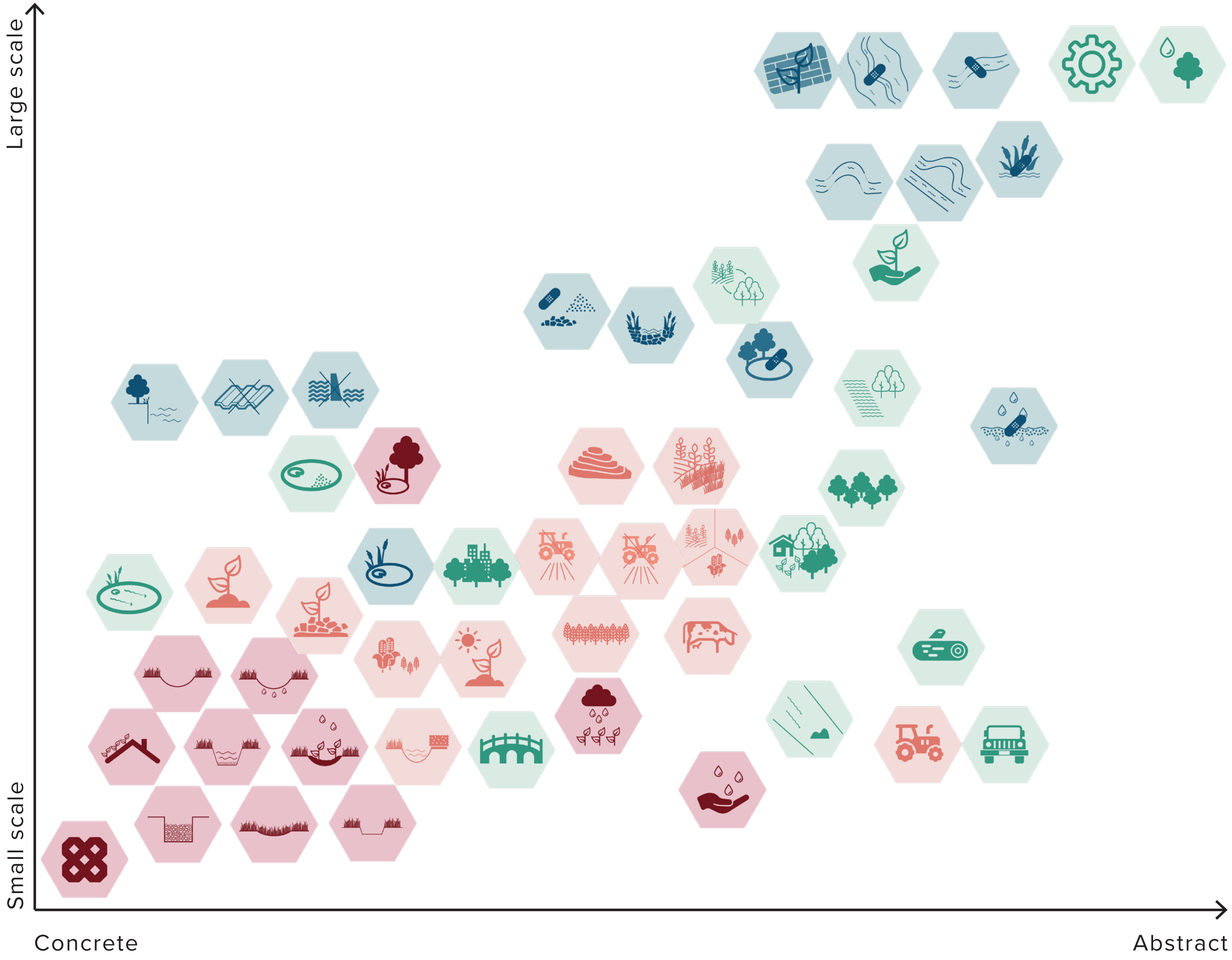
Forest

Hydro morpholgy

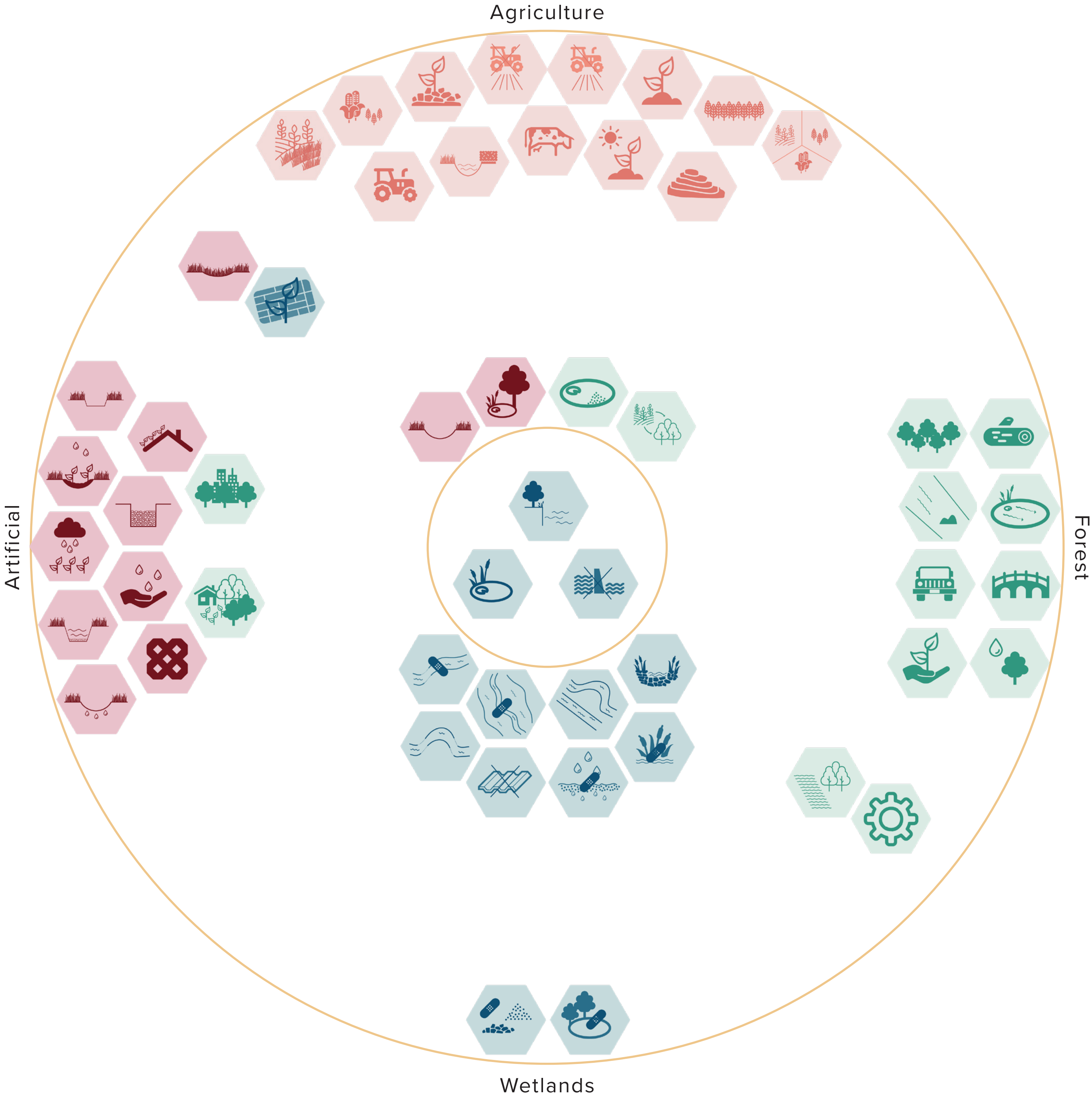
Urban



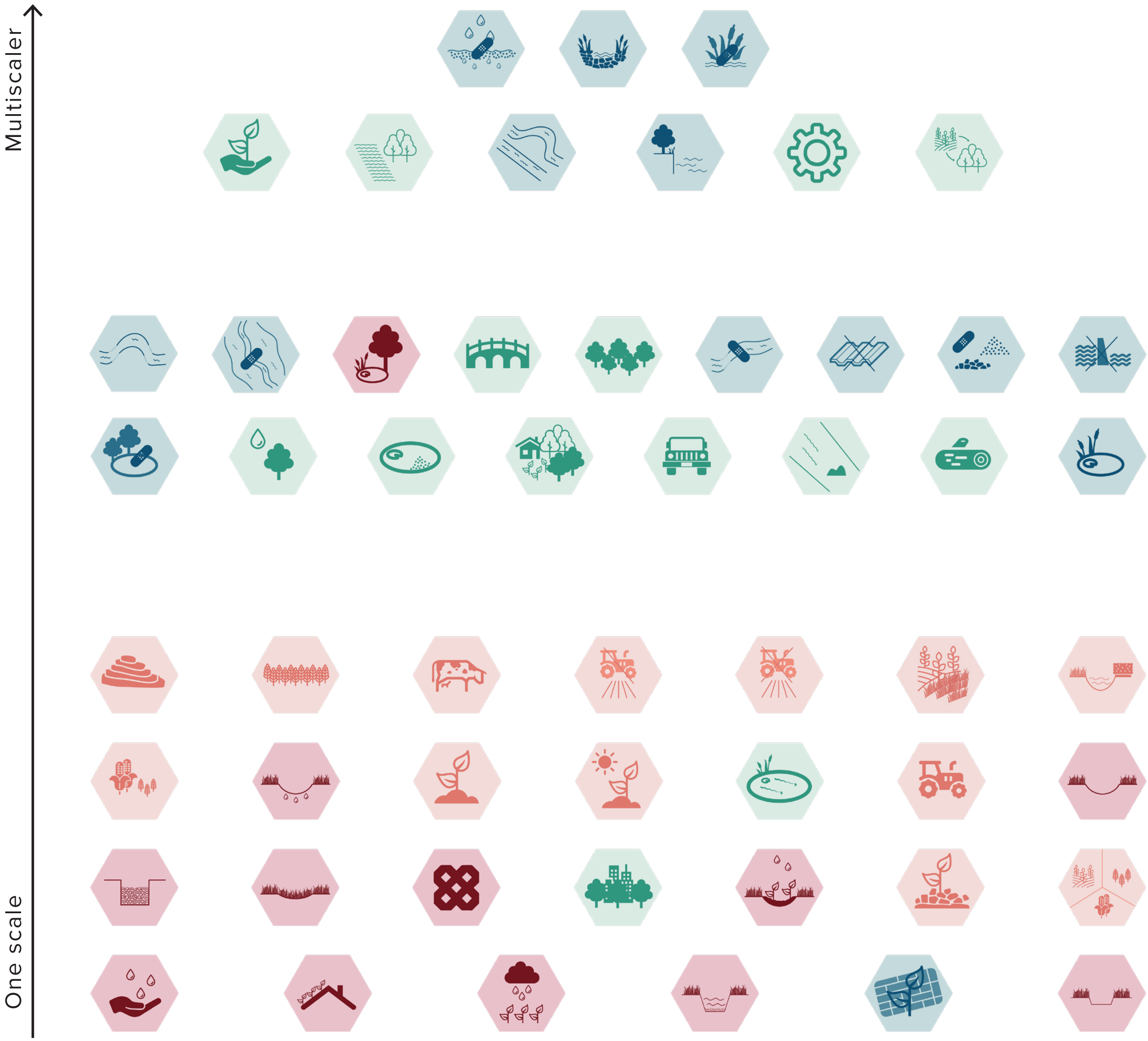
Organised scale and abstractness



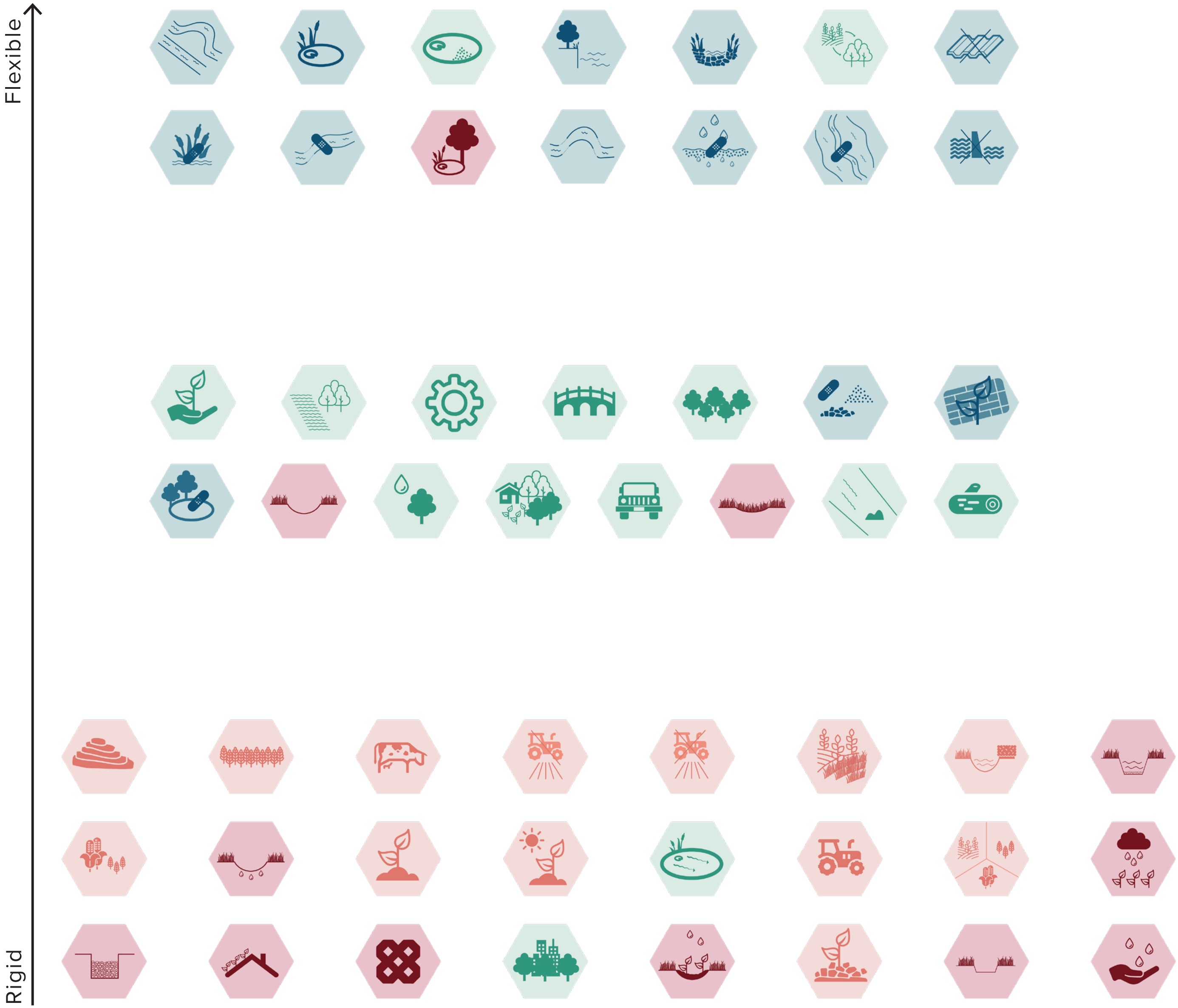
Organised by land use



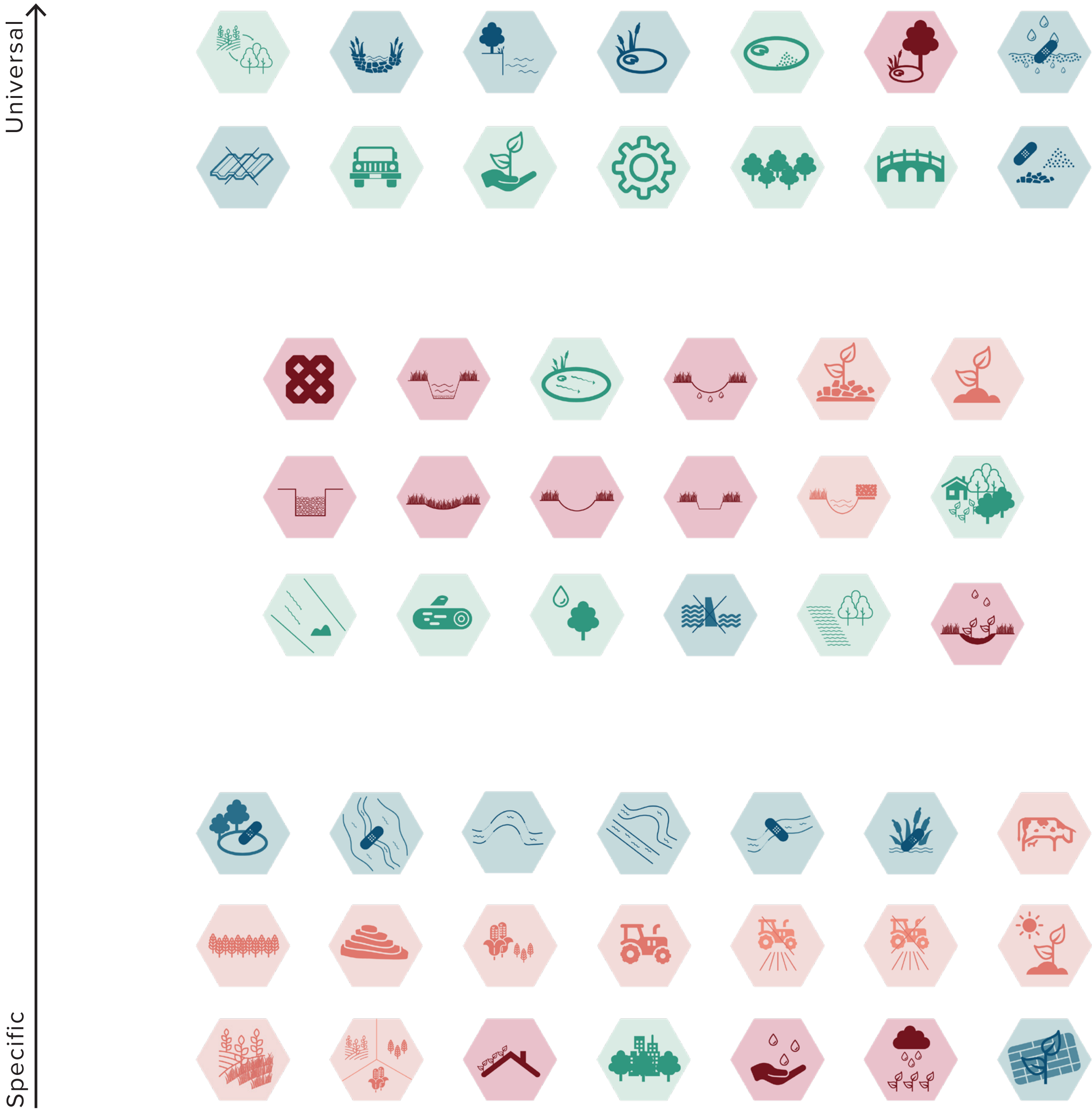
Organised by scale



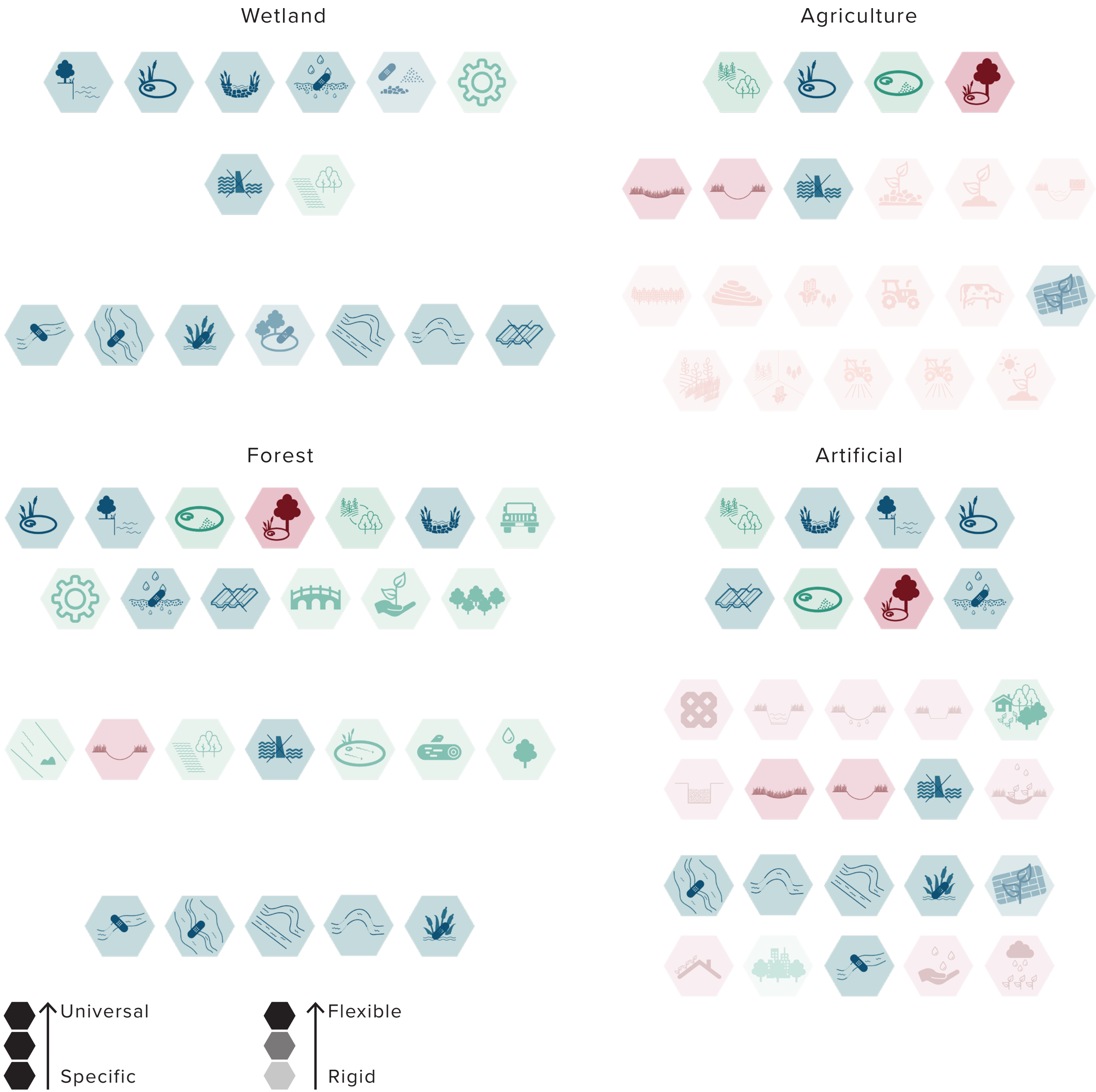
Organised by flexibility (by combining landuse and scale)



Organised by applicability

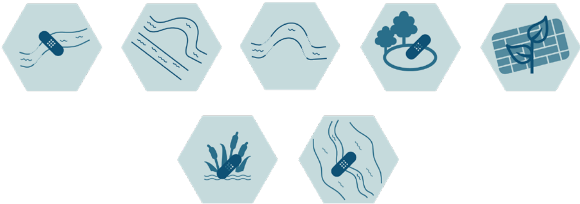


Organised by applicability, landuse, & flexibility



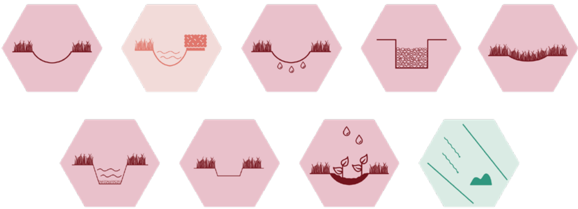
Organised by type

Large water structures



Holding water

Guiding water



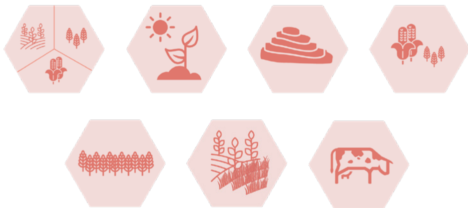
Improving soil structure

Improving urban areas

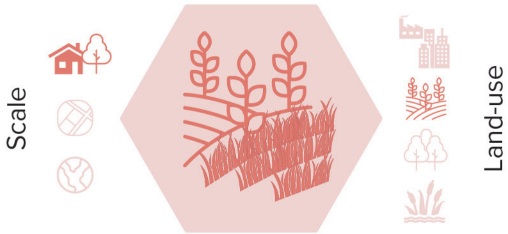
Adding or maintaining greenery

Changing built structures

Improving agricultural practises

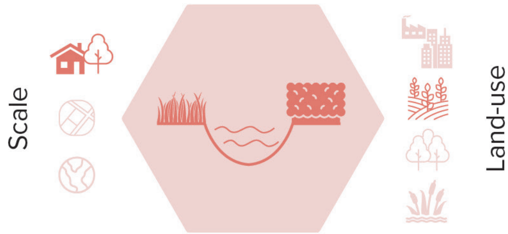


Meadows and pastures



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.

Buffer strips and hedges

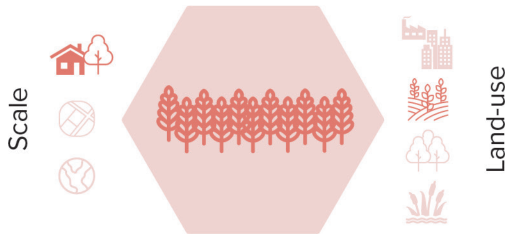


Buffer strips provide effective water infiltration, and they slow surface run-off. Permanent vegetation along buffer strips promotes the natural retention of water. By implementing hedges alongside buffer strips, soil erosion can be reduced and slow surface run-off, especially along sloped areas.

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.

Strip cropping along contours

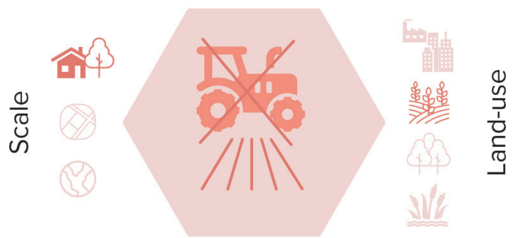


Strip cropping is the practice of using closely sown crops to create natural dams for water to improve soil strength and stop erosion. This practice is used on steep or long slopes.

Intercropping

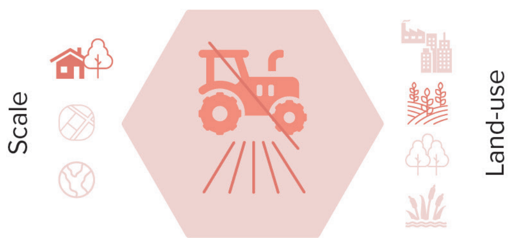
Intercropping is the practice of growing two or more crops next to each other. By intercropping, greater yield can be produced, and land can be more productively utilised. By using a combination of deep-rooted and shallow-rooted crops, infiltration rates of soil can be improved. By using intercropping,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

No till agriculture



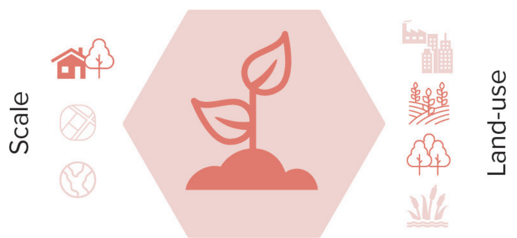
Tillage, the mechanical modification of soil, can disturb soil structure and increase soil erosion problems. By altering soil structures, the retention capacity can be decreased. By implementing no till agriculture, water infiltration into the soil will increase and reduce soil erosion.

Low till agriculture



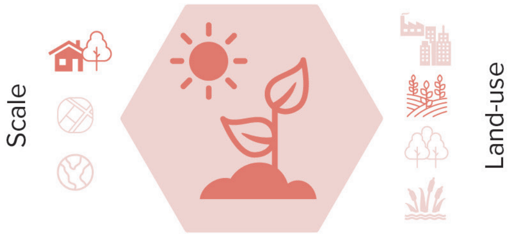
Tillage, the mechanical modification of soil, can disturb soil structure and increase soil erosion problems. By implementing low till agriculture, water movement slows and can lead to more significant infiltration. By altering soil structures, the retention capacity can be decreased.

Green cover



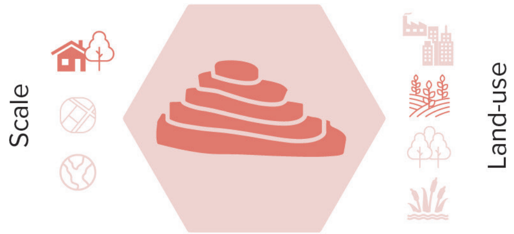
Green cover is the planting of crops in the late summer or autumn. Green cover protects the soil against erosion. Green cover can also improve soil structures and improve the infiltration of soil.

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.

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.

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.

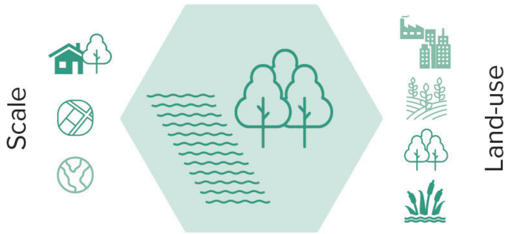
Reduced stocking density

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.

Mulching

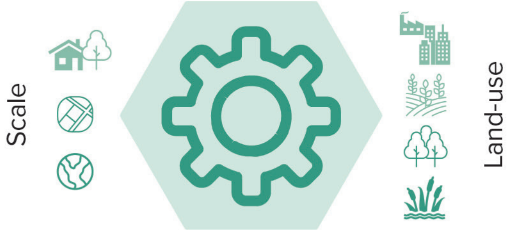
Mulching is the application of adding material to the surface of the existing soil. Preferably the mulch is an organic material. Mulching can improve the capacity of the soil to store water.

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.

Maintenance of forest cover in headwater areas

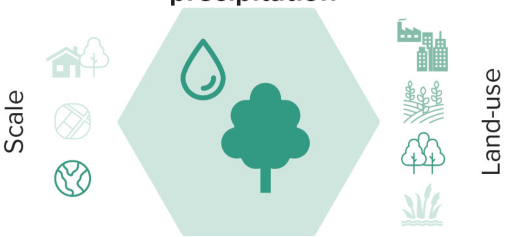


Maintenance of forest cover in headwater areas is the management and conservation of forested lands in the upper regions of a river basin. By implementing forest in headwater areas, the soil has a better infiltration capacity and can help regulate water availability. Forest cover in headwater areas can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

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.

Targeted planting for catching precipitation

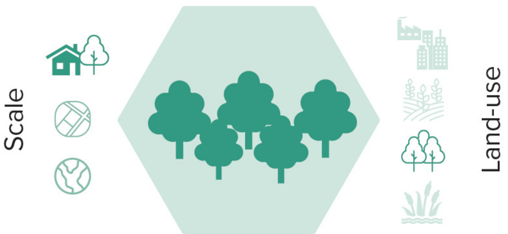


The afforestation of reservoir catchments extends the lifespan of the reservoir and improves water quality. The roots control soil erosion and increase water infiltration rates into the soil. The forest in reservoir catchments should be managed naturally to prevent water quality from depleting.

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.

Continuous cover forestry

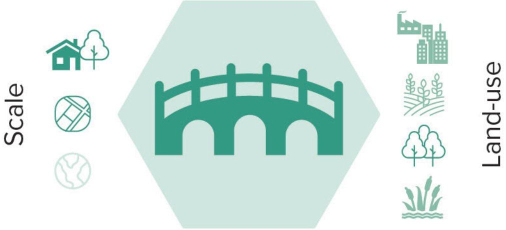


Continuous cover forestry combines a range of forest management practices. The main principle is the protection of the soil and the creation of a continuous cover. This strategy includes a natural forest hydrological cycle with beneficial hydrological effects. Continuous cover forestry also reduces the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

Water sensitive driving

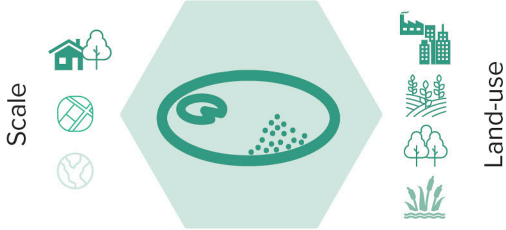
‘Water sensitive’ driving is the avoidance of off-road driving and through wet areas. By implementing these driving styles, soil structures will not damage. The measure also avoids the creation of different flow paths that could disrupt water cycles. The benefits of water-sensitive driving are visible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

Appropriate design of roads and stream crossings



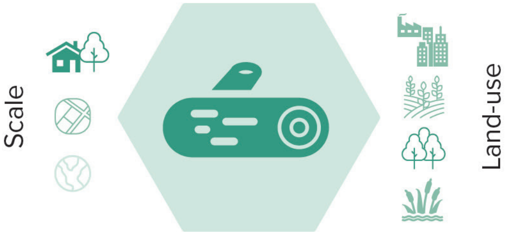
The design and materials used in the design of roads and stream crossings can strongly impact the erosion risk and water quality of rivers. Poorly designed stream crossings can cause sediment accumulation and change flow patterns.

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.

Coarse 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.

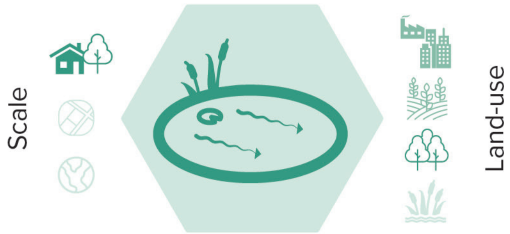
Urban forest parks

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.

Trees in urban areas

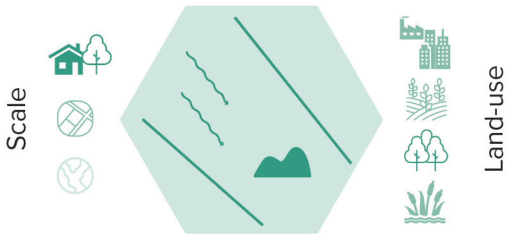
Urban trees provide microclimate regulation and hydrological benefits. They enhance infiltration capacity and rainfall storage. They also serve as biodiversity refuges and intercept precipitation, reducing the amount of precipitation sewer, and water infrastructure have to process.

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.

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.

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.

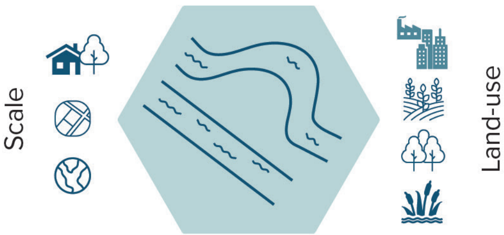
Wetland restoration and management

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.

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.

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.

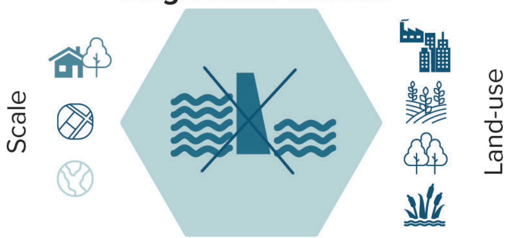
Reconnection of oxbow lakes and similar features

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.

Riverbed material restoration

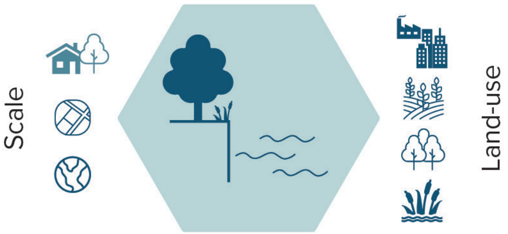
Re-naturalising involves restoring the natural structure of the riverbed. Riverbed material is sediment eroded upstream that is deposited on the river floor. With coarse sediment, the riverbed can be levelled. The main objective of riverbed material restoration is erosion control.

Removal of dams and other longitudinal barriers



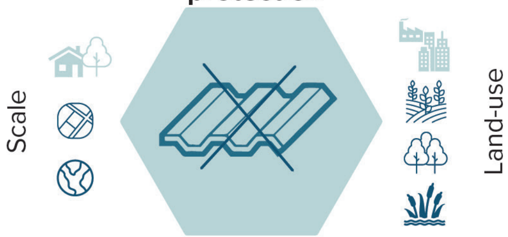
Dams and other barriers disrupt sediment flow and disturb fauna in rivers. Removing dams and other barriers involves destroying obstacles and restoring the river profile. When this is implemented, ecological and sedimentary continuity needs to be considered.

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.

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.

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.

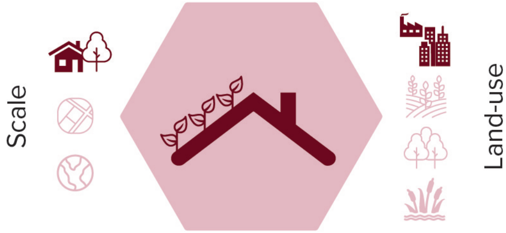
Restoration of natural infiltration to groundwater

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.

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.

Green roofs

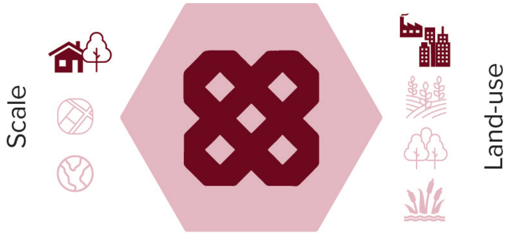


Green roofs cover a building's roof with vegetation and a drainage layer. There are two types: extensive, which covers the entire roof with low-maintenance vegetation, and intensive, which requires more maintenance and can include planters, trees, and water features. Green roofs intercept rainfall and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

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.

Permeable paving

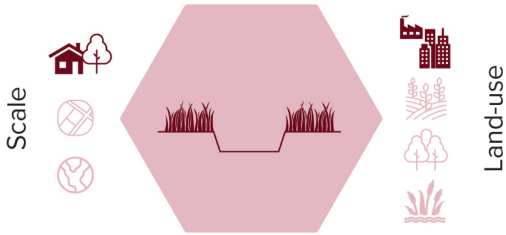


Permeable paving allows rainwater to infiltrate through the surface of paved areas. There are two types: porous pavements and permeable pavements. It can be used in most ground conditions and is commonly used on low-traffic roads and car parks. All kinds of permeable paving provide rainfall infiltration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

Swales

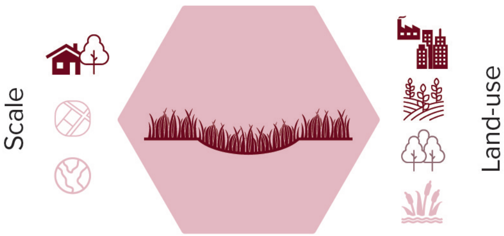
Swales are vegetated channels that store or transport surface water, reducing run-off rates. They can be used to promote infiltration. Swales can improve water quality, and can provide biodiversity. They can be used in a wide range of situations. There are three types: standard conveyance, enhanced dry,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

Channels and rills



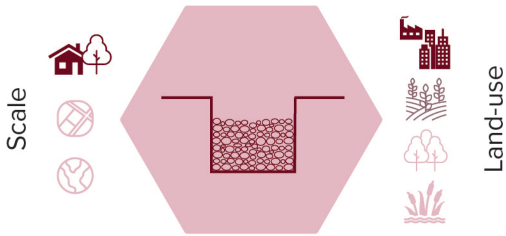
Channels and rills are shallow channels with open surface water that capture and slow run-off. They can collect and store debris, treat pollution, and guide water downstream. They can be designed in different varieties, and the planting can improve water quality.

Filter strips



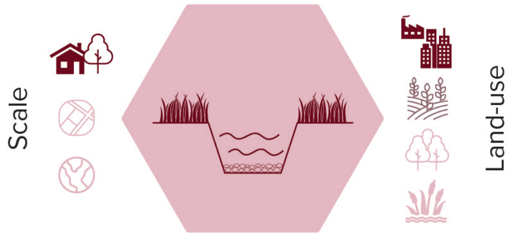
Filter strips are gently sloping strips that treat run-off through vegetative filtering. They intercept sedimentation and let water infiltrate. Filter strips can be used as a pre-treatment technique in small drainage areas. They can serve as buffers between confilcting land uses and help with groundwater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

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.

Infiltration trenches

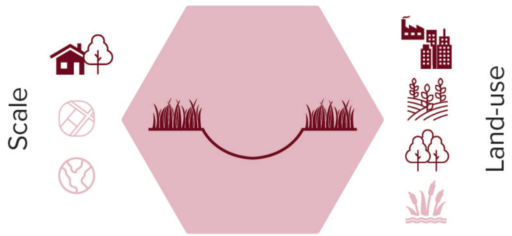


Infiltration trenches are shallow channels filled with rubble or stone. These trenches let water infiltrate into the soil. Infiltration trenches help reduce run-off, recharge groundwater and improve water quality.

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.

Detention basins

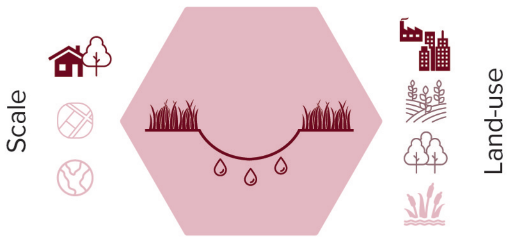


Detention basins are vegetated impressions in the landscape that holds run-off. They allow pollutants and sediments to settle. Detention basins do not allow infiltration, and water is drained into nearby water structures.

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.

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.

2.4 ELABORATION

Choice of pattern

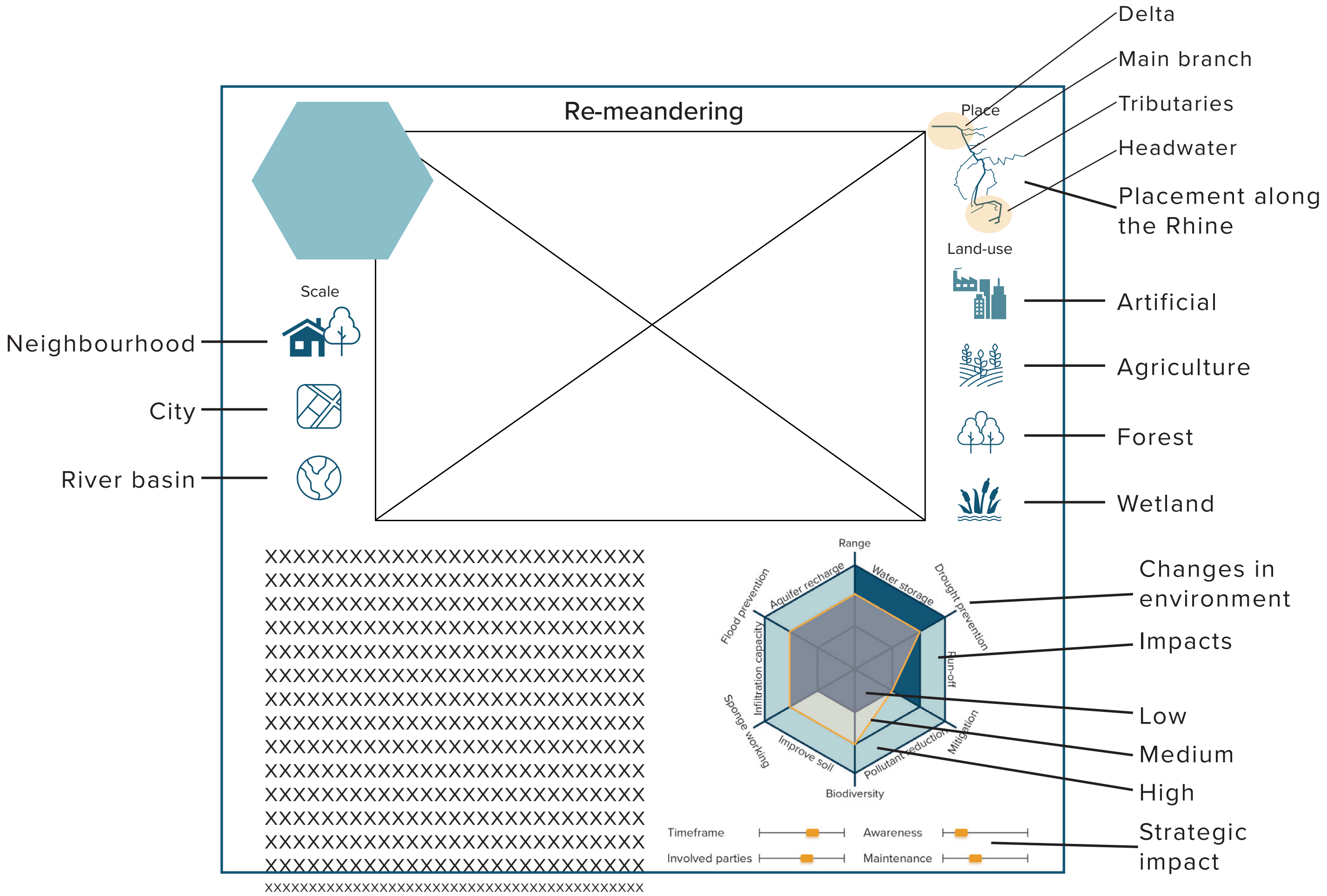
As mentioned, a filtering system is created to implement the patterns in a design location. In the scheme on the right page the elaborated pattern set-up is shown. Here the information used in the patterns is displayed. On page 36 and 37, the filtering of the patterns is explained in a diagram.

The patterns find their origin in the Natural Water Retention Measures. This set from the EU Directorate General Environment gives three different types of information, namely impacts, benefits, and applicability. For the patterns, this information has been transformed into different outputs. First, the physical impacts will be elaborated. The physical impacts are one of the rings on the hexagonal diagram on the patterns. It contains information on the infiltration capacity, aquifer recharge, water storage, run-off, pollutant reduction, and improvement of the soils that each pattern can provide. These physical impacts have been chosen based on their capability to mitigate drought.
The second is changes in the environment. The changes in the environment are derived from the physical impacts with some input from natural water retention measures that were not used before. These changes entail:

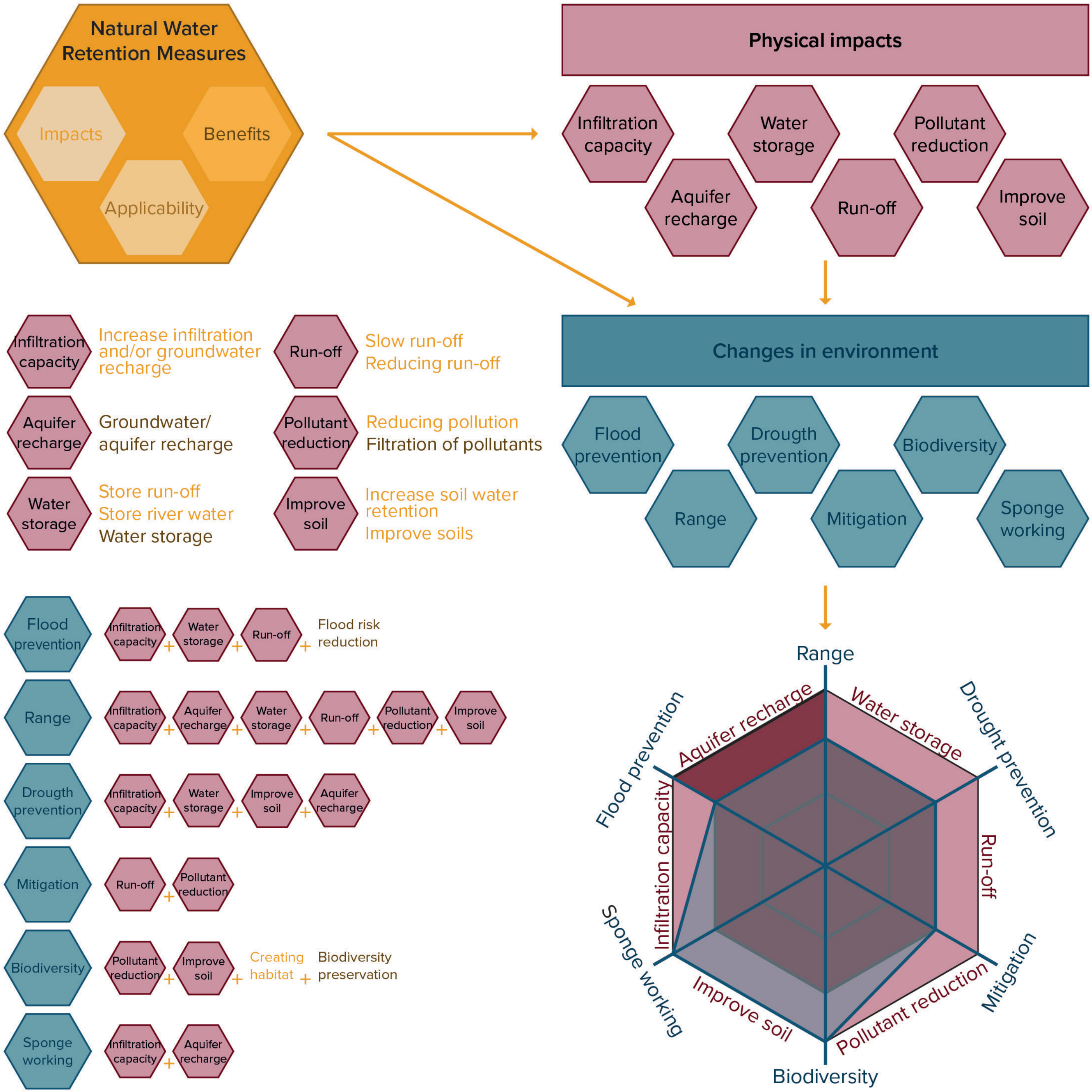
- Flood prevention, how much does this pattern help with the prevention of flooding?
- Range, how far does the impact of this pattern reach? This can be local, regional or an impact on the whole streamflow of the Rhine.
- Drought prevention, how much does this pattern help with the prevention of drought?
- Mitigation, can this pattern reduce run-off and the pollution caused by this?
- Biodiversity, does this pattern help with improving biodiversity?
- Sponge working, does this pattern create a soil that can handle more water recharge?

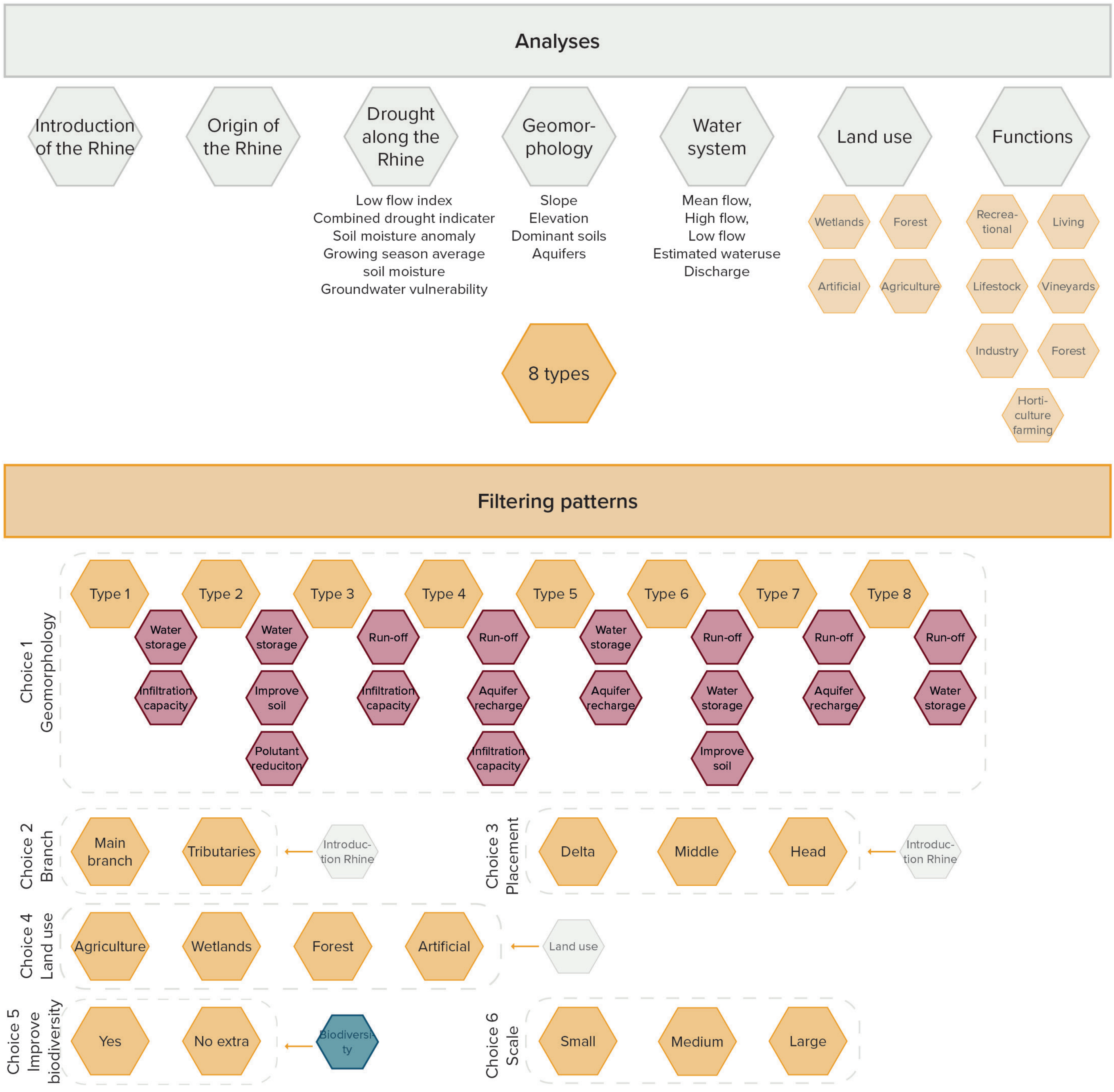
A system to filter the patterns has been thought out to find out what patterns are best applicable to each location. The patterns have been extensively tested in an excel file. For the patterns, the sequence is not really of matter, but for the sake of this thesis, the following order is used. The choices are based on the design area.
The first choice consists of the geomorphology of the chosen area. From the analyses, one of the eight different typologies can be determined.
The next step will be determining if the design location is on the river's main branch or along a tributary.
The third choice is the general area of the design location. Is this in the delta, middle or headwater of the catchment area?
The fourth step is determining the primary land use. This choice is also found in the analysis and can be determined from the analysis.
The fifth step is whether biodiversity improvement is needed in the specific area. This is to be judged per design location.
The sixth and final step is the scale of the design. Small-scale designs are under 1 km2, medium scale 1 to 25 km2, and large-scale anything above.

When following these steps, a set of patterns will be determined. These can then be implemented into the design location and improve the drought problems.



Re-meandering
Place
Delta
Main branch
Tributaries
Headwater
Placement along the Rhine
Land-use
Artificial
Agriculture
Forest
Wetland
Scale
Neighbourhood
City
River basin
Range
Water storage
Drought prevention
Run-off
Mitigation
Pollutant reduction
Biodiversity
Improve soil
Sponge working
Infiltration capacity
Flood prevention
Aquifer recharge
Changes in environment
Impacts
Low
Medium
High
Timeframe
Involved parties
Awareness
Maintenance
Strategic impact

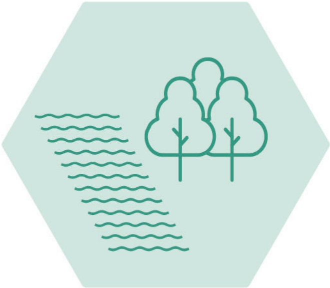

Natural Water Retention Measures
Impacts
Benefits
Applicability
Physical impacts
Infiltration capacity
Water storage
Pollutant reduction
Aquifer recharge
Run-off
Improve soil
Changes in environment
Flood prevention
Drougth prevention
Biodiversity
Range
Mitigation
Sponge working
Infiltration capacity
Increase infiltration and/or groundwater recharge
Run-off
Slow run-off
Reducing run-off
Aquifer recharge
Groundwater/ aquifer recharge
Pollutant reduction
Reducing pollution
Filtration of pollutants
Water storage
Store run-off
Store river water
Water storage
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
Polutant reduciton
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
Biodiversi-ty
Choice 6 Scale
Small
Medium
Large

PATTERN CATALOGUE

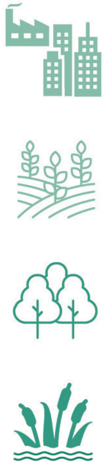
3.

Forest riparian buffers

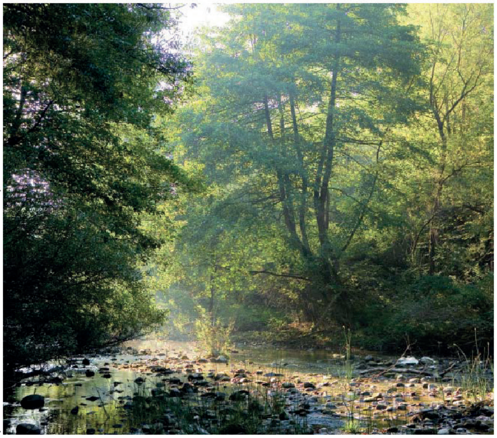


Place

Land-use



Scale

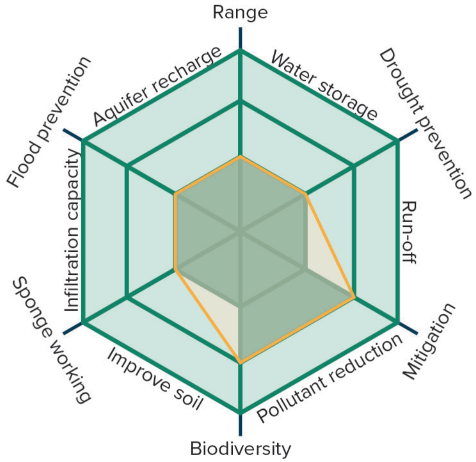


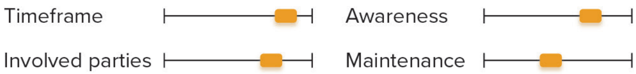
(Dountchev, Dimova et al. 2017)

(Massachusetts Clean Water Toolkit n.d.)

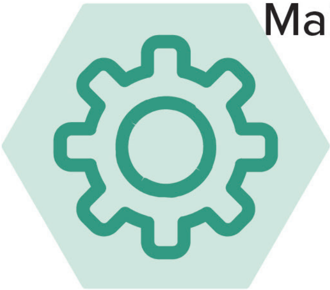
Forest riparian buffers are forest areas alongside streams and water bodies. They help increase water infiltration into groundwater and aquifers and can positively affect water quality by taking up nutrients. These forest strips along open water can help with slowing down run-off, storing this water and by slowing down run-off also decrease sediments inputs into the river. The roots of the trees help with erosion control and infiltration. Mixed vegetation is more beneficial as a buffer. This buffer is most effective when the space required is proportional to its width in relation to the density of the stream network. For this reason, Forest riparian buffers would be more effective on the Rhine tributaries rather than the stream's main branch.

(Dountchev et al., 2017; European Commission & Office International de l'Eau, 2014a)





Maintenance of forest cover in headwater areas



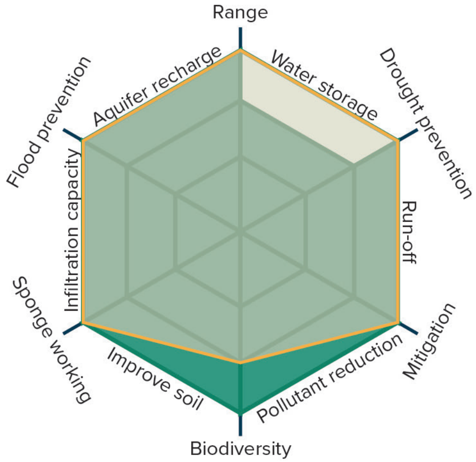
Scale

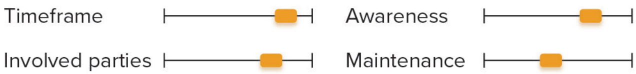
(Kutorman 2012)

Place

Land-use

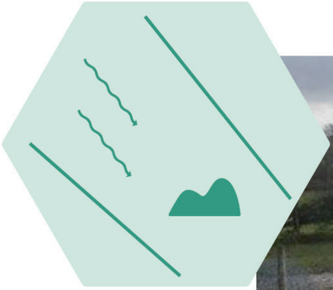
Maintenance of forest cover in headwater areas is the management and conservation of forested lands in the upper regions of a river basin. Maintaining these areas is crucial for downstream ecosystems by regulating the quantity and quality of water resources downstream. By implementing forest in headwater 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)

Overland flow areas



Place

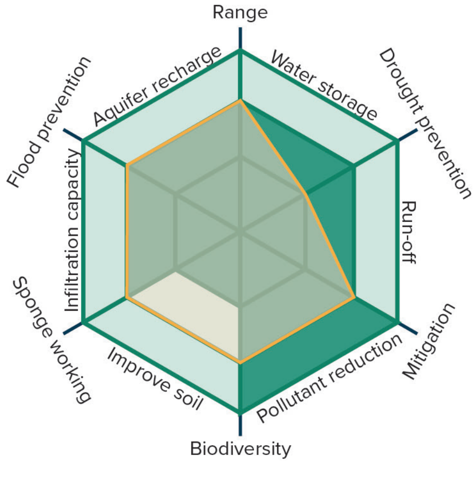
(CDW group, n.d.)

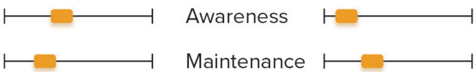
Scale

Land-use

Overland flow areas are designed to minimise the impact on the water quality by intercepting excess sediment produced from forest management or during harvesting season. Overland flow areas are designed as a semi-permeable dam in a ditch with lateral ditches connected to divert water. During periods of high flow, the ditches overflow allowing the water to reach the receiving streamflow. The water will slow down before it reaches the streamflow, and sediment, carried by the water, will be deposited on land. Wetlands can act as overland flow areas. The overland flow areas only function in smaller scale ditch networks or as part of larger water treatment system.

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



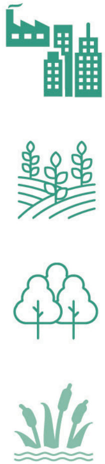


Land use conversion

(Ward, n.d.)

Place

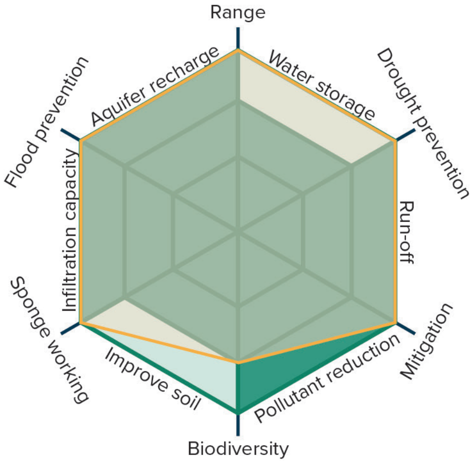
Land-use

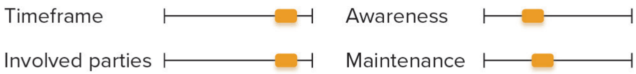


Scale

Land use conversion is the process of transforming the purpose or function of a piece of land from one type to another. This involves changing the way land is utilised. This practice is usually done on a large scale. Land use conversion can have significant social, economic, and environmental implications. It can occur naturally or be a planned change. Afforestation is a form of land use conversion.
Land use conversion can have diverse impacts. It can affect ecosystem biodiversity, water resources, and social structures. For rivers, land use conversion is the most effective in headwater areas. Here benefits to infiltration and water quality will be most noticeable.

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





Afforestation of reservoir Catchments

(Shlomo Aronson Architects, 1986)

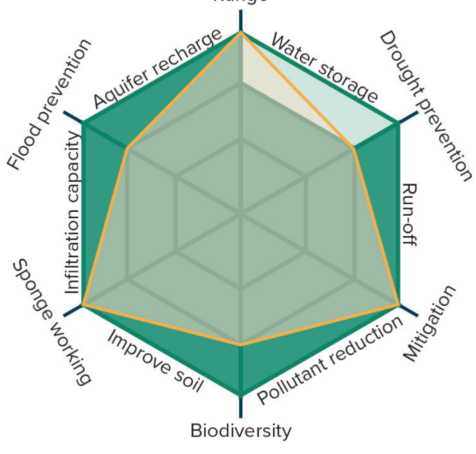
Place

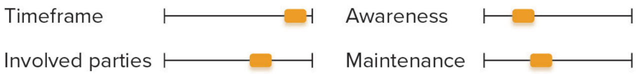
Land-use

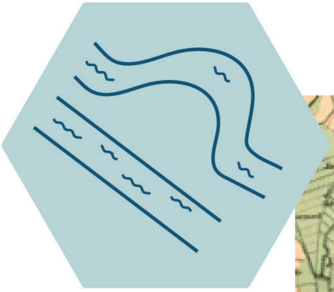
Scale

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.

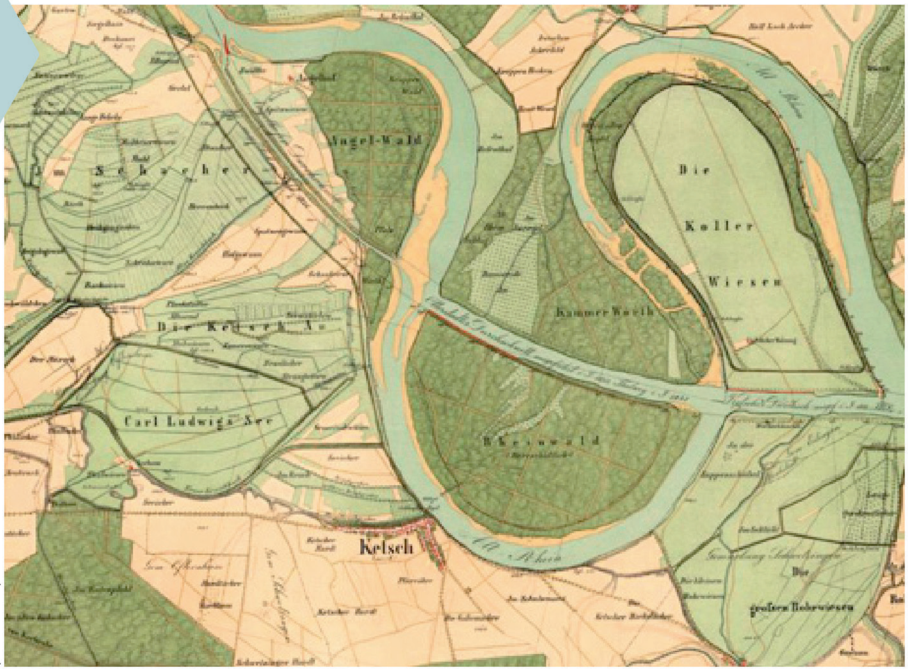
(European Commission & Office International de l'Eau, 2014a)







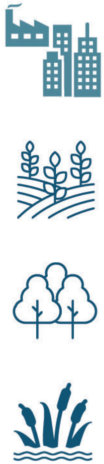
Re-meandering



(Yao 2022)

Place

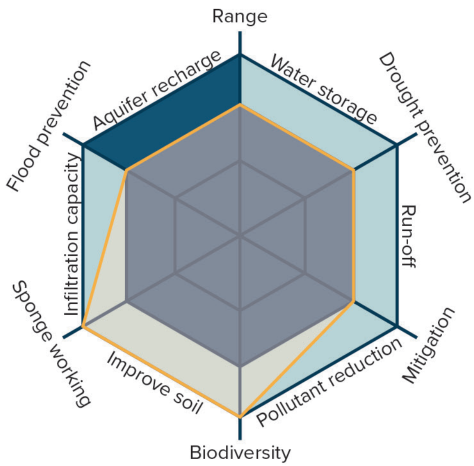
Land-use

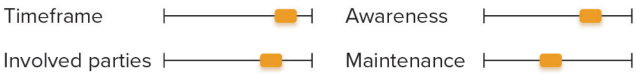


Scale

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)



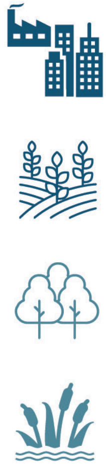


Re-naturalization of polder areas

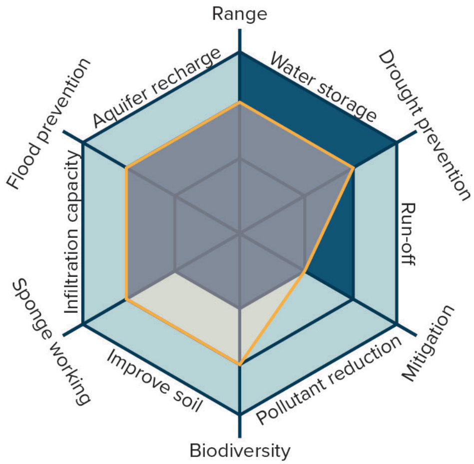
(Frans lemmens, 2014)

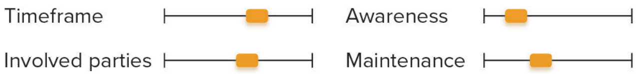
Place

Land-use



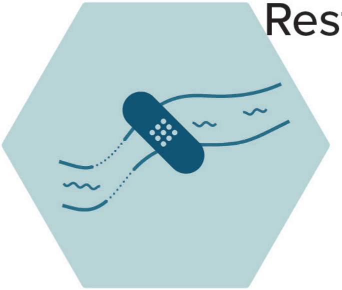
Scale





A polder is a piece of land surrounded by dikes with its own hydrological system. In this area, groundwater can be artificially controlled, and it has no connection to other water structures other than an artificial system. A polder can be used as a flood prevention measure. Because it is mainly located downstream of larger river structures, it has a high flood storage capacity. Seasonal flooding can improve ecological situations in polder areas. However, rising groundwater levels and subsidence can decrease the infiltration capacity of polder areas and have consequences for agricultural use.

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



Restoration and reconnection of seasonal streams

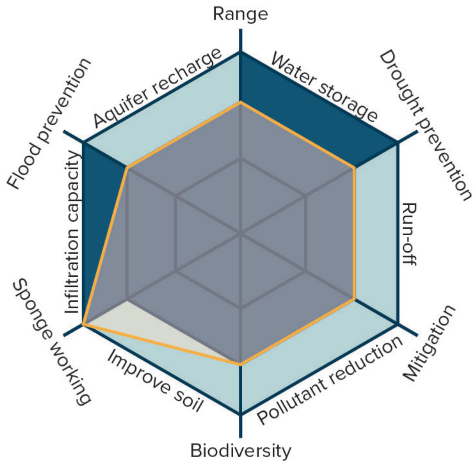
Place

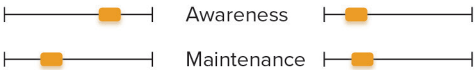
Land-use

Scale

(Launay, 2017)

Seasonal streams are dry for some periods of the year. They flow when smaller upstream waters flow and groundwater is high enough. These streams mainly feed from precipitation and meltwater. Because of this flow regime, seasonal streams create room for dynamic habitats. Seasonal streams have, therefore, a high biodiversity value. Seasonal streams can be reconnected by decreasing human pressures and maintaining and protecting the river system. Restoring and reconnecting seasonal streams can improve the overall functioning of the river by restoring connectivity, altering flows, and improving water retention during floods. In upstream situations, the preservation of buffer space should be taken into account, as well as a limitation to pumping groundwater. Downstream the maintenance or prevention of natural dams should be considered, and invasive plants that could jam the river flow should be removed.



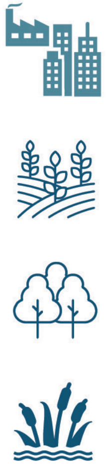


(European Commission & Office International de l'Eau, 2014a)

Wetland restoration and management

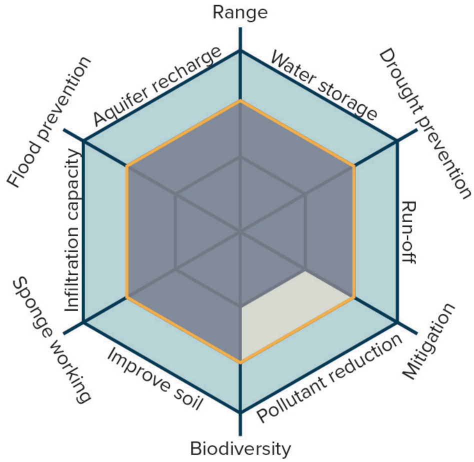
Place

Land-use



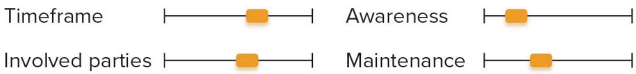
Scale

(PxHere, n.d.)



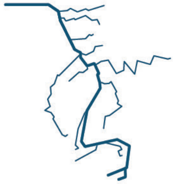
A wetland is an area of marsh, fen, peatland, or water. It can be a natural or artificial made structure and occur permanently or temporarily. The water in the area can be static as well as flowing. A wetland provides water retention, biodiversity enhancement and water quality improvement. They can be 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

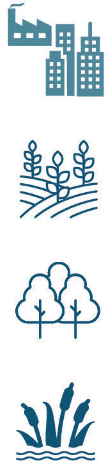
Place



(Šafarek, n.d.)

Scale

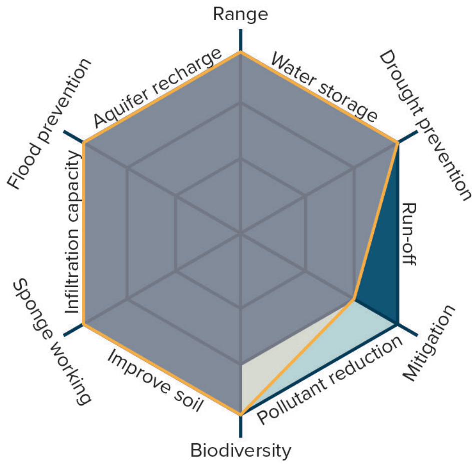
Land-use

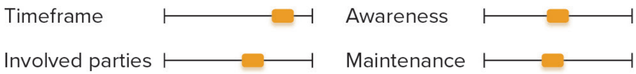


A floodplain is a relatively flat area next to a river or stream. These watercourses can experience periodic flooding. Floodplains are mainly naturally occurring structures shaped by the river's flow and sediment deposition. Because of periodic flooding, the floodplains are often composed of fertile 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)





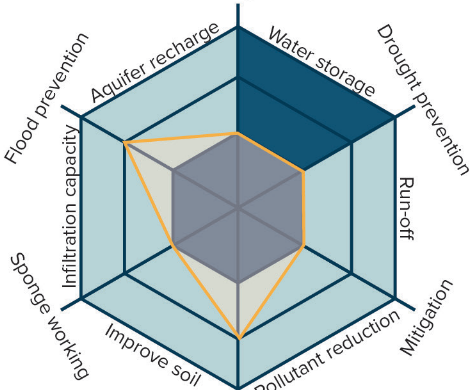
Lake restoration

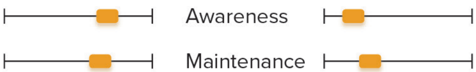
(IISD Experimental Lakes Area)

Scale

Place

Land-use





A lake is a water retention facility. By storing water, its primary purpose can be water supply irrigation, fishing and recreation. Lake restoration is the process of improving the functionality of a lake's ecosystem. Human activities or natural factors have damaged these ecosystems. Lake restoration aims to restore the balance of the aquatic environment, improve water quality and promote biodiversity. Lake restoration applies to many different scale types but requires different methods for each scale.

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

Retention ponds

Scale

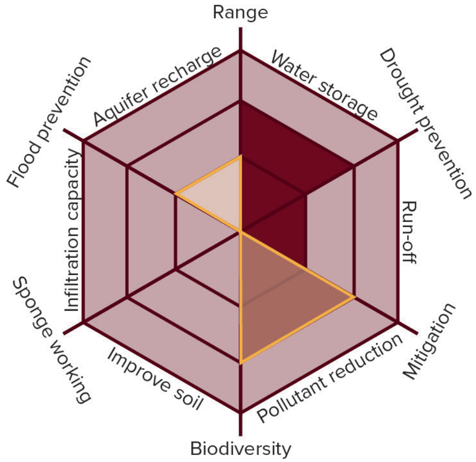
Place

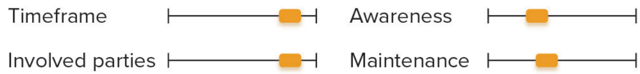
Land-use

(TrapBag, 2021)

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)



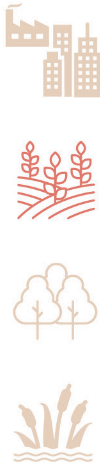


Crop rotation

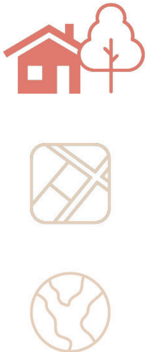
(University of Minnesota, 2020)

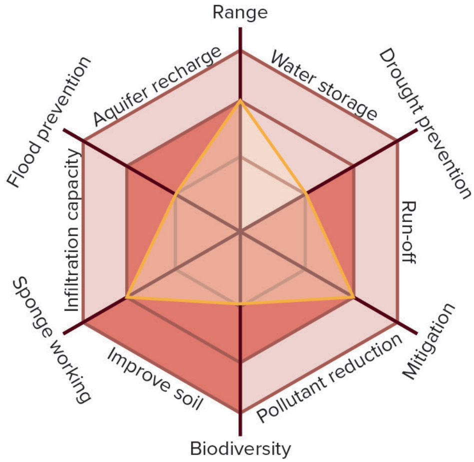
Place

Land-use



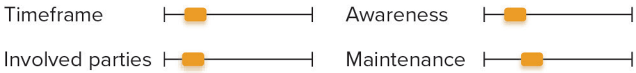
Scale





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)



REFERENCES

Primary Sources

Alexander, C., Ishikawa, S., & Silverstein, M. (1977). *A Pattern Language: Towns, Buildings, Construction*. Oxford University Press.

Dountchev, A., Dimova, D., Dimitrov, M., & WWF-Bulgaria. (2017). *Riparian forests: Benefits, present condition, conservation*. https://wwfeu.awsassets.panda.org/downloads/after_life_conservation_plan_en.pdf

European Commission, & Office International de l'Eau. (2014a). *Pilot Project - Atmospheric Precipitation - Protection and efficient use of Fresh Water: Integration of Natural Water Retention Measures in River Basin Management*. Retrieved 14 March from http://nwrm.eu/index.php/measures-catalogue

European Commission, & Office International de l'Eau. (2014b). *Polder management near Altenheim, Germany*. Retrieved 16 March from http://nwrm.eu/case-study/polder-management-near-altenheim-germany

The Food and Agriculture Organization of the United Nations, International Union of Forest Research Organizations, & U.S. Department of Agriculture. (2021). *A guide to forest-water management* (FAO Forestry paper, Issue.

Figures

Kutorman. (2012). *Kutorman* [Photo]. https://kutman.com/indexc6ad.html?option=com_content&view=article&id=16&Itemid=18&lang=en

Launay, B. (2017). *The Calavon River, a Mediterranean IRES, during flowing (left) and dry phases (right)* [Photo]. https://phys.org/news/2017-11-advancing-science-european-intermittent-rivers.html

Lemmens, F. (2014). *The Netherlands, Jisp, Aerial, Village and polder landscape*. [Photo]. https://www.sfgate.com/travel/article/Exploring-Holland-s-charming-Polder-Country-5613997.php#photo-6559430

Massachusetts Clean Water Toolkit. (n.d.). *Riparian Forest Buffers* [Photo]. https://megamanual.geosyntec.com/npsmanual/riparianforestbuffers.aspx

PxHere. (n.d.). *Wetlands as sustainable tool for counteracting climate change* [Photo]. https://www.dutchwatersector.com/news/wetlands-as-sustainable-tool-for-counteracting-climate-change

Šafarek, G. (n.d.). *atural flood prevention: floodplains work like a sponge and reduce downstream floods*. [Photo]. https://medwet.org/2017/02/floodplains-and-flooding-risk-prevention/

University of Minnesota. (2020). Diversifying crop rotations improves environmental outcomes while keeping farms profitable. https://twin-cities.umn.edu/news-events/diversifying-crop-rotations-improves-environmental-outcomes-while-keeping-farms

Ward, J. D. (n.d.). *Land use conversion* [Photo]. USDA Forest Service. https://www.forestryimages.org/browse/detail.cfm?imgnum=4166013

Yao, J. (2022). *The ideal river: How control of nature shaped the international order* [Map]. Manchester University Press, Manchester.