Restoring Rivers

A pattern book

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Colophon

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Restoring Rivers
Integrating a renaturalised Maas river basin with the cultivated landscape to enhance climate resilience

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All images are produced by the author, unless stated otherwise.

Urbanism

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1 Introduction

The pattern language

The pattern language is a method introduced by architect Christopher Alexander in 1977. It helps to design and understand complex systems, including landscapes (Salingaros, 2000). A pattern language consists of patterns, which are design principles. They provide a systemic way to present solutions while always describing the related problem. Each pattern consists of a theory supporting a hypothesis, practical implications, time, scale, and an informative illustration (Rooij & van Dorst, 2020). This way, interventions are clearly communicated and transferable to different areas.

The patterns of this pattern book can be used in different ways. For this thesis, the patterns were used for the maximisation method, which led to a design for the Noordelijke Maasvallei in Limburg. All patterns are connected to different topics. They can be used individually. However, these patterns will show the greatest effect when implemented together.

Pattern groups

This pattern language is divided into four groups: renaturalisation, ecology, agriculture and urban. The groups are based on the questions of this thesis and the analysis done before creating the pattern language.

Renaturalisation (R)

The patterns belonging to renaturalisation describe different ways of creating a renaturalised river and surrounding environment. The focus of this topic is related to creating space for water to deal with wetter and drier scenarios of the future.

Ecology (E)

This group contains patterns that relate to improving ecology for a more climate-resilient ecosystem. Whereas some patterns relate closely to the renaturalisation of rivers, some dive deeper into improving the ecosystem as a whole.

Agriculture (A)

Agricultural patterns delve into methods of climate resilient agriculture that can deal with a wetter and drier climate. It focuses on ways to make agriculture more nature-inclusive, in which the natural system is embraced instead of shunned.

Urbanisation (U)

Finally, the urban group consist of patterns that could be used to make cities, towns and different human activities more climate resilient, whilst including the natural (river) system in the urban environment, or without damaging the natural ecosystem.

A pattern

Figure 1.1 shows an example of a pattern. All patterns follow the same layout, as explained below.

Number

Each pattern is given a number to easily identify the patterns when used elsewhere. Each pattern starts with the first letter of the group it belongs to (R, E, A, U).

Title

The title indicates a quick idea of what the pattern is about.

Hypothesis

A short description of what the pattern will address.

Illustration

A visual illustration showing the function of the pattern.

Related patterns

Patterns that strengthen, go well together or need to be implemented together within this pattern.

Conflicting patterns

Patterns that cannot be implemented simultaneously or that counteract this pattern.

Theoretical background

An explanation of the pattern, backed up by theory that explains how the pattern works, what principles it builds on, and what it can achieve.

Practical implications

A description of considerations when implementing the pattern, and how to apply it effectively.

Time

Each pattern has an indication of the time it takes to implement the measure and how long it takes until the effect is visible. They are divided into:

0-10 years
10-25 years
25-50 years
50-75 years

Scale

The scale of the pattern will also be shown by implementation and effect. This will be on one of the following scales:

Micro: *Local*
Meso: *The Noordelijke Maasvallei*
Macro: *Downstream Maas*

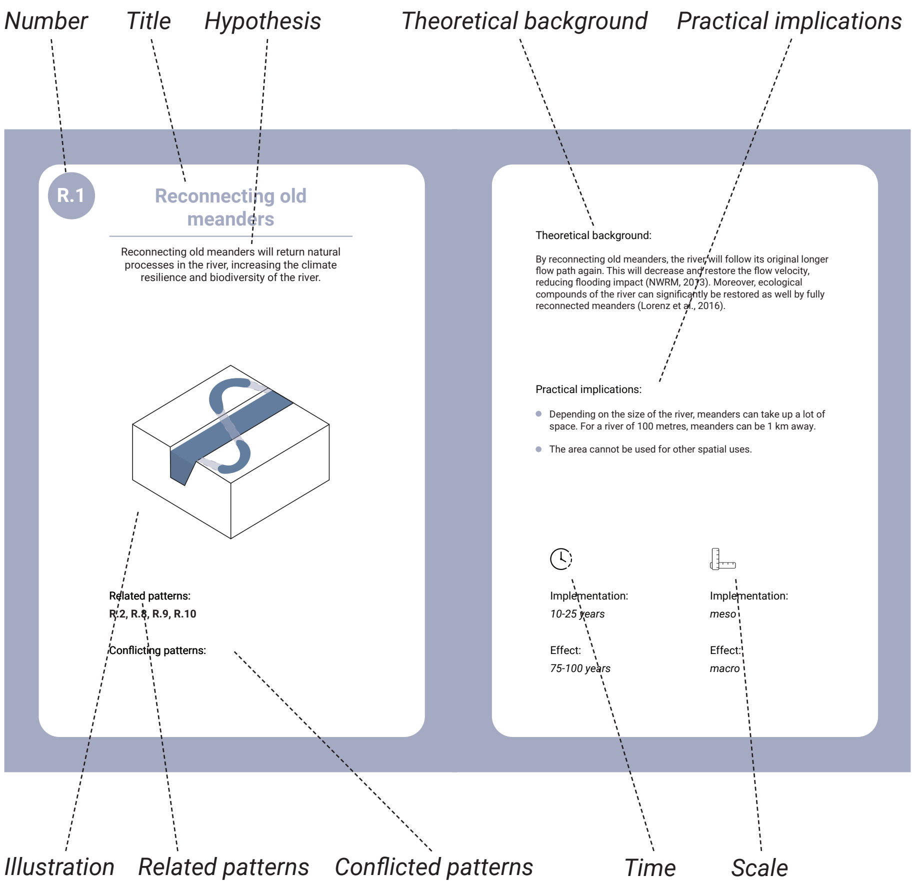


Figure 1.1: Example of a pattern showing the pattern layout.

Pattern field

Implementation effect of the patterns

The patterns of this pattern language serve as starting points for the maximisation method in chapter 4.3. However, each pattern can also be implemented separately. The effects of the patterns differ. Some patterns are quick to implement and easy to reverse, while others are more challenging to implement and have a lasting impact on the area. Additionally, the scale of their effect can play a crucial role in deciding which patterns to apply.

Pattern fields are used to visualise characteristics and relations of the patterns. The pattern field in Figure 1.2 presents the effects of implementing the patterns based on their scale and flexibility. This pattern field can support decision-making by indicating which patterns are suitable to apply, and at what moment in time.

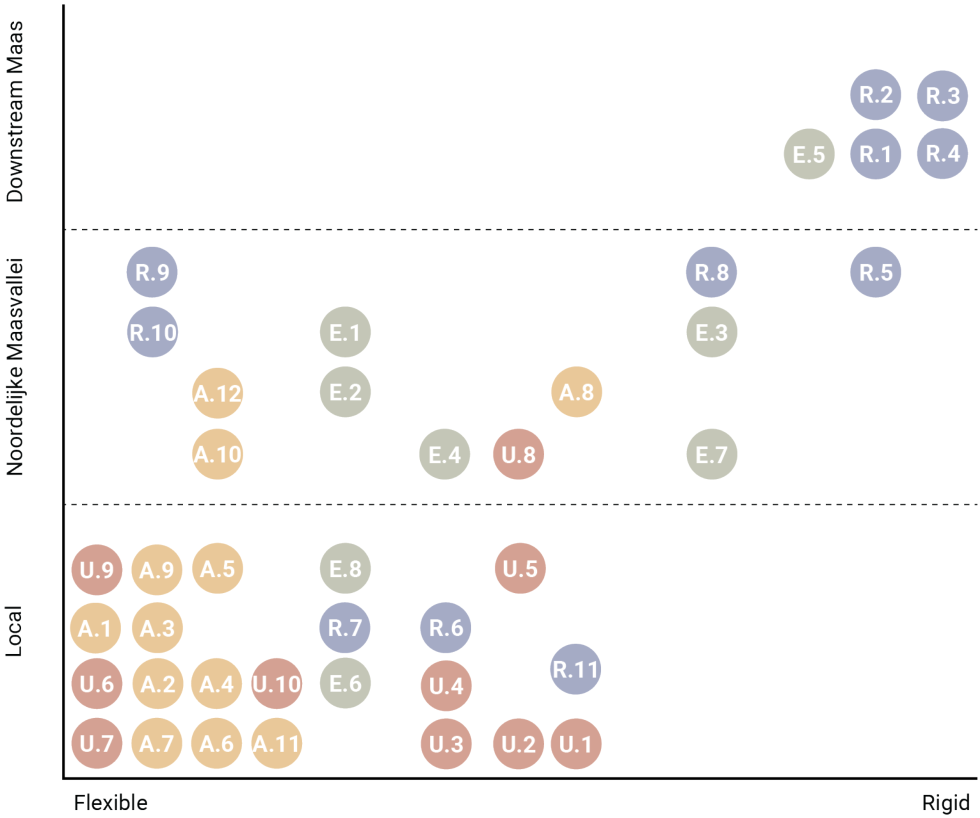


Figure 1.2: Pattern field dividing the patterns by their effect of implementation on scale and on flexibility.

Pattern evaluation

To show the purpose of each pattern and how it contributes to climate resilience, all patterns have been evaluated following the criteria that are derived from the analysis of this thesis:

Water availability

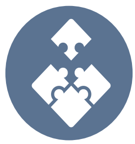
Drinking water supply
Crop water efficiency
Infiltration and recharge
Shipping navigability
Water quality

Water safety

Urban flood safety
Crop field drainage
River space capacity
Infrastructure resilience

Ecological resilience

River nature
Ecosystem connectivity
Peatland stability
Nutrient stability
Heat mitigation



Complementary criteria

Water retention
Natural river dynamics
Land use compatibility
Discharge adaptability

The scoring is based on what impact or effect the pattern has to the evaluation criteria:

++	very positive
+	positive
0	no effect
-	negative
- -	very negative

Evaluation of the patterns for renaturalisation

		R1	R2	R3	R4
Water availability	Drinking water supply	0	0	0	0
	Crop water efficiency	0	0	0	0
	Infiltration and recharge	+	+	+	+
	Shipping navigability	-	-	-	-
	Water quality	0	0	0	0
Water safety	Urban flood safety	++	++	++	++
	Crop field drainage	0	0	0	0
	Infrastructure resilience	0	0	0	0
Ecological resilience	River nature	+	+	+	+
	Ecosystem connectivity	+	+	0	0
	Peatland stability	0	0	0	0
	Nutrient stability	0	0	0	0
	Heat mitigation	0	0	0	0
	Fauna refuge	0	0	0	0
Complementary criteria	Water retention	0	0	0	0
	Natural river dynamics	++	++	++	++
	Land use compatibility	-	-	-	0
	Discharge adaptability	++	++	++	++

Figure 1.3: Evaluation of the patterns for renaturalisation.

	R5	R6	R7	R8	R9	R10	R11
	0	+	++	0	0	0	0
	0	0	+	0	0	0	0
	+	++	++	0	0	0	++
	0	0	0	--	+	+	0
	0	0	0	0	+	+	++
	++	0	+	+	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	++	+	0
	++	0	0	++	++	++	++
	++	0	0	+	+	+	+
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	++	0	0	0	0	0	++
	+	++	++	+	0	0	+
	++	0	0	++	++	++	+
	0	0	+	0	0	0	0
	++	0	++	++	+	+	0

Evaluation of the patterns for ecology

		E1	E2	E3
Water availability	Drinking water supply	0	0	0
	Crop water efficiency	0	0	0
	Infiltration and recharge	++	0	++
	Shipping navigability	0	0	0
	Water quality	0	++	0
Water safety	Urban flood safety	0	+	0
	Crop field drainage	+	0	0
	Infrastructure resilience	0	0	0
Ecological resilience	River nature	0	++	0
	Ecosystem connectivity	+	+	++
	Peatland stability	+	+	0
	Nutrient stability	++	0	++
	Heat mitigation	+	0	+
	Fauna refuge	+	+	++
Complementary criteria	Water retention	0	0	0
	Natural river dynamics	0	++	0
	Land use compatibility	+	0	+
	Discharge adaptability	0	+	0

Figure 1.4: Evaluation of the patterns for ecology.

E4	E5	E6	E7	E8
0	+	0	+	0
0	0	0	0	0
++	+	0	++	+
0	0	-	0	0
0	+	0	++	0
0	+	0	0	0
0	+	0	0	0
0	0	0	0	0
0	++	++	0	0
++	++	+	++	+
0	+	0	++	++
++	0	0	+	+
+	+	0	+	+
++	++	++	++	+
0	+	0	++	-
0	0	0	0	0
+	+	+	+	0
0	+	++	0	0

Evaluation of the patterns for agriculture

		A1	A2	A3	A4	A5
Water availability	Drinking water supply	0	0	0	0	0
	Crop water efficiency	++	0	0	++	++
	Infiltration and recharge	+	+	0	++	++
	Shipping navigability	0	0	0	0	0
	Water quality	0	0	0	0	0
Water safety	Urban flood safety	0	0	0	0	0
	Crop field drainage	0	++	++	+	+
	Infrastructure resilience	0	0	0	0	0
Ecological resilience	River nature	0	0	0	0	0
	Ecosystem connectivity	0	0	0	0	0
	Peatland stability	0	0	0	0	0
	Nutrient stability	0	0	0	+	+
	Heat mitigation	0	0	0	0	0
	Fauna refuge	0	0	0	0	0
Complementary criteria	Water retention	+	++	0	+	+
	Natural river dynamics	0	0	0	0	0
	Land use compatibility	0	++	++	0	0
	Discharge adaptability	0	++	0	0	0

Figure 1.5: Evaluation of the patterns for agriculture.

	A6	A7	A8	A9	A10	A11	A12
	0	0	0	0	0	++	0
	+	+	++	0	+	++	0
	++	+	++	0	+	+	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	++	+	++	++	+	0	0
	0	0	0	+	0	0	+
	0	0	0	0	0	0	0
	0	0	++	0	++	0	0
	0	0	0	0	0	0	0
	++	++	++	0	++	0	0
	0	0	+	0	0	0	0
	0	0	++	0	++	0	0
	+	+	+	0	+	++	0
	0	0	0	0	0	0	0
	0	0	++	++	++	0	++
	0	0	0	++	0	0	0

Evaluation of the patterns for urbanisation

		U1	U2	U3	U4
Water availability	Drinking water supply	0	++	+	0
	Crop water efficiency	0	0	0	0
	Infiltration and recharge	+	+	+	++
	Shipping navigability	0	0	0	0
	Water quality	0	+	++	0
Water safety	Urban flood safety	++	0	++	++
	Crop field drainage	0	0	0	0
	Infrastructure resilience	+	++	0	+
Ecological resilience	River nature	0	0	0	0
	Ecosystem connectivity	+	0	+	++
	Peatland stability	0	0	0	0
	Nutrient stability	0	0	0	0
	Heat mitigation	+	0	+	0
	Fauna refuge	+	0	+	+
Complementary criteria	Water retention	++	++	++	++
	Natural river dynamics	0	0	0	0
	Land use compatibility	+	++	+	+
	Discharge adaptability	++	0	++	++

Figure 1.6: Evaluation of the patterns for urbanisation.

	U5	U6	U7	U8	U9	U10
	0	0	0	0	0	0
	0	0	0	0	0	0
	+	0	0	0	0	+
	0	0	0	0	0	0
	0	0	0	0	0	0
	++	++	++	++	+	+
	0	0	0	0	0	0
	+	++	++	++	++	++
	+	0	0	0	0	0
	+	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	+	0	0	0	0	0
	0	0	0	0	+	++
	+	+	0	+	+	0
	++	++	++	++	++	0
	++	++	++	++	+	0

2

The patterns

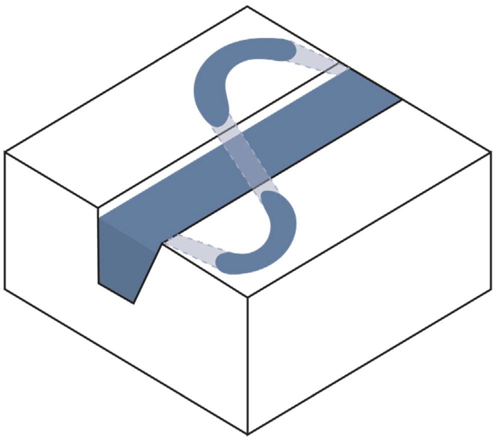
Patterns for

Renaturalisation

R.1

Reconnecting old meanders

Reconnecting old meanders will return natural processes in the river, increasing the climate resilience and biodiversity of the river.



Related patterns:

R.2, R.8, R.9, R.10

Conflicting patterns:

Theoretical background:

By reconnecting old meanders, the river will follow its original longer flow path again. This will decrease and restore the flow velocity, reducing flooding impact (NWRM, 2013). Moreover, ecological compounds of the river can significantly be restored by fully reconnected meanders (Lorenz et al., 2016).

Practical implications:

- Depending on the size of the river, meanders can take up a lot of space. For a river of 100 metres, meanders can be 1 km away.
- The area cannot be used for other spatial uses.

Implementation:

10-25 years

Effect:

75-100 years

Implementation:

meso

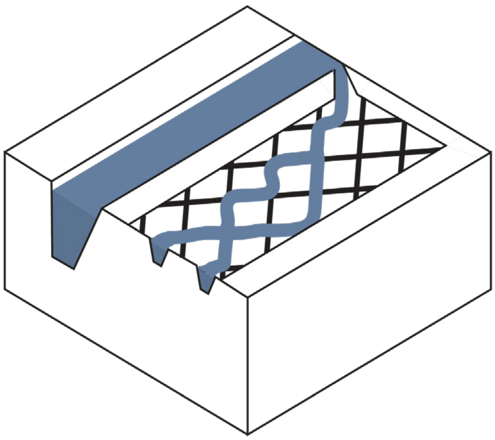
Effect:

macro

R.2

New routes for meandering

By letting straight man-made canals follow a more natural, meandering route, flow velocity will decrease and water will flow more gradually, providing more flood resilience.



Related patterns:

R.3, R.4, R.5, R.8, R.9, R.11

Conflicting patterns:

Theoretical background:

Meandering rivers and streams can accommodate more water in high water peaks, increasing the flood resilience of the surrounding area. Moreover, the slowed down flow velocity will provide more chances for water to infiltrate into the soil. This process recharges the groundwater level, thereby increasing the drought resilience (NWRM, 2013).

Practical implications:

- Depending on the size of the river, meanders can take up a lot of space. For a river of 100 metres, meanders can be 1 km away.
- The area cannot be used for other spatial uses.

Implementation:

10-25 years

Effect:

75-100 years

Implementation:

meso

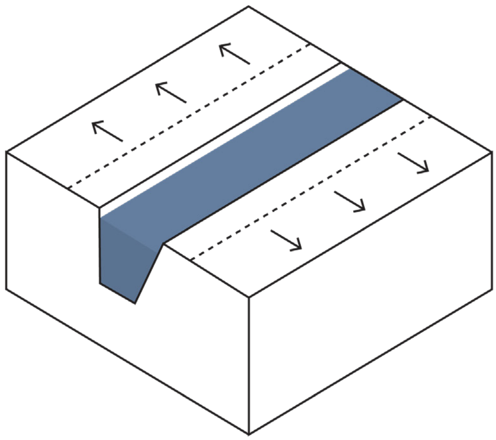
Effect:

macro

R.3

Widening flood plains

Widening flood plains will provide space for the river to decide its own pathand and create new side streams and ponds which will increase climate resilience and biodiversity.



Related patterns:

R.2, R.4, E.2, A.2, U.5, U.9

Conflicting patterns:

Theoretical background:

Widening flood plains can provide space for the river to flood in times of high water peaks. Moreover, by letting the river flow free in these areas, new landscape features will come into existence. The river can meander and create side channels, ponds and backwaters. This will provide more space for water to infiltrate and create a new ecosystem with a wider variety of flora and fauna. (Huinink & Van Zadelhoff, 2004)

Practical implications:

- Floodplain widening can cause a change in habitat, which can lead to a loss of certain species in this area.
- There are possibilities for other land uses.

Implementation:

5-10 years

Effect:

50-75 years

Implementation:

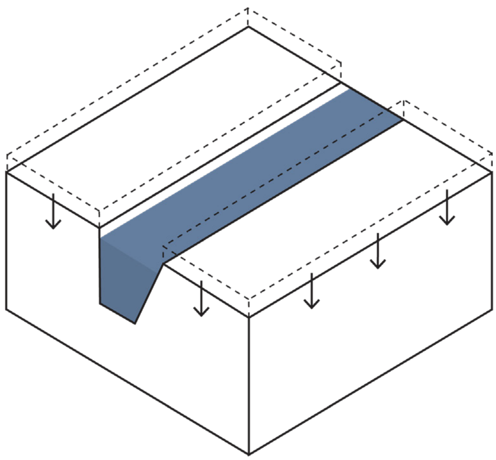
meso

Effect:

macro

Lowering river banks

Lowering river banks or floodplains provides opportunities for the river to find its natural flow and create a biodiverse ecosystem like in the past.



Related patterns:

R.2, R.3, R.9, R.10, E.2, U.7

Conflicting patterns:

U.5, U.9

Theoretical background:

Lowering flood plains or river banks will widen the area in which a river can flow. This will create opportunities for the river to find its natural flow again. The river can meander, create side channels, ponds and backwaters. This will provide more space for water to infiltrate and create a new ecosystem with a wider variety of flora and fauna. (Huinink & Van Zadelhoff, 2004)

Practical implications:

- Floodplain lowering can cause a change in habitat, which can lead to a loss of certain species in this area.
- The practice should be imitated as a natural erosion process, to ensure the river will be connected to the floodplain and its natural processes.

Implementation:

5-10 years

Effect:

50-75 years

Implementation:

meso

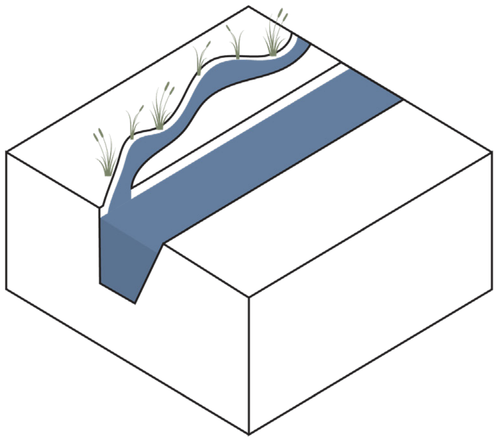
Effect:

macro

R.5

Side channels

The creation of a side channel from the river will create new ecological connections and water retention opportunities.



Related patterns:

R.2, R.8, R.9, R.10, R.11 E.2, E.5,

Conflicting patterns:

Theoretical background:

Adapted rivers have a high water velocity and do not provide space for flora and fauna to thrive. However, by creating side channels sedimentation and erosion processes return and water will flow slower, providing a larger habitat for certain species. Moreover, water has more space to be distributed in high peaks and water quality will improve through the filtering of natural plants. Side channels can also be connected to surface water bodies as an ecological connector between ponds and the river. It can also create more water retention opportunities. (Schoor et al., 2012)

Practical implications:

- The side channel should get the change to naturally form itself by allowing erosion and sedimentation processes. In the first phases, diverse habitats can be motivated by varying in flow velocity and heights of banks.
- Side channels are more prone to accumulating sediment, so periodic monitoring (especially in the first phases) would be advised.

Implementation:

5-10 years

Effect:

25-50 years

Implementation:

micro

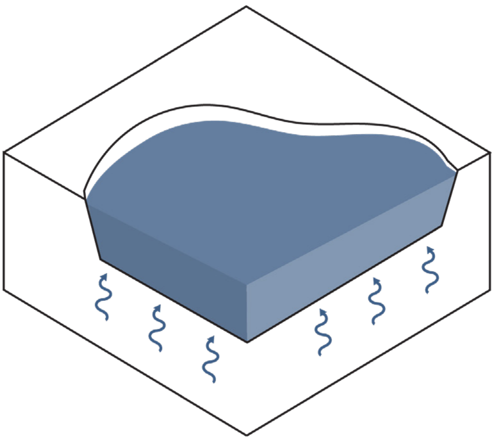
Effect:

meso

R.6

Seepage ponds for water storage

Seepage ponds can store water during periods of rainfall, to provide water during periods of drought.



Related patterns:

E.7, E.10

Conflicting patterns:

Theoretical background:

Seepage is a natural phenomenon that forms when the groundwater level exceeds the surface level during periods of rainfall. Water comes up from the groundwater to the surface and forms ponds. In periods of rainfall, seepage ponds are common. By storing this water it could provide water in drier periods, for either irrigation, drinking water or other purposes. Furthermore, seepage ponds are ecological hubs as well. There are different ways to store this water. A common way is to locate the water to ditches or to retention ponds. bron

Practical implications:

- Some seepage ponds provide a habitat for certain species, these should be untouched to protect the natural ecosystem.

Implementation:

<5 years

Effect:

10-25 years

Implementation:

micro

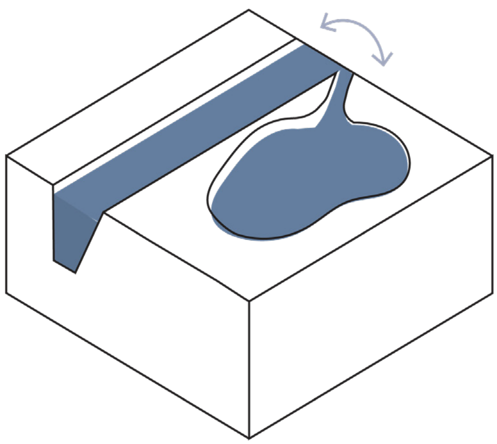
Effect:

micro

R.7

Seasonal retention ponds

Retention ponds can store water in rainy periods to provide water in dry periods.



Related patterns:

E.7, A.2

Conflicting patterns:

A.1

Theoretical background:

Retention ponds are a way to store water in wet periods. This water can either come from excess rainfall or from excess river flow. This water can then be used for irrigation, drinking water or ecological purposes. There are different options to store retention water. It can be located to existing ponds and ditches, or in designated areas such as on fields or in wadis. (Atlas Natuurlijk Kapitaal, n.d.)

Practical implications:

- Flooded areas will temporarily be unusable, unless combined with a flood tolerant practice.
- Technical advancements might be needed to relocate water to a certain area where the water will be used.

Implementation:

<5 years

Effect:

10-25 years

Implementation:

micro

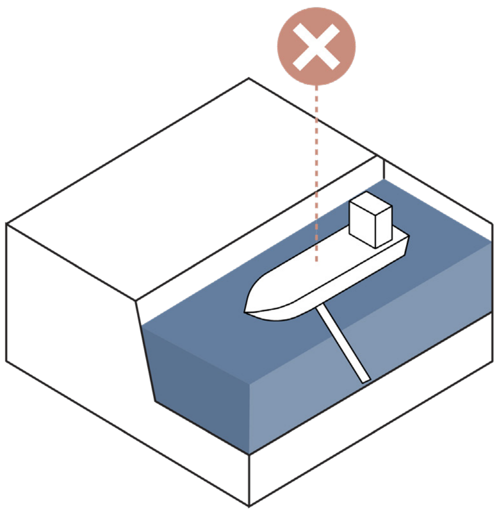
Effect:

micro

R.8

Stop dredging

Ending river dredging will allow natural erosion and sedimentation to return, strengthening climate resilience and supporting biodiversity.



Related patterns:

R.1, R.2, R.5, R.9, R.10 E.6

Conflicting patterns:

Theoretical background:

Since the industrial revolution, rivers have been heavily dredged (deepened and straightened) for the accommodation of shipping (Asselman et al., 2018). This has stopped the occurrence of erosion and sedimentation processes that provide biodiversity of flora and fauna and natural resilience against extreme weather events. By stopping to dredge, the natural processes of the river can return. As a result, it will be able to naturally deal with climate change and provide better conditions for the return of aquatic life.

Practical implications:

- If there continues to be a large shipping demand on the river of intervention, ships will either have to take other routes over canals (R.9) or reduce in size (R.10).
- It can be implemented over an entire river course, or in smaller sections.

Implementation:

<5 years

Effect:

25-50 years

Implementation:

macro

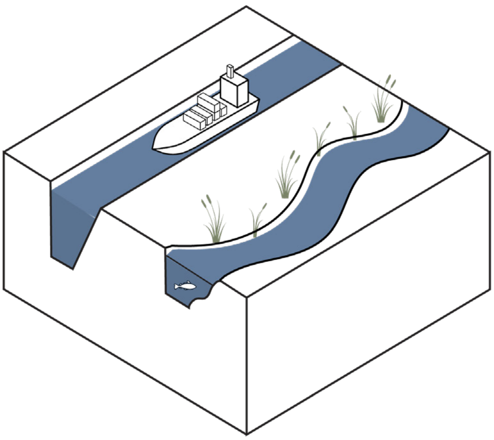
Effect:

meso

R.9

Shipping on specific canals only

By allowing ships to only navigate over existing man-made canals, the river can be left natural and undisturbed.



Related patterns:

R.1, R.2, R.4, R.5, R.8

Conflicting patterns:

Theoretical background:

Currently, rivers are dredged to provide navigability for ships, interfering with the natural habitat (Meyer, 2022). However, when canals or lateral canals exist, ships can only follow this route without going over the original river. This way, erosion and sedimentation processes can return to the river again. The removal of large vessels on rivers can drastically improve the ecology of the ecosystem, with the return of fish and other aquatic species (Spear et al., 2024).

Practical implications:

- Canals still interfere with river flow, as they rely on water from the main channel to maintain navigable levels. Therefore, the river should be able to deal with more drought, or ship size restrictions should be implemented (R.10).
- Complete routes might not be available on canals, so looking at different options is necessary.

Implementation:

<5 years

Effect:

25-50 years

Implementation:

macro

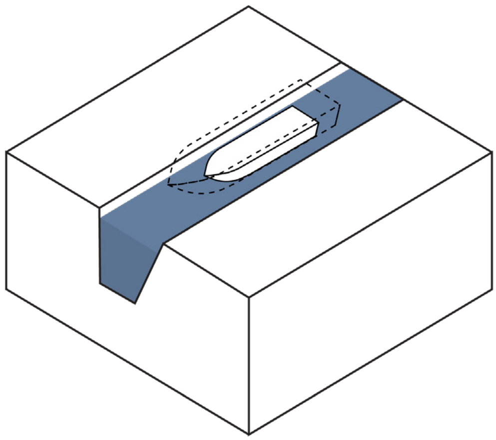
Effect:

meso

R.10

Smaller vessels

Smaller vessels will be able to navigate on shallower depths over streams with natural processes in dry periods.



Related patterns:

R.1, R.4, R.5, R.8

Conflicting patterns:

Theoretical background:

Ships for commercial transportation have been growing over time, leading to deeper and straighter rivers (Meyer, 2022). However, before the industrial revolution and its impact on river alteration, smaller ships were able to navigate over natural river courses (Spear et al., 2024). By implementing restrictions on ship size, transportation on natural rivers could still be possible. Moreover, in periods of drought, smaller ships will be able to sail over shallower depths of both rivers and canals.

Practical implications:

- Smaller vessels still cause waves and noise disturbances. Although this is less than for bigger vessels, it will interfere with the habitat of certain aquatic species.

Implementation:

<5 years

Effect:

25-50 years

Implementation:

macro

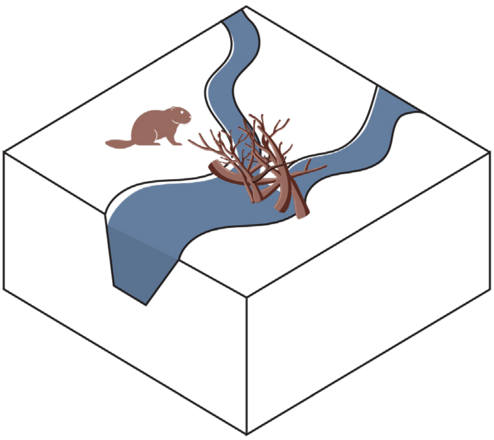
Effect:

meso

R.11

Beaver or branch dams

Natural formed dams slows down water flow in rivers and streams, creating space for fauna and decreasing flood risk.



Related patterns:

R.2, R.5

Conflicting patterns:

Theoretical background:

Natural formed dams can slow down the water flow of streams and rivers. It forces the water to find a different route or to be temporary stored in a certain place. This will decrease the flood risk of the area and even boost the ecology of the water body. Beavers are animals that naturally make these dams, so encouraging this or introducing more beavers in the area would be beneficial (Grudzinski et al., 2022). However, man-made branch dams could also be effective, though they would be a less natural solution.

Practical implications:

- Branch dams should be kept at a reasonable amount to prevent excessive sedimentation.

Implementation:

5-10 years

Effect:

10-25 years

Implementation:

micro

Effect:

meso

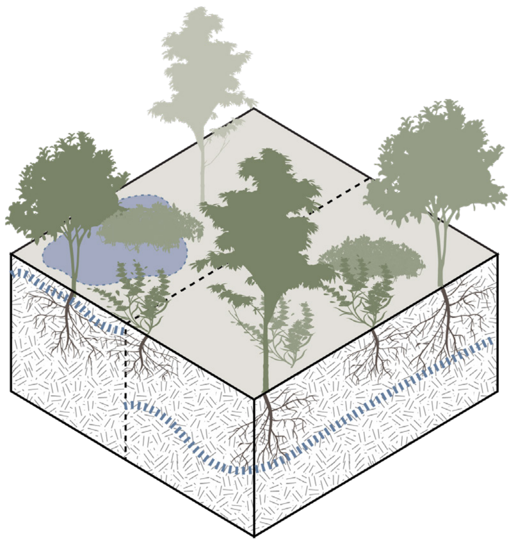
Patterns for

Ecology

E.1

Climate resilient vegetation

Climate resilient plants will be able to cope with the fluctuations of wet and dry climate conditions, improve soil stability, and support other ecological life.



Related patterns:

E.3, E.4, E.7, A.8, A.10, U.2, U.5

Conflicting patterns:

Theoretical background:

With climate conditions becoming more extreme both in wet and dry periods, vegetation should be able to deal with these fluctuations. There are plants that are tolerant towards both dry and wet soils (Hunt, 2015). Planting such vegetation would provide a healthy ecosystem all year round. Moreover, plants can hold moisture, improving soil stability and provide opportunities for other species above and under the soil to thrive (Grover, 2025).

Practical implications:

- Species should always be native in order to provide the best conditions for the local ecosystem.
- Soil type plays an important role in determining the type of vegetation to get the best outcomes for both soil and plants.

Implementation:

<5 years

Effect:

5-10 years

Implementation:

micro

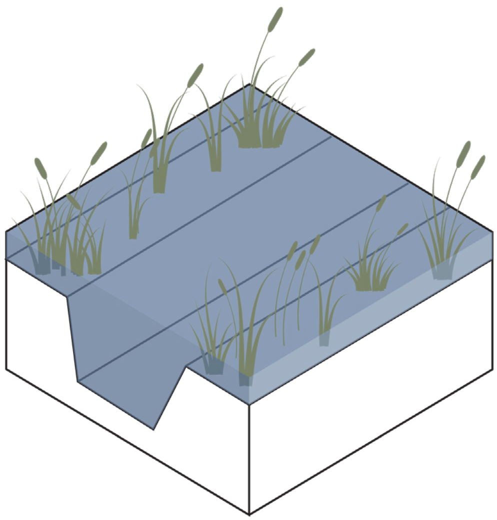
Effect:

meso

E.2

Riparian vegetation

Riparian vegetation tolerates both high and low water levels and can be planted along riverbanks and in wetlands to improve the overall ecosystem quality.



Related patterns:

R.3, R.4, R.5, R.6, R.11, E.7, E.8, U.3

Conflicting patterns:

Theoretical background:

Riparian zones are zones of vegetation that can handle both wet and dry feet and are often planted on the edge of waterways as a buffer zone between water and land. They provide unique ecological characteristics and other benefits such as filtering of water from nutrients or sediments and protection of runoff from sloping areas (USDA, n.d.). Vegetation in these zones would be able to deal with the differences in water level of the river while also providing ecological benefits to the river body.

Practical implications:

- For protection against erosion, plants with bigger root structures would be more beneficial.
- It is important to use native species in order to provide the best conditions for the local ecosystem.

Implementation:

<5 years

Effect:

10-25 years

Implementation:

micro

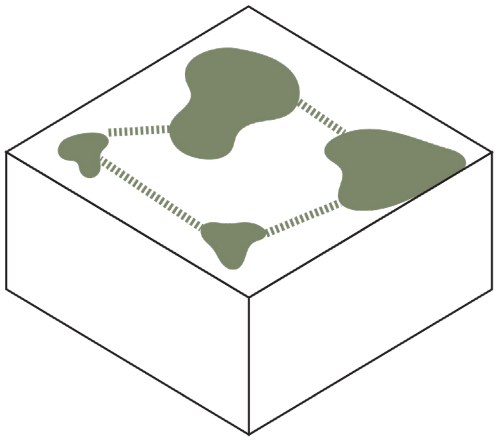
Effect:

meso

E.3

Green corridors

Connecting nature hubs through green corridors creates a larger ecosystem, similar to the past, where species will have a bigger habitat to live in.



Related patterns:

E.1, E.4, E.7, A.8, A.10, U.4

Conflicting patterns:

Theoretical background:

Natural areas are often fragmented over a landscape and being cut off from each other by agriculture or urban areas. As a result, the habitat area of wildlife is significantly smaller than before. Implementing green corridors will provide a natural link between these natural areas, so wildlife will have a larger area to live in (Hyseni et al., 2021). Moreover, when implemented on a large scale, green corridors will increase the overall nature in an area as well. This will stabilise the soil and increase the water holding capacity leading to more resilience in dry and wet periods.

Practical implications:

- Green corridors can be implemented on different scales for different types of species. From larger pathways for larger mammals over agricultural fields, to small green pathways in urban areas for insects.
- Planting native vegetation is important to fit the local surroundings.

Implementation:

5-10 years

Effect:

10-25 years

Implementation:

macro

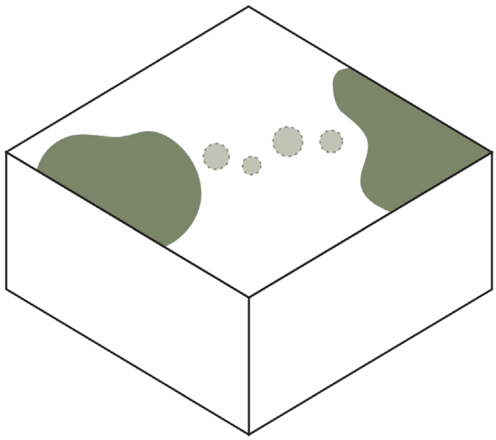
Effect:

macro

E.4

Stepping stones

Implementing small habitat islands can serve as refuge for animals between larger patches of nature, expanding the natural habitat for all species.



Related patterns:

E.1, E.3, E.7, A.8, A.10, U.4

Conflicting patterns:

Theoretical background:

Stepping stones are small patches of green that serve as a refuge for animals travelling between larges natural habitats. Therefore, they can be seen as a connector and will expand the total area of nature. By applying this practice, animals can move more freely and the ecosystem will resemble its former state. Moreover, it will add more green in general, which stabilises the soil and increase water holding capacity, leading to more drought and flood resilience. (Lynch, 2019)

Practical implications:

- Stepping stones must be connected as organisms should be able to move between them, or the distance between them should be kept small.
- They are most beneficial when implemented with green corridors.

Implementation:

5 years

Effect:

5-10 years

Implementation:

micro

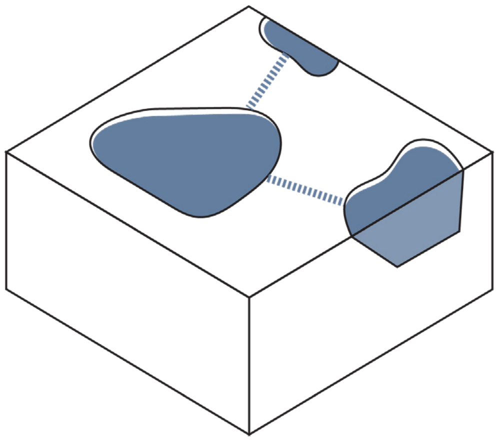
Effect:

macro

E.5

Blue corridors

Connecting and expanding nature hubs through blue corridors creates a larger ecosystem, in which species will have more space to move and a bigger habitat to live in.



Related patterns:

R.5, U.1, U.4

Conflicting patterns:

Theoretical background:

Blue corridors are connectors or ïĺhighwaysĺÍ that connect water bodies to each other, providing a way for aquatic species to move around between larger water bodies. Blue corridors are important for improving biodiversity in the water system, and to make sure large ecological water hubs are connected to the local ecological water system. (Hyseni et al., 2021)

Practical implications:

- Man-made structures (for keeping the water level steady e.g.) blocking the routes should be avoided, or be combined with structures through which species can still travel, such as a fish ladder.

Implementation:

5-10 years

Effect:

10-25 years

Implementation:

macro

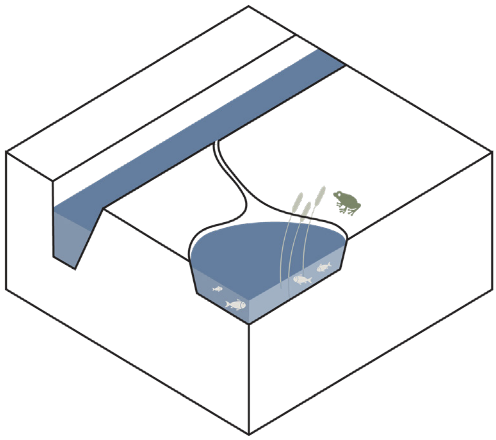
Effect:

macro

E.6

Climate refugia

Aquatic refugia protect aquatic species and ecosystems against disturbances such as periods of drought and heat.



Related patterns:

R.3, R.5, R.11, E.7, U.3

Conflicting patterns:

Theoretical background:

Aquatic refugia are crucial in river and other water systems with variable flow regimes, as they provide habitat for aquatic species and support ecosystem recovery after extreme events. During periods of high discharge or drought, remaining floodplain water, side channels, or other connected water bodies function as refugia. Aquatic refugia are, therefore, essential for ecological resilience. (Webb et al., 2012)

Practical implications:

- Man-made structures should be avoided, but minimal intervention might be required to maintain a sufficient water level.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

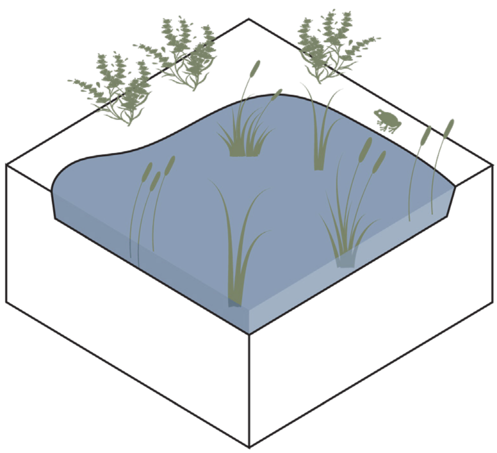
Effect:

macro

E.7

Wetland recovery

Recovering wetlands will expand the natural ecosystem and provide opportuntities for water storage.



Related patterns:

R.6, R.7, E.1, E.2, E.3, E.4, E.8, A.2, A.3

Conflicting patterns:

Theoretical background:

Wetlands are areas with interesting dry and wet characteristics. Wetlands could play a major role in climate resilience. They reduce flood risk by storing excess water from streams, rivers and rainfall and increase drought resilience by having a large water infiltration capacity, being able to provide water when needed (Wu et al., 2020).

Practical implications:

- It is important to use native species in order to provide the best conditions for the local ecosystem.
- Wetlands could be combined with certain agricultural practices, if not done intensively.

Implementation:

10-25 years

Effect:

50-75 years

Implementation:

meso

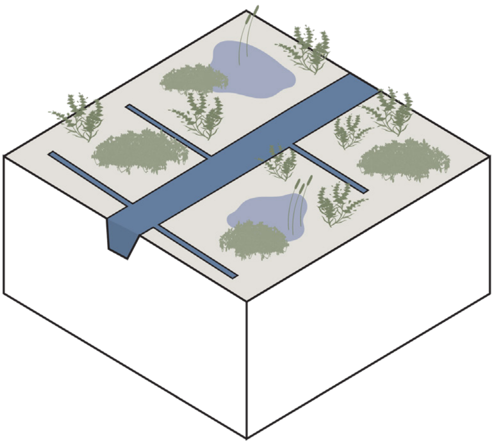
Effect:

macro

E.8

Rewetting peatlands

To keep peatlands from sinking and emitting CO_2, they should be kept wet in periods of drought.



Related patterns:

E.1, E.7, A.3

Conflicting patterns:

Theoretical background:

In order to prevent subsidence of the soil and CO_2 emissions from peatlands, the groundwater level should be increased in dry periods and maintained at a certain level. This will provide good conditions for the local ecology and increase biodiversity. (Hendriks et al., 2024)

Practical implications:

- If implemented in a agricultural area, new forms of cultivation should be used in order to produce yield.
- Rewetting is not a natural method and should be monitored well. Every polder or field is different and should get the right amount of water to prevent seepage.
- Rewetting requests a lot of water, and with water shortages rising it is important to only apply this method when absolutely necessary.

Implementation:

<5 years

Effect:

5-10 years

Implementation:

micro

Effect:

micro

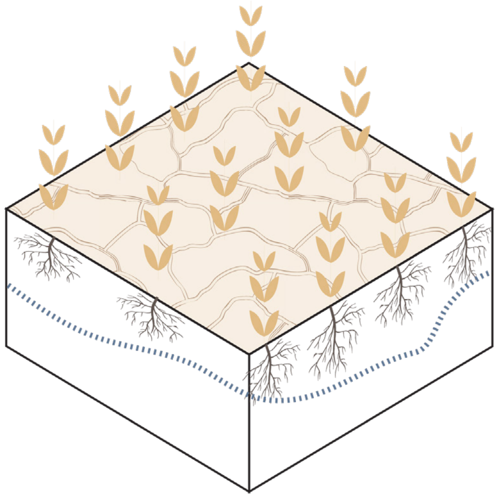
Patterns for

Agriculture

A.1

Drought resilient crops

Drought-resilient crops will ensure successful cultivation with reduced water input in areas that experience long periods of droughts.



Related patterns:

A.4, A.7, A.8, A.10, A.11

Conflicting patterns:

R.7, E.7, E.8, A.2

Theoretical background:

Drought resilient crops, or drought tolerant crops, are plants that can produce yields under low-water conditions. There are different types of crops that can be used, some crops are drought tolerant by themselves such as sesame, millet, sorghum and quinoa, whereas other currently used crops could be modified to varieties that are more drought tolerant. (Alvar-Beltràn et al., 2021)

Practical implications:

- For the implementation of drought tolerant crops it is important to look at the preferred soil type of crops and the climate they grow in.

Implementation:

<5 years

Effect:

5-10 years

Implementation:

micro

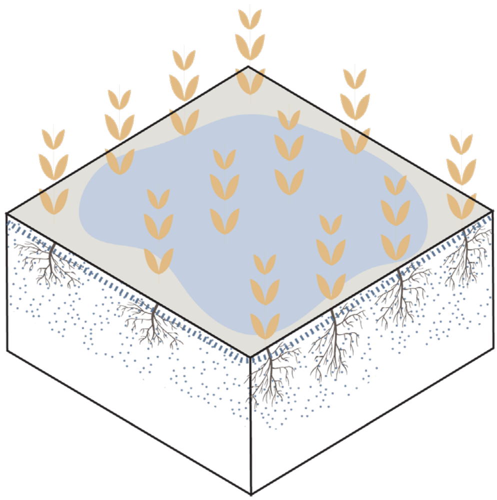
Effect:

micro

A.2

Flood resilient crops

Crops that are resilient to unexpected large quantities of water can be planted in flood-prone areas while providing suffcient yield.



Related patterns:

R.7, E.7, E.8, A.5, A.7, A.8

Conflicting patterns:

A.1

Theoretical background:

Flood resilient, or flood tolerant crops, can be planted during long rainy periods or in areas that regularly flood. Some crops are tolerant to wet conditions by themselves, whereas other crops can be adapted to survive longer in a waterlogged field. Examples of crops that survive for longer than a week are winter wheat and rice. Crops that can survive for 2 to 4 days are maize and soybeans, but can survive longer in partially waterlogged conditions. (Bailey-Serres et al., 2012)

Practical implications:

- For the implementation of flood tolerant crops it is important to look at the preferred soil type of crops and the climate they grow in.

Implementation:

<5 years

Effect:

5-10 years

Implementation:

micro

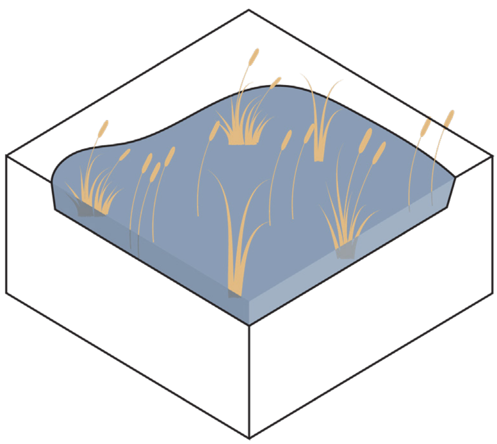
Effect:

micro

A.3

Wet cultivation

Crops resilient to constant waterlogging can provide cultivation opportunities in areas such as wetlands and peatlands.



Related patterns:

E.7, E.8

Conflicting patterns:

A.4, A.5

Theoretical background:

In peatlands and wetlands there is a constant layer of water on the surface. Most crops cannot survive wet feet, but there are different crops that can grow in such conditions. Four common crops that can grow in a sea climate such as the Netherlands are reed, cattail, elephant grass and willow trees. Most of these crops can be used for livestock feed, though reed provides opportunities for the construction of buildings as well. (Bestman et al., 2019)

Practical implications:

- For the implementation of wet cultivation crops it is important to look at the preferred soil type of crops and the climate they grow in.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

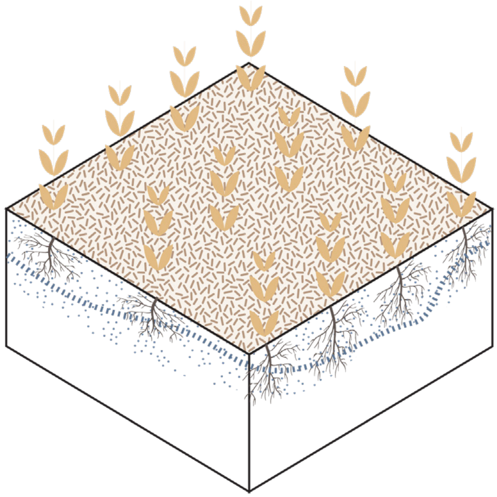
Effect:

micro

A.4

Mulching

Mulching helps conserve soil moisture, improves soil health, and protects the soil from extreme temperatures.



Related patterns:

A.1, A.7, A.8

Conflicting patterns:

A.3

Theoretical background:

Mulching is the practice of covering the soil with crop residues. This increases the moisture in the soil as it reduces direct soil evaporation. Moreover, it decreases the crops to heat exposure in a warm climate. (Alvar-Beltràn et al., 2021)

Practical implications:

- Applying mulch too early in the season could keep the soil too cold and wet, delaying crop growth.
- Applying too thick of a layer could prevent irrigation water from reaching the soil.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

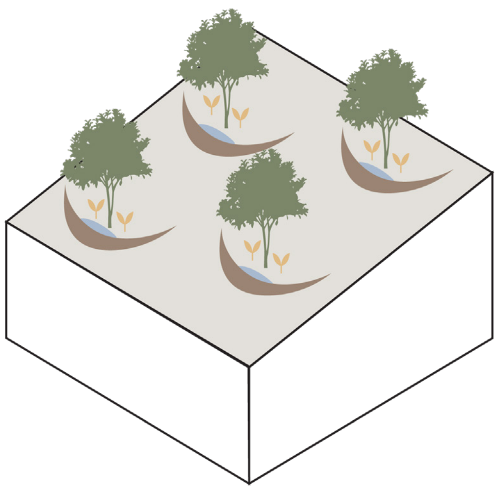
Effect:

micro

A.5

Half-moons

Half-moon bunds can be implemented on sloping fields to protect the soil from eroding and store water for a slow uptake in the soil.



Related patterns:

A.2, A.7

Conflicting patterns:

A.3

Theoretical background:

Half-moon pits are a water-harvesting technique that uses a semi-circular basin surrounding the crops to trap rainwater. This will allow the water to infiltrate in the area where the crops are growing and reduce surface runoff and soil erosion. (Alvar-Beltràn et al., 2021)

Practical implications:

- Half moons have the risk of waterlogging if applied incorrectly. Choosing the right crop is therefore important.
- On loose soils, extra protection might be needed to keep the structure in place.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

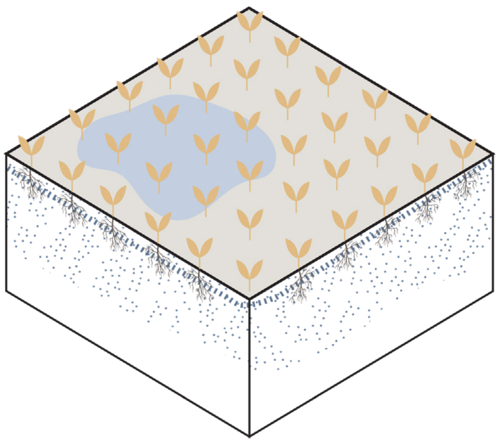
Effect:

micro

A.6

Cover crops

In the fallow period, cover crops can be planted to improve soil health, increase the infiltration capacity and prevent erosion.



Related patterns:

A.7

Conflicting patterns:

Theoretical background:

Cover crops are planted in between growing seasons, instead of leaving the field empty. This will reduce soil erosion and increase the soil organic matter, which leads to a better uptake of water and nutrients. (Alvar-Beltràn et al., 2021)

Practical implications:

- It is important to look at the preferred soil type of the cover crops and the climate they grow in.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

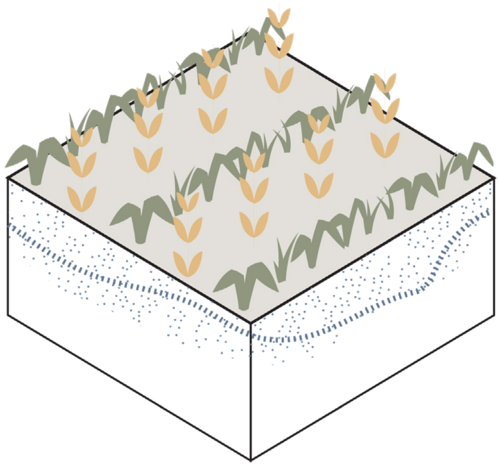
Effect:

micro

A.7

Intercropping

Intercropping increases plant water availability, water use efficiency and reduce soil evaporation.



Related patterns:

A.1, A.2, A.4, A.5, A.6, A.9

Conflicting patterns:

Theoretical background:

Intercropping is the practice where alternating crops are cultivated together, or where a cash crop is cultivated with a non-crop. This reduces the negative impacts of monoculture, as it increases water holding capacity due to varying root systems and the residue mulch from one of the crops. Moreover, intercropping provides climate resilience after weather extremes, as the increased biodiversity ensures that multiple species can provide fast recovery after disturbances. (Huss et al., 2022)

Practical implications:

- It is important to consider the preferred soil type of the plants and the climate they grow in.
- Not all plants grow well together, some plants will shade other plants for instance. Finding the right combination of plants is important for optimal growth.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

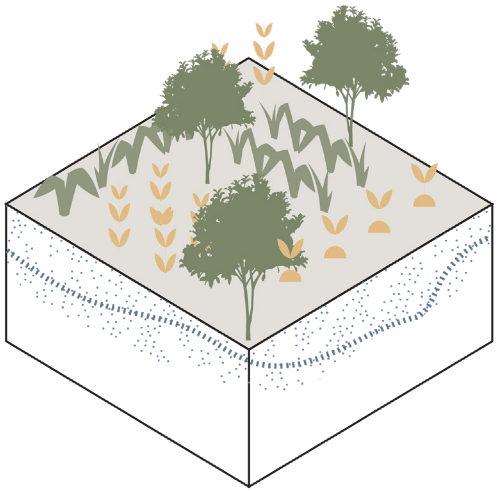
Effect:

micro

A.8

Agroforestry

Including trees and shrubs in a diverse agricultural system will improve the water holding capacity of the soil, reduce evaporation, and enhance biodiversity.



Related patterns:

E.1, E.3, E.4, A.1, A.2, A.4, A.9, A.10

Conflicting patterns:

Theoretical background:

Agroforestry is a practice in which agricultural crops are mixed with trees and shrubs, which has multiple benefits. The larger root systems stabilise the soil, thereby reducing soil erosion. Moreover, it improves the soil organic matter, which increase the water holding capacity and the uptake of nutrients. The leaves from the trees help enriching the soil as well, and hold moisture on the surface. Canopy covers reduce evaporation from direct sunlight and keep moisture under the leaves. (Alvar-Beltràn et al., 2021)

Practical implications:

- It is important to consider the preferred soil type of the plants and the climate they grow in.
- Not all plants grow well together, some plants will shade other plants for instance. Finding the right combination of plants is important for optimal growth.

Implementation:

5-10 years

Effect:

10-25 years

Implementation:

micro

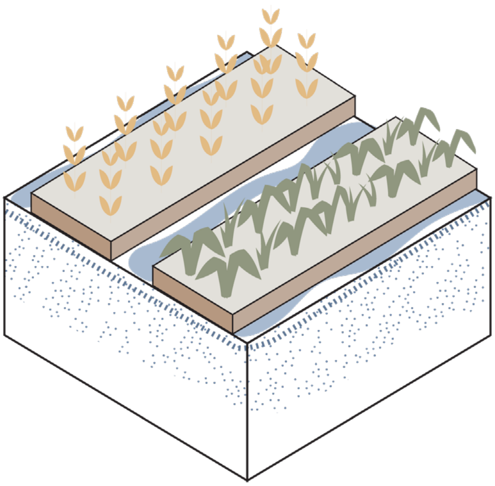
Effect:

meso

A.9

Raised bed system

A raised bed system improves crop growth during wet periods by keeping the root zone elevated above saturated soil, reducing the risk of waterlogging.



Related patterns:

A.2, A.7, A.8

Conflicting patterns:

Theoretical background:

In a raised bed system, crops are planted on a slightly higher level to reduce damage from flooding and waterlogging. This increases the removal capacity of excess water and prevents root damage from waterlogging when groundwater levels are high. (Alvar-Beltràn et al., 2021)

Practical implications:

- It is important to consider the preferred soil type of the crops and the climate they grow in.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

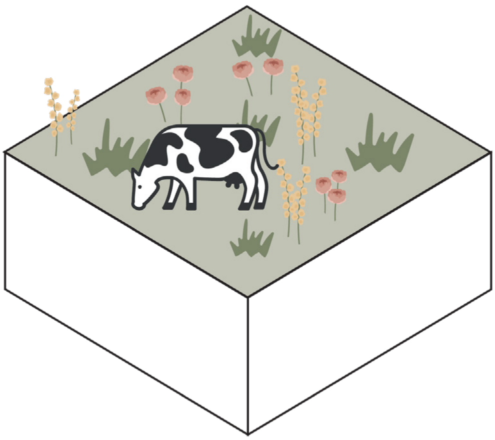
Effect:

meso

A.10

Flower-rich meadow

A flower-rich meadow improves biodiversity and increases the water-holding capacity of the soil, creating resilient and more natural grasslands for livestock feed.



Related patterns:

E.3, E.4, A.1, A.8

Conflicting patterns:

Theoretical background:

In a flower-rich meadow, grasslands are combined with different species of grass and other flowers or herbal plants. It provides a way for livestock feed that is in less need of additional supplements. Not only does it increase the biodiversity within the vegetation, but it also attracts different types of animals, especially meadow birds. The diverse root system such a meadow provides, will increase the soil organic layer, thus increasing the water holding capacity of the soil. (Willem Erisman et al., 2017)

Practical implications:

- No tillage would be allowed to improve the resilience of the ecosystem.
- It is important to consider the preferred soil type of the plants and the climate they grow in.

Implementation:

<5 years

Effect:

5-10 years

Implementation:

micro

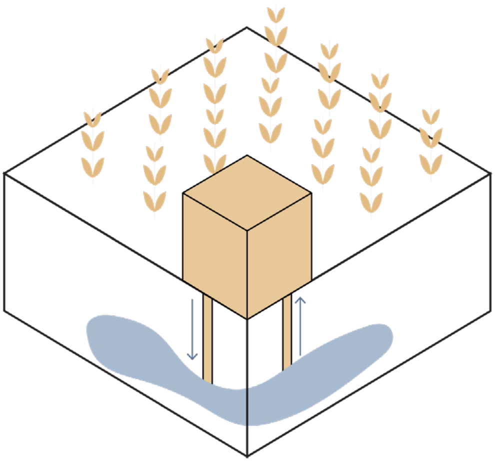
Effect:

meso

A.11

Aquifer storage and recovery

Aquifer storage and recovery (ASR) can store excess water which can be used in periods of drought for irrigation.



Related patterns:

A.1, U.2

Conflicting patterns:

Theoretical background:

With aquifer storage and recovery (ASR) excess (rain) water is infiltrated and stored in aquifers through wells or infiltration ponds. In times of drought, this water can be recovered from the same wells, providing enough water for irrigation or drinking water. ASR is useful for when there is a lack of space aboveground. Furthermore, the water is protected from external sources such as fluctuations in temperature and algae growth. In the Netherlands, ASR is often used in the greenhouse sector. (Zuurbier et al., 2013)

Practical implications:

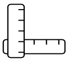
- Monitoring of the system is important for maintaining the water quality and quantity.
- It can be implemented on different scales.

Implementation:

<5 years

Effect:

<5 years



Implementation:

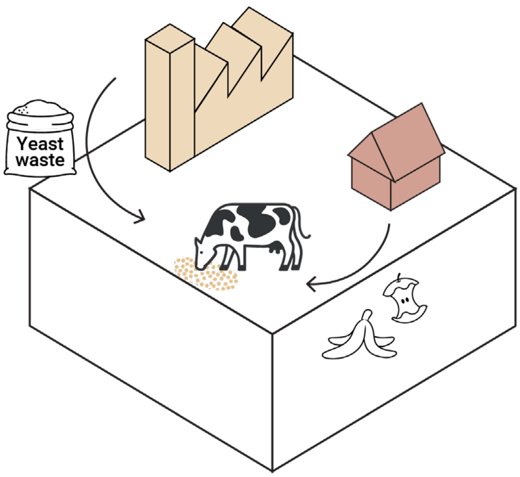
micro

Effect:

micro/meso

A.12 Residual flows for livestock feed

The use of residual flows from industry will decrease the demand on crop cultivation for livestock feed and open up space for renaturalisation.



Related patterns:

A.10

Conflicting patterns:

Theoretical background:

Industrial and household waste can be used to make livestock feed (Geerdink et al., 2025). Examples of these are crop residues, waste from beer breweries and other organic waste. By focusing more on the use of residual flows for livestock feed, the system becomes more efficient and will need less fields for growing crops such as maize and grass. Therefore, space will become available to can be used for renaturalisation of the river, or to be used for ecological purposes.

Practical implications:

- A well-functioning system across scales is needed to replace feed crops with residual flows.
- Local interactions are preferred, but national coordination is also necessary.

Implementation:

<5 years

Effect:

5-10 years

Implementation:

macro

Effect:

meso

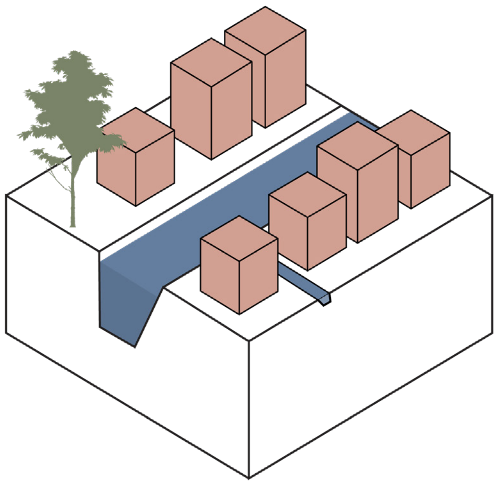
Patterns for

Urbanisation

U.1

Urban waterways

Urban waterways provide space to catch and store excess water in wet periods.



Related patterns:

E.2, E.5, U.2, U.3

Conflicting patterns:

Theoretical background:

Urban waterways can store excess water in periods of (heavy) rainfall. It is an open waterway above surface that can hold water for a period of time, whereafter it will be discharged when possible. Urban waterways can be newly constructed or reconstructed in existing waterways. (P?tz & Bleuz?, 2012)

Practical implications:

- A natural riverbank would be most ideal. If this is not possible a stone stepped quay can be constructed.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

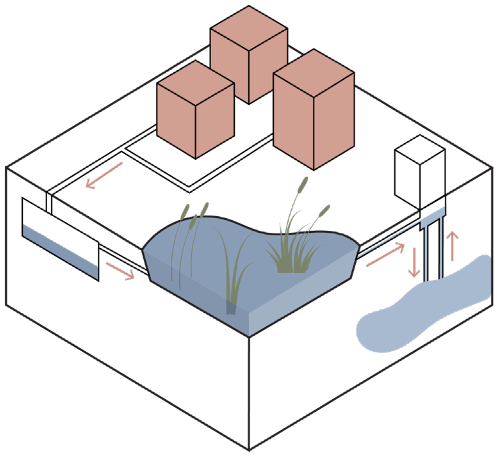
Effect:

micro

U.2

Underground water buffers

An urban underground water buffer captures excess water from rainfall and stores it locally in the deeper, water-bearing sand layers, available for later use.



Related patterns:

A.11, U.1, U.4, U.10

Conflicting patterns:

Theoretical background:

An urban water buffer stores water locally in a sand-bearing layer under the urban fabric during periods of heavy rainfall. This water will then be available for later use. This practice is useful for when there is a lack of space aboveground. Moreover, since the water is stored below the surface, it is protected from external sources such as pollution and fluctuations in temperature. Urban water buffers can also be filled to keep the groundwater level constant against foundation pole decay. (P?tz & Bleuz?, 2012)

Practical implications:

- It can be combined with a helophyte filter to filter the water before storing it. Monitoring of the system is important for maintaining the water quality and quantity.
- It can be implemented on different scales (whole neighbourhood or just one building). “

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

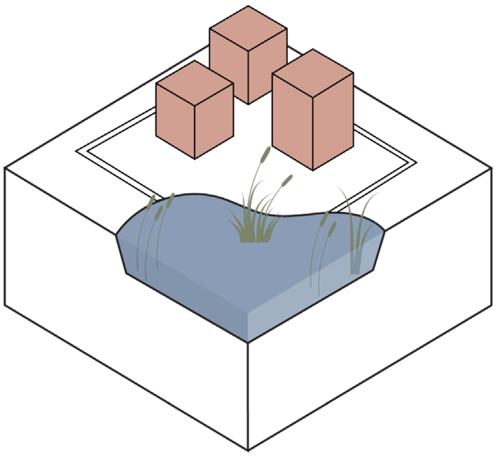
Effect:

micro

U.3

Urban buffer ponds

Urban buffer ponds, or rain ponds can store excess rainwater in wet periods and support the local ecology.



Related patterns:

E.2, U.1

Conflicting patterns:

Theoretical background:

Rain buffer ponds temporarily store excess rainwater and allow it to drain off slowly. The constant drainage makes room for water from the next precipitation event. Next to acting as a water retention pond, it also acts as a habitat for different types of flora and fauna, improving the biodiversity of the urban area. Moreover, the vegetation can have a purification effect on the water. (P?tz & Bleuz?, 2012)

Practical implications:

- The vegetation should be resilient to change in water level, therefore riparian vegetation would be advised.
- The ponds require regular maintenance to remove litter for instance.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

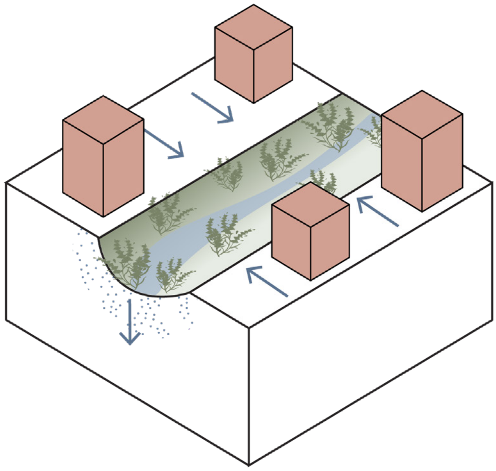
Effect:

micro

U.4

Lowered urban green

Incorporating lowered nature areas in cities can retain water, enhance infiltration, and provide cooling.



Related patterns:

E.1, E.2, U.2

Conflicting patterns:

Theoretical background:

Lowered green spots in urban areas can be used to store and infiltrate excess rainwater from roofs and the hardened surface. The green area should be lowered in order for water to naturally flow towards the infiltration area. In the Netherlands, they are often called wadis. Moreover, implemeting green areas in the cities will have a cooling effect. The vegetation used can be grass, shrubs, perennials, a combination of these or a lowered planter. (P?tz & Bleuz?, 2012)

Practical implications:

- It can be combined with a helophyte filter which filters the water while being stored.
- The needed surface should be 50% of the connected hardened surface the water is coming from.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

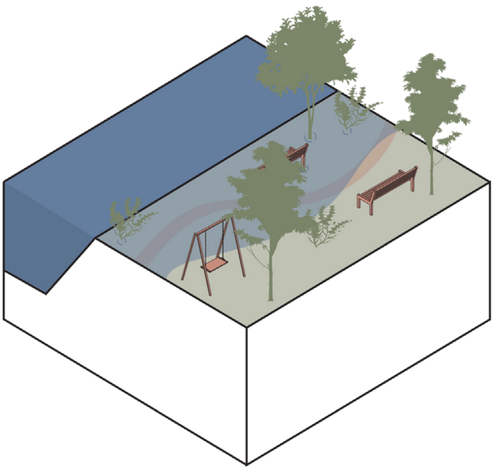
Effect:

micro/macro

U.5

Floodplain parks

Parks in floodplains can provide recreational space while allowing room for a renaturalised, flood-prone river.



Related patterns:

R.3, U.9

Conflicting patterns:

R.4

Theoretical background:

A floodplain park can be designed to be flood resistant. This means that the vegetation and furniture should be able to withstand submersion for multiple days in a row. This could be heavy stone benches and vegetation such as willow trees or swamp cypresses. During the dry season, people can enjoy a green park with a river view. (Prominski et al., 2012)

Practical implications:

- Safety measures are important, as the area can still be swampy after a flooding event.

Implementation:

5-10 years

Effect:

5-10 years

Implementation:

micro

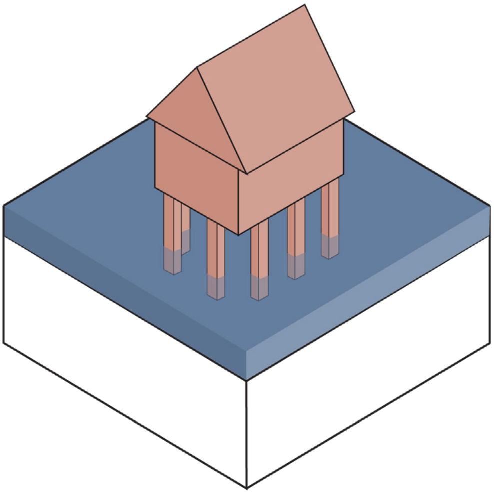
Effect:

meso

U.6

Raised buildings

Elevated constructions such as stilt houses can be built in areas that are prone to flooding without disrupting the natural (river) dynamics.



Related patterns:

U.8

Conflicting patterns:

Theoretical background:

Raised constructions, such as houses on stilts or buildings on raised surfaces, can be built in areas that are prone to flooding. The lower level can have a different function, such as parking or storage. After cleaning, these areas can be used again. (P?tz & Bleuz?, 2012)

Practical implications:

- Building on dikes is costly and could cause issues when raising the dike is necessary.
- Stilt houses as a separate neighbourhood should have a flexible connection to the infrastructure, or be able to be self-sufficient.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

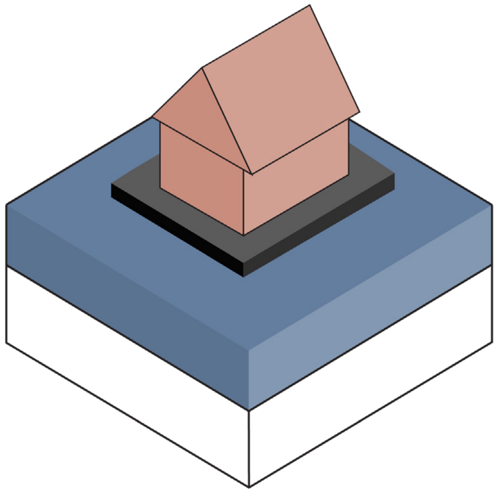
Effect:

meso

U.7

Floating buildings

Floating constructions allow for living in water without being affected by changes in water level.



Related patterns:

R.4

Conflicting patterns:

Theoretical background:

Floating, or amphibious, buildings will suffer no water damage in times of flooding as the building will rise with the water level. This practice is useful in areas with an abundance of water and changing water levels, as the building floats and adapts to its surroundings. (P?tz & Bleuz?, 2012)

Practical implications:

- The building should have a flexible connection to the infrastructure, or be able to be self-sufficient.
- A light-weight construction such as a wooden skeleton is necessary.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

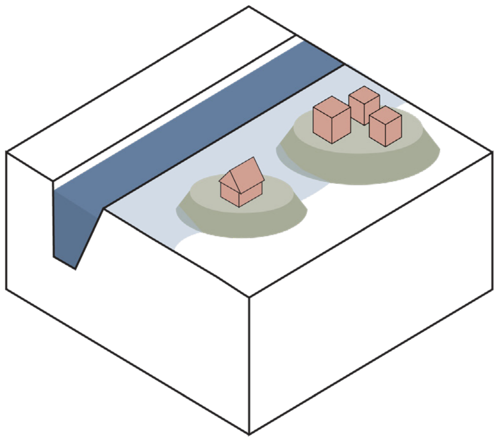
Effect:

meso

U.8

Terpen

Terpen provide elevated land in flood-prone areas to offer a safe site for construction.



Related patterns:

U.6

Conflicting patterns:

Theoretical background:

Man-made hills (terpen) can be constructed to rise above the highest flood level. Therefore, buildings can be safely constructed there, or the hill can serve as a refuge during a flood. Often, vulnerable functions are located here, such as utilities, emergency services, and hospitals. (P?tz & Bleuz?, 2012)

Practical implications:

- The future should be considered when constructing the mound, as maximum flood levels can rise over time.

Implementation:

5-10 years

Effect:

5-10 years

Implementation:

micro

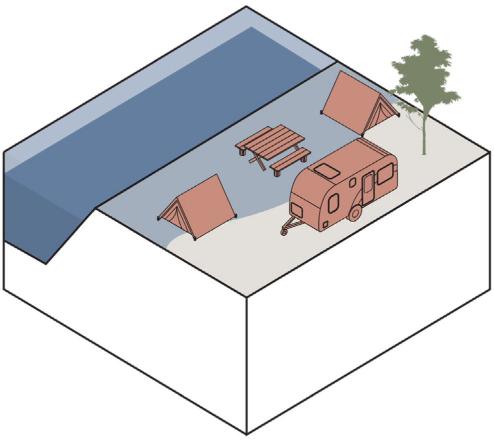
Effect:

meso

U.9

Temporary recreation

Floodplains can be used for temporary recreational activities during dry periods.



Related patterns:

R.3, U.5

Conflicting patterns:

R.4

Theoretical background:

Recreation in floodplains or retention areas in dry periods is a way to use an otherwise empty space. Moreover, the area is attractive due to its close proximity to water. Examples of temporary recreational activities are camping and event sites. (Prominski et al., 2012)

Practical implications:

- A quick escape plan is necessary for these sites, as even during dry summers heavy rainstorms can cause flooding from rain rivers within a day.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

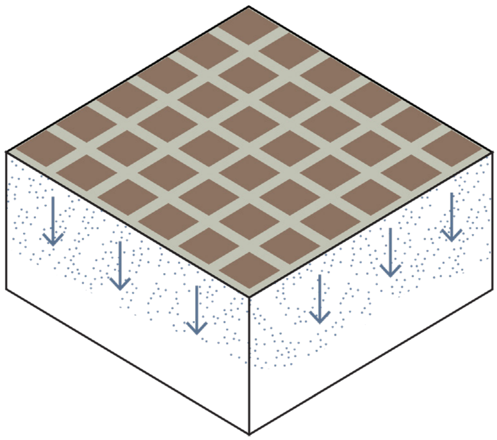
Effect:

meso

U.10

Permeable pavement

Permeable pavements allow for better infiltration capacity of urban environments.



Related patterns:

U.2

Conflicting patterns:

Theoretical background:

Permeable pavement are porous types of pavers with voids, open structures or partially pervious materials that allow water to pass through and infiltrate into the soil. Rainwater is able to infiltrate directly into the ground, relieving sewage systems and preventing urban floods. Moreover, the groundwater level will be replenished, which is beneficial for periods of drought. There are different types, examples are: porous bricks, open-joint bricks, open paving patterns, grass-concrete pavers, gravel, shells or other stones, a mix of grass and gravel, and woodchips. (P?tz & Bleuz?, 2012)

Practical implications:

- There is no buffering capacity, so for periods of heavy rainfall a retention option would be necessary.

Implementation:

<5 years

Effect:

<5 years

Implementation:

micro

Effect:

micro

3

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