European Commission

Selecting, designing and implementing

Natural Water Retention Measures in Europe

Capturing the multiple benefits of nature-based solutions

NWRM

Natural Water Retention Measures

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Environment

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A1 - Meadows and pastures

Meadows are areas or fields whose main vegetation is **grass or non-woody plants,** used for **mowing** and **haying**. Pastures are grassed or wooded areas, moorland or heathland, generally used for **grazing**. Due to their rooted soils and their permanent cover, meadows and pastures provide runoff attenuation and greater infiltration, thus good conditions for the uptake and storage of water during temporary floods. They also protect water quality by trapping sediments and assimilating nutrients.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☑
- Forest and semi-natural areas ☐
- Wetlands ☐

Financial costs (Capital, operation & maintenance)

Meadows and pastures operational costs (under intensive management) lie between €159 and €420/ha/year for grazed grassland and between €189 and €358/ha/year for hayed grassland. **Conversion** from arable land to permanent grassland costs about €200/ha (€14/ha/yr) and the loss of revenue can reach €140/ha/year (over 20 years), though conversion from arable is more likely on the most marginal arable land.

Scale

This measure operates at field and farm scale.

Design

Meadows and pastures can be implemented and combined with other measures such as **controlled traffic farming** and **reduced stocking density**; the latter may be particularly important to ensure the benefits of meadows and pastures restoration are effective.

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A1 - Meadows and pastures

Potential biophysical effects

Runoff	High
Reducing pollution	None
Soil conservation	High
Habitat	None
Climate Change	Medium

Ecosystem services delivered

Provisioning	None
Regulation & maintenance	High
Cultural	None
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	None
2020 Biodiversity Strategy	High

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Compared to arable land, **runoff attenuation** can reach 50 to 66% on grassland (Spain) and 23 (wet year) to 100% (dry year) on meadows (Poland). Meadows also contribute to reducing runoff through increased **evapotranspiration** (8 to 35% compared to arable land in Poland) and **infiltration**, permitted by improved soil structure and organic matter content. Well managed meadows and pastures thereby contribute to **reducing flood risks** but coordinated measures need to be taken at the catchment scale. Groundwater recharge may be achieved but depends on management and soil types.

Higher vegetation coverage results in greater **filtration of pollutants** and contributes to limiting **erosion and sediment** delivery. If no additional nutrients are applied and the hay is harvested this will also reduce the amount of nutrients and lead to lower nutrient losses. Thus, meadows and pastures play a role in preserving/improving **qualitative status** of surface water and provide better protection for ecosystems. Interactions with stocking density where poaching is a risk may be important.

If well managed, meadows and pastures finally contribute to **climate change** adaptation and **mitigation** since improved organic matter content in vegetation coverage enables to absorb more CO_2.

Meadows and pastures are finally key elements in High Nature Value systems regarding the prevention of biodiversity loss and contribute to more **sustainable agriculture** through reducing the negative impacts of agriculture production.

High *Medium* *Low* *None*

A2 - Buffer strips and hedges

Buffer strips are areas of **natural vegetation cover** (grass, bushes or trees) at the margin of fields, on arable land, proximate to transport infrastructure and water courses, on headlands or within fields (e.g. beetle banks). Buffer strips and hedges offer good conditions for effective water **infiltration** and **slowing surface flow**; they therefore promote the natural retention of water. They can also significantly reduce the amount of suspended solids, nitrates and phosphates originating from agricultural run-off.

Land surface relevant for application

- Artificial surface ○
- Agriculture land ✓
- Forest and semi-natural areas ○
- Wetlands ○

Financial costs (Capital, operation & maintenance)

Literature provides references in buffer strips establishment costs ranging between €400 and 800/ha, and €4.73 and 5.08/m for planting hedges. Maintaining a 3m wide buffer strip costs between €75 and 100/ha while management of hedgerows costs about €64/100m. Loss of revenue is estimated at €140/ha/year. Payment rates will typically be determined by the regulations concerning Rural Development Programmes.

Scale

Buffer strips and hedges operate at the field/farm scale.

Design

There are a **variety** of buffer strip types, the dimensions of which differ according to location, vegetation type and **requirements** across member states (from 0.6 to 20m). The effectiveness of the buffer strip to have significant impacts will depend on the width of the strip, the **slope** and the type of **soil**. The adjacent land-use (arable or pasture) impacts on the effectiveness of buffer strips. Beetle banks usually measure between 2 and 4m.


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Case studies: Field Margins in Heilbronn, Gremany; Floodbreaking Hedgerows in Southern France

A2 - Buffer strips and hedges

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

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The vegetation on the buffer strip reduces the energy (flow speed) of surface water which leads to greater infiltration (also aided by improved structure of buffer strip soils). Buffer strips **reduce runoff** by 50 to 78% compared to no buffer strip. In addition, increased evapotranspiration will contribute to increasing the capacity for water retention. While buffer strips will not significantly attenuate peak flows, they will reduce **flood risks** through greater retention and reduction of the surface water energy. However, this will reflect the relative size of the buffer strip. Higher infiltration may contribute to groundwater recharge, relative to the size of the buffer strip.

Buffer strips and hedges **trap/filter** sediments and pollutants: tests in hilly areas resulted in 42 to 96% P reduction in runoff, 27 to 81% N reduction and 55 to 97% sediment reduction. Thus they contribute to improving the status of **hydromorphology** quality elements and to preventing **water status deterioration**.

By increasing CO_2 absorption, buffer strips and hedges participate in climate change mitigation and adaptation. Habitat provision and connectivity contributes to better protection for ecosystems, more use of Green Infrastructure and prevention of biodiversity loss. By providing habitats for pollinators and bio-control species, and by reducing the impacts of erosion, buffer strips contribute to more **sustainable agriculture**, even if they take land out of production.

High Medium Low None

A3 - Crop rotation

Crop rotation is the practice of growing a series of **dissimilar/different types of crops** in the **same area in sequential seasons**. Judiciously applied crop rotation can improve soil structure, reduce erosion and increase infiltration capacity, thereby reducing downstream flood risk. A traditional element of crop rotation is the replenishment of nitrogen through the use of green manure in sequence with cereals and other crops. Crop rotation also mitigates the build-up of pathogens and pests that often occurs when one species is continuously cropped.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☑
- Forest and semi-natural areas ☐
- Wetlands ☐

Financial costs (Capital, operation & maintenance)

An average cost of 32€/ha is needed for changing rotations and **increasing fallow index** in crop rotations. Crop rotation maintenance costs concern mainly **inputs costs** (about 400€/ha), which appear to be higher with tillage (by 20€/ha) and lower with no tillage (by 40€/ha) than inputs costs under monoculture. In Europe, **subsidies** supporting crop rotation have been estimated to be around 128€/ha/year.

Scale

Crop rotation is designed and implemented at the farm scale and field scale. In terms of drainage, the concerned area is the field itself.

Design

Overall, crop rotation should take into consideration the time necessary between two growing seasons and the need for **alternating** between plant families, introducing **green cover in winter** and cereals and grassland in the rotation, alternating winter and **spring crops**, alternating “cleaning” and “dirty” crops, introducing species that are fast and aggressive. Nitrogen balance analysis and field tests can help identify the most efficient rotations in a specific context.

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A3 - Crop rotation

Potential biophysical effects

Runoff	Medium
Reducing pollution	High
Soil conservation	High
Habitat	None
Climate Change	Medium

Ecosystem services delivered

Provisioning	Low
Regulation & maintenance	Medium
Cultural	Medium
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	Low
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Medium

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Impacts of crop rotation depend highly on the **rotation scheme**, the **choice of crops** and the cultivation **practices**. Crop rotation may have a positive impact on the rate of accumulation (depletion) of soil organic matter, pore morphology and connectivity, enhancing **water absorption**. Through increased infiltration and decreased runoff, crop rotation contributes to reducing flood risks and to providing groundwater recharge.

Crop rotation improves **fertilization efficiency** by making mineral elements more available, increasing humus and organic matter, thus enabling lower nitrate inputs. It implies that the soil is not left bare thus pollutants are better caught; however, the effectiveness in reducing nitrate losses depends on the rotation scheme and nutrients input. Crop rotation is also efficient in managing grass cover, thus in decreasing the need for pesticides. Runoff reduction finally contributes to reducing soil erosion. If well designed and managed, crop rotation can thereby help to improve **physio-chemical water status**.

Introducing legumes into rotations can improve **carbon sequestration**. Compared to monoculture, crop rotation is an **effective and natural mean** to fight pests and grass. It increases agriculture sustainability by maintaining good conditions for further cropping, through improved **soil fertility**. Tests in France showed higher yields for wheat included in a rotation than under wheat monoculture. Finally, crop rotation increases **landscape heterogeneity**.

High *Medium* *Low* *None*

A4 - Strip cropping along contours

Strip cropping is used to maintain the soil fertility and prevent **erosion** when a slope is steep or long, or when one does not have an alternative method. It **alternates strips** of closely sown crops such as hay, wheat, or other small grains with strips of row crops, such as corn, soybeans, cotton, or sugar beets. Strip cropping creates natural **barriers** for water, helping to preserve the strength of the soil, and includes layers of plants which absorb minerals and water more effectively than others.

Land surface relevant for application

Artificial surface	
Agriculture land	✓
Forest and semi-natural areas	
Wetlands	

Financial costs (Capital, operation & maintenance)

Strip cropping is one of the **least costly** conservation practices. The investment cost includes labour and/or fuel, and possibly a change in cropping sequences, particularly if grasses and legumes have to be included in a long-term crop rotation. Subsidies accorded for supporting such practices are estimated to be around €110/ha/year in Europe.

Scale

Strip cropping is applicable at field scale.

Design

Strip crops have to provide cover in periods when erosion occurs. Strips should be designed to facilitate operation of machinery, **parallel** to each other and close to the contour. Strips width depends on the erosion prediction technology. Sediments accumulation should be removed and distributed around the field to maintain the effectiveness of the practice. Strip cropping should finally be combined with other soil **management practices**: reduced tillage, crop rotation...

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A4 - Strip cropping along contours

Potential biophysical effects

Runoff
Reducing pollution
Soil conservation
Habitat
Climate Change

Ecosystem services delivered

Provisioning
Regulation & maintenance
Cultural
Abiotic

Contribution to policy objectives

Water Framework Directive
Floods Directive
Birds & Habitats Directive
2020 Biodiversity Strategy

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Densely vegetated strips increase surface roughness and hydraulic resistance to flow; that reduces the transport capacity of the runoff and slows it down, along with the greater efficiency of closely sown plants in absorbing water. Across slopes, strip cropping helps to intercept water runoff compared to up-down slope cropping, thus contributes to reducing **flood risks** particularly when used in a planned conservation system including a combination of measures. It also highly reduces the **rate of sediments** moving down the slopes, contributing to soil erosion control. Moreover, crop rotation among the strips enables clear-tilled crops to benefit from the sediment deposited in the previous year. Greater infiltration contributes to groundwater recharge.

Strip cropping has a beneficial impact on the **filtration of pollutants**, since strips plants absorb and assimilate nutrients efficiently. By reducing sediment loss and filtering pollutants, it enables to improve and maintain **water status of hydro-morphology quality** elements and provide better protection for ecosystems. Strip cropping is also efficient in increasing biodiversity into agro-systems (by providing habitats, which can increase species richness) and sustainability of agriculture.

High Medium Low None

References & Learn more:
http://nwrm.eu/measures-catalogue

A5 - Intercropping

Intercropping is the practice of growing **two or more crops in proximity**. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a shorter crop that requires partial shade. **Numerous types** of intercropping, all of which vary the temporal and spatial mixture to some degree, have been identified: mixed intercropping, row cropping, relay cropping, etc.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☑
- Forest and semi-natural areas ☐
- Wetlands ☐

Financial costs (Capital, operation & maintenance)

Costs associated with intercropping are low. Subsidies available for supporting practices like intercropping are estimated to be around €110/ha/year in Europe.

Scale

Intercropping is applicable at field scale.

Design

Mixtures have to be well thought through in intercropping systems. Intercropping should include crops which will **not compete** too much for light, water, nutrients and space, such as deep-rooted and shallow-rooted plants, or tall with short crops. Efficient mixtures will depend on the local environmental conditions. A **Cereals-legume** mixture is found often to be energy-efficient as well. **Trees** can also be part of intercropping systems.

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A5 - Intercropping

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

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By implementing cover crops where the soil would otherwise be left bare (under other crops, between rows) intercropping contributes to increasing **water infiltration** (4 times in Mediterranean vineyards with grass compared to no grass) and **reducing runoff** (20 to 55% in the Sahel compared to sole crops). Reducing runoff and increasing infiltration provide erosion and sediment control (50% reduction in soil loss in Sahel compared to monoculture). Along with the filtration of pollutants, this helps to address the **WFD objectives** of restoring and maintaining good surface water status. Intercropping also contribute to flood risk reduction and groundwater recharge, and can reduce **wind erosion** compared to a bare soil.
Intercropping leads to a more stable plant system, a better **soil structure** and improved fertility particularly when it concerns **legumes**. It enables a more efficient use of resources (light, water, nutrients), thus an increased **productivity** compared with each sole crop of the mixture.
By providing habitats for insects and soil organisms and increasing biodiversity in agro-systems, intercropping make agro-systems **more resilient**. Along with the preservation of soil fertility, it contributes to maintaining good conditions for further cropping and thus to making agriculture more sustainable

High *Medium* *Low* *None*

A6 - No-till agriculture

Tillage is a **mechanical modification** of the soil which, if done intensively, can disturb the soil structure, thus increasing erosion, decreasing water retention capacity and reducing soil organic matter. No-till (no tillage) farming is a way of growing crops or pasture from year to year increasing water infiltration, organic matter retention and cycling of nutrients in the soil. The main benefit of no-till is improvement in soil **biological fertility**, making soils more resilient and eliminating soil erosion in some areas.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☑
- Forest and semi-natural areas ☐
- Wetlands ☐

Financial costs (Capital, operation & maintenance)

No-till systems require **direct drilling machinery** (k€10) as an alternative to ploughing. If no-till is used in conjunction with winter cover crops, rollers may be necessary prior to drilling of spring crops. Costs remain lower than a ploughing system. **Fuel savings** range between €30 to 67/ha and reduction in labour costs is around €21/ha. However, additional herbicides and fertilizers costs reach €18 and 16/ha.

Scale

No-tillage is applicable at field scale.

Design

No-till can be **combined with other agricultural measures** such as green cover/cover crops, mulching, controlled traffic farming. The last of these is especially relevant as it can help to avoid problems of soil compaction due to the lack of machinery movements in no-till systems, particularly on wetter soils.

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Case studies: No Tillage field trials in lower Austria, Cover crops and no-tillage in an Olive Grove, Andalusia, Spain

A6 - No-till agriculture

Potential biophysical effects

Runoff	Medium
Reducing pollution	High
Soil conservation	High
Habitat	None
Climate Change	High

Ecosystem services delivered

Provisioning	Low
Regulation & maintenance	High
Cultural	None
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	None
2020 Biodiversity Strategy	High

Studies report that no-till increases **soil water retention** in the upper soil layer by 6 to 12% compared to ploughing; in some cases runoff has been reduced by 40%. Flood risk reduction has not been quantified, but follows from increased water retention, infiltration and runoff reduction. Catchment level promotion of no-till together with other measures thus contributes to mitigating flood risks.

No-till can **reduce P and N loss** by 30 to 88% and **soil erosion** by 89% in hilly areas. Thus it contributes to improving and preserving water status of hydro-morphological quality elements and preventing water status deterioration.

No-till increases **soil** aggregate stability, soil organic carbon (by 20 to 1300kgC/ha/yr), pore structure, biological activity, infiltration rate, hydraulic conductivity and soil strength, but decreases the aeration of wet soils, increases acidity and P accumulation. These changes either result in higher or lower CO_2 emission (+220 to -57%) but CO2 emissions from fuel use are lower in no-till systems (50 to 83%). No-till contributes to preserving soil biodiversity by increasing earthworm's biomass (300%) and **invertebrate's** population and species, thus supporting wider biodiversity, which helps to address Biodiversity Strategy goals.

Combined with other measures, no.till can contribute to sustainable agriculture but its main impacts are linked to soil type and climate. In Europe, yields results may be 5% lower with no till than with tillage, but they are higher in Southern Europe.

High *Medium* *Low* *None*

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A7 - Low-till agriculture

Low-till agriculture, also known as conservation or reduced till, leaves at least 30% of **crop residue** on the soil surface, during the critical soil erosion period. This slows water movement, which reduces the amount of soil erosion and potentially leads to greater infiltration.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☑
- Forest and semi-natural areas ☐
- Wetlands ☐

Financial costs (Capital, operation & maintenance)

Low-till systems require special machinery for practices such as sowing, discing and harrowing. Contractor charges (capital and labour) range between 32 and 67€/ha. Different practices require different labour inputs, ranged between €23 to 254/ha.

Scale

Low-till agriculture is applicable at field scale.

Design

Low-till can be **combined with other agricultural measures** such as green cover/cover crops, mulching, controlled traffic farming. Controlled traffic farming is especially relevant as it can help to avoid problems of soil compaction due to machinery movements, particularly on the wetter soils typical of northern Europe. However, the presence of crop or mulch residues may reduce the effectiveness of reduced tillage for water infiltration.

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A7 - Low-till agriculture

Potential biophysical effects

Runoff	Medium
Reducing pollution	Low
Soil conservation	High
Habitat	None
Climate Change	None

Ecosystem services delivered

Provisioning	Low
Regulation & maintenance	Medium
Cultural	None
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	Medium
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Low

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Evidence of the impact of low-till agriculture appears to be mixed, either reducing runoff (by 32% in Hungary) or not (Spain). Catchment level promotion of low-till can contribute to mitigating flood risks, in combination with other measures.

The impact of low-till on reducing pollutant sources seems low. Regarding **erosion and sediment delivery**, reduced tillage shows positive impacts if combined with catch crops (12 to 84% reduction in erosion susceptibility). Reduced tillage may thus contribute to improving and preserving water status of hydro-morphological quality elements.

Impacts of low-till on soil are variable: low-till can lead to a 12% increase of soil organic matter in the upper layer only, and 9% increase in bulk density at 0.15-0.30m depth. According to some studies, **infiltration potential** is higher for conservation tillage than for conventional tillage in silty soils but lower in sandy loam soils. Others show that increased bulk density offsets the effects of increased macro-porosity on infiltration.

Reduced tillage does not contribute significantly to climate change adaptation and mitigation. Combined with other measures, it can contribute to sustainable agriculture but its impacts are linked to soil type and climate.

High *Medium* *Low* *None*

A8 - Green cover

Green cover (including cover crops or catch crops) refers to crops sown on arable land, to **protect the soil** which would otherwise lie bare during the **winter**, against wind and water erosion. Green cover can be inter-sown with the primary (harvested) crop or after it is harvested. Green cover is not harvested but is plowed back into the soil. It contributes to improving the structure of the soil, diversify the cropping system, and mitigate the loss of soluble nutrients.

Land surface relevant for application

Artificial surface	○
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	○

Green cover can be implemented on any field and under forest.

Financial costs (Capital, operation & maintenance)

Seeds cost is the most important in implementing green cover and reaches €18 and 36€/ha. Plantation and destruction also create costs. Total capital cost ranges between €40 and 140/ha, including crushing, stubble ploughing and rolling, and maintenance cost between €52 and 63/ha.

Scale

Green cover is applicable at field scale.

Design

Green cover can be introduced in crop rotations or as part of strip cropping. Combinations of measures related to **soil conservation practices** will enable water quality status improvement and flood risk reduction. Green cover should be **early sown** in order to benefit from water and sun (this may be limitation in northern countries), be composed by species adapted to needs, such as legumes, and have sowing density adapted to yield objectives.

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Case studies: Holter-Hammrich area - flood protection, nature conservation, Germany; Cover crops and no-tillage in an Olive Grove, Spain

A8 - Green cover

Potential biophysical effects	
Runoff	High
Reducing pollution	High
Soil conservation	High
Habitat	Low
Climate Change	Medium

Ecosystem services delivered	
Provisioning	Medium
Regulation & maintenance	High
Cultural	None
Abiotic	None

Contribution to policy objectives	
Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	Low
2020 Biodiversity Strategy	High

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Green cover usually **increases evapotranspiration and infiltration** compared to bare soil, which results in **runoff reduction** (up to 80% or 50mm). In some cases it can reduce evapotranspiration, thus increase soil water retention, which enhances groundwater recharge. By slowing and reducing runoff, green cover contributes to reduced flood risks, decreased erosion (up to 50%) and sediments loss (up to 4.2%). Associated with no tillage, it results in between 12 and 46% of **water savings**.
Through uptake from the soil, green cover reduces **pollutant leftovers** (by 10 to 46kgN/ha) and concentration in drainage water (by 23 to 85% for NO3-). Thus it contributes to preventing surface water deterioration by reducing both pollutant leaching and sediments loss. Enhanced groundwater recharge may help to maintain good groundwater status. Green cover can catch 300kgC/ha, up to 0.38tN/ha (catch crops) and make nutrients available, improving **soil fertility**. Through taking up carbon, green cover plays a role on climate change mitigation.
Green cover provides **habitats** and enables maintaining good conditions for further cropping thus contributing to sustainable agriculture. Finally, it may have a positive impact on the **yield** of following crops (+1 to +75% for legume cover).

High Medium Low None

A9 - Early sowing

Early sowing refers to sowing up to 6 weeks **before the normal sowing season**. This allows for an earlier and quicker establishment of winter crops that can provide cover over winter and of a root network that leads to soil protection. The period in which the soil lies bare is shorter and, therefore, erosion and runoff are less significant and water infiltration is improved. Early sowing can also help to mitigate summer drought impacts on spring sown crops, like the extreme evapotranspiration rates of Mediterranean regions. However, it may require specific cultivation techniques and cannot be applied for all crops.

Land surface relevant for application

- ☐ Artificial surface
- ☑ Agriculture land
- ☐ Forest and semi-natural areas
- ☐ Wetlands

Financial costs (Capital, operation & maintenance)

The measure in itself does **not incur costs**. But there may be capital or maintenance costs associated with changes in tillage and other practices that are used to implement early sowing. Early sowing can be associated with different pest and disease risks which may require different management to conventional practices, but might not incur additional costs. It may also help to spread on-farm workload.

Scale

This measure acts at the field level and operations at larger scales such as whole farms may be constrained by crop rotations.

Design

Early sowing of spring crops requires an appropriate seedbed. This might require the use of **reduced tillage** methods such as direct drilling. In northern countries where soils may be saturated, the use of early sowing in combination with methods including reduced or no-tillage and controlled traffic farming may be desirable to avoid soil compaction.

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A9 - Early sowing

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

Early sowing can increase the level of **vegetation cover** up to 25%. The impacts of early sowing on evapostranspiration and soil water retention are likely to be similar to those for green cover: more soil coverage might reduce runoff, increase soil water retention and enhance water storage. Runoff reduction and enhanced infiltration can significantly contribute to groundwater recharge, flood risk reduction and **erosion control** (up to 50%). Early sowing also contributes to **filtering pollutants** by taking up residual nutrients. Through reducing sediment loss and nitrate leaching, it thereby contributes to improving the hydromorphology status of surface water, and preventing status deterioration.

Early sowing provides a better protection for ecosystems and habitat for fauna. Reduced nitrate leaching and reduced soil erosion make agriculture more sustainable. Early sowing also contributes to **absorbing CO2**; increased carbon sequestration in the soil plays a role in climate change adaptation and mitigation.

Finally, early sowing can increase yields: trials led to 1% to 100% increase.

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High Medium Low None

A10 - Traditional terracing

Traditional terraces consist of nearly **level platforms** built along contour lines of slopes, mostly sustained by stone walls, used for farming on hilly terrain. By reducing the effective slope of land, terracing can reduce erosion and surface runoff by slowing rainwater to a non-erosive velocity. This helps to increase soil depth and in turn also increases the degree of infiltration and improves soil moisture. This measure focuses on maintaining existing or traditional terracing, which involve less disturbance of the terrain than modern terracing.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☑
- Forest and semi-natural areas ☐
- Wetlands ☐

Financial costs (Capital, operation & maintenance)

The measure relates to existing structures; however the construction cost for new terracing using heavy machinery would be €893/ha/yr. Maintaining existing terracing costs about €200/ha/yr.

Scale

This measure is applied at field level, over hillsides limiting the upstream drainage area.

Design

Traditional terracing can be applied across a **wide range of slopes**: terraced based olive production in the Mediterranean occurs on moderate (>15%) to steep (>25%) slopes. The measure can be used in conjunction with others measures that reduce soil erosion risk such as reduced/zero tillage and cover crops.

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Case studies: Traditional terracing in Veneto, Italy, Water retention spaces, reforestation and grazing management in southern Portugal

A10 - Traditional terracing

Potential biophysical effects

Runoff
Reducing pollution
Soil conservation
Habitat
Climate Change

Ecosystem services delivered

Provisioning
Regulation & maintenance
Cultural
Abiotic

Contribution to policy objectives

Water Framework Directive
Floods Directive
Birds & Habitats Directive
2020 Biodiversity Strategy

Studies in Canada show that traditional terracing can **reduce runoff** by 25% of growing season rainfall; tests in Italy resulted in an increase of runoff storage by 50%. These impacts contribute to reducing flood risk in areas of high slopes. The reduction in runoff and greater infiltration rates also indicate a benefit for the filtration of pollutants. Traditional terracing has a significant impact on **controlling erosion and sediment** loss. Thanks to maintenance of the existing terrace walls, soil loss reduction can reach 19t/ha/yr (Canada) to 61.6t/ha/yr (Malaysia), which is more than 95% in both cases. Traditional terracing thus contributes to improving the hydromorphology status of surface water, and preventing status deterioration by reducing consequent sediment delivery.
Traditional terracing provides a better protection for ecosystems and makes agriculture more sustainable by maintaining soil cover of slopes and reducing impacts from runoff. Preservation of traditional terracing can protect the established biodiversity associated with that system.
Traditional terracing finally contributes to the cultural **heritage and landscape** character of some areas. Abandonment and subsequent disrepair is the main risk to this measure. This may also result in homogenisation of these landscapes.

High Medium Low None

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A11 - Controlled traffic farming

Controlled traffic farming (CTF) is a system which **confines all machinery loads** to the least possible area of permanent traffic lanes. CTF system can reduce tracking to 15% instead of 75% of the area, always in the same place. The permanent traffic lanes may be cropped or non-cropped depending on a wide range of variables and local constraints. It can be used in both arable and pasture systems. CTF enables slowing of runoff on fields and prevents soil deterioration.

Land surface relevant for application

- Artificial surface ○
- Agriculture land ✓
- Forest and semi-natural areas ○
- Wetlands ○

Financial costs (Capital, operation & maintenance)

The cost of changing to CTF based on a 3m track gauge for all equipment is about €22.8/ha but CTF leads to **machinery cost savings** of about €213.6/ha. The overall reduction cost reaches €51.60/ha. A 6m tractor-based non plough CTF system is less profitable than conventional plough based practice on medium soil (21.6€/ha) but more profitable on heavy soil (30€/ha).


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Scale

CTF system is applicable at field and farm scale

Design

Traffic lanes should correspond to 15% of the field. Bare tramlines' width varies from one missing 18cm row to two missing 30cm rows; fuzzy tramline can be used when weed competition is a concern and sown tramlines when soil throw is needed for herbicide incorporation. Design should consider the most efficient direction for the in-paddock operation and water movement, the most convenient access for loading and unloading and take care with areas prone to being wet.

A11 - Controlled traffic farming

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

The main contribution of CTF to policy objectives concerns flood risks reduction. CTF reduces the area of permanent traffic lanes, thus **limitating compaction**. This results in enhanced infiltration (between 84 and 400% according to literature), and increased hydraulic resistance, which slows runoff. Compaction mitigation permitted by CTF can thereby decrease the risk of flooding; it also contributes to erosion and sediment control.
Compaction enhances nutrient losses through inhibiting uptake by crops and facilitating leaching and denitrification. By enabling improved soil structure, increased infiltration and water storage, CTF **enhances the uptake** of nutrients by crops thus decreases nutrient losses (between 1.5 and 15.55 kg/ha for N, 0.42 to 4.20 kg/ha for P). Through this mechanism and by decreasing erosion, CTF contributes to preventing surface water deterioration.
Soil conservation helps maintaining good conditions for further agriculture; thus it helps to make agriculture more sustainable.
Yields under CTF appear to increase by about 4% (+8% on non trafficked beds and decrease on traffic lanes).

High Medium Low None

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A12 - Reduced stocking density

Livestock, particularly heavy species such as cattle, can have damaging impacts on soil: compaction, destruction of soil structure and loss of vegetation. These can reduce infiltration, resulting in pooling and water logging with impacts of denitrification. Soil compaction also increases the risk of runoff with consequent impacts on water quality and flood risks. Reduced stocking density will **limit soil** compaction, thereby facilitating more rapid infiltration during precipitation events and potentially reducing peak flows and sediment runoff.

Land surface relevant for application

- ☐ Artificial surface
- ☑ Agriculture land
- ☐ Forest and semi-natural areas
- ☐ Wetlands

Financial costs (Capital, operation & maintenance)

The measure does not imply direct capital or maintenance costs. But if reductions in stocking density are offset by increased housing then costs may be incurred. For cattle capital costs might range from €860 to €2500 per head for a straw bedded solid floor house.

Scale

This measure operates at field/farm scale.

Design

Reduced livestock density can be combined with measures on Meadows and Pastures and Controlled traffic farming (to reduce soil compaction on pastures).

© SRUC

A12 - Reduced stocking density

Potential biophysical effects

Runoff
Reducing pollution
Soil conservation
Habitat
Climate Change

Ecosystem services delivered

Provisioning
Regulation & maintenance
Cultural
Abiotic

Contribution to policy objectives

Water Framework Directive
Floods Directive
Birds & Habitats Directive
2020 Biodiversity Strategy

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Potential improvements in soil physical properties (compaction, bulk density) resulting from reduced livestock numbers can lead to **decrease runoff rates** through both reduced surface flow (-50%) and greater infiltration (+400%). Catchment level changes in livestock management together with other measures would thus contribute to flood risk reduction. Increased vegetation cover and improved soil structure would result in smaller areas of bare soil; this would reduce the risk of **erosion** and consequent sediment delivery, thus improving the hydromorphology status of surface water and providing better protection for ecosystems.

Reduced stocking densities would directly reduce the output from fields but that might be offset at the broader farm level through increased use of housing. **Pollutants loads** at the field scale may be both reduced by lower livestock numbers and increased filtration due to greater vegetation and infiltration. This contributes to preventing water status deterioration.

Reduced stocking density can improve sustainability particularly with respect to **soil quality.** However, if the viability of livestock production in marginal areas is reduced there may be a risk of **land abandonment** with negative environmental impacts, such as risks to traditional biodiversity.

High Medium Low None

A13 - Mulching

A mulch is a **layer of material** applied to the surface of an area of soil in order either to conserve moisture, improve the fertility and health of the soil, reduce weed growth or enhance the visual appeal of the area. Mulching as NWRM uses organic material (bark, wood chips, grape pulp, shell nuts, green waste, leftover crops, compost, manure, straw, dry grass, leaves etc.). When applied correctly it can dramatically improve the capacity of soil to store water.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☑
- Forest and semi-natural areas ☐
- Wetlands ☐

Financial costs (Capital, operation & maintenance)

Mulch cost can vary between €0.05 and 0.15/m2 depending on thickness, mulch type and percentage of soil cover.

Scale

This measure operates at field scale.

Design

Mulch is put on the soil just before plantation, after preparing the soil. The soil must be clean and prepared as for conventional cultivation. In France, between 50 and 300 m^3/ha of mulch is applied on fields. Mulch is often used on soils with low organic matter rates and combined with other soil conservation practices such as no till.

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A13 - Mulching

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

Mulching is one of the measures that can be taken on agricultural fields and areas to reduce flood risks. Under dry conditions, mulching can **slow surface runoff** and runoff at the plot outlet, which appears to be delayed as mulching rate increases. Soil water retention increases for high mulching rates compared to bare soil, which also contributes to reducing runoff. Reducing and slowing down runoff finally contribute to decreasing flood risk.

Tests show that sediment concentration in runoff can be 15 times lower under high mulching rate than on bare soils. The erosive response of soil under simulation quickly decreases with time after prolonged storms (30 min) due to the exhaustion of available erodible particles. That may help to control **erosion and sediments delivery.**

By increasing water infiltration in the soil, mulching contributes to increasing groundwater recharge thus improving groundwater quantitative status.

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High Medium Low None

Project funded by the EU – DG Environment

F1 - Forest riparian buffers

Riparian buffers are **tree covered areas alongside streams** and other water bodies. While most commonly associated with set-asides following forest harvest, riparian buffers can also be found in urban, agricultural and wetland areas. By preserving a relatively undisturbed area adjacent to open water, they can serve a number of functions related to water quality and flow moderation: taking up excess nutrients, increasing infiltration, slowing water and thus decreasing sediment inputs to surface waters.

Land surface relevant for application

Artificial surface	○
Agriculture land	○
Forest and semi-natural areas	✓
Wetlands	✓

Treed riparian buffers can also be created in agricultural or urban areas (see F5, F11, A2).

Financial costs (Capital, operation & maintenance)

Typically, land is not acquired for forest riparian buffers. The land occupied by the buffer is usually owned by the farmer or forest owner who manages the adjacent lands. The main cost associated with forest riparian buffers is the **foregone income** associated with land that cannot be harvested for forestry or agricultural purposes.

Scale

Riparian buffers are most effective at a small spatial scale and are typically applied in **headwater areas** (F2) where the local effects of sediment and nutrient retention are most pronounced.

Design

The space required for riparian buffers is proportional to the density of the **stream network** to be buffered and the width of the forest riparian buffer. Typically, the buffers have a **fixed width**, ranging from 2 to 20m. The effectiveness of a buffer is approximately proportional to its width. Forest riparian buffers can have synergies with in-stream or in-catchment measures, since they exist at the interface between terrestrial and aquatic environments.

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Case studies: Slowing the Flow at Pickering, UK; Dyke relocation on the river Elbe near Lenzen, Germany

F1 - Forest riparian buffers

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

Intact forests can have greater **water holding capacity** than cutover or non forest covered areas. Because of their rougher ground surface, they can **slow runoff** more effectively than bare ground. However, riparian forest buffers have a limited ability to store and slow terrestrial runoff due to their relatively small breadth.
When operating properly, forest riparian buffers can significantly reduce nitrogen leaching following forest clearcutting and have the potential to contribute to **denitrification** of runoff from adjacent agricultural areas. Well functioning forest riparian buffers can also intercept **pollutants** including sediments, particulate matter and phosphorus associated with overland flow events, preventing them from reaching streams. Forest riparian buffers are typically applied to water courses often much smaller than WFD water bodies, so do not have a direct effect on WFD quality status, but can potentially improve the water quality of streams feeding WFD water bodies.
Forest riparian buffers can play an important role in biodiversity preservation, both by direct provision of **riparian habitat** and by providing habitat "**corridors**". They contribute to the creation of **aquatic habitat** by moderating the stream temperature regime and by acting as a source of coarse woody debris. Riparian buffers can assist in preserving spawning habitat for some salmonid species.

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High Medium Low None

F2 - Maintenance of forest cover in headwater areas

Headwaters are **source areas** for rivers and streams. Forests in headwater areas can thus have a beneficial role for water quantity and quality. Indeed, forest soils generally have better **infiltration** capacity than other land cover types, acting as a "sponge", slowly releasing rainfall. In areas of high relief, afforestation of headwater catchments can contribute to slope stabilisation and may reduce the risks associated with landslides.

Land surface relevant for application

Artificial surface	
Agriculture land	
Forest and semi-natural areas	✓
Wetlands	✓

Targeted land use conversion through afforestation (F5) could transform artificial or agricultural surface to headwater forest catchments.

Financial costs (Capital, operation & maintenance)

Costs associated with afforestation of headwater catchments include the cost of tree **planting** and steps necessary to ensure seedling establishment. **Land acquisition** costs can range from nil to extremely high depending on whether the land is already owned by the state, and if it is not, what compensation is needed for expropriation.

Scale

Because of the fractal nature of rivers, headwater forests can have a beneficial effect at almost all spatial scales. Typically, any catchment smaller than 1km^2 is considered to be a headwater catchment.

Design

The creation or maintenance of headwater forest catchments is dependent on **large scale** land conversion or preservation. Typically, an area of several ha to tens of km2 must be afforested for there to be significant downstream benefits. The most beneficial headwater catchments for afforestation are likely to be those located **upstream of urban or peri-urban** areas where flood risk reduction or improvements in water quality are desired.

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F2 - Maintenance of forest cover in headwater areas

Potential biophysical effects

Runoff	High
Reducing pollution	Medium
Soil conservation	High
Habitat	High
Climate Change	High

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	High
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	Low
2020 Biodiversity Strategy	High

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Forests often have high rates of **evapotranspiration** and canopy **interception**. Thus, headwater forest areas are able to reduce the absolute volume of water which may eventually contribute to runoff. Moreover, **forest soils** are characterized by high porosity, high organic matter content, good infiltration capacity and high water holding ability, enabling precipitation to be delayed on its way to generating runoff and increasing infiltration and **groundwater recharge** rates. Therefore, headwater forest catchments can play an important role in **flood risk** reduction.

Forests are able to effectively retain atmospherically deposited **pollutants** such as nitrogen, as well as metals and organic pollutants, providing direct benefits for groundwater chemical status. Compared to bare soils, forest cover can significantly **reduce erosion** and sediment delivery, thus contributing to improving water and habitat quality in downstream water bodies.

Land conversion to afforest headwater catchments creates terrestrial forest **habitats**, which may have high biodiversity or recreational values, particularly when indigenous or local species are used. Streams in forests have the potential to support diverse biological communities. Moreover, growing forests are a significant source of natural biomass production. Depending on the rates of tree growth, headwater forest catchments can have the ability to absorb or retain CO^2, thus offering significant **climate change** mitigation possibilities.

High Medium Low None

F3 - Afforestation of reservoir catchments

Afforestation of previously bare or heavily eroded areas in reservoir catchments can control soil erosion, thereby extending the life of the reservoir and improving water quality. Water quality can also be improved if precipitation is able to **infiltrate** into forest soils before flowing to the reservoir. However less precipitation may be available for reservoir recharge due to the potentially greater interception and evapotranspiration associated with forests.

Land surface relevant for application

- Artificial surface
- Agriculture land
- Forest and semi-natural areas ✓
- Wetlands

Afforestation of artificial or agricultural surfaces is a form of land use conversion (F5).

Financial costs (Capital, operation & maintenance)

Typically, the responsible authority owns much of the catchment thus **land acquisition** costs may be relatively minor. If not, acquisition costs may be considerable and other mechanisms such as easements or landowner **agreements** should be considered. The capital costs of afforestation can be lower than the cost of other approaches to controlling water quality in drinking water.

Scale

Reservoirs are typically located in **mesoscale** catchments so as to have sufficient contributing area for precipitation capture. However, the benefits are largely scale independent.

Design

Generally **as much of the reservoir** catchment as possible should be afforested such that protection can be maximized without undue reduction in reservoir inputs due to higher evapotranspiration from forest cover. The **riparian** areas should be prioritized. Afforestation of more steeply sloping areas is likely to result in greater benefits related to sediment retention.

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F3 - Afforestation of reservoir catchments

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

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Afforestation of reservoir catchments can be part of a program to reduce flood risks. Forests are able to return a significant fraction of precipitation to the atmosphere through **evapotranspiration** and forest soils can **slow the transit** of water, reducing the height of the flood peak flows (depending on the wetness of the soils and the depth of water in the reservoir). Increased infiltration can contribute to groundwater recharge.

Forests can **intercept** atmospheric pollutants and have the potential to reduce downstream concentrations of heavy metals, nutrients and organic pollutants (reservoirs also enable photodegradation). This can contribute to improved **water quality** in the reservoir and indirectly in downstream water bodies. Forests and reservoirs are also efficient at retaining sediment.

Increased vegetation growth contributes to **carbon sequestration**, and reservoirs themselves can provide sedimentation of dissolved organic carbon. The measure can thus contribute to climate change adaptation; however, the standing biomass in reservoir catchment forests should not be harvested by large scale clear cut methods so as to avoid negative impacts on reservoir water quality (See Continuous Cover Forestry measure, F6).

Afforestation using **endemic or indigenous** species will create terrestrial habitat, providing significant contribution to biodiversity preservation and potential for natural biomass production. Forests are also widely prized for their amenity and recreational value.

High Medium Low None

F4 - Targeted planting for 'catching' precipitation

In the Mediterranean basin, land use change and deforestation may have led to changes from an open monsoon-type regime with frequent summer storms over inland mountains, to a regime dominated by closed vertical atmospheric recirculation, where feedback mechanisms suppress storms over the coastal mountains and lead to increased summer time sea surface warming. This warming leads to **torrential rains** in autumn and winter. Targeted afforestation in some parts of the Mediterranean may be one means of **combating drought and desertification**.

Land surface relevant for application

- Artificial surface ○
- Agriculture land ○
- Forest and semi-natural areas ✓
- Wetlands ○

Targeted afforestation of artificial or agricultural areas may create forests for catching precipitation.

Financial costs (Capital, operation & maintenance)

Given the large area required for afforestation, land acquisition does not seem a reasonable option due to the undoubtedly great expense. Better solutions would involve changes to **subsidies** or other **support systems** to encourage afforestation of the appropriate areas.

Scale

The evidence from modelling studies suggests that targeted planting to affect precipitation patterns in the Mediterranean basin only works when applied at a **very large** spatial scale.

Design

The hypothesized changes in precipitation regime which would be addressed by this measure were caused by large scale deforestation and drainage in regions bordering the **Mediterranean**. The available evidence to date suggests that this measure is only applicable in the Mediterranean basin.

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Case studies: *Reforestation in Veneto, Italy; Water retention spaces and reforestation in southern Portugal*

F4 - Targeted planting for 'catching' precipitation

Potential biophysical effects

Runoff	Medium
Reducing pollution	None
Soil conservation	Medium
Habitat	None
Climate Change	High

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	None
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Low
Floods Directive	None
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Low

The overall goal of this measure is to restore and **enhance regional precipitation** by altering regional weather patterns. Trees are able to increase evapotranspiration rates above levels possible from bare ground. If successful, this measure will contribute to **climate change mitigation.** An increase in summer rainfall events will contribute to groundwater and aquifer recharge, potentially improving the quantitative status of groundwaters. Tree cover can also **improve soil structure** through increased accumulation of organic matter and improvements to soil permeability, leading to greater infiltration and increased soil water retention.

Afforestation has the potential to **reduce erosion** and sediment delivery (through root networks) and to reduce the energy of precipitation reaching the soil surface, thereby reducing the rate at which sediments are detached from parent materials and made available for transport.

Targeted tree planting has a high potential for natural **biomass production**, which should be used as part of a strategy for **carbon sequestration**. It also has the potential to preserve or improve biodiversity by providing habitat types used by endemic species. Furthermore, wetter summers may leave vegetation in the region less susceptible to **fire**, which will also contribute to prevention of biodiversity loss.

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High *Medium* *Low* *None*

F5 - Land use conversion

Land use conversion is a general term for large scale geographic change. Afforestation is one such land conversion in which trees are planted on **previously non forested** areas. It may occur deliberately or through the abandonment of marginal agricultural land. Planting indigenous broadleaves and low intensity forestry may lead to benefits such as enhanced evapotranspiration.

Land surface relevant for application

Artificial surface	✓
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	

Financial costs (Capital, operation & maintenance)

Capital costs will depend on the method used for afforestation (natural succession or plantation). Depending on the manner in which the forest is used, there may be **maintenance costs** for example associated with trails and public access points. Key additional costs relate to land acquisition or compensation for the foregone income associated with land use prior to afforestation.

Scale

Land use conversion can be applied at **all spatial scales**. The larger the afforested area is, the greater the benefits will be observed.

Design

Land use conversion through afforestation is probably most beneficial in areas of marginal agricultural land, areas with **steep slopes** and significant erosion or landslide risk and near **urban** areas. The benefits of increased infiltration and improvements to water quality are likely to be greatest in **headwater areas**.

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Case studies: Habitat Reconstruction in the forests of the Körös Valley, Hungary

F5 - Land use conversion

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

The high rates of **evapotranspiration** from growing forests can dry out soils, providing more infiltration and **storage capacity**. Forests provide organic carbon to the soil, leading to both higher water holding capacity and greater infiltration capacity. Forest soils also have higher hydraulic resistance. As a result, forests tend to **reduce peak flows** by retaining water from landscape-scale runoff, returning water to the atmosphere and moderating rates of snowmelt.

The **organic matter** in forest soils can retain metals, persistent organic pollutants and mercury. Forests also play an important role in intercepting atmospheric nitrogen and in supporting biological and abiological processes. Land use conversion can thus contribute to improvements both in **groundwater** quantitative and chemical status.

Forests play an important role in **slope stabilisation** and in controlling erosion and sediment transport. They have a high potential to create valuable terrestrial **habitat**, especially if native or indigenous tree species are used, and to provide natural biomass. Forest cover contributes to reducing peak temperature by intercepting radiation in the canopy. Growing forests have the potential to retain CO^2 both in growing biomass and in organic matter in the soil, and thus have significant **climate change mitigation potential**. Forests may also offer important recreational and cultural opportunities, as well as aesthetic value.

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High Medium Low None

F6 - Continuous cover forestry

Continuous cover forestry (CCF) includes a broad range of forest management practices targeting the **reduction in the number or size of clear-cuts,** which may have some beneficial hydrological effects. Continuous cover forestry ensures that there is an uninterrupted tree canopy, which will have higher interception than a site with discontinuous tree cover, and that the soil surface is never exposed, which will limit sediment production.

Land surface relevant for application

- [ ] Artificial surface
- [ ] Agriculture land
- [x] Forest and semi-natural areas
- [ ] Wetlands

The measure is not relevant for other semi-natural areas besides forests.

Financial costs (Capital, operation & maintenance)

If **new machines** must be purchased for CCF, it will constitute a cost for the forest owner or manager. The ongoing maintenance costs associated with CCF should be similar to those incurred with conventional forestry, except for logging costs, which may be higher. CCF provides a more continuous income, which may or may not be beneficial depending on the remaining time between the conversion to CCF and the originally planned final logging.

Scale

The measure can be applied at a **local scale** (less than 10 km^2) where the effects will be most apparent.

Design

To achieve maximum benefits, continuous cover forestry should be practiced on a **large spatial scale** and combined with other measures designed to promote biodiversity in the forest landscape.

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F6 - Continuous cover forestry

Potential biophysical effects

Runoff	Medium
Reducing pollution	Medium
Soil conservation	Medium
Habitat	Low
Climate Change	Medium

Ecosystem services delivered

Provisioning	Medium
Regulation & maintenance	High
Cultural	Medium
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	Low
Birds & Habitats Directive	Medium
2020 Biodiversity Strategy	High

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CCF has the potential to increase **runoff storage** on a landscape scale since it avoids the reductions in evapotranspiration and canopy interception associated with clearcutting. CCF may provide ecosystem service benefits associated with water storage and retention and reduce local flooding.

Intact forest canopy may be more efficient at **intercepting pollutants** and under some circumstances at reducing leakage of **mercury**, which is hypothetically related to higher water tables associated with a reduction in evapotranspiration following clearcutting. Continuous growing forest may prevent **nitrogen** leaching to groundwater by taking it up from the soil and atmosphere, which can improve groundwater chemical status. CCF will also reduce local sediment releases associated with clearcutting. The effect may be apparent in large downstream rivers.

CCF may have positive **greenhouse gas benefits** through reduced physical disturbance of the soil, cooler soil temperatures resulting in lower rates of carbon mineralisation and drier soils facilitating reduced leaching of organic carbon. If continuous cover forestry has mixed age stands, biodiversity benefits should be realized. The benefits of CCF for **habitat protection** will be greater than the possible habitat benefits of even age conifer monocultures.

CCF should also provide more **recreational** opportunities and have greater aesthetic and cultural value than single species monocultures.

High Medium Low None

F7 - 'Water sensitive' driving

Off road driving has potentially severe negative consequences for water quality, through rutting and enhanced erosion. Some damages can be minimized or mitigated if drivers exercise a few simple precautions. **Avoiding driving in wet areas** whenever possible will limit soil compaction and rutting. In colder regions of Europe, driving on frozen soils will reduce the potential for compaction and damage. Driving **parallel to contour lines** of hill slopes will reduce the potential for rut formation and concentration of flow paths.

Land surface relevant for application

Artificial surface	○
Agriculture land	○
Forest and semi-natural areas	✓
Wetlands	✓

Water sensitive driving in agricultural areas may be related to "A11 Controlled Traffic Farming".

Financial costs (Capital, operation & maintenance)

There can be increased capital costs for retrofitting forest harvesting **equipment** with GPS systems to link with computerised maps of areas where driving damage is likely, or for modifying equipment by the addition of extra wheels or tracks so as to reduce the amount machinery compresses soils. Success of this measure requires also additional planning.

© DNR

Scale

Water sensitive driving has extremely local effects. However, the benefits associated with water sensitive driving can be seen at larger spatial scales.

Design

Typically, this measure in its easiest form will be most effective in relatively **flat areas** where water tends to accumulate in the forest landscape, and on **wet soils** and in areas where groundwater is close to the surface. However mountainous areas require specific attention regarding erosion control. Compared to conventional forest harvesting, greater care must be taken to identify wet or fragile soils and to plan harvest roads and tracks.

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F7 - 'Water sensitive' driving

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

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One of the main concerns about ruts and wheel tracks produced when driving heavy forest machinery on sensitive soils is the potential for methylation and mobilization of **mercury.** By preventing it, water sensitive driving contributes to improving the chemical status of priority substances. Since methylmercury bioaccumulates in aquatic food webs, the measure also contributes to better management of **fish stocks**. Through preventing the concentration of flows in ruts, it contributes to erosion and sediment control during forestry operations, which also impacts on survival of aquatic organisms.

Water sensitive driving is a **preventative** measure, which when performed properly can prevent water status deterioration. It is likely to have a low to moderate effect on achievement of WFD policy objectives, largely because of the size **mismatch between the scale** of damage associated with inadequate care to water and the size of WFD water bodies.

Driving in a manner which does not produce rutting will also help to maintain the **natural hydrologic** behaviour of the forest, the natural infiltration, recharge and soil water retention properties of forest soils.

Poorly planned and executed driving on wet or fragile soils can leave **unattractive scars** on the landscape which can take many years to recover. Thereby, water sensitive driving has a positive effect on aesthetic value of forests.

High Medium Low None

F8 - Appropriate design of roads and stream crossings

Forest access roads and other roads in rural areas often cross streams and other small watercourses. The bridges or culverts used to cross these watercourses must be **designed appropriately** if negative impacts on the aquatic environment (such as increased sediment mobilisation and changes in flow patterns, flooding upstream of the road crossing leading to downstream sediment pollution) are to be minimised.

Land surface relevant for application

Artificial surface	
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	

Financial costs (Capital, operation & maintenance)

Implementing this measure may incur **greater capital costs** than would be incurred if it were not followed. Forest roads may need to be longer to avoid excessive slopes and to follow the contours of the landscape; stream crossings may be more expensive as they will need to be larger and more robust than a minimalist approach. However it may result in lower maintenance costs and avoidance of costs associated with compliance failure. Field studies are required.

Scale

The beneficial effects of properly designed stream crossings will be most apparent at a small spatial scale but can have beneficial effects on downstream rivers.

Design

Ideally, the road should be designed so as to **minimise slope** and should be built on the most **stable** locations. Soft and fragile soils and areas where groundwater is close to the soil surface should be avoided. This measure can be performed in combination with water sensitive driving (F7) so as to minimize the impact of driving on water quality in the forest landscape.

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F8 - Appropriate design of roads and stream crossings

Potential biophysical effects

Runoff	None
Reducing pollution	Medium
Soil conservation	High
Habitat	High
Climate Change	None

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	None
Abiotic	Low

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	Medium
Birds & Habitats Directive	Medium
2020 Biodiversity Strategy	Medium

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When roads and stream crossings in the forest landscape are designed, built and maintained in the correct manner, they have a high potential to **reduce erosion** and control sediment transport, particularly when unpaved roads are planned to run along contour lines instead of up and down hillslopes. This prevents sediment in runoff from smothering fish spawning beds and habitat of red list species such as freshwater pearl mussel and can help to **preserve fish stocks.** It can also help to maintain corridors for aquatic mammals such as otter and beaver, ensuring aquatic **habitat connectivity**: properly designed stream crossings do not create aquatic habitat *per se* but instead prevent its destruction. Properly designed road and stream crossings also have the potential to reduce mobilisation of sediment-associated pollutants including phosphorus. The measure has a high potential for preventing **surface water status** deterioration, protecting both biological and chemical quality elements.

Appropriately designed stream crossings can contribute to a reduction in flood risk. Poorly designed crossings which constrict high flows can lead to **localised flooding** upstream of the stream crossing.

In the case of larger streams and small rivers, it is possible that poorly designed stream crossings could impede navigation. They can also be dangerous for recreational watercrafts.

High *Medium* *Low* *None*

F9 - Sediment capture ponds

Sediment capture ponds are **engineered ponds** placed in networks of forest ditches to slow the velocity of water and allow the deposition of suspended materials. They can also be implemented in other areas. Sediment capture ponds are most useful for managing the effects of ditch construction and maintenance, road work and final felling.

Land surface relevant for application

Artificial surface	✓
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	

Sediment capture can also be used downstream of managed wetlands.

Financial costs (Capital, operation & maintenance)

There will be **slightly higher costs** associated with creation of ditch networks when sediment capture ponds are present, as the volume of material excavated will be slightly larger than it would be if no ponds were created. Maintenance costs are associated with dredging of sediment capture ponds.

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Scale

The dense network of forest ditches in which sediment capture ponds are typically placed means that each pond drains a relatively small area.

Design

Sediment capture ponds are generally **small scale** (10s of metres). This measure is most suitable for managed forests in **northern and central Europe** for which productivity is improved if water can be removed from the landscape. Sediment capture ponds can be combined with other forest measures including riparian buffers, continuous cover forestry, peak flow control structures and overland flow areas.

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Case studies: Rural runoff attenuation in the Belford catchment, UK; Sediment capture ponds in the Latvian State forests

F9 - Sediment capture ponds

Potential biophysical effects

Runoff	Medium
Reducing pollution	High
Soil conservation	High
Habitat	Low
Climate Change	None

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	None
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	Low
Birds & Habitats Directive	Low
2020 Biodiversity Strategy	High

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The primary purpose of sediment capture ponds is to reduce the potential for **surface water status** deterioration associated with forest management activities. By reducing one dimension of the **environmental footprint** of forestry, sediment capture ponds contribute to more sustainable land management.
Sediment capture ponds may have a limited ability to reduce bank erosion by slowing flow velocities but their primary focus is to **limit sediment delivery** by increasing deposition. That may have positive effects on spawning habitat for species such as freshwater pearl mussel.
Suspended sediment can be a major water pollutant in managed forests, as can phosphorus and heavy metals transported with suspended material. By slowing water velocities in forest ditches, sediment capture ponds can help to **reduce pollutant** sources and prevent pollutants from reaching receiving waters.
Because of their small size, sediment capture ponds have moderate water storage potential, but a **network of ponds** distributed across the landscape may have a significant ability to **store and slow runoff**, especially during dry conditions when the ponds are empty and have an ability to retain added precipitation. Therefore, multiple ponds spread throughout a forest may play an appreciable role in flood risk reduction.

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References & Learn more:
http://nwrm.eu/measures-catalogue

F10 - Coarse woody debris

Coarse woody debris consists of **large sections of deadfall**: tree stems or stumps that either fall into or are deliberately placed in streams. It can be deployed with varying degrees of naturalness. Coarse woody debris will generally **slow water flow velocity** and can reduce the peak of flood hydrographs downstream. It can also improve **aquatic biodiversity** by providing additional habitat.

Land surface relevant for application

- Artificial surface ○
- Agriculture land ○
- Forest and semi-natural areas ✓
- Wetlands ○

Financial costs (Capital, operation & maintenance)

Literature mentions total costs associated with coarse woody debris implementation : between k€1,5 and k€7.

Scale

Coarse woody debris is most effective at moderating the flow regime of relatively small streams and rivers.

Design

Coarse woody debris can be a feature in any watercourse but will probably have the highest water retention and biodiversity benefits in **forest headwater streams**. Riparian forest buffers are a natural synergy for this measure: when the trees in the riparian area fall into the stream, they will immediately become coarse woody debris.

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Case studies: *Slowing the flow at Pickering, UK; Rural runoff attenuation in the Belford catchment, UK*

F10 - Coarse woody debris

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

Coarse woody debris will **slow the flow** of small streams and rivers, providing increased storage of water in stream channels. However, the storage benefits are limited, with the main benefit being the slowing of river water. As coarse woody debris reduces the height of **flood peaks** in smaller streams, it can reduce flow velocity across larger landscapes, thereby contributing to a reduction in downstream flood risk.

Coarse woody debris increases the structural complexity of stream channels. This creates additional **aquatic habitat** in rivers and lakes, which can be important for both fish and aquatic invertebrates. Coarse woody debris that is both in the water and on the banks can also improve **riparian** habitat by providing dead wood and additional habitat structure. Therefore it can be an important contributor to biodiversity preservation in small streams and has the potential to improve Water Framework Directive biological quality elements in downstream waterbodies (as it provides refugia in the small streams used by juvenile fish).

Improved habitat and greater biodiversity may improve angling opportunities, thereby contributing to enhanced **recreational** opportunities. Coarse woody debris could be problematic for navigation under some circumstances.

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High *Medium* *Low* *None*

F11 - Urban forest parks

Urban forest parks can deliver a broad range of **hydrology-related** and other **ecosystem services**. Forests in urban areas have great amenity value, can improve air quality, moderate local microclimates, improve urban biodiversity and contribute to climate change mitigation as well as having ancillary hydrological benefits. Forest soils often have greater infiltration capacity than other urban land covers and can be an important location for aquifer recharge.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land
- Forest and semi-natural areas
- Wetlands

Financial costs (Capital, operation & maintenance)

There is no evidence of specific costs associated to urban forest parks, which will vary widely depending on size and the context in which they are developed.

Scale

Typically, a forest is assumed to have an area of **at least 1ha.** However, smaller urban forest parks may be possible and will have locally similar benefits to larger parks.

Design

A network of urban forest areas will have higher recreational value than a single forest block. When new urban developments are being planned, consideration should be given to the possibility of creating urban forest parks. Urban forests have very similar functionality and benefits to urban trees and can have synergies with all other **urban measures.**

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Case studies: Kylmäojankorpi forested wetland, Vantaa, Finland ; River Tolka constructed wetland and enhancements, Ireland

F11 - Urban forest parks

Potential biophysical effects

Runoff	High
Reducing pollution	High
Soil conservation	High
Habitat	High
Climate Change	High

Ecosystem services delivered

Provisioning	Medium
Regulation & maintenance	High
Cultural	High
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	Low
Birds & Habitats Directive	Medium
2020 Biodiversity Strategy	High

The soils under urban forest parks will have a higher ability to **increase infiltration** and groundwater recharge than impermeable urban surfaces; higher porosity and more textured soil surfaces lead to slower flow rates and potentially less overland flow. Associated with higher organic matter content, this contributes to increased soil water retention and helps to resist erosion. Forests generally have greater **evapotranspiration and interception** rates than other vegetation types. In wet or temperate areas, this can reduce the amount of water entering drainage networks. The intensity of precipitation reaching the ground is reduced, thereby reducing sediment delivery.

Many **atmospherically** deposited pollutants including nitrogen and heavy metals are intercepted by growing forests and retained in forest soils. Forest soils also have an ability to reduce aquatic pollutant sources. Urban forests reflect much of the incoming solar energy and reduce the amount of ground level warming. Trees are typically not harvested, resulting in a greater long-term **CO^2 sequestration** potential. Urban forest parks have a high potential to create **habitat** for plants and animals. If they are created using native or indigenous species, there can be significant biodiversity benefits.

The **recreational opportunities** afforded by urban forest parks are one of their most important ecosystem service benefits. Moreover, the iconic forest parks in European cities are important components of regional **cultural identity** and the presence of trees can provide a valuable counterpoint to built up areas

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High Medium Low None

F12 - Trees in urban areas

Trees in urban areas can have **multiple benefits** related to aesthetics, microclimate regulation and urban hydrology. They can also be important biodiversity refugia and can contribute to reducing particulate air pollution. Trees intercept precipitation, and the area around urban trees may also have greater infiltration capacity than the impermeable surfaces often found in urban areas: both of these reduce the amount of rainfall which must be processed by sewers and other water transporting infrastructure.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land
- Forest and semi-natural areas
- Wetlands

Financial costs (Capital, operation & maintenance)

The capital costs of trees will depend on the **age** at which they are planted, with older, larger trees being more expensive than younger, smaller trees. The costs of pruning and maintaining trees need to be considered when planning trees in urban areas. In dry or drought prone areas, this measure may incur additional costs associated with **irrigation.**

Scale

The measure can be implemented at a very local scale (less than 0,1km^2).

Design

Urban trees are typically located in **parks** and **along roadways**. The space required for urban trees will depend on their crown size and root network. While crown size can be managed through pruning, the root network of urban trees is potentially extensive and may cause damage to existing underground infrastructure, especially leaky sewers which trees may tap for water and nutrients. Trees in urban areas have synergies with urban forests and other urban measures.

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F12 - Trees in urban areas

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

Trees in urban areas will increase **evapotranspiration**, which can reduce the amount of runoff entering storm drains and can increase the water holding capacity of the soil. Because the area around urban trees is often permeable, they provide a **localised** (although limited) potential to store runoff. The effects on flood risk reduction may be noticeable when **summed** across all the trees in an urban area. Under some circumstances, trees in urban areas can increase infiltration and enhance groundwater recharge.
Trees in urban areas are able to **intercept particulate air pollution**. This can result in improvements in air quality and the health of urban populations. Trees in urban areas can contribute to reductions in water pollution by intercepting and retaining nutrients including nitrogen and phosphorus.
Trees in urban areas have high potential for **climate change adaptation and mitigation**. While individual trees do not sequester large amounts of carbon, when it is summed across a city, the effect can be considerable. Trees in urban areas can also limit peak temperatures at ground level by both shading and cooling (through transpiration).
Trees in urban areas have high potential to create **terrestrial habitat**. The effects on biodiversity preservation are apparent for bird species and there are probably benefits for insects and lichens.
Trees in urban areas can have high **aesthetic** value. They can be an important element of urban planning and design and can greatly improve the attractiveness of urban environments.

High Medium Low None

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F13 - Peak flow control structures in managed forests

Peak flow control structures are designed to reduce flow velocities in networks of forest ditches. Peak flow control structures are **engineered ponds** designed to limit the rate at which water flows out of a ditch network. Because the structures slow water flow, they will contribute to sediment control and can reduce the size of flood peaks. Peak flow control structures may have a limited lifespan as sediment will eventually fill in the upstream detention pond.

Land surface relevant for application

Artificial surface	○
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	○

The measure shares similarities with U10 (Detention Basins) and U11 (Retention Ponds) and may also be used in agricultural areas.

Financial costs (Capital, operation & maintenance)

Implementation costs are highly dependent on the material applied and the location. While wooden structures are cheaper and considered nature friendly, they have a limited life span. Their application requires interventions at source. Stone or concrete structures tend to be bigger with pronounced flood mitigation purposes.

Scale

Peak flow control structures are most effective in small headwater catchments but can also work in catchments of about 0.1 km².

Design

Peak-flow control structures require space. Their scale will depend on the flow and slope required in order to increase the morphological diversity of the watercourse.

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Case studies: Rural runoff attenuation in the Belford catchment, UK; Restoration of Durrow floodplain alluvial woodland, Ireland

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F13 - Peak flow control structures in managed forests

Potential biophysical effects

Runoff	High
Reducing pollution	High
Soil conservation	High
Habitat	Low
Climate Change	None

Ecosystem services delivered

Provisioning	Medium
Regulation & maintenance	High
Cultural	None
Abiotic	None

Contribution to policy objectives

Water Framework Directive	High
Floods Directive	Low
Birds & Habitats Directive	Low
2020 Biodiversity Strategy	Medium

Peak flow control structures have the potential to reduce **erosion** occurring in headwater areas and impacting downstream areas. They address WFD objectives through reducing the hydromorphological degradation (extensive gully formation) caused by the loss of capacity to mitigate run-off upstream. Capturing eroded soils is very effective at removing sediment bound **pollutants**. The prevention of sediment loss can contribute to the preservation of fish stocks and to maintaining spawning sites, albeit some structures can prevent fishes from passing. The size of peak flow control structures can be important; a row of smaller structures is likely to have greater benefits to habitat diversity.
Slowing down flood peaks has the potential to reduce downstream **flood risk**, although this effect will only be realised at the catchment scale if the measure is implemented on a wider scale.

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F14 - Overland flow areas in peatland forests

Overland flow areas are set aside to be used to **minimise the negative impacts** of forest management on **water quality**: they collect some of the excess sediment produced during ditch maintenance and other forest management operations. Overland flow areas are created by building a semi-permeable **dam** in a forest ditch and **lateral ditches** upstream of the dam (to transport water into the surrounding catchment). At periods of high flow, water will overflow the lateral ditches; its velocity will be slowed and much of the sediment will be deposited. At periods of low flows, the permeable dam will slow water flow and cause deposition of sediment.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☑
- Forest and semi-natural areas ☑
- Wetlands ☐

Existing wetlands may function as overland flow areas under some circumstances.

Financial costs (Capital, operation & maintenance)

Typically there are no costs of land acquisition for overland flow areas as they are situated in the forest itself. Other costs may be linked to investigations or studies to determine the likely amount and timing of runoff to be processed and the precautions needed to avoid any damage. There may be **opportunity costs** if the overland flow area is sited on productive forest land. Using an area for overland flows can influence the choice of tree species and temporary water cover can increase operation costs; that in turn may impact the income which could potentially be obtained from forest harvesting.

Scale

Overland flow areas are only suitable for application in relatively small areas such as those drained by a single ditch or small ditch network.

Design

Overland flow areas will typically be located within the ditch network of **managed boreal forests**. Their dimensions will be dependent on the size of the upstream catchment. Ideally, the space needed will not impact on productive forest areas. This measure can be part of a bundle of measures designed to minimize forestry impacts on water quality, including water sensitive driving, sediment capture ponds, appropriate design of roads and stream crossings and peak flow control structures.

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F14 - Overland flow areas in peatland forests

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

One of the primary purposes of overland flow areas is to **store runoff**. Storing runoff on land allows **sediments** to be deposited, which can help to prevent sediment pollution of downstream receiving waters. Slower water flowing over rougher environments (terrestrial vs. ditch) will also facilitate the deposition of suspended material. Sediment-related **pollutants** including phosphorus and heavy metals will be filtered out and deposited onto land. Preventing sediment inputs to receiving lakes and streams may help to preserve spawning or pearl mussel **habitat**. This would help to maintain fish stocks. Thereby, overland flow areas can help to prevent deterioration of surface water body WFD status and make forestry more **sustainable** as they can limit some negative impacts associated with sediment pollution.

There is a potential for overland flow areas to increase soil water retention and infiltration as they retain water on the landscape instead of routing it directly to ditches or streams. However, the effects are likely to be moderate as overland flows typically occur when soils are at their wettest. Peak flow control structures can have a moderate effect on water storage. Typically, the effect is quite local and short lived but it may be sufficient to mitigate some flood peaks during spring runoff. As such, overland flow areas can make a **limited contribution** to reducing flood risk.

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High Medium Low None

N1 - Basins and ponds

Detention basins and ponds are water bodies **storing surface run-off**. A detention basin is free from water in dry weather flow conditions, whereas a pond (e.g. retention pond, flood storage reservoir, shallow impoundment) contains water during dry weather, and is designed to hold more when it rains.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land ✓
- Forest and semi-natural areas ✓
- Wetlands ✓

Financial costs (Capital, operation & maintenance)

Basins and ponds are rather high land-take measures. One of the primary costs is therefore the cost of **land acquisition** or the opportunity cost of not using that land for development. Construction costs scale with the storage **volume** of the basin/pond; references mention €44 000/ha. Since these basins have a long lifespan, once in operation only minimal maintenance costs arise (about €58/ha/yr).

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Scale

The size of the basin/pond has to be adapted to the drainage area

Design

Basins and ponds require large accessible and **relatively flat** areas. They can have typical depth of 3-5 m and size around 500-5000 m3. However it depends on the drainage area. The basin/pond floor should be made as **level as possible** to maximise storage and infiltration potential and minimise the risk of erosion. Basins and ponds should not be sited on unstable ground and ground stability should be verified prior to construction. They are more effective when primary treatment is provided upstream

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Case studies: Restoration of Amalvas and Žuvintas wetlands, Lithuania; Rural runoff attenuation in the Belford catchment, UK

N1 - Basins and ponds

Potential biophysical effects

Runoff	High
Reducing pollution	Medium
Soil conservation	Low
Habitat	Low
Climate Change	None

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	Medium
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Low
Floods Directive	High
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Low

Basins and ponds have a significant potential to **store runoff**. The total volume corresponds to the volume of the basin or the volume available in the pond (total volume minus the volume of water already in the pond before the rain event). Basins do not allow long term storage. In a case study in Northumberland (UK), basins and ponds contributed to peak flow reductions of 15-30%. Reduction and storage of surface runoff therefore contributes to **reducing flood risk** as an alternative to hard flood defences. It also provides water for other purposes like irrigation.

Depending on the design of the basin or pond and the underlying geology and water table, this measure can increase **infiltration**. However in some cases (if the underlying geology is impermeable or if there is a risk of contaminated runoff), the pond or basin can be designed with an impermeable bed.

Ponds and basins can be effective at **pollutant removal**, as a result of the settling of particulate pollutants and uptake by vegetation. Therefore, they have the potential to improve water quality in receiving water bodies through addressing urban diffuse pollution and reducing chemical pollution. As a **green infrastructure** component, increased application of detention basins will contribute to meeting the objectives of the 2020 Biodiversity Strategy, particularly in urban areas. Basins and ponds can also provide recreational opportunities in urban areas.

High Medium Low None

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N2 - Wetland restoration and management

A wetland is an area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters. Wetland restoration and management can involve: **technical**, spatially **large-scale** measures; technical **small-scale** measures such as clearing trees; changes in **land-use and agricultural** measures. It can improve the hydrological regime of degraded wetlands and generally enhance habitat quality.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ✓
- Forest and semi-natural areas ✓
- Wetlands ✓

Artificial wetlands can also be incorporated in to SuDS.

Financial costs (Capital, operation & maintenance)

Land acquisition may be needed for restoring wetlands, for example the conversion of agricultural areas. Costs may vary widely depending on the scale and nature of the measure. Maintenance requirements can include mowing and grazing or maintenance of hydraulic structures, but again potentially in some cases on a large scale. Additional costs may occur in relation to awareness raising activities and involvement of stakeholders, and investigations and studies may be significant for large-scale projects.

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Scale

Wetlands can occur naturally in a wide range of settings and at varying scales. The scales for restoration and maintenance also vary widely, from small urban wetland creation to wetland restoration at a **landscape scale**.

Design

Natural wetlands are most likely to occur in flat areas with certain soil conditions or in topographic depressions. Restoration of wetland habitats may involve recreation of the **natural hydrological** conditions occurring in those situations, in cases where they have been altered over time. This can therefore be contributed to by a wide range of other hydrological alterations and measures. There are no specific design criteria for wetland restoration, with every situation being **unique.**

HYDROMORPHOLOGY
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Case studies: Wetland restoration in Persina, Bulgaria; Kylmäojankorpi forested wetland, Vantaa, Finland

N2 - Wetland restoration and management

Potential biophysical effects

Runoff	High
Reducing pollution	Medium
Soil conservation	Medium
Habitat	High
Climate Change	High

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	Medium
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	High
2020 Biodiversity Strategy	High

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Wetlands function like natural sponges, storing water and slowly releasing it. A network of many small wetlands can **store** a large amount of water, depending on where and how it is established. Some wetlands can resupply aquifers, while others are fed by groundwater moving upwards. Natural swamps have a large hydraulic resistance due to the often dense vegetation, and are usually flat areas with only slight topographic variations, which contributes to **slowing runoff**. A study in Finland showed a case study wetland to **reduce peak flows** by up to 38%, and **reduce stream discharge** by up to 47%. Wetland restoration may be combined with floodplain restoration or re-meandering so as to reduce flood risks. In coastal areas, wetlands can support protection against sea storms and surges.

Wetlands contribute to improving the **physico-chemical quality** of surface water through encouraging settlement of particulate matter, denitrification and the uptake of nutrients by vegetation. They create aquatic and riparian **habitat** and hold an important part of Europe's biodiversity. They can also be important spawning areas for fish species. Wetlands may account for 40% of the global reserve of **terrestrial carbon** and can make an important contribution to combating climate change, as long as they remain in good status. Wetlands also provide **cultural benefits**, potentially providing large areas of natural habitat that is valuable for activities such as bird watching.

Project funded by the EU – DG Environment

N3 - Floodplain restoration and management

A floodplain is the area bordering a river that naturally provides space for the retention of floods and rainwater. Floodplains have often been drained and in many places they have been separated from the river by structures. They have also been covered by sediments. Restoration and management of floodplains aims to restore their **retention capacity** and **ecosystem functions**, by reconnecting them to the river. It requires measures such as modification of the channel, removal of sediment, creation of lakes or ponds in the floodplain, modification of agricultural practices, afforestation, plantation of native grasses, shrubs and trees, creation of grassy basins and swales, wetland creation, invasive species removal, riparian buffer installation and development.

Land surface relevant for application

Artificial surface	○
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	✓

Financial costs (Capital, operation & maintenance)

The Sigmaplan case study provides costs associated with large-scale floodplain restoration: dyke heightening (€300 (wall on top) to €16 100/m (Quay wall)); inner dike adaptation (€770/m); outer dike construction (€840/m); outlet sluices (€19 000/ha); inlet sluices (€4 000/ha). Engineering costs are typically 10% of the investment cost and maintenance costs less than 1.5% of the investment cost.

Scale

This measure cannot be implemented in catchments with a small area, as the river will have limited or no floodplain.

Design

The slope of the river and floodplain is one of the most important parameters when evaluating the retention potential of the floodplain: shallow slopes reduce discharge peaks and prolong retention periods, while steeper slopes reduce the effects of retention, especially when the flood wave is contained completely within the channel (Habersack).

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N3 - Floodplain restoration and management

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

By allowing the natural functioning of rivers, floodplain restoration measures have high potential to **control runoff** and reduce flood risk, since they should aim to maximise the capacity of the floodplain to store river water. Breaches in the summer dikes, by-pass channels and oxbow lakes can enhance this function. The roughness of the vegetation contributes to slowing down water. Floodplain restoration creates **connectivity** between surface flows and groundwater. The associated changes in land use and reduction in surface runoff can lead to higher recharge of water into the ground. Increased organic matter content can increase soil water retention, while removal of sediment improves soil permeability. A significant change of land cover can reduce pollution by activating filtration by vegetation and soil. Floodplain restoration enables recovery of natural erosion and sedimentation processes, therefore **reducing sediment transport** downstream. It contributes to creating terrestrial, aquatic and riparian **habitats**, increasing fish populations, improving biodiversity and providing natural biomass. The restoration site can be planted with native grasses, shrubs, and trees, which will discourage the establishment of invasive vegetation. Floodplains are likely to contribute to **climate change adaptation** through the fixation of carbon dioxide by photosynthesis and C-burial. They also provide **recreational opportunities** and aesthetic value.

High Medium Low None

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Project funded
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References & Learn more:
http://nwrm.eu/measures-catalogue

N4 - Re-meandering

A river meander is a natural bend in the river, which increases the river length and allows it to decrease flow velocity. In the past, rivers have been straightened and channelised to, for example, gain land for cultivation, facilitate log floating and/or speed up the drainage of water and control/limit the river bed movements. River re-meandering involves creating a **new meandering course** or **reconnecting** cut-off meanders, therefore slowing down the river flow. The new form of the river channel creates new flow conditions and often has a positive impact on sedimentation and biodiversity. Newly created or reconnected meanders provide habitats for a wide range of aquatic and land species.

Land surface relevant for application

Artificial surface	
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	✓

Financial costs (Capital, operation & maintenance)

The literature refers to capital costs of €0.4M/km of river, for river re-meandering. Additional costs are linked to land acquisition and compensation.

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Scale

Meanders may be present on small streams as well as on large rivers.

Design

The functional area of a river in a meandering system is the minimal space required for meanders to reach the maximum amplitude they would reach under natural conditions. River re-meandering is mostly implemented in **lowlands** (less than 200m elevation), in areas where slopes are around 0.5 - 1% (i.e. conditions in which meanders naturally occur). River re-meandering is commonly implemented along with floodplain and wetland restoration and management.

Case studies: Restoration of river Hermance, France; Floodplain restoration of the river Slampe, Latvia

N4 - Re-meandering

Potential biophysical effects

Runoff	Medium
Reducing pollution	High
Soil conservation	High
Habitat	High
Climate Change	Medium

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	High
Abiotic	None

Contribution to policy objectives

Water Framework Directive	High
Floods Directive	High
Birds & Habitats Directive	High
2020 Biodiversity Strategy	High

Expanding the functional area of the river contributes to slowing runoff on the banks and to increasing runoff storage capacity. Increased stream length and reconnection of old meanders increases the storage capacity of the river itself and contributes to slowing down flow. That in turn can contribute significantly to **flood risk reduction**. Re-meandering also has the potential to enhance infiltration and groundwater recharge.

Re-meandering, especially when implemented along with buffer zones, wetlands and afforestation, can provide significant contributions to **pollution reduction.** Changes in the river profile and decreased water velocities contribute to reduced erosion and increased sedimentation.

River re-meandering provides **habitat** for a range of flora and fauna such as aquatic plants, otter, salmon, insects, birds, fish, macroinvertebrates , phytoplankton and kingfishers. Hydraulic annexes, quiet water areas and wet lowlands contribute to enhancing the resilience of ecological communities. Reduced erosion also has a positive impact on aquatic and riparian biodiversity. Potential vegetation development can provide shade and reduce water temperatures, therefore enabling native species to adapt to climate change and compete with non-native species.

River re-meandering contributes to improving the status of biology, physico-chemical and hydromorphology quality elements, and to preventing surface water status deterioration. It also provides recreational opportunities and **aesthetic value**.

High *Medium* *Low* *None*

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N5 - Stream bed re-naturalisation

The stream bed represents the floor of the river, between each riverbank. In the past, many stream beds have been artificially reconstructed with concrete or big stones, with the aim of, for example, flood prevention or supporting changes to agricultural practices. Such alterations modify flows and decrease habitat for fauna and vegetation diversity. They lead to uniformed flows in the rivers and often having the effect of reducing travel time along the river. Stream bed re-naturalisation involves **removing concrete or inert** construction from the stream bed, in order to avoid those damages and restore biodiversity.

Land surface relevant for application

Artificial surface	
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	✓

Financial costs (Capital, operation & maintenance)

There is no information on costs associated with stream bed re-naturalisation, which will be very case-specific and often implemented in conjunction with other measures.

Scale

Stream bed re-naturalisation can play a role at large scale (more than 1km²).

Design

Design parameters associated with stream bed re-naturalisation will vary considerably depending on the length and size of the river. The measure is often implemented along with the following NWRM: natural bank stabilisation, flood plain restoration and management and river re-meandering.

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Case studies: Renaturation of the Seymaz river, Switzerland; Restoration of river Hermance, France

N5 - Stream bed re-naturalisation

Potential biophysical effects

Runoff	Medium
Reducing pollution	High
Soil conservation	Low
Habitat	High
Climate Change	Low

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	Medium
Abiotic	None

Contribution to policy objectives

Water Framework Directive	High
Floods Directive	High
Birds & Habitats Directive	High
2020 Biodiversity Strategy	High

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Stream bed re-naturalisation has the potential to **reduce flood risk**. By diversifying the channel width and water depth, it can increase the water storage capacity of the river. By diversifying river flow velocity, it contributes to slowing down flows and **controlling erosion** and sedimentation.
Restoring the natural design of the bed, banks and river flow helps to **intercept pollutant** pathways through sedimentation, filtration by vegetation and the creation of islands. Therefore, stream bed re-naturalisation contributes to improving the status of physico-chemical and hydromorphology quality elements.
Diversifying flows, water depth and channel width contributes to improving the diversity of **habitats** offered by the river and to creating new habitats. Stream bed re-naturalisation also fosters the development of riparian habitats on river banks. This leads to enhanced natural biomass production and helps to create and preserve **biodiversity**.
Stream bed re-naturalisation contributes to better management of fish stocks, and helps to improve the status of biology quality elements and prevent surface water deterioration.
Stream bed re-naturalisation can provide recreational opportunities (through the diversification of the activities offered by the river) and aesthetic value.

High *Medium* *Low* *None*

Project funded
by the EU – DG Environment

References & Learn more:
http://nwrm.eu/measures-catalogue

N6 - Restoration and reconnection of seasonal streams

Seasonal streams or intermittent rivers are rivers for which surface water naturally **ceases to flow** at some point in space and time. They comprise a large proportion of the global river network and are characterised by dynamic exchanges between terrestrial and aquatic habitats. The abundance and distribution of seasonal streams and their natural intermittent flow regimes are being altered by climate change, water abstraction and inter-basin transfers. Restoring and reconnecting them with the river contributes to favouring the **overall functioning** of the river by restoring lateral connectivity, diversifying flows and providing water retention during floods.

Land surface relevant for application

Artificial surface	
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	✓

Financial costs (Capital, operation & maintenance)

There is no information on costs associated with this measure, which will be very case-specific.

Scale

The length of temporary streams may vary from a few hundred metres to multiple kilometres.

Design

This measure can be treated as an integral part of 're-naturalising' a catchment, and hence may fit with a range of other measures to restore the natural functions of rivers, especially Reconnection of oxbow lakes and similar features (N7).

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Case studies: Revitalization of the upper Drau River in Austria; Polder management near Altenheim, Germany

N6 - Restoration and reconnection of seasonal streams

Potential biophysical effects	
Runoff	High
Reducing pollution	Medium
Soil conservation	High
Habitat	High
Climate Change	Low

Ecosystem services delivered	
Provisioning	Medium
Regulation & maintenance	High
Cultural	Medium
Abiotic	None

Contribution to policy objectives	
Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	High
2020 Biodiversity Strategy	High

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Through increasing the total river length and the interception surface during flood events, reconnection of seasonal streams contributes to **storing** runoff and river water. It contributes to **slowing river flow** by temporarily diverting a part of the flow to the tributaries. Groundwater recharge in ephemeral stream channels can be increased by their reconnection to the main river. By storing large quantities of water, limiting flood intensity and playing an essential role in the river basin functioning, restoration and reconnection of seasonal streams can contribute to **climate change** adaptation.

Headwater streams can intercept nutrients and contaminants before they reach larger perennial streams, depending on the extent of the vegetative cover and soil organic matter rate on the stream banks. By slowing down the river flow, the measure contributes to **reducing erosion** on the river bed and banks, as well as favouring sediment deposition. Riparian environments created by ephemeral and intermittent streams, especially when they are reconnected with the main stream, provide structural elements of food, cover, nesting and breeding habitat, and movement/migration corridors for wildlife. Restoration and reconnection of seasonal streams contributes to the establishment of floral and faunal species and to avoiding **fragmentation**, therefore preserving **biodiversity**.

The measure can improve the status of hydromorphology, chemical and biology quality elements, and improve groundwater status.

N7 - Reconnection of oxbow lakes and similar features

Oxbow lakes are former meanders that have been cut off from the river, thus creating a small lake with a U form. Oxbow lakes occur naturally, but may also occur due to artificial river straightening. Reconnecting an oxbow lake with the river involves **removing terrestrial lands** between both water bodies, therefore favoring the overall functioning of the river by restoring lateral connectivity, diversifying flows and cleaning the river section of the present oxbow, and thereby providing better water retention during floods.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ✓
- Forest and semi-natural areas ✓
- Wetlands ✓

Financial costs (Capital, operation & maintenance)

Literature reports that capital costs for reconnecting oxbow lakes and similar features range between €0.1 and 2 million, and maintenance costs between €0.01 and 1 million. Land acquisition and investigations studies are part of the total cost.

Scale

Oxbow lakes and similar features are present in floodplains where the meandering course of a river has altered over time. In order for these conditions to occur they are likely to have a drainage area above 10 km^2.

Design

Reconnection facilities are usually located at inflow and outflow points of an old meander. Where the bed of the main river has been significantly deepened since its previous connection to the oxbow lake, re-connection may only possible along with the construction of a weir to **raise the water level**. If the measure involves cutting through a dyke or embankment, appropriate consideration of flood management requirements must be taken into account.

Case studies: Conservation of Mura banks, Slovenia; Wachau and Danube restoration in Austria

N7 - Reconnection of oxbow lakes and similar features

Potential biophysical effects

Runoff	Medium
Reducing pollution	Low
Soil conservation	Medium
Habitat	High
Climate Change	Medium

Ecosystem services delivered

Provisioning	Medium
Regulation & maintenance	High
Cultural	Medium
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	Medium
Birds & Habitats Directive	Medium
2020 Biodiversity Strategy	High

Reconnected oxbows and side arms fill in and retain water from the main river, which can play an important role in case of high waters and floods. Although the retention capacity of the single application is usually not large, **cumulative effects** on flood risk reduction can be high.

The re-connection of oxbows and side arms may significantly impact **sediment erosion/deposition patterns** through re-distribution of flow and altered velocities. As long as appropriately designed, this may improve the status of hydromorphology quality elements and help to prevent surface water status deterioration.

Oxbow lakes and re-connected side arms may play an important role in **creating habitats** but care should be paid not to destroy pre-existing oxbow lake habitats. Often these habitats are used for spawning places by fish and other aquatic groups, so fish stocks can increase. That in turn contributes to improving the status of biology quality elements. Bank **vegetation** often expands after re-connection because of improved water regime, and populations of water birds, amphibian, reptilian and mammal species can increase. Restoration of natural green areas significantly contributes to 2020 Biodiversity Strategy and provides aesthetic and cultural value.

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High Medium Low None

N8 - Stream bed re-naturalization

Riverbed material represents the sediment eroded upstream, transported by the river and deposited on the river floor. It can be composed of coarse and/or fine material. Its re-naturalisation involves recovering the **natural structure and composition** of the bedload where this has been altered over time, in particular restoring the equilibrium between coarse and fine sediment

Land surface relevant for application

- Artificial surface ○
- Agriculture land ○
- Forest and semi-natural areas ○
- Wetlands ✓

Financial costs (Capital, operation & maintenance)

The main cost is associated with renaturalisation work that requires engines and human work.

Scale

The measure is usually implemented where current rates of erosion are high.

Design

Bed levels should be raised in a manner that does not increase flood levels. This may be achieved by basing the design on a maximum **water depth** based on the level at which flows are exceeded 90% of the time. The **material** used for the river bed should preferably be taken from the alluvial plain or the high water bed of the river. Backwater effects, i.e. impacts on upstream water levels, have to be considered in the design and development of the project.

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Case studies: Restoration of the Odense river, Denmark; River restoration of the lower Aurino in Italy

N8 - Stream bed re-naturalization

Potential biophysical effects

Runoff	Medium
Reducing pollution	High
Soil conservation	Medium
Habitat	High
Climate Change	None

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	Low
Abiotic	None

Contribution to policy objectives

Water Framework Directive	High
Floods Directive	High
Birds & Habitats Directive	Medium
2020 Biodiversity Strategy	High

Restoring the natural shape of a stream bed and allowing better connection to tributaries should improve the **storage capacity** of the river. Reduction and storage of surface runoff contributes to reducing peak flows in receiving watercourses. The measure allows reconnection with the functional **floodplain** (assuming there are no artificial barriers preventing the connection), and hence contributes to slowing down drainage, which may help to adapt for climate change-related **floods and droughts**.
Giving back its natural shape and composition to the stream bed, along with slowing down the river flow during flood events, plays a role in combating **erosion**. Reconstituting the natural stream bed creates obstacles to pollutants and contributes to recovering its **filtration and purification** features. This may improve the status of hydromorphology quality elements, and the chemical status. It may also contribute to preventing surface water and groundwater status deterioration, and play a role in protecting habitats.
An improved continuity between water and floodplain, the provision of spawning grounds for fish, the diversification of the stream bed, depth and flow velocity all improve **aquatic and riparian ecosystems,** offering new habitats. It therefore enhances natural biomass production, contributing to preserving biodiversity and to managing fish stocks better. The temporal dynamics in naturally functioning floodplains also ensure the survival of many habitats and species identified as important for biological quality. Through these processes, it may contribute to improving the status of **biology** quality elements.

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High Medium Low None

Project funded
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References & Learn more:
http://nwrm.eu/measures-catalogue

N9 - Removal of dams and other longitudinal barriers

Dams and other longitudinal barriers are obstacles that cut across the river section and cause discontinuities for sediment and fauna, as well as altering the depths and dynamics of flow both upstream and downstream. Removing them involves **complete destruction of the obstacle,** restoring the slope and longitudinal profile of the river, therefore allowing re-establishment of natural fluvial dynamics, as well as sediment and ecological continuity.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☐
- Forest and semi-natural areas ☐
- Wetlands ☑

Financial costs (Capital, operation & maintenance)

The physical removal of a single dam or weir in itself, particularly on smaller channels, may not be very expensive, but it is often combined with other restoration works, leading to higher costs overall. Costs may be higher if the facility is not removed altogether but is **modified or reconstructed** (€0,05 to 1 million). **Investigations** are important to understand the impacts upstream and downstream from removing a barrier: studies and maintenance costs can reach 15% of the capital cost.

Scale

The measure is applied predominantly to small and medium sized rivers. Whilst it is also applicable to large rivers, where removal is not possible, improvements to management of the dam may help to re-establish some of the natural functions.

Design

Some dams and weirs are constructed in order to control river flows and erosion. **Assessment** of the possible negative impacts of removing the dam and of the feasibility of mitigation options is necessary. Every situation needs to be considered individually. The measure could be **combined** with reconnection of floodplains, oxbow lakes and other retention volumes in order to mitigate flood risk and to further restore the natural erosion and sediment transport rates.

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Case studies: Renaturation of the Seymaz river, Switzerland; Órbigo River ecological status improvement, Spain

N9 - Removal of dams and other longitudinal barriers

Potential biophysical effects

Runoff	Medium
Reducing pollution	Low
Soil conservation	Low
Habitat	Medium
Climate Change	Low

Ecosystem services delivered

Provisioning	Medium
Regulation & maintenance	Medium
Cultural	None
Abiotic	Low

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	Low
Birds & Habitats Directive	Medium
2020 Biodiversity Strategy	Medium

Removal of longitudinal barriers restores **river continuity**, de-fragments stream **habitats** and improves their quality. This contributes to improving the status of hydromorphology quality elements and to improving ecological status by providing **increased diversity** of (migratory) fish and other aquatic communities (such as benthic invertebrates and macrophytes). Along with improving the conditions for seasonal fish **migration and reproduction**, these effects significantly contribute to addressing Habitats and Birds Directives and 2020 Biodiversity Strategy.

The measure also results in the restoration of the natural pattern of erosion, sediment transport and deposition, which may result in increased erosion and sediment delivery downstream.

Impacts on flood risk reduction can be **controversial**. On the one hand, dams and weirs are built as flood protection measures, in which case their removal might be expected to increase flood risk. However in some cases their removal prevents the risks of accidents during floods. This needs to be considered on a case-by-case basis.

Potentially the restoration of river continuity may also improve navigation conditions.

If removal is found not to be possible, many dams and weirs are suitable for reconstruction with addition of small hydropower facilities and fish passages, which provide abiotic ecosystem services.

High Medium Low None

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N10 - Natural bank stabilisation

A riverbank may consist of natural and/or artificial terrain following the river flow. In the past, many artificial banks have been built with concrete or other types of retention walls, therefore limiting river's natural movements. This can lead to degradation of the river, increased river flows and velocities, increased erosion and reduced biodiversity. Natural bank stabilisation involves **recovering its ecological components,** thus reversing such damages and allowing the bank to be stabilised, as well as allowing the river to move more freely. Nature-based solutions such as bioengineering are preferable, but civil engineering approaches may need to be used in case of strong hydrological constraints.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land ✓
- Forest and semi-natural areas ✓
- Wetlands ✓

Financial costs (Capital, operation & maintenance)

Some publications mention total cost of €225 000 for 200 m length of banks stabilised. However the measure is often implemented together with other measures, hence not necessarily costed in isolation.

Scale

This measure can be implemented on any river with artificial banks, thus with various catchment areas.

Design

The banks are usually steep, between 3:1 and 1.5:1. It is recommended that **local materials** (soil and vegetation species) should be used, for long term sustainability and to allow re-establishment of natural exchanges between the river and groundwater. The measure is often implemented along with floodplain restoration and management and wetland restoration and management.

Case studies: natural bank stabilisation along the Odelouca river, Portugal; Revitalization of the upper Drau River in Austria

N10 - Natural bank stabilisation

Potential biophysical effects

Runoff	Medium
Reducing pollution	Medium
Soil conservation	High
Habitat	High
Climate Change	Low

Ecosystem services delivered

Provisioning	Medium
Regulation & maintenance	High
Cultural	Medium
Abiotic	None

Contribution to policy objectives

Water Framework Directive	High
Floods Directive	Medium
Birds & Habitats Directive	High
2020 Biodiversity Strategy	High

Through improving the stability of banks, natural bank stabilisation increases the capacity of rivers to **store water**. Replacing concrete banks with natural vegetation also generally increases the roughness of the bank and hence slows down river flow. Thereby, this measure can make a contribution to reducing flood risk.
An increased surface area of natural materials allows for increased natural filtration and biological pollutant decomposition, which contributes to increasing the capacity of the river to naturally **purify the water**. Stabilising banks prevents river flow from eroding the river banks, although activating the typical hydromorphological processes can lead to small scale erosion and sedimentation and the development of a broad and gently sloping bank profile. An increased sinuosity ratio and variations in river velocities, width and depth lead to restoration of natural hydromorphological structures. These mechanisms contribute to **controlling erosion**, improving the status of physico-chemical and hydro-morphology quality elements. By slowing down the flow and giving back its natural features to the river, natural bank stabilisation creates **aquatic and riparian habitats**, thus potentially increasing fish populations and natural biomass production, improving the status of biology quality elements and preserving biodiversity. Replacing concrete banks with natural materials and vegetation also improves the **aesthetic** value of the area.

High Medium Low None

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Project funded
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N11 - Elimination of riverbank protection

Riverbank protection is an inert or living construction providing bank fixation. However riverbank protection is also an obstacle for the lateral connection of the river, constraining the river channel and reducing or preventing connectivity to the floodplain. Eliminating river bank protection involves **removing all or some parts of bank protection**, particularly inert protection, in order to enhance lateral connections, diversify flows and habitats, and also cap floods in the mainstream. It is a prerequisite for many other measures like re-meandering or widening, as well as initiating later channel migration and dynamics.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☐
- Forest and semi-natural areas ☐
- Wetlands ☑

Financial costs (Capital, operation & maintenance)

Elimination of riverbank protection is generally implemented as a component of more complex projects and thus included in wider budgets.


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Scale

This measure can be implemented on any part of a river with riverbank protection.

Design

Elimination of riverbank protection is mainly implemented in **downstream reaches** of catchments with significant natural floodplain extent. It can be combined with other measures such as natural bank stabilisation, wetland restoration, floodplain reconnection and restoration, re-meandering and riparian buffer zones.

Case studies: Órbigo River ecological status improvement, Spain; Fluvial and ecosystem restoration of the Arga-Aragon Rivers, Spain

N11 - Elimination of riverbank protection

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

Elimination of riverbank protection restores links between rivers and floodplains, thus improving the capacity of the river to **store water** for long periods. New vegetation and a wider space for water **slow down** the river flow, reducing peak flows in receiving watercourses, and consequently reducing flood risk and erosion.

Elimination of riverbank protection enhances **sediment and pollutant deposition** in the re-connected reaches and across the floodplain, thus reducing their load in the river. The combination of biological, chemical and physical processes that occur in floodplains can improve water quality across a wide range of compounds and elements. Reduced flows also contribute to the filtration of pollutants, potentially improving **surface water qualitative status** and preventing surface and groundwater status deterioration. It also provides better protection for ecosystems. The continuity between river and floodplain, as well as reduced peak flows, provides benefits to fish species and hence can improve **aquatic ecosystem quality** and fish stocks. Re-opened river banks provide spawning grounds for fish and diversify riparian habitats. More broadly, the measure contributes to increasing biomass production and preserving biodiversity.

Elimination of riverbank protection also facilitates access to the river, increasing recreational opportunities, and provides aesthetic value compared to artificial infrastructure.

High *Medium* *Low* *None*

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Project funded
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N12 - Lake restoration

A lake is a natural water retention facility. It can store water (for flood control) and provide water for many purposes such as water supply, irrigation, fisheries, tourism, etc. In addition, it serves as a sink for carbon storage and provides important habitats for numerous species of plants and animals, including waders. Restoring lakes involves **enhancing their structure and functioning** where they have been drained or degraded in former times.

Land surface relevant for application

- Artificial surface ☐
- Agriculture land ☐
- Forest and semi-natural areas ☐
- Wetlands ☑

Financial costs (Capital, operation & maintenance)

The literature refers to capital costs of €4 000/ha for lake restoration. Since lakes have a long (permanent) lifespan, only minimal maintenance costs should arise once in operation (depending on the exact nature of the restoration).

Scale

Lakes, by their size, can drain large catchment areas.

Design

The design will vary considerably depending on the extent of restoration, the current and existing lake design, and the scale.

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N12 - Lake restoration

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

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Lakes constitute natural reservoirs, which make water available for a variety of uses (for example recreational, ecosystems, irrigation). The runoff storage capacity of a lake corresponds to the total volume of the lake minus the volume already occupied by water. Hydraulic infrastructure can be built or modified to increase the total capacity of the lake. In passing through the lake, river water is not only slowed down but also has its physico-chemical characteristics altered/ regulated. These mechanisms contribute to **reducing peak flows** in receiving watercourses, effectively maintaining the natural **flood risk** management capacity of a catchment. Protection against floods can be improved through an integrated strategy taking into account all water uses.

Lake restoration has the potential to **improve water quality** in receiving water bodies. It can improve sediment circulation through appropriate management and/or reduce sediment delivery downstream and diversity of ecosystems in the lake will increase resilience to - and capacity to treat - pollutants.

Lake restoration preserves aquatic habitats and can increase species diversity. Along with the benefits to temperature and water quality, this can contribute to increasing fish stocks. Restoration of lake and their surroundings can also benefit riparian vegetation and species, and provide an overall increase in biomass production. Restoration of the food chain, as a result of improving production of phytoplankton and zooplankton, creates optimum conditions for aquatic and terrestrial ecosystems. Lake restoration is thus a key measure for reaching **good water ecological status**. Lake can have recreational and cultural benefits, becoming popular areas to visit for example for sailing, fishing and bird watching.

N13 - Restoration of natural infiltration to groundwater

Restoration of natural infiltration to groundwater, also known as "Artificial Groundwater Recharge" in the engineering literature, can include: (i) **surface structures** to facilitate/augment recharge (such as soakaways and infiltration basins); (ii) **subsurface indirect recharge** – infiltration capacity is enhanced through wells drilled within the unsaturated zone; and (iii) subsurface direct recharge – infiltration and recharge of the groundwater aquifer is accomplished through wells reaching the saturated zone.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land ✓
- Forest and semi-natural areas ✓
- Wetlands ✓

Financial costs (Capital, operation & maintenance)

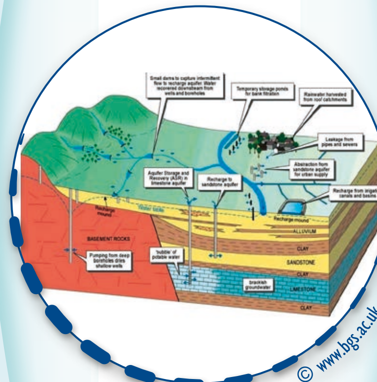
The costs can vary considerably depending on the type of mechanism and the scale. The case study in Los Arenales, Segovia, provides information on costs linked to restoration of reference condition infiltration for a 3ha infiltration zone: M€0.6 (investigation and studies); M€0.4 (water intake); M€2.5 (transfer conveyance); M€0.9 (recharge channel).

Scale

Upstream drainage area can be any scale, ranging from a single plot to large catchments greater than 1000km2.

Design

The design will vary considerably depending on the type of mechanism used for recharge, so site-specific consideration is necessary. Depending on the type of infiltration features and the source of the water, pre-treatment may be necessary to **prevent pollution** from reaching groundwater.
This type of measure overlaps with a range of other measures that provide infiltration to groundwater by various means.



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Case studies: Managed Aquifer Recharge in Los Arenales , Segovia, Spain; Aquifer recharge in Malta

N13 - Restoration of natural infiltration to groundwater

Potential biophysical effects

Runoff	High
Reducing pollution	High
Soil conservation	Medium
Habitat	None
Climate Change	None

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	Medium
Abiotic	None

Contribution to policy objectives

Water Framework Directive	High
Floods Directive	Medium
Birds & Habitats Directive	High
2020 Biodiversity Strategy	High

Restoration of natural infiltration to groundwater has a significant impact on **runoff storage**, since rainfall water is able to percolate downward through pores in the soil and fractures in rock until reaching the saturated zone. Surface structures performed to increase water infiltration can capture river water at times of high flow and provide storage. Increased infiltration contributes to **storing large amounts of water and to enhancing groundwater recharge**. It therefore plays a significant role in reducing flood risk and erosion (through reduced runoff).

Restoration of natural infiltration to groundwater will help to decrease concentrations of **pollutants** originating in adjacent areas before they reach rivers (proportionally this is likely to have a greater impact on smaller streams). Interception of nutrients and organic materials by the soil contributes to improving soil quality.

Infiltration and purification help to prevent groundwater and surface water status deterioration by restoring a more natural water balance and intercepting pollutant pathways. Slowing runoff and infiltration contribute to protecting habitats and prevent biodiversity loss.

Groundwater resources and their long-term replenishment are controlled by long-term climate conditions. Restoration of natural infiltration to groundwater contributes toward **climate change** adaptation. It also may provide various cultural services, for instance through maintaining spring flows used in historical equipments, particular in southern Europe

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High Medium Low None

N14 - Renaturalisation of polder areas

A polder is a low-lying tract of land enclosed by embankments (barriers) known as dikes that forms an artificial hydrological entity, meaning it has no connection with outside water other than through manually operated devices. Its re-naturalisation involves enhancing polders with **natural characteristics**, allowing better water storage in watercourses inside the polder, as well as increased biodiversity.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land ✓
- Forest and semi-natural areas ✓
- Wetlands ✓

Financial costs (Capital, operation & maintenance)

Capital and maintenance costs vary significantly depending on the type and the size of the polder. The capital cost for renaturalisation of the Altenheim polder was M€28.

Scale

Polders tended to be developed in the lower reaches of large rivers with **large upstream catchments** (more than 100km^2).

Design

Renaturalisation of polder areas can include the implementation of other measures such as wetland and floodplain restoration, natural bank stabilisation and elimination of riverbank protection.

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Case studies: Polder management near Altenheim, Germany

N14 - Renaturalisation of polder areas

Potential biophysical effects

Runoff	High
Reducing pollution	None
Soil conservation	Medium
Habitat	High
Climate Change	None

Ecosystem services delivered

Provisioning	High
Regulation & maintenance	High
Cultural	Medium
Abiotic	High

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	Medium
2020 Biodiversity Strategy	Medium

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Renaturalisation of polder areas has a significant impact on **river water storage** (water is stored in watercourses and hydraulic annexes inside of the polder instead of being pumped out of the polder). It also has a positive impact on infiltration and soil water retention. Flood retention areas such as polders provide cost-effective protection against **flood** damage, with additional ecological benefits as a result of renaturalisation measures.

Ecological flooding contributes to raising **groundwater levels**, including outside of the polder. Due to ecological flooding, soils inside renaturalised polders are constantly enriched by organic sediments, which serve as fertiliser for plants.

Water courses in renaturalised polders can provide habitat for a variety of invertebrate and fish species, and thus enhance fish stocks. In some cases, ground beetle and dragonfly species can establish in alluvial forests. However it is possible that populations of mosquitos and other pests could also increase, with negative consequences for the nearby human populations. Renaturalised polders also have **cultural value**, for example in the Netherlands, where they act as recreational areas.

High Medium Low None

Project funded
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U1 - Green roofs

Green roofs are multi-layered systems that cover the roof of a building with **vegetation and/or green landscaping** over a drainage layer. There are two types of green roof: **extensive** green roofs (sedum roofs, eco-roofs or living roofs) cover the entire roof area with lightweight, low growing, self-sustaining, low maintenance planting. **Intensive** green roofs (roof gardens) are landscaped environments with high amenity benefits. Green roofs are designed to **intercept rainfall**, which is slowed as it flows through the vegetation and a drainage layer.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land
- Forest and semi-natural areas
- Wetlands

Green roofs can be grown on any pitch of roof, including vertical walls.

Financial costs (Capital, operation & maintenance)

Capital costs are likely to be higher when green roofs are retrofitting than when they are being incorporated in a **new building**. Capital costs range between €25-130/m² for extensive design and €130-300/m² for intensive design.. Maintenance costs are up to €55/ m² for each maintenance event on extensive green roofs.

Scale

Green roofs can be incorporated on building roofs of any size.

Design

There should be multiple outlets from the green roof, to reduce the risks from blockages. The structural roof strength must provide for the full additional load of saturated green roof elements. The **waterproof membrane** should have good root penetration resistance and substrate thicknesses should be between 100 and 250 mm. **Maintenance** (vegetation, membrane...) is important to ensure continued effectiveness.

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Case studies: Green roofs in Vienna, Austria; Green roofs in Geneva, Switzerland; Urban green roofs in Helsinki, Finland

U1 - Green roofs

Potential biophysical effects	
Runoff	High
Reducing pollution	Low
Soil conservation	None
Habitat	Low
Climate Change	Low

Ecosystem services delivered	
Provisioning	Low
Regulation & maintenance	Medium
Cultural	Low
Abiotic	None

Contribution to policy objectives	
Water Framework Directive	Low
Floods Directive	Medium
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Low

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Increased **evapotranspiration** occurs as a result of introduction of vegetation to an otherwise hard surface, and contributes to reducing runoff. Well designed, green roofs are effective at **reducing peak flow** from frequent, less extreme rainfall events, thereby contribute to **flood risk management**. Their effectiveness may vary between 5 to 95% reduction in runoff, depending on substrate type and depth, antecedent conditions, season, rainfall intensity and volume.
As green roofs can make localised contributions to water quality of runoff, they have potential to contribute towards improved physico-chemical quality elements and **chemical status** as a source-control component in an effective sustainable drainage system. They can help to prevent surface water status deterioration.
When widespread across an urban area, green roofs may contribute to improvements to air quality, lower air temperatures and higher humidity levels, thus assisting with **climate regulation**. They can potentially contribute to carbon sequestration.
Although the biodiversity of the vegetation on green roofs may be low or managed, it is greater than for a hard roof. Green roofs are an example of green infrastructure, with the potential to assist with ecological **habitat connectivity**.
The introduction of green spaces to urban areas finally contributes to **aesthetic benefits**: intensive green roofs are designed for small-scale **domestic/amenity/recreational** use.

High · Medium · Low · None

U2 - Rainwater harvesting

Rainwater harvesting involves **collecting and storing rainwater** at source for subsequent use, for example, using water butts or larger storage tanks. Water butts are the most widely applied and simple rainwater harvesting technique, collecting rainwater runoff from roofs via a connection to the roof down-pipe. They are primarily designed for **small scale use** such as in household gardens, although a range of non-potable uses is possible.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land
- Forest and semi-natural areas
- Wetlands

Financial costs (Capital, operation & maintenance)

A storage tank can generally be situated on the same land from which it takes its stormwater, thus no further land acquisition is expected to be necessary. While a simple water butt is low cost, the capital cost range is **considerable** depending on the system design and how it is incorporated into the building structure, from €5 to €60/m² roof area services. Maintenance costs are low: €0.25-€1.00 /m² roof area services.

Scale

The contributing area to a rainwater harvesting system will generally be a single roof.

Design

Rainwater harvesting can be used in a sustainable drainage system train, e.g. downstream of green roofs and in conjunction with other **SuDS measures**. The dimensions of rainwater harvesting must consider whether the system is solely designed to provide water supply, or whether **additional capacity** will be included to store runoff. Regular **inspection and maintenance** (tank, inlets and outlets, pumps and treatment filters, roof / drainage area filters...) is essential for systems to ensure effective ongoing operation.

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Case studies: Domestic Rainwater Harvesting in Malta

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U2 - Rainwater harvesting

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

Capturing rainwater at source and storing it make it available for irrigation or other (usually) non-potable purposes. Rainwater harvesting **stores runoff** with the potential therefore to reduce both the rate and total volume of runoff. However the actual effectiveness of rainwater harvesting is highly dependent on whether the system is specifically designed for runoff storage or whether the primary aim is **water storage**. Unless space is specifically allocated for runoff storage, then there may be insufficient space to provide benefit. This may vary with region, season and the use of the water: for instance in the UK, water harvested for irrigation is unlikely to be used in winter, so storage will remain full, leaving no space for runoff storage. Rainwater harvesting thereby contributes to **flood risk management** when designed to accommodate it. Through this and along with providing sustainable water supply, it plays a role in climate change adaptation.

Although providing a contribution to sustainable water use, rainwater harvesting has **limited potential** to significantly influence any aspect of the Water Framework Directive, at least when considered in isolation. It neither has direct biodiversity benefit.

High *Medium* *Low* *None*

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U3 - Permeable surfaces

Permeable paving is designed to allow rainwater to **infiltrate through an otherwise impermeable surface**, either into underlying layers (soils and aquifers), or to be stored below ground and released at a controlled rate to surface water. Two types can be distinguished: porous pavements, where water is infiltrated across the entire surface, and permeable pavements, where materials such as bricks are laid to provide void space through to the sub-base. It is most commonly used on roads and car parks.

Land surface relevant for application

Artificial surface	✓
Agriculture land	
Forest and semi-natural areas	
Wetlands	

Financial costs (Capital, operation & maintenance)

According to Environment Agency, permeable paving **costs less on a lifecycle basis** than traditional surfaces, with reduced maintenance costs (€1 to 5/m²/ yr) outweighing increased capital costs. Those vary considerably (€40 to €90/m²), depending on design approaches and construction materials. Use of **recycled materials may** significantly reduce costs. No land acquisition is required, as the pervious pavement replaces a hardstanding area.

Scale

It generally takes runoff only from the permeable area itself, although can be designed to treat a small catchment area.

Design

The design can vary considerably depending on the type of material used and whether infiltration is to be allowed. Infiltration to underlying soils should only be allowed where suitable conditions exist, considering slope stability, soil permeability, groundwater levels and any ground contamination. Regular **inspection and maintenance** (during and after heavy rainfall) is important.

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Case studies: Sustainable stormwater management in Fornebu, Norway; Leidsche Rijn sustainable urban development, Netherlands

U3 - Permeable surfaces

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

Permeable paving stores rainfall-runoff from artificial surfaces and either releases it at a controlled rate, or infiltrates to groundwater. Effectiveness at **runoff and peak flow reduction** varies from 10 to 100% depending on the situation, and can decrease significantly over time without sediment management. Permeable paving can be an effective source control component of a **SuDS 'train'**, thereby contributing significantly to sustainable runoff management, particularly in urban areas. Used in conjunction with other SuDS features, it can reduce the risk of surface **runoff flooding** and contribute to the reduction in peak river flows in small catchments. Preventing rapid runoff also makes water available for other purposes and plays a role in enhancing recharge.

Permeable paving can be designed to allow infiltration where appropriate, although the potential for pollution to groundwater needs to be considered. It thus enhances the potential of the landscape to **store water** during floods.

Generally, the measure has a positive impact on **removing diffuse pollution**, including suspended solids and hydrocarbons, through intercepting surface runoff and capturing/filtering pollutants. Permeable paving can thus make a **small contribution** to improving **water quality** in receiving waters and enhancing **recharge** to groundwater.

Permeable paving finally provides a minor contribution towards improved green infrastructure and protection of ecosystems.

High Medium Low None

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Project funded by the EU – DG Environment

U4 - Swales

Swales are broad, shallow, linear vegetated **channels** that can store or convey surface water (reducing runoff rates and volumes) and remove pollutants. They can be used as conveyance features to pass runoff to the next stage of a SuDS treatment train, and can be designed to promote infiltration where soil and groundwater conditions allow. There are three kinds of swale, giving different surface water management capabilities: standard conveyance swale, enhanced dry swale (promotes infiltration) and wet swale (permanently wet base).

Land surface relevant for application

- Artificial surface ✓
- Agriculture land
- Forest and semi-natural areas
- Wetlands

Swales can also be appropriate where there is runoff from low permeability surfaces in other areas, e.g. agricultural.

Financial costs (Capital, operation & maintenance)

Swales are **low land-take** measures and can often be incorporated within the masterplan for new developments without significant opportunity costs for land use. Cost ranges generally fall within €15 to 80/m² of swale area constructed. Ongoing maintenance is required to maintain the functionality of the swale and ranges between €0.50-€4.00/m² swale area. Where infiltration is intended, geotechnical investigations may be required.

Scale

The contributing catchment area of swales tends to be relatively small, for example a car park, road surface or small field

Design

Swales are most effective if applied at the **start of a SuDS 'train',** for example, feeding in to a detention or infiltration basin. Generally, swales are efficient and easier to construct and maintain if the channel is trapezoidal or parabolic in shape, with shallow sides (between 1 in 3 and 1 in 4), shallow depths (less than 600mm) and a shallow gradient (between 1 in 100 and 1 in 300). They should be located in **sun lit areas** to allow for vegetation growth. Regular inspection and maintenance is essential.

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Case studies: Sustainable stormwater management in Fornebu, Norway; Water retention spaces in southern Portugal

U4 - Swales

Potential biophysical effects

Runoff	High
Reducing pollution	Medium
Soil conservation	Medium
Habitat	Low
Climate Change	Low

Ecosystem services delivered

Provisioning	Low
Regulation & maintenance	Medium
Cultural	Low
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Low
Floods Directive	High
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Medium

Swales are primarily intended to **slow runoff**, although they also contribute some additional storage volume. Their efficiency is highly dependent on good design and catchment/ local landscaping characteristics; in general they can reduce mean runoff by more than 50%. Used in conjunction with other SuDS features, they contribute towards sustainable runoff management, particularly in urban areas, to reducing the **risk of surface runoff flooding** and towards reductions in **peak river flows** in small catchments.
Because of dense vegetation, swales are effective in local **sediment capture** and in reducing concentrations of associated **pollutants**. Along with the interception of surface runoff, this contributes to reducing diffuse pollution. Thus, swales can make a small contribution to improving **water quality** in receiving waters.
Swales are often designed to allow **infiltration** (although the potential for pollution to groundwater needs to be considered), thus can make a minor contribution to enhanced recharge. They also contributes towards biodiversity preservation and climate change adaptation. Finally, swales comprise green infrastructure in urban areas, thus contributing to the Biodiversity Strategy.

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High *Medium* *Low* *None*

U5 - Channels and rills

Channels and rills are **shallow open surface water channels** incorporated in to the start of a SuDS train. They collect water, slow it down and provide storage for silt deposited from runoff. They can have a variety of cross sections to suit the urban landscape, and can include the use of planting to provide enhanced visual appeal, water treatment and biodiversity.

Land surface relevant for application

Artificial surface	✔
Agriculture land	
Forest and semi-natural areas	
Wetlands	

Financial costs (Capital, operation & maintenance)

Channels and rills should only be used as conveyance features within a SuDS train, in combination with other measures. Therefore, it is not relevant to provide isolated costs for this measure alone.

Scale

Channels and rills should only be used to collect runoff from a small area.

Design

Channels and rills provide a conveyancing function within a **SuDS 'train'**. For example, they may connect a green roof to an infiltration feature. Channels and rills can be incorporated into landscaping, e.g. in **pedestrianised** areas, without significant loss of land. They can be designed to any dimensions, which should aim to slow runoff and encourage sediment deposition, and have a shallow depth. Channels and rills should be constructed on stable land, and not with a steep slope. Regular **inspection and maintenance** is important for channels and rills to ensure effective ongoing operation.

Case studies: Dyke relocation on the river Elbe in Germany, Reconstruction of Lepiku channel in Tallinn Botanic Garden, Estonia

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U5 - Channels and rills

Potential biophysical effects

Runoff	Low
Reducing pollution	Low
Soil conservation	Low
Habitat	Low
Climate Change	None

Ecosystem services delivered

Provisioning	None
Regulation & maintenance	Low
Cultural	Low
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Low
Floods Directive	Low
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Low

Channels and rills provide a small amount of storage, and help to control the **rate of runoff**. When used as an integral part of a sustainable drainage system, they contribute to good management of surface water and hence help to reduce the risk of **urban flooding**.
Channels and rills can contribute to reducing urban **diffuse pollution** through reducing total runoff and encouraging deposition of sediments and pollutants, thus providing water quality improvements. Through reducing the transport of **sediment** further downstream, they also reduce the treatment requirements of downstream SuDS. However, in isolation their effect on water quality of receiving waters is likely to be negligible.
In some cases, channels and rills may include planting, which creates a limited amount of new aquatic **habitat**. Channels and rills provide a limited contribution towards improved green infrastructure and protection of ecosystems.
In some cases, channels and rills can be attractively designed, thereby providing **aesthetic** value.

High Medium Low None

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U6 - Filter strips

Filter strips are uniformly graded, gently sloping, **vegetated strips** of land that provide opportunities for **slow conveyance** and (commonly) **infiltration.** They are designed to accept runoff as overland sheet flow from upstream development and often lie between a hard-surfaced area and a receiving stream, surface water collection, treatment or disposal system. They are often used as a pretreatment technique before other sustainable drainage techniques. They can serve as a buffer between incompatible land uses, and can provide localised groundwater recharge in areas with pervious soils.

Land surface relevant for application

Artificial surface	✓
Agriculture land	✓
Forest and semi-natural areas	
Wetlands	

Filter strips are effective when receiving overland sheet flow from an adjacent area.

Financial costs (Capital, operation & maintenance)

Capital costs for filter strips can range between €3 and €30/m^2 filter strip area. They vary considerably depending on the **design** of the filter strip and the use of **substrate materials** such as gravel to increase the effectiveness of the filter strip. Maintenance costs vary from €0.50-€6.50/m^2 filter strip area.

Scale

Filter strips are suited to treating runoff from small areas such as roads, roofs, small car parks and other impervious surfaces.

Design

Filter strips should be used as the **first stage of a SuDS** 'train'. They need to be located immediately adjacent to their drainage area, and not in areas where significant footfall is expected or where there is a risk of leaching contaminants into groundwater. The maximum drainage length of a filter strip should be 50m, and the minimum width 6m. To gain maximum water quality treatment, incoming runoff should be distributed with a water depth of less than 50mm. Regular inspection and **maintenance** is needed.

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U6 - Filter strips

Potential biophysical effects

Runoff	Low
Reducing pollution	High
Soil conservation	High
Habitat	Low
Climate Change	Low

Ecosystem services delivered

Provisioning	None
Regulation & maintenance	Medium
Cultural	Low
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Low
Floods Directive	Low
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Medium

Due to their rough surface, filter strips provide some **slowing of runoff**. In isolation, they provide little benefit in terms of flood risk reduction because they do not store runoff and provide limited control of peak flow rates. Their contribution to groundwater recharge is also limited due to the short residence time. Filter strips are generally used as the first stage in a SuDS 'train' and in that respect form a component of coordinated **flood risk** management.

Under low to moderate velocities, filter strips effectively **reduce particulate pollutant** levels by removing sediments, organic materials and trace metals from local runoff. Appropriate design (including slope, width and vegetation type), adequate maintenance and limited fertiliser use are important to achieving high effectiveness. Through contributing to a reduction in diffuse pollution, filter strips can make a small contribution to preserving and improving **water quality** in receiving waters.

Filter strips introduce **permanent vegetation** to what may otherwise have been an artificial surface or arable land, and thus contribute to creating habitat. They provide an improvement over traditional drainage and urban land cover regarding green spaces and biodiversity, and may provide some **aesthetic** value. As a **green infrastructure** component, their increased application will provide a small contribution to meeting the objectives of the 2020 Biodiversity Strategy in urban areas.

High · *Medium* · *Low* · *None*

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Project funded by the EU – DG Environment

U7 - Soakaways

Soakaways are buried chambers that store surface water and allow it to soak into the ground. They are typically square or circular excavations either filled with rubble or lined with brickwork, pre-cast concrete or polyethylene rings/perforated storage structures surrounded by granular backfill. Soakaways provide storm water attenuation, and storm water treatment. They also increase soil moisture content and help to recharge groundwater. They store rapid runoff from a single house or from a development and allow its efficient infiltration into the surrounding soil.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land
- Forest and semi-natural areas
- Wetlands

Soakaways may also be applicable for artificial surfaces in agricultural areas, such as farmyards.

Financial costs (Capital, operation & maintenance)

Soakaway costs are generally greater than €90/m² of storage volume. Maintenance cost is between €0.25-1.25/m² treated area. **Geotechnical investigations** are required to confirm the land stability and underlying soil/geology conditions. These may need to be intrusive and require analysis of land contamination to determine the suitability of infiltration techniques.

Scale

Soakaways are generally designed to collect and infiltrate runoff from a small area such as an individual house or car-parking area.

Design

Soakaways may be a part of a wider **SuDS scheme**. They should not be used within 5m of building **foundations** or roads or in areas of **unstable land** without considering their impacts, where the groundwater table is less than 1m below the base of the soakaway, in close proximity to other soakaways or infiltration features, or where the risk of contamination to the **groundwater** is high. Runoff should **be pre-treated** to allow for removal of particulates and oils. Regular inspection and maintenance is important.

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Case studies: Leidsche Rijn sustainable urban development, Netherlands

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U7 - Soakaways

Potential biophysical effects	
Runoff	High
Reducing pollution	Low
Soil conservation	None
Habitat	None
Climate Change	None

Ecosystem services delivered	
Provisioning	None
Regulation & maintenance	High
Cultural	None
Abiotic	None

Contribution to policy objectives	
Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Low

Soakaways function by **collecting runoff** and **infiltrating** it to the underlying soils. They are generally designed to infiltrate all water from the contributing drainage area up to a **1 in 30 year event**. Soakaways thus enhance the potential of the landscape to store water during floods and contribute to reducing the risk of **surface runoff flooding** and peak river flows in small catchments.

Soakaways can provide full infiltration from areas of hardstanding which results in a significant, although localised, contribution to **groundwater recharge**. The volume contribution from each individual soakaway is, however, small.

Soakaways can provide additional improvements to **water quality** prior to infiltration to soil or groundwater, by filtration through the soakaway substrate, although pre-treatment is recommended, and the potential for pollution to groundwater needs to be considered: soakaways could pose a higher risk than some other infiltration measures, since they bypass the vegetation and soil layers. Runoff reduction also contributes to reducing urban diffuse pollution.

As a component in sustainable urban water management, soakaways finally provide a limited contribution towards improved green infrastructure and protection of ecosystems.

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High Medium Low None

U8 - Infiltration trenches

Infiltration trenches are **shallow excavations** filled with rubble or stone. Ideally they should receive lateral inflow from an adjacent impermeable surface. They allow water to **infiltrate** into the surrounding soils from the bottom and sides of the trench. In doing so, they **reduce runoff** rates and volumes and can help replenish groundwater and preserve base flow in rivers. They are effective at removing pollutants and sediment but must be designed with an effective pre-treatment system.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land
- Forest and semi-natural areas
- Wetlands

Infiltration trenches may also be applicable for artificial surfaces in agricultural areas, such as farmyards and roads.

Financial costs (Capital, operation & maintenance)

Construction costs for infiltration trenches vary between €70 and €90/m^3 stored volume, depending on the depth, geometry and underlying soil/geology conditions, and there will be minor ongoing maintenance costs. **Geotechnical investigations** are required to confirm the land stability and underlying soil/geology conditions. These may need to be intrusive and require analysis of land contamination to determine the suitability of infiltration techniques (€0.5-€10k).

Scale

Infiltration trenches are generally designed to collect and infiltrate runoff from a small area such as a car-park.

Design

Infiltration trenches should be 1-2m deep and filled with stone aggregate, with a sufficiently **high void ratio**. They should have a high-level outfall with a **flow control device** to accommodate excess runoff. They are restricted to flat sites (2% max). They should not be used for primary treatment of runoff on brownfield sites or other pollution hot-spots if the risk of contamination to groundwater is high, and should only be used in areas with **low sediment loading**, unless upstream pre-treatment is included.

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Case studies: Infiltration trenches in Kungsbacka, Sweden

U8 - Infiltration trenches

Potential biophysical effects

Runoff	High
Reducing pollution	Medium
Soil conservation	Medium
Habitat	None
Climate Change	None

Ecosystem services delivered

Provisioning	Low
Regulation & maintenance	High
Cultural	None
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Low

Infiltration trenches function by **collecting runoff** and **infiltrating** it to the underlying soils. They are generally designed to infiltrate all water from the contributing drainage area up to a **1 in 30 year event**. Effectiveness can reduce significantly over time if high levels of sediment are allowed to enter the trench. Infiltration trenches thus enhance the potential of the landscape to store water during floods, and reduce the risk of **surface runoff flooding** ; they may contribute to a reduction in peak river flows in small catchments.

Infiltration trenches can provide full infiltration from areas of hardstanding which results in a significant, although localised, contribution to **groundwater recharge**. They may thereby contribute to improving **groundwater status**, although the volume contribution from each trench is small.

Infiltration trenches can be effective at **pollutant removal**, which will be improved by good design and adequate maintenance: they are effective at sediment control only where it is entrained in runoff in low concentrations (otherwise requiring pre-treatment). However, the potential for pollution to groundwater needs to be considered since infiltration trenches bypass the vegetation and soil layers. Through reducing diffuse pollution, infiltration trenches may make a small contribution to preserving and improving surface **water quality**.

As a component in sustainable urban water management, infiltration trenches provide a limited contribution towards improved green infrastructure. Where used in agricultural areas, they contribute to more sustainable practices.

High Medium Low None

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U9 - Rain gardens

Rain gardens are small-scale **vegetated gardens** used for storage and infiltration. They are typically applied at a property level and close to buildings, for example to capture and infiltrate roof drainage. They can use a range of components: grass filter strips, ponding areas, organic/mulch areas, planting soil, woody and herbaceous plants, sand beds. The filtered runoff is either collected and returned to the conveyance system or infiltrated into the surrounding ground.

Land surface relevant for application

Artificial surface	✓
Agriculture land	
Forest and semi-natural areas	
Wetlands	

Financial costs (Capital, operation & maintenance)

The construction cost of rain gardens will vary considerably depending on the **site preparation** required and the **type of planting** selected. If the rain garden is excavated and new growing media installed, costs will be much higher. A simple rain garden constructed in a domestic garden will have little cost for the homeowner. In contrast, rain gardens at the street level will require maintenance by municipal authorities, although these are not expected to be onerous.

Scale

Individual components of rain gardens are designed to capture runoff from a small surface area, for example a roof or car park.

Design

Rain gardens are typically **small** and used at a property level. Minimum widths of 3 m and length to width ratios of 2:1 will allow scattered planting of small trees and shrubs and will facilitate operation and maintenance, although smaller areas can also be used effectively. Native species should be carefully selected to be able to withstand occasional **flooding** and prolonged inundation of the roots. Rain gardens may be used as part of a wider **SuDS scheme**.

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Case studies: Rain garden in the Day Brook, UK

U9 - Rain gardens

Potential biophysical effects

Runoff	High
Reducing pollution	Medium
Soil conservation	Medium
Habitat	Medium
Climate Change	Low

Ecosystem services delivered

Provisioning	Low
Regulation & maintenance	High
Cultural	Low
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Medium
Floods Directive	High
Birds & Habitats Directive	None
2020 Biodiversity Strategy	High

Rain gardens are effective at **capturing runoff** from medium sized rainfall events: the use of trees will increase evapotranspiration and the garden can be designed to infiltrate captured storage, thus reducing runoff. Rain gardens thereby reduce the risk of **flooding** in conjunction with other SuDS features in urban areas, and provide a contribution to climate change adaptation.

Where infiltration is allowed, rain gardens contribute to **groundwater recharge**, thereby improving groundwater status, although the volume contribution from each rain garden is small.

Rain gardens can be highly effective at absorbing **hydrocarbons and heavy metals** through vegetative uptake and the composition of soils. They capture sediment, reducing suspended solid concentrations downstream. Through reducing diffuse pollution, rain gardens make a small contribution to preserving and improving surface **water quality**.

By creating new areas of diverse vegetation, rain gardens contribute to increasing **biodiversity** and providing **aesthetic** benefits in urban landscapes. They may provide some contribution to lowering peak temperatures and increasing localised uptake of CO2. As a green infrastructure component, particularly where native planting is used, increased application of rain gardens will contribute to meeting the objectives of the 2020 **Biodiversity Strategy.**

High Medium Low None

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Project funded
by the EU – DG Environment

U10 - Detention basins

Detention basins are **vegetated depressions** designed to hold runoff from impermeable surfaces and allow the settling of **sediments** and associated pollutants. Stored water may be slowly drained to a nearby watercourse, using an outlet control structure to control the flow rate. Detention basins can provide water quality benefits through physical filtration to remove solids/trap sediment, adsorption to the surrounding soil or biochemical degradation of pollutants. They may provide ancillary **amenity** benefits.

Land surface relevant for application

Artificial surface	✓
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	

Detention basins are effective when receiving runoff from low permeability surfaces.

Financial costs (Capital, operation & maintenance)

Detention basins are **high land-take measures** used within the urban environment. The primary cost is therefore the cost of **land acquisition** or the **opportunity cost** of not using that land for development. This will depend on the land values at the site. Geotechnical investigations are required to confirm the land stability and underlying soil/geology conditions (€1k-€10k). Construction costs range between €10 and 110/m³.

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Scale

Detention basins can be designed to accommodate any volume of runoff. The contributing area is unlikely to be greater than 1 km², since SuDS should deal with runoff close to source.

Design

Detention basins should be incorporated in a wider **sustainable drainage system**. The size of a basin depends on the topography, the contributing area, the relationship between the amounts of incoming and discharged water, and the **storage requirements**. CIRIA recommends a maximum depth of 3m, a flat bottom and side slopes not greater than 1 in 4. Detention basins should not be built where water storage may cause slope instability or foundation problems. Regular inspection and maintenance is essential.

Case studies: Sustainable stormwater management in Fornebu, Norway; Leidsche Rijn sustainable urban development, Netherlands

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U10 - Detention basins

Potential biophysical effects

Runoff	High
Reducing pollution	Medium
Soil conservation	Medium
Habitat	Medium
Climate Change	Low

Ecosystem services delivered

Provisioning	Medium
Regulation & maintenance	High
Cultural	Low
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Low
Floods Directive	High
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Low

Detention basins **temporarily store runoff**, then releasing it at a slower rate downstream. They are not designed to allow infiltration. The storage capacity is dependent on the design of the basin, which can be sized to accommodate any size of rainfall event. Detention basins thereby can reduce the risk of surface **flooding** in conjunction with other SuDS features, and in doing so contribute to climate change adaptation.
Detention basins can be effective at **capturing sediment** in urban or rural runoff and at **pollutant removal**; effectiveness varies considerably and is improved by good design and maintenance. Through reducing diffuse pollution, detention basins make a small contribution to preserving and improving surface **water quality**.
Detention basins may provide minor biodiversity benefits (although unlikely to provide significant habitat improvements). As a **green infrastructure** component, increased application of detention basins will contribute to meeting the objectives of the 2020 Biodiversity Strategy. Where used to intercept and store runoff from low permeability surfaces in agricultural areas, detention basins can contribute to more sustainable agricultural practices. Finally, by creating green areas, they provide **aesthetic** and recreational benefits.

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High Medium Low None

Project funded by the EU – DG Environment

U11 - Retention ponds

Retention ponds are ponds or pools designed with **additional storage capacity** to attenuate surface runoff during rainfall events. Retained runoff is released at a controlled rate. Ponds are created by using an existing natural depression, by excavating a new depression, or by constructing embankments. They can provide both storm water attenuation and water quality treatment. Well-designed and maintained ponds can offer aesthetic, amenity and ecological benefits to the urban landscape.

Land surface relevant for application

- Artificial surface ✓
- Agriculture land ✓
- Forest and semi-natural areas ✓
- Wetlands

Financial costs (Capital, operation & maintenance)

Retention ponds are **high land-take measures** used within the urban environment. The primary cost is therefore the cost of **land acquisition** or the **opportunity cost** of not using that land for development. This will depend on the land values at the site. Geotechnical investigations are required to confirm the land stability and underlying soil/geology conditions. Capital costs range between €10 and 60/m^3 storage volume, and there will be ongoing relatively minor maintenance costs.

Scale

The drainage area required to support a retention pond can be as low as 0.03-0.1 km^2. There are no constraints on the maximum drainage area, although SuDS should treat runoff close to source.

Design

Retention ponds should be combined with **upstream sustainable drainage components**, such as smaller detention basins and swales. Ponds would be sited at a low point in the catchment where it can receive drainage by gravity. Soils should be sufficiently **impermeable** to stop the water drying out. In areas of contaminated soils or groundwater the pond should be fully sealed to prevent transfers with the aquifer. Regular inspection and maintenance is important.

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Case studies: Retention pond in Chêne Bougerie, Switzerland; Ecological adapted stormwater treatment in Kretinga , Lithuania

U11 - Retention ponds

Potential biophysical effects

- Runoff
- Reducing pollution
- Soil conservation
- Habitat
- Climate Change

Ecosystem services delivered

- Provisioning
- Regulation & maintenance
- Cultural
- Abiotic

Contribution to policy objectives

- Water Framework Directive
- Floods Directive
- Birds & Habitats Directive
- 2020 Biodiversity Strategy

Retention ponds reduce peak runoff through **storage** and **controlled outflow release** (although as they do not infiltrate runoff they therefore provide little total volume reduction). Typically, they will be designed for events up to the 1 in 30 year storm. Ponds can reduce the risk of surface **flooding** in conjunction with other SuDS features, which contributes to climate change adaptation.
Retention ponds can be effective at **pollutant removal**; effectiveness will be improved by good design and maintenance and increased residence time. They are also highly effective at intercepting **sediment**. Through reducing diffuse pollution, retention ponds play a role in preserving and improving surface **water quality**.
Creation of ponds will create new **aquatic and riparian habitat**, therefore increasing natural biomass production and contributing to biodiversity preservation. Increased application of retention ponds may also contribute to meeting the objectives of the 2020 Biodiversity Strategy through the use of green infrastructures. Where used as rural SuDS components, retention ponds can contribute to more sustainable agricultural practices. Ponds also increase the aesthetic/cultural value of the landscape.

High *Medium* *Low* *None*

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U12 - Infiltration Basins

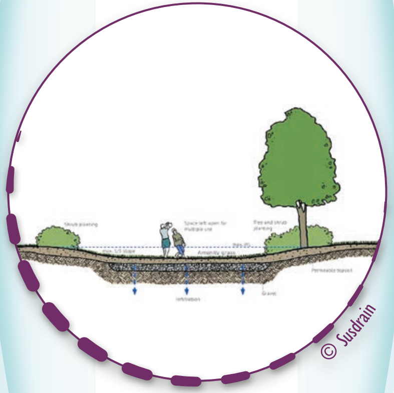
Infiltration basins are **vegetated depressions** designed to hold runoff from impervious surfaces. They allow the settling of sediments and associated pollutants, and allow water to **infiltrate** into underlying soils and groundwater. Infiltration basins are dry except in periods of heavy rainfall, and may serve other functions at other times (e.g. recreation). They provide runoff storage and flow control as part of a **SuDS 'train'**. Infiltration basins may also act as "bioretention areas" of shallow landscaped depressions, typically under-drained and relying on engineered soils, vegetation and filtration to reduce runoff and remove pollution.

Land surface relevant for application

Land surface	Relevant
Artificial surface	✓
Agriculture land	✓
Forest and semi-natural areas	✓
Wetlands	

Financial costs (Capital, operation & maintenance)

The primary cost of infiltration basins is **land acquisition** or the opportunity cost of not using that land, which depends on land value. Geotechnical investigations are also required. Construction costs range between €15 and 90/m^3 of detention volume and there will also be some ongoing annual maintenance costs.



Scale

In general, infiltration basins are designed to treat small drainage areas, typically covering a **number of properties** (from 2 to 20 hectares). They should not be used as solutions for larger drainage areas due to the increased risk of sediment loading to the basin.

Design

Infiltration basins should not be used in areas where there is a pollution risk to groundwater. Ground stability should be verified prior to construction. To guarantee infiltration potential, the seasonally high **groundwater table** should be more than 1m below the floor, which should be made as level as possible. An outflow control structure and an emergency spillway should be included where required. Regular inspection and maintenance is needed.

Case studies: Leidsche Rijn sustainable urban development, Netherlands

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U12 - Infiltration Basins

Potential biophysical effects

Runoff	High
Reducing pollution	Medium
Soil conservation	Low
Habitat	Medium
Climate Change	Low

Ecosystem services delivered

Provisioning	Medium
Regulation & maintenance	High
Cultural	Low
Abiotic	None

Contribution to policy objectives

Water Framework Directive	Low
Floods Directive	High
Birds & Habitats Directive	None
2020 Biodiversity Strategy	Medium

Infiltration basins are designed to **store runoff** to be infiltrated. They typically infiltrate 50% of their storage volume within 24 hours of filling. The required volume depends on the conditions of the underlying soil and the size and characteristics of the drainage area. Evidence indicates that infiltration basins can be effective in **reducing peak runoff** by 40% (large storms) and up to 87% (small storms), and in slowing runoff for events that exceed their storage capacity. Used in conjunction with other SuDS features, infiltration basins thus reduce the risk of **surface runoff flooding** and contribute to the reduction in peak river flows in small catchments.

Infiltration basins are highly effective at providing **enhanced groundwater recharge**, thus contributing to improving **quantitative status** of underlying groundwater bodies. However, infiltration performance decreases over time.

Infiltration basins can be effective at **pollutant removal** (up to 88% reduction), thereby reducing urban diffuse pollution. As a **green infrastructure** component, they contribute to meeting the objectives of the 2020 Biodiversity Strategy in urban areas.

High *Medium* *Low* *None*

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