*Disclaimer: This document has been prepared by the Natural Water Retention Measures (NWRM) Working Group which is co-chaired by the EPA and the OPW to inform the Programme of Measures for the 3rd Cycle River Basin Management plan. The information contained in this document has been sourced from other existing studies and research papers and references for same have been provided throughout. It is recommended that the reader should consult with these original reports/studies to obtain more detailed information. The methodology used to rank and score specific measures was informed by existing studies and based on the authors informed opinion and as such are open to interpretation and further refinement.*

# Natural Water Retention Measures (NWRM)

# Evidence and Opportunities for use in Ireland

Working Group

September, 2020

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Oifig na nOibreacha Poiblí
Office of Public Works

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# 1 Overview

## 1.1 Background

The Water Policy Advisory Committee (WPAC) requested that the National Technical Implementation Group (NTIG) develop a proposal for including Natural Water Retention Measures (NWRM) as part of a broader suite of mitigation measures that could contribute to the achievement of environmental objectives set out in the second River Basin Management Plan.

This report and its findings are intended to build a useful knowledge base of evidence for use of NWRM in the Irish context. It is supplementary to the report which focuses on implementation of NWRM in terms of policy and funding - *Overview and Recommendations for Use in Ireland.*

This report largely draws upon the existing knowledge base contained within the following published studies:

- European Commission DG Environment study *Atmospheric Precipitation - Protection and efficient use of Fresh Water: Integration of Natural Water Retention Measures in River basin management (2013-2014)*
- UK Environment Agency's *"Working with Natural Processes – Evidence Directory" (2018).*

Where required, additional data and evidence has been added to either add to or supplement that already contained within the above resources. It is intended that this report will bring all of these findings together and highlight those NWRM that are relevant in the Irish context.

## 1.2 Objectives

The objectives in writing this report are summarised below:

- Define Natural Water Retention Measures (NWRM) and highlight the various categories of measures that exist;
- Briefly summarise the key features of each measure largely drawing on the resources listed in Section 1.1;
- Outline a methodology for selecting targeted measures for strategic prioritisation in Ireland;
- Provide more detailed descriptions and evidence for the prioritised measures;
- The findings from this review will then feed into a complimentary report which examines policy level options for strategic implementation of such measures.

# 2 Key Features

## 2.1 Natural Water Retention Measures

Natural Water Retention Measures (NWRM) are multi-functional measures that aim to protect and manage water resources and address water-related challenges by restoring or maintaining ecosystems as well as natural features and characteristics of water bodies using, or replicating, natural means and processes (EU NWRM, 2015). They are designed to enhance and preserve the water retention capacity of aquifers, soil, river channels and their associated ecosystems. The over-all effect is primarily to slow the inflow of water to rivers and streams, and to then attenuate the flow in-stream.

There are many aspects of NWRM that can lead to significant multiple benefits in an integrated catchment management context particularly in relation to water quality, flood risk reduction, biodiversity and climate.

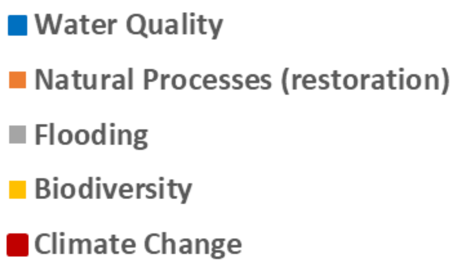
## 2.2 Context

NWRM should be used as part of the overall Integrated Catchment Management (ICM) approach. There are no "one size fits all" approaches, the measures are designed to be used on a site-specific basis, and also as part of a suite of measures designed to complement each other. They are usually thought of as "soft" engineering, i.e. less reliant on the "pipes and concrete" engineering approach but some structures such as barriers, gates, banks etc. may be utilised in some scenarios. However, it is important that even the introduction of these structures do not impede the ecosystem functioning of the river. NWRM are not designed as "no upkeep" measures, with no aftercare. Whilst some measures are designed to be self-sustaining, others require ongoing maintenance or active management.

NWRM can offer multiple benefits that may include;

- improving water quality
- regulating water storage and delivery
- flood risk reduction
- sequestering carbon
- supporting and enhancing biodiversity
- improving amenity value (e.g. angling and walking)
- health benefits (e.g. mental health benefits/improved air quality)
- aesthetic quality (e.g. visually desirable features such as ponds)
- cultural benefits (i.e. tourism and recreational value of rivers)
- climate change resilience (e.g. increased buffering to extreme rainfall events)
- reducing carbon emissions (reduced carbon intense hard engineering)

The above list can be grouped into two sub-categories: environmental benefits and social benefits – this report is focussed only on the environmental benefits of NWRM. It was therefore decided to assess each measure under the following key headings in terms of their associated environmental benefit:




NWRM have been utilised in many guises historically. Most recently the move towards Sustainable Urban Drainage Systems (SuDS) in the urban setting has seen widescale rollout of some NWRM. In fact, many other planning and design strategies in recent years have incorporated elements of NWRM but have not labelled them as such; examples include:

- Natural Flood Management (NFM)
- Nature based solutions
- Green/bio/eco/soft engineering
- Catchment based flood management
- Engineering with nature
- Multi-objective floodplain management (used in the US)
- Working with natural processes (WWNP)
- Sustainable Urban Drainage Systems (SuDS)
- Rural Sustainable Urban Drainage Systems (RSuDS)

The evidence from the literature highlights that NWRM are most effective when used strategically as part of an overall catchment management approach. The treatment train approach for the implementation of SuDs is a good example of such strategic implementation. The "train" involves a number of measures designed in a sequential manner to provide further and higher levels of treatment down the "train". Multiple measures can provide different complimentary forms of treatment in sequence or allow for further removal of key pollutants to meet a required standard. This strategy is best implemented considering catchments from "source to sea" thus maximising the opportunities for appropriate measures within each river sub-catchment. This is illustrated in the UK Environment Agency's WWNP Evidence Directory Report schematic reproduced in Figure 2-1 below. Given the broad range of catchment types across the country there is no "one size fits all" approach with individual catchments requiring tailored plans to take account of local issues such as land use channel width, soil type, gradient etc.

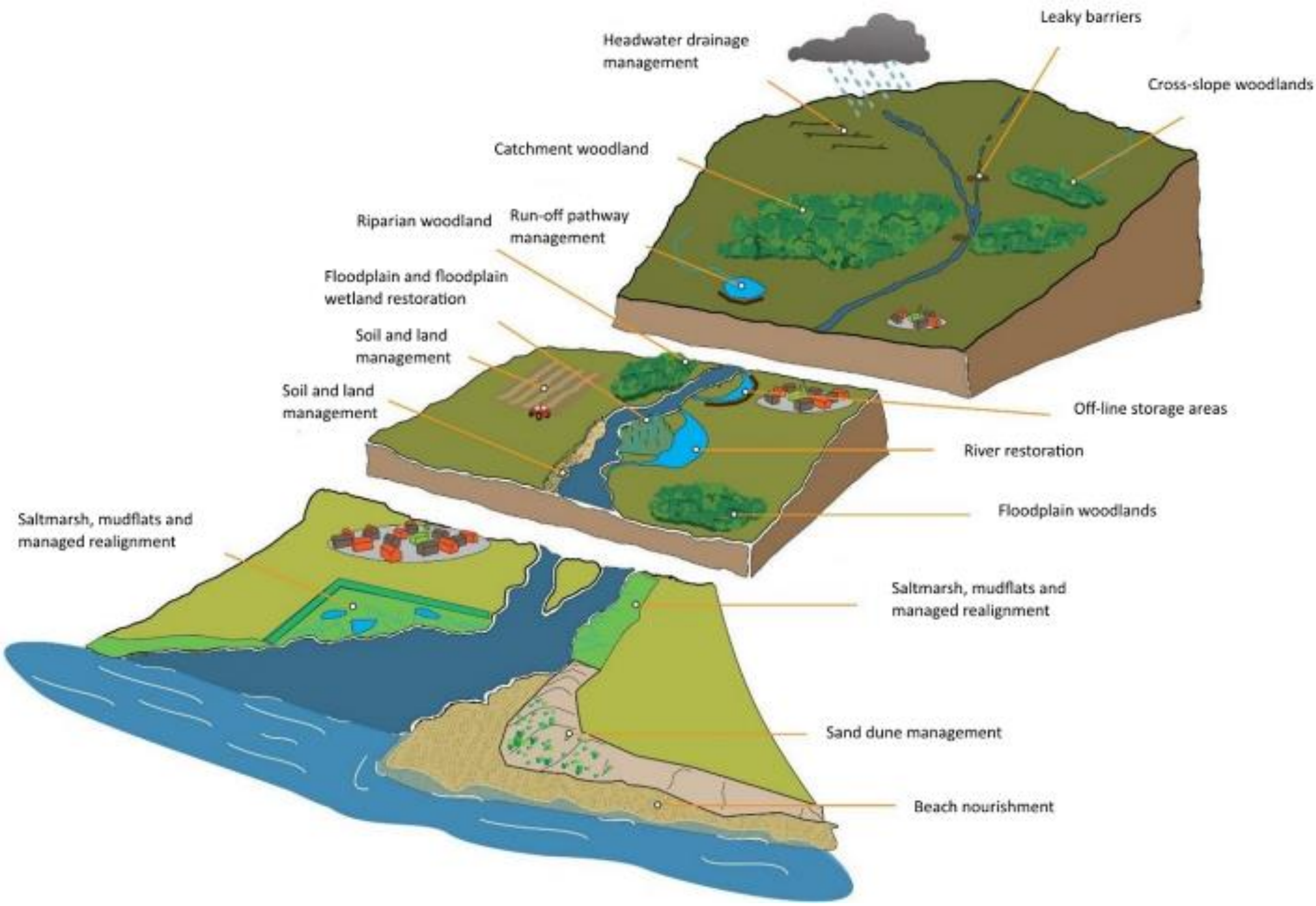



***Figure 2-1 Incorporation of NWRM within a catchment must be considered from source to sea as part of the ICM approach (image reproduced from the WWNM report published by the Environment Agency, 2018)***

# 3 Catalogue of measures

The main repository of easily accessible knowledge on the European context is the Natural Water Retention Measures (NWRM) DG Environment study which provides a comprehensive overview of a large cohort of measures together with numerous case studies and evidence (EU NWRM, 2015). Another large study was also carried out in the UK by the Environment Agency in conjunction with other aligned agencies. Working with Natural Processes (WWNP) aimed to present evidence of the current state of the scientific evidence underpinning NWRM and provide interested stakeholders with up to date information about the effectiveness of a range of different measures from a flood risk and ecosystem services perspective (Environment Agency, 2018). It must be noted that some measures are more suited to a particular setting such as the built or natural environment.

The European Study grouped NWRM into 4 main thematic areas or settings (see Figure 2.1):

- Agriculture
- Forest
- Urban
- Hydromorphology.

WWNP took a slightly different approach and grouped measures by their position in the landscape:

- River and floodplain management
- Woodland management
- Run-off management
- Coast and estuary management

Synergies between both studies naturally exist and each thematic area has an associated suite of measures backed by case studies.

Both studies provided an excellent evidence base for this current review in the Irish context and should continue to be consulted for further detail to complement this review. However, in the Irish context, specific measures relating to peatland areas were lacking from both studies and this review also provides an opportunity to include other relevant measures for Ireland that have features in recent research.

It must be noted that measures can also be categorised into man-made interventions (e.g. a constructed wetland) and restoration/rehabilitation of natural ecosystems (e.g. restoration/ rehabilitation of a peatland). However, for the purposes of this report, the structure as set out in the European Study has been adopted.

A review of existing best practice for Ireland in terms of peatland restoration/rehabilitation and NWRM was carried out and a suite of measures was produced and is contained in Appendix 1 – see Figure 3.1 for a summary list. A brief review of the final list of measures is included below.

**River Restoration**

- Basins and ponds
- Wetland restoration and management
- Floodplain restoration and management
- Re-meandering
- Stream bed re-naturalization
- Restoration and reconnection of seasonal streams
- Reconnection of oxbow lakes and similar features
- Riverbed material renaturalisation
- Removal of dams and other longitudinal barriers
- Natural bank stabilisation
- Elimination of riverbank protection
- Lake restoration
- Restoration of natural infiltration to groundwater

**Forest**

- Forest riparian buffers
- Maintenance of forest cover in headwater areas
- Afforestation of reservoir catchments
- Targeted planting for 'catching' precipitation
- Land use conversion
- Continuous cover forestry
- Water sensitive driving
- Appropriate design of roads and stream crossing
- Sediment capture ponds
- Coarse woody debris
- Urban forest parks
- Trees in urban areas
- Peak flow control structures
- Overland flow areas in peatland forests

**Agriculture**

- Meadows and Pasture
- Buffer strips and hedges
- Crop Rotation
- Strip cropping along contours
- Intercropping
- No till agriculture
- Low till agriculture
- Green Cover
- Early sowing
- Traditional terracing
- Controlled traffic farmig
- Reduced stocking density
- Mulching
- Re-wetting drained organic lands

**Urban**

- Green Roofs
- Rainwater Harvesting
- Permeable surfaces
- Swales
- Channels and rills
- Filter Strips
- Soakaways
- Infiltration Trenches
- Rain Gardens
- Detention Basins
- Retention Ponds
- Infiltration basins
- Detention Basins

**Peat**

- Drain blocking
- Artificial wetlands
- Wetland lakes
- Bunding
- Spagnum inoculation
- Land re-profiling
- Clearance of inappropriate vegetation on peatlands

***Figure 3-1 NWRM grouped into various settings [Note: many measures cross between multiple settings and are not limited only to the areas shown here]***

## 3.1 Measures identified within EU NWRM project

The following provides a brief overview of the majority of measures that have been identified as NWRM within the European Study – measures not applicable for Ireland have been removed. A selection of other additional measures identified during this review are included in Section 3.2. The brief summary provided below has been taken directly from the existing evidence directory compiled within the European Study (EU NWRM, 2015).

### 3.1.1 Agriculture

#### *3.1.1.1 Meadows and Pasture*

Due to their rooted soils and their permanent cover, meadows and pastures provide good conditions for the uptake and storage of water during temporary floods. They also protect water quality by trapping sediments and assimilating nutrients. The measure offers the potential for temporary flood storage, increased water retention in the landscape and runoff attenuation.

#### *3.1.1.2 Buffer Strips and Hedges*

Buffer strips are areas of natural vegetation cover at the margin of fields, arable land, transport infrastructures and water courses. Due to their permanent vegetation, buffer strips offer good conditions for effective water infiltration and slowing surface flow; they can also significantly reduce the amount of suspended solids, nitrates and phosphates originating from agricultural run-off. The practice of riparian fencing contributes to the creation of riparian buffer strips and is included in this categorisation. Buffers are not always linear strips and can take many forms.

In areas where there are Arterial Drainage Schemes or Drainage Districts riparian tree planting may need to be spaced to allow access to the watercourse for maintenance activities.

Buffer strips can be sited in riparian zones, or away from water bodies as field margins, headlands or within fields. Hedges across long, steep slopes may reduce soil erosion as they intercept and slow surface run-off water before it builds into damaging flow, particularly where there is a margin or buffer strip alongside. *Note that buffer strips are not always linear – they can also be targeted areas of woodland or plots.* There is even some evidence that buffer plots/zones may be more effective when specific delivery pathways are clearly evident.

#### *3.1.1.3 Arable measures*

*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 (i.e. selecting a suitable crop) crop rotation can improve soil structure and fertility by alternating deep-rooted and shallow-rooted plants. In turn this can reduce erosion and increase infiltration capacity, thereby reducing downstream flood risk.

*Strip Cropping along Contours*

Strip cropping alternates strips of closely sown crops such as hay, wheat, or other small grains with strips of row crops, such as maize, or sugar beets. Strip cropping helps to stop soil erosion by creating natural dams for water, helping to preserve the strength of the soil. Certain layers of plants will absorb minerals and water from the soil more effectively than others. When water reaches the weaker soil that lacks the minerals needed to make it stronger, it normally washes it away. When strips of soil are strong enough to slow down water from moving through them, the weaker soil can't wash away like it normally would. Because of this, farmland stays fertile much longer. There is no available information on the extent of strip cropping in Europe. The practice has been widespread in North America as a means of mitigating soil erosion from wind and water.

*Inter-Cropping*

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.

*Low/No-Till Agriculture*

Intensive tillage can disturb the soil structure, thus increasing erosion, decreasing water retention capacity, reducing soil organic matter through the compaction and transformation of pores. No-till farming (also called zero tillage or direct drilling) is a way of growing crops or pasture from year to year without disturbing the soil through tillage. This measure increases the amount of water that infiltrates into the soil and increases organic matter retention and cycling of nutrients in the soil. In many agricultural regions it can eliminate soil erosion. The most powerful benefit of no-tillage is improvement in soil biological fertility, making soils more resilient.

*Green Cover (Cover Crops)*

Green cover (including cover crops or catch crops) refers to crops planted in late summer or autumn, usually on arable land, to protect the soil, which would otherwise lie bare during the winter, against wind and water erosion. Green cover crops also improve the structure of the soil, diversify the cropping system, and mitigate the loss of soluble nutrients.

*Early Sowing*

Early sowing refers to sowing up to six 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 run-off are less significant and water infiltration is improved. Early sowing can also help to mitigate summer drought impacts on spring sown crops, in particular the extreme evapotranspiration rates of Mediterranean regions. However, early sown plants are frost sensitive; therefore, farmers run the risk of losing the crops because of the low temperatures.

#### 3.1.1.4 Controlled Traffic Farming

Controlled traffic farming (CTF) is a system which confines all machinery loads to the least possible area of permanent traffic lanes. Current farming systems allow machines to run at random over the land, causing varying levels of compaction. Soils don’t recover quickly, taking as much as a few years in some instances. A proper CTF system on the other hand can reduce tracking to just 15% of the land area and this is always in the same place.

#### 3.1.1.5 Land Management Practice

This measure is aimed at optimising land management practices though appropriate stocking density to achieve multiple benefits. Livestock, particularly heavy species such as cattle, can have several damaging impacts on soil including compaction, destruction of soil structure (poaching) and loss of vegetation. These impacts can reduce infiltration of water into the soil, resulting in pooling and water logging with consequent impacts of denitrification and nitrous oxide emissions. Soil compaction will also increase the risk of run-off with consequent impacts on water quality and flood risks. All livestock, where inappropriately managed can have several damaging impacts on soil including compaction, destruction of soil structure (poaching) and loss of vegetation, encroachment of scrub. These impacts can reduce infiltration of water into the soil, resulting in pooling and water logging with consequent impacts of denitrification and nitrous oxide emissions. Soil compaction will also increase the risk of run-off with consequent impacts on water quality and flood risks.

It must be noted that altering stocking density is a complex undertaking and may not always have a positive impact in terms of biodiversity or water quality. For example, reducing sheep numbers in upland areas can result in an increase in deer abundance with some studies showing that deer grazing leads to a reduction in structural heterogeneity of vegetation mosaic compared with sheep grazing.

Decisions on stocking density for at risk farmland need to be taken in consultation with an agricultural advisor and should take into account soil type, topography, soil moisture content, weather conditions, alternative grazing grounds, farming enterprise and socio economic impacts.

##### *3.1.1.6 Mulching*

Mulching as NWRM is using organic material (e.g. bark, wood chips, grape pulp, shell nuts, green waste, leftover crops, compost, manure, straw, dry grass, leaves etc.) to cover the surface of the soil. It may be applied to bare soil, or around existing plants. Mulches of manure or compost will be incorporated naturally into the soil by the activity of worms and other organisms. The process is used both in commercial crop production and in gardening, and when applied correctly can dramatically improve the capacity of soil to store water. It may also be a useful measure to consider in the urban environment.

### 3.1.2 Forestry

#### *3.1.2.1 Forest Riparian Buffers*

By preserving a relatively undisturbed area adjacent to open water, riparian buffers can serve several functions related to water quality and flow moderation. The trees in riparian areas can efficiently take up excess nutrients and may also serve to increase infiltration. Riparian buffers serve to slow water as it moves off the land. This can decrease sediment inputs to surface waters.

#### *3.1.2.2 Maintenance of Forest Cover in Headwater Areas/ Afforestation of Reservoir Catchments*

Forests in headwater areas have a beneficial role for water quantity and quality. Creating or maintaining forest cover in headwater catchments is a widely-used practice in many major cities including New York, Istanbul and Singapore, as these cities are reliant on headwater forests for drinking water. Forest soils generally have better infiltration capacity than other land cover types and may act as a “sponge”, slowly releasing rainfall. In areas of high relief, afforestation of headwater catchments can contribute to slope stabilization and may reduce the risks associated with landslides. On the other hand, afforestation of headwaters in dry areas may lead to reduction of water yield.

#### *3.1.2.3 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. Afforestation may occur deliberately or through the abandonment of marginal agricultural land. Depending on the tree species planted and the intensity of forest management, afforestation may have variable levels of environmental benefits. The NWRM related benefits include potentially enhanced evapotranspiration associated with growing forests and better water holding capacity associated with forest soils. The greatest environmental benefits are associated with planting of indigenous broadleaves and low intensity forestry.

#### 3.1.2.4 *Continuous Cover Forestry*

Continuous cover forestry is a broad range of forest management practices which have some beneficial hydrological effects. The main idea behind continuous cover forestry is a reduction in the number or size of clearfells. Some definitions of continuous cover forestry state that no clearfells should be larger than 0.25 ha. Continuous cover forestry ensures that there is an uninterrupted tree canopy and that the soil surface in never exposed. An uninterrupted tree canopy will have higher interception than a site with discontinuous tree cover. Ensuring that soils are never exposed will limit sediment production.

#### 3.1.2.5 *Water Sensitive Driving*

Off road driving has potentially negative consequences for water quality. Some of these damages can be minimized or mitigated if drivers of vehicles exercise a few simple precautions. Avoiding driving in wet areas whenever possible will limit soil compaction and rutting. Rutting can concentrate flow paths and lead to increased erosion. Driving parallel to contour lines of hill slopes will reduce the potential for rut formation and concentration of flow paths but may not always be feasible, especially in areas of high relief. Use of brash cover or specially designed logging mats in off road driving during forest logging operations may help to reduce soil compaction and rutting. Reduction of truck tire pressure on unpaved forest roads may also be considered as one aspect of this NWRM.

#### 3.1.2.6 *Appropriate design of roads and stream crossings*

Forest access roads and other roads in rural areas often cross streams and other small watercourses. Design and material used in forest road building may have strong impact on erosion risk and water quality in streams. The bridges or culverts used to cross these watercourses must be designed appropriately if negative impacts on the aquatic environment are to be minimized. Appropriate designed or implemented stream crossings avoid numerous negative effects on the aquatic environment including increased sediment mobilization and changes in flow patterns. Sediment Capture Ponds

Sediment capture ponds are engineered ponds placed in networks of forest, agricultural or peat drainage ditches to slow the velocity of water and cause the deposition of suspended materials. In a forest setting, sediment capture ponds are most useful for managing the effects of ditch construction and maintenance, road work and final felling. In the agricultural setting, they can capture sediment losses from drainage activities, livestock poaching and losses from bare soils. Whilst sediment capture ponds have a limited lifespan, depending on how much suspended material is in the inflowing water, ponds can be maintained by removal of accumulated sediment. Like most water protection methods, sediment capture ponds function well during base and moderate flow events. Catchment area, hydraulic properties of ditches, discharge rate and soil characteristics are among factors influencing functioning of sedimentation capture ponds. Effective functioning largely depends also on expertise and skill of professionals designing and implementing these and other measures.

#### 3.1.2.7 *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. Coarse woody debris can be used to form coffer or placer dams which effectively limit water flow. This measure can also consider the use of deadfall coarse woody debris that naturally falls into streams. Coarse woody debris will generally slow water flow velocity and can reduce the peak of the flood. In addition to its role in slowing streamflow and facilitating sediment accumulation, coarse woody debris can improve aquatic biodiversity by retaining food and providing additional habitat, such as refuges and spawning sites.

Caution must be used in the design and implementation of these measures to ensure that they do not become barriers to fish passage.

#### *3.1.2.8 Urban Forest Parks/ Trees in Urban Areas*
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 (and trees in urban settings) often have greater infiltration capacity than other urban land cover and can be an important location for aquifer recharge. Trees also transpire, which dries the soil and gives greater capacity for rainfall storage. Trees in urban areas can have multiple benefits related to aesthetics, microclimate regulation and urban hydrology. Trees in urban areas can also be important biodiversity refuges and can contribute to reducing particulate air pollution. Trees intercept precipitation, reducing the amount of rainfall which must be processed by sewers and other water transporting infrastructure.

#### *3.1.2.9 Peak Flow Control Structures*
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 will have a limited lifespan as sediment will eventually fill in the upstream detention pond. However, ponds can be maintained by removal of accumulated sediment.

#### *3.1.2.10 Overland Flow Areas in Peaty Forests*
Overland flow areas collect some of the excess sediment produced during ditch maintenance and other forest management operations such as road building or harvesting. Overland flow areas are created by building a semi-permeable barrier in a forest ditch. Upstream of the barrier, lateral ditches are constructed to transport water into the surrounding catchment. During periods of high flow, water will overflow the lateral ditches and travel across land to reach the receiving lake or stream. As the water travels across land, its velocity will be slowed and much of the sediment being carried will be deposited. At periods of low flows, the permeable dam will slow water flow and cause deposition of sediment.

### 3.1.3 River restoration

#### *3.1.3.1 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 ponds, flood storage reservoirs, shallow impoundments) contains water during dry weather, and is designed to hold more when it rains.

#### *3.1.3.2 Wetland Restoration (Rehabilitation) and Management*
Wetlands, whether natural or artificial, can provide water retention, biodiversity enhancement or water quality improvement. Wetland restoration/*rehabilitation* and management can involve: technical, spatially large-scale measures (including the installation of ditches for rewetting or the cutback of dykes to enable flooding); technical small-scale measures such as clearing trees; changes in land-use and agricultural measures, such as adapting cultivation practices in wetland areas. They can improve the hydrological regime of degraded wetlands and generally enhance habitat quality. Creating artificial or constructed wetlands in urban areas can also contribute to flood attenuation, water quality improvement and habitat and landscape enhancement.

#### *3.1.3.3 Floodplain restoration and management*
Floodplains in many places have been separated from the river by dikes, berms or other structures designed to control the flow of the river. They have also been covered by legacy sediments. Major floodplains roles have thus been lost, due to land drainage, intensive urbanization and river channelization. The objective is to restore them, their retention capacity and ecosystem functions, by reconnecting them to the river. This can be done in a variety of

ways including modification of the channel, removing sediment, creation of lakes or ponds in the floodplain, new/modification of agricultural practices, plantation of native grasses, shrubs and trees, creation of grassy basins and swales, wetland creation, invasive species removal and riparian buffer installation.

#### *3.1.3.4 Re-meandering*

River re-meandering consists in 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 very often also has a positive impact on sedimentation and biodiversity. The newly created or reconnected meanders also provide habitats for a wide range of aquatic and land species of plants and animals.

#### *3.1.3.5 Stream Bed Re-naturalisation*

In the past, riverbeds were artificially reconstructed with concrete or big stones, therefore modifying flows and decreasing fauna habitat and vegetation diversity. Those modifications were aiming at flood prevention or supporting changes of agricultural practices for example. This has led to uniformed flows in the rivers and often having effect of reducing travel time along the river. Streambed re-naturalization consists of removing concrete or inert constructions in the riverbed and on riverbanks, then replacing them with appropriate vegetation structures.

Arterial Drainage with the associated large excavations has led to uniformed flows. The OPW with IFI carry out instream river enhancement works on important salmonid drained rivers (with suitable gradients). This can involves rehabilitating spawning gravels and increasing instream diversity with enhancement structures to replicate more natural channel sinuosity and depth variation at low flow levels.

#### *3.1.3.6 Restoration and reconnection of seasonal streams*

Seasonal streams or intermittent rivers are rivers for which surface water ceases to flow at some point in space and time. Seasonal streams provide essential ecosystem services to society, including flood control and irrigation. Despite their values and ongoing alterations, seasonal streams are chronically under-studied and protective management is inadequate. Restoring and reconnecting seasonal streams with the river enhances the overall functioning of the river by restoring lateral connectivity, diversifying flows and ensuring the proper functioning of these seasonal streams for a better water retention during floods.

#### *3.1.3.7 Reconnection of oxbow lakes and similar feature*

An oxbow lake is an ancient meander that was cut off from the river, thus creating a small lake with a U form. If the cut-off was due to man-made intervention and when appropriate, reconnecting it with the river consists in removing terrestrial lands between both water bodies, therefore favouring the overall functioning of the river by restoring lateral connectivity, diversifying flows and cleaning the river section of the present oxbow for better water retention during floods.

#### *3.1.3.8 Riverbed material re-naturalization*

Riverbed re-naturalization consists of recovering the natural structure and composition of the bed load, specifically the equilibrium between coarse and fine sediment. In the case of a deficit of coarse sediment leading to river incision, the main objective is to level-up the riverbed with this type of sediment, by reactivating bank erosion in terrains contributing to this type of sediment. It should be noticed that in case of excess fine sediment causing inundations, silting of hydro-electric dams or degradation of fish habitats, the main objective is to control erosion on slopes and riverbanks providing this type of sediment.

#### *3.1.3.9 Removal of dams and other longitudinal barriers*
Dams and other transversal barriers are obstacles crossing the river section and causing discontinuities for sediment and fauna. Removing them involves physically removing all associated obstacles, restoring the slope and the longitudinal profile of the river, therefore allowing re-establishment of fluvial dynamics, as well as sedimentary and ecological continuity.

#### *3.1.3.10 Natural bank stabilisation*
In the past, many artificial banks were built with concrete or other types of retention walls, therefore limiting rivers' natural movements, leading to degradation of the river, increased water flow, increased erosion and decreased biodiversity. River bank re-naturalisation involves recovering its ecological components, thus reversing such damage whilst maintaining the stability of the bank, as well as allowing rivers to move more freely. However, this measure is case specific and may not be appropriate in some situations. Furthermore, while nature-based solutions such as bioengineering are preferable, civil engineering solutions may still need to be considered in more challenging hydrological regimes.

#### *3.1.3.11 Removal of riverbank protection*
A riverbank protection is an inert or living construction providing bank fixation but also an obstacle for the lateral connection of the river. Removal of hard engineered structures therefore involves demolition and regrading some parts of the bank protection. Such work enhances lateral connectivity of the river with the surrounding land, diversify flows (depth, substrate, and speed) and habitats, but also cap floods in the mainstream. Similar to 'natural bank stabilisation' it is case specific and may not be appropriate in some situations. It is a prerequisite for many other measures like re-meandering or widening, as well as initiating later channel migration and dynamics.

#### *3.1.3.12 Lake Restoration (Rehabilitation)*
Lakes can provide water retention services. They can store water (for flood control) and provide water for many purposes such as water supply, irrigation, fisheries, tourism, etc. In addition, they can serve as a sink for carbon storage and provide important habitats for numerous species of plants and animals, including waders. In the past, lakes have sometimes been drained to free the land for agriculture purposes or have accumulated excess levels of fine sediment due to runoff from land and drains. Restoring or rehabilitating lakes involve enhancing their structure and functioning where they have been drained in former times.

#### *3.1.3.13 Restoration of natural infiltration to groundwater*
Previous modifications of the landscape have reduced the infiltration capacity of many European soils, thereby limiting the rate at which precipitation is able to infiltrate and recharge groundwater aquifers. Restoration of natural infiltration to groundwater enables a lowering of run-off from surrounding land and enhances the condition of groundwater aquifers and water availability. The natural cleaning processes associated with infiltration can improve water quality. This measure can also be known as "Artificial Groundwater Recharge" in the engineering literature.

Mechanisms to restore or enhance natural infiltration capacity 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.

#### *3.1.3.14 Re-naturalisation 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-naturalization involves enhancing polders with sub-natural characteristics, allowing better water storage in watercourses inside the polder, as well as increased biodiversity.

### 3.1.4 Urban

#### *3.1.4.1 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 cover the entire roof area with lightweight, low growing, self-sustaining, low maintenance planting. They are only accessed for maintenance. Vegetation normally consists of hardy, drought tolerant, succulents, herbs or grasses. Extensive green roofs are often known as sedum roofs, eco-roofs or living roofs.

Intensive green roofs are landscaped environments with high amenity benefits including accessible planters or trees and water features. These impose a greater load on the roof structure and require significant ongoing maintenance including irrigation, feeding and cutting. Intensive roofs are also termed roof gardens.

#### *3.1.4.2 Rainwater Harvesting*

Rainwater harvesting involves collecting and storing rainwater at source for subsequent use, for example, using water butts or larger storage tanks. They are primarily designed for small scale use such as in household gardens, although a range of non-potable uses is possible.

A limitation of rainwater harvesting as an NWRM is that during wet periods, water butts are often full and water use may be low, resulting in little or no attenuation or reduction in outflow rates or volumes. As a result, there are differing opinions about the role of rainwater harvesting in providing a water retention function. Tanks can be specifically designed and managed to accommodate storm water volumes, which is likely to be more effective when applied at a larger scale than individual properties. In general, however, rainwater harvesting should be considered only as a source-control component in a SuDS 'train' where, in combination with other measures, they will contribute to effective and sustainable water management.

#### *3.1.4.3 Permeable Surfaces*

Permeable paving is designed to allow rainwater to infiltrate through the surface, either into underlying layers (soils and aquifers), or be stored below ground and released at a controlled rate to surface water. Permeable paving is used as a general term, but two types can be distinguished:

- Porous pavements, where water is infiltrated across the entire surface (e.g. reinforced grass or gravel, or porous concrete and cobblestones)

- Permeable pavements, where materials such as bricks are laid to provide void space through to the sub-base, by use of expanded or porous seals (rather than mortar or other fine particles).

It is most commonly used on roads and car parks, but the measure can also apply to broader use of permeable areas to promote greater infiltration.

#### *3.1.4.4 Swales*

Swales are broad, shallow, linear vegetated channels which can store or convey surface water (reducing runoff rates and volumes) and remove pollutants. The promotion of settling is enhanced using dense vegetation, usually grass, which promotes low flow velocities to trap particulate pollutants. In addition, check dams or berms can be installed across the swale channel to promote settling and infiltration. Thus, swales are effective in improving water quality of runoff, by removing sediment and particulate pollutants. In wet swales, the effectiveness is further enhanced by providing permanent wetland conditions on the base of the swale.

#### *3.1.4.5 Channels and Rills*

The main role of channels and rills are to capture runoff at the start of a SuDS train, allow deposition of sediment and convey the runoff to downstream SuDS features. They can also be used in between SuDS features as connectors. They collect water, slow it down and provide storage for silt and oil that is captured.

The outlets are designed to act as a mini oil separator, making them effective at treating pollution and reducing treatment requirements downstream. Clearly channels can be included in many situations and settings but would not always considered to be NWRM unless specifically designed to perform these functions and used in conjunction with other measures.

Planting in channels and rills can visually enhance the urban landscape and offer biodiversity and amenity value. These features can be applied to all new developments and can be retrofitted to existing developments.

#### *3.1.4.6 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.

Filter strips are generally planted with grass or other dense vegetation to treat the runoff through vegetative filtering, sedimentation, and (where appropriate) infiltration. They are often used as a pre-treatment technique before other sustainable drainage techniques (e.g. swales, infiltration and filter trenches). Filter strips are best suited to treating runoff from relatively small drainage areas such as roads and highways, roof downspouts, small car parks, and pervious surfaces.

#### *3.1.4.7 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. The supporting structure and backfill can be substituted by modular, geocellular units.

Soakaways provide storm water attenuation, and storm water treatment. They also increase soil moisture content and help to recharge groundwater, thereby offering the potential to mitigate problems of low river flows. They store rapid runoff from a single house or from a development and allow its efficient infiltration into the surrounding soil. They can also be used to manage overflows from water butts and other rainwater collection systems or can be linked together to drain larger areas including highways.

#### *3.1.4.8 Infiltration Trenches*

Infiltration trenches are shallow excavations filled with rubble or stone. They allow water to infiltrate into the surrounding soils from the bottom and sides of the trench, enhancing the natural ability of the soil to drain water. Ideally, they should receive lateral inflow from an adjacent impermeable surface but point source inflows may be acceptable with some design adaptation (effectively they are a form of soakaway).

#### *3.1.4.9 Rain Gardens*

Rain gardens are small-scale vegetated gardens used for storage and infiltration. The term ‘rain garden’ is often used interchangeably with ‘bioretention area’ (although the latter could also be applied more loosely to other measures such as filter strips or swales).

Rain gardens are typically applied at a property level and close to buildings, for example to capture and infiltrate roof drainage. They use a range of components, typically incorporated into the garden landscape design as appropriate.

#### *3.1.4.10 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 do not generally allow infiltration: see Section 3.1.4.12 for infiltration basins. 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.

Detention basins are landscaped areas that are dry except in periods of heavy rainfall and may serve other functions (e.g. recreation). Hence, they have the potential to provide ancillary amenity benefits. They are ideal for use as playing fields, recreational areas or public open space. They can be planted with trees, shrubs and other plants, improving their visual appearance and providing habitats for wildlife. Features that oscillate between wet and dry conditions have been found to support a greater diversity of microbes, which can work to better remove contaminants.

#### *3.1.4.11 Retention Ponds*

Retention ponds are ponds or pools designed with additional storage capacity to attenuate surface runoff during rainfall events. They consist of a permanent pond area with landscaped banks and surroundings to provide additional storage capacity during rainfall events. They are created by using an existing natural depression, by excavating a new depression, or by constructing embankments. Existing natural water bodies should not be used due to the risk that pollution events and poorer water quality might disturb/damage the natural ecology of the system.

#### *3.1.4.12 Infiltration Basins*

Infiltration basins are vegetated depressions designed to hold runoff from impervious surfaces, 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 (e.g. recreation). They provide runoff storage and flow control as part of a SuDS 'train'. Storage is provided through landscaped areas that allow temporary ponding on the land surface, with the stored water allowed to infiltrate into the soil. The measure enhances the natural ability of the soil to drain water by providing a large surface area in contact with the surrounding soil, through which water can pass. As with detention basins, features that oscillate between wet and dry conditions have been found to support a greater diversity of microbes, which can work to better remove contaminants.

## 3.2 Additional measures

The area of NWRM is a dynamic and evolving discipline and other additional measures exist that are not captured within the European study. In addition, other measures which are best suited for Irish conditions are also required specifically related to peatlands. Data and evidence for the measures below have been drawn upon from recent research projects and other relevant literature.

### 3.2.1 Agroforestry

Agroforestry is a land use system in which trees are grown in combination with agriculture on the same land. The system gives land owners the flexibility to graze and even cut silage and hay while growing trees for timber in the same field. Agroforestry provides a number of ecosystem services, including benefits to water quality through improved soil infiltration and a reduction in overland flow; reduction in nutrients due to reduced intensity and increased nutrient uptake and reduced soil erosion and machinery related soil disturbance.

### 3.2.2 Re-wetting organic soils

Drain blocking and other measures (including bunding etc.) can be used to re-wet drained organic soils to restore the high water table necessary for natural wetland conditions to be promoted. This measure is primarily aimed at marginal farm lands located on cutover peat. The key benefits of this measure lie in $CO_2$ sequestration for climate change adaption and water quality improvements from associated runoff. However, multiple other benefits also accrue including slowing and reducing runoff with (flood benefits) and increased biodiversity. Coupling this measure with other complimentary measures, such as raised and blanket bog restoration/rehabilitation, offers a unique opportunity to achieve maximum benefits in terms of climate change and re-naturalisation.

### 3.2.3 Engineered ditches

Engineered ditches are constructed by re-engineering traditional drainage ditches with dams/flow control structures to create a series of linear ponds. Water is held back and attenuated within the ditch with the outflow to the waterbody dampened to reduce the impact on peak flow conditions. As water flow is significantly slowed, opportunities for sediment removal by settlement are greatly improved behind the flow barriers with associated benefits for other pollutant removal such as particulate bound phosphorus.

### 3.2.4 Detainment bunds for overland flow

Detainment bunds have been trialled as a means of improving water quality from agricultural runoff particularly focused on particulate phosphorus (P) and sediment (SS). Short-term overland (ephemeral) flow can occur on pasture lands during intense rainfall events when soil is saturated or infiltration capacity has been met. These ephemeral flows form in lands which are usually dry and typically only flow for short periods of time (e.g. hours) in direct response to high intensity rainfall. These flows have the potential to transport a disproportionately large amount of sediment and nutrients from agriculture lands over short periods of time depending on land use in the contributing catchment. Detainment bunds temporarily pond ephemeral water behind an earth bund for the purpose of allowing SS and associated nutrients to settle out, eventually being reincorporated into the soil matrix. This measure has proven very effective locally at the farm scale during studies carried out in New Zealand (Levine et. al., 2019).

### 3.2.5 Drain blocking

Drain blocking on high or cutover bogs typically involves using peat or plastic dams to block the drain and restore the high water table which is necessary for bog growth. The process typically involves clearing the drain, adding a 'key' in the side of the drain to ensure a tight seal before blocking with peat taken from a nearby 'borrow pit'. Alternatively, plastic sheet piling can be used whereby it is inserted into the drain and pushed down into the peat to create a seal as above. The key benefits of drain blocking lie in preventing/slowing runoff from peatland areas (with associated sediment/nutrient/COD benefits for water quality) increased biodiversity, sediment removal, water quality improvement and flood prevention. It must be noted that this measure is difficult to implement in upland areas where blanket bog is present.

### 3.2.6 Artificial wetlands

Artificial wetlands are engineered ponds or low-lying areas that mimic naturally occurring wetlands. They are usually constructed by creating shallow ponds and/or depressions in the land and controlling inflows/outflows to create a permanently wet area. These areas are then filled with wetland plants which are carefully chosen to suit the habitat involved. The design needs to take account of the site's hydrology, landscape and functional ecology. Artificial wetlands have the potential to provide suitable equivalent habitat to natural or restored wetlands. The key benefits of artificial wetlands lie in increased biodiversity, sediment removal, water quality improvement and flood prevention.

### 3.2.7 Wetland lakes

Artificial wetland lakes are engineered lakes constructed by creating depressions in the land and controlling inflows/outflows to create a permanently wet area which can vary in depth – this measure is associated with peatland restoration/rehabilitation and is more focused on biodiversity than water treatment. Wetland plants can be added to the artificial waterbody and islands incorporated to provide refuges for birds and aquatic mammals. These lakes can be stocked with fish for biodiversity or to create an amenity for anglers. The key benefits of artificial wetland lakes lie in increased biodiversity, sediment removal, water quality improvement and flood prevention.

### 3.2.8 Bunding

There are two forms of bunding which can be carried out as part of peatland restoration/ rehabilitation works: marginal bunding and bunding on high bog. Marginal bunds are constructed on cutover areas at the margins surrounding high bog. The aim of these embankments is to retain a shallow area of water behind it to promote establishment of peat-forming vegetation on cutover areas (i.e Sphagnum regeneration). This measure is best suited to locations where the cutover is extremely flat, there is contributing flow from nearby high bog, peat conditions are suitable to prevent significant vertical losses of water through the peat and there is an adequate marginal drain in place behind the proposed bund location. Bunding in areas of high bog follows essentially the same approach except water is retained by creating a long linear embankment on the high bog surface, or much larger peat bunds constructed on or close to the margins. This measure is typically carried out along with drain blocking to re-wet raised/blanket bogs and restore wet peatland conditions. The main benefit relates to water retention and water quality in associated runoff but also promotes carbon sequestration and biodiversity restoration.

### 3.2.9 Sphagnum Inoculation

Inoculation with Sphagnum is a method of raised bog restoration/rehabilitation for re-establishing peat-forming vegetation in areas where the surface vegetation has been removed or significantly degraded. The process involves preparing the raised bog by creating a flat surface, Sphagnum moss is then harvested from a donor peatland site and spread across the prepared surface which is then protected and federalised to promote growth. Key to the success of this approach is the existence of suitable hydrological conditions for Sphagnum to survive prior to inoculation. Key benefits from this measure include storing/slowing runoff, biodiversity restoration/habitat creation and climate change adaptation and mitigation

### 3.2.10 Land reprofiling

Excavation and re-profiling can be used as a peatland restoration/rehabilitation measure on high or cutover bog, to create more suitable topography and hydrological conditions for peat-forming habitats. This measure is typically utilised in combination with drain blocking and wetland creation as part of an integrated peatland restoration/rehabilitation approach and has similar benefits to other peat measures for water quality, habitat, climate regulation and biodiversity.

### 3.2.11 Clearance of inappropriate vegetation on peatlands

This measure involves the felling/removal of inappropriate conifer plantations in order to increase the area of blanket bog cover; felling of naturally regenerated conifers from open bog can also be carried out. The removal of trees/scrub other than conifers which have naturally regenerated can have the benefit of stopping the spread of invasive species or problematic native tree species which have significant impacts on raised bog habitats by increasing interception and evapotranspiration rates. This measure is typically carried out along with drain blocking to re-wet raised/blanket bogs and restore wet peatland conditions. Key benefits include biodiversity restoration, climate regulation and water quality. It must be noted that this measure can be difficult to implement given the access issues for heavy machinery in peatland areas and can have negative consequences if poorly managed.

## 3.3 Case Studies

### 3.3.1 International

#### *3.3.1.1 'Slowing the Flow at Pickering'*

Pickering is a small town in Yorkshire, England. The town has a history of frequent flooding from the Pickering Beck. The catchment area to the town is circa 69km$^2$. Following flooding in 2007, a flood alleviation scheme was proposed but a cost-beneficial solution was not found.

The "Slowing the Flow at Pickering" project was initiated in 2009 to look at how changes in land use and land management could help to reduce flood risk.

The project combined a range of NWRM and an engineered flood storage area as follows:

- 129 large woody debris dams;
- Blocking of moorland drains with heather bales, no-burn buffer zones on moorland watercourses, reseeding of heather, and repair of eroded moor footpaths;
- 19 ha of riparian woodland and 15 ha of farm woodland planted;
- New forest operational plans;
- A 120,000m$^3$ constructed flood storage area.

The scheme was designed to provide protection up to the 25-Year flood. This standard of protection is provided by the 120,000m$^3$ constructed flood storage area, whereas the other measures are estimated to provide an additional 8,000 – 9,000m$^3$ of storage to delay flow and thus reduce peaks.

In December 2015 and January 2016, the UK, like Ireland, experienced extreme rainfall events in the form of Storm Desmond, Storm Eva, and Storm Frank. Flooding caused by Storm Eva resulted in the evacuation of 2,200 homes in York, North Yorkshire, UK over the Christmas period 2015 (BBC News, 2015). On the 26th of December 2015 Pickering experienced 50mm of rainfall over a 36hr period. This rainfall event resulted in flooding in the town but no properties were flooded. A post-event review carried out by the Slowing the Flow Partnership suggest that the measures reduced the peak flow by 15-20% and that half of the reduction was due to the upstream land management measures and half due to the flood storage area (SFP, 2015). The review did not provide an estimation of how extreme the event in Pickering was. UK Met Office figures show that the rainfall experienced in Pickering was less than half that of other areas in Yorkshire (Met Office, 2016).

This project demonstrates that NWRM can successfully be implemented as part of a flood relief scheme when used in combination with a traditional engineered solution.

#### *3.3.1.2 Scotland – Eddleston Water*

Eddleston Water is tributary of the River Tweed in the Scottish Borders, with a catchment of 70km$^2$. The catchment is rural, contains a mix or forestry, rough grazing, improved grassland, arable and peatland, and is comparable in land-usage to catchments in Ireland.

The river is designated as a Special Area of Conservation (SAC) for its salmon, lampreys, otters and aquatic plants. The river contributes to flood risk in the downstream town of Peebles and the small village of Eddleston, with 582 properties having been identified as being at risk from the 1in-200-year flood event in these communities. The ecological status of Eddleston Water was classified as 'bad' in 2009, under WFD criteria, by the Scottish Environment Protection Agency, mainly due to historical straightening of the channel.

Eddleston Water Project commenced in 2009 with the aim of reducing flood risk and restoring Eddleston Water. The project is led by a charitable organisation, The Tweed Forum, comprising all of the organisations with an interest in the management of the Tweed and its environs and is funded by the Scottish Government, along with contributions from other public and private sources, and EU Interreg funding.

Land manager 'buy-in' was achieved by the Tweed Forum acting as a trusted intermediary, exploring opportunities and reducing the administrative burden on land managers willing to implement measures.

The project combined a range of NWRM as follows:

- 142 hectares of newly planted woodland;
- 22 upstream off-line "leaky" ponds;
- 101 large woody structures;
- Re-meandered 2.8 km of channel;
- Removing flood bank protection;
- Encouragement of good practice, e.g. fencing off water courses to reduce poaching.

The project includes extensive monitoring and has produced some initial findings, including:

- The timing of peak flow at sites with large woody debris structures is substantially delayed when compared to sites without structures;
- Measurements of water levels show that ponds in the upper catchment can readily store water, but modelling suggests this will only have a relatively small effect on total sub-catchment runoff at this scale;
- Habitat variability and associated macroinvertebrate species richness have increased in re-meandered sections.

This project demonstrates that large-scale NWRM projects can be implemented by non-government bodies.

### 3.3.2 Irish Examples

#### *3.3.2.1 Urban measures (SuDS)*

The Greater Dublin Strategic Drainage Study (GDSDS) was commissioned in 2001. Development in the region in the preceding decades led to overloading of the existing systems, as was evident from a marked deterioration in water quality, increased risks of flooding and concerns that the drainage system and wastewater treatment plants had insufficient capacity to cater for future development.

The objectives of the GDSDS was to identify policies, strategies and projects for the development of a sustainable drainage system for the Greater Dublin Region i.e. the Local Authority areas of Dublin City, Fingal, South Dublin, Dun-Laoghaire-Rathdown and the adjacent catchments of Counties Meath, Kildare and Wicklow.

The GDSDS developed Regional Drainage Policies for new developments, including a policy on incorporating SuDS. This policy states that the 'assumption must be that SuDS will be used, with the onus of responsibility with the developer to provide SuDS measures to the Councils' satisfaction, or to demonstrate that SuDS cannot be provided or is not applicable.'

The objective of including SuDS in new developments is to limit discharge rates to pre-development rates while also providing treatment.

This policy has resulted in the widespread use of SuDS in the Greater Dublin areas since 2005. Research in 2010 documented a non-exhaustive list of 95 developments in Dublin City that had incorporated SuDS[1]. These developments included residential and commercial developments of varying sizes.

The City-West business campus was a case-study example of SuDS in the GDSDS (Figure 1.2). The 77ha business campus included multiple SuDS features including permeable paving, retention basins, and retention ponds.

[1] https://data.smartdublin.ie/dataset/sustainable-urban-drainage-sytems-SuDS-resgister-and-map

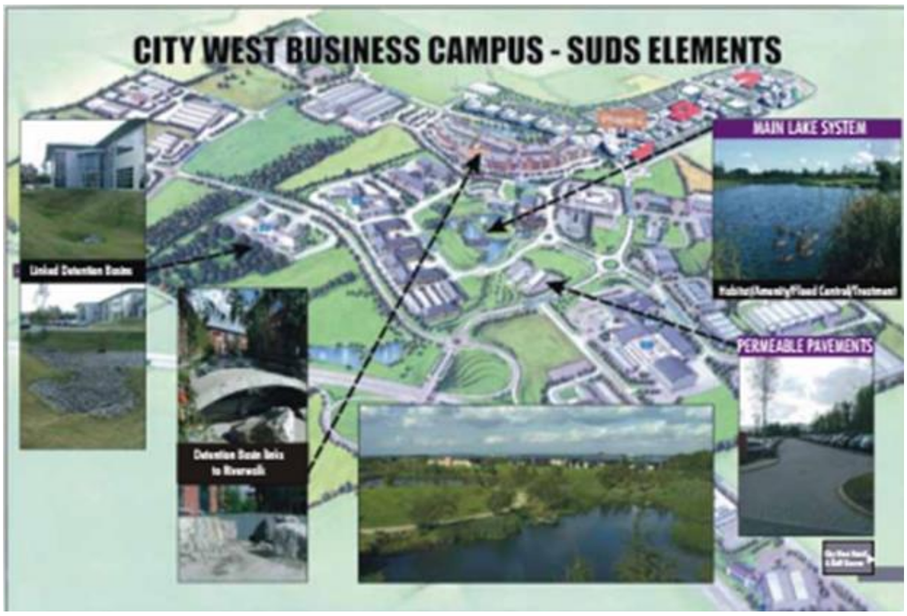



***Figure 3-2 City West SuDS features (GDSDS, 2005)***

#### *3.3.2.2 Lough Boora Discovery Park*

Lough Boora Discovery Park, located in western Co. Offaly, is a leading visitor attraction in the midlands offering patrons with walking and off-road cycling routes, an outdoor sculpture exhibition and stocked lakes for angling. The site is a prime nature refuge in the region, home to countless species of birds and wildlife. The Lough Boora site encompasses over 3,000ha of cutaway peatland, which was commercially harvested by Bord na Móna for energy over an extended period. When industrial peat production ceased the site was left as a bare and barren landscape.

Initial efforts in repurposing of these lands were primarily concentrated on grassland development for agriculture and planting with coniferous forestry. An integrated land use plan was developed for the site (1995) which included all proposed land use development activities at the site such as: grassland establishment; afforestation; natural re-colonisation and; permanent wetland habitats development. The plan also proposed a wide scale development of wildlife habitats across the range of land types and for the development of a range of outdoor amenity facilities for public use – leading to the evolution of the Discovery Park present today. Whilst the concept of NWRM was not the primary focus or goal of this plan, most of the actions undertaken at the site would meet the criteria.

***Figure 3-3 Lough Boora Discovery Park (Source: Shannon International River Basin District Project Peatlands Report, 2008)***

The Turraun area of cutaway peatland (north of the Boora peat works) includes artificial wetlands created when lower lying land areas were flooded with the erection of embankments to retain water on a permanent basis. With the cessation of mechanical pumping and the erection of these embankments, together with drain blocking activities, other wetland habitats such as low shrub, open grassland and areas of heather growth have emerged. Areas of wetland containing rich plant communities (high biodiversity) including reed, bulrush, bog cotton and others have colonised in low-lying areas that are not permanently flooded but are now returned to wet conditions.

Many more areas in this location were designated for natural re-colonisation alongside wetland areas that were either permanently flooded or flooded periodically by winter inundation providing refuge for many species of bird. All of the above listed measures provide water retention that slows runoff and stores water, providing benefits for flood prevention and water treatment along with all the associated biodiversity benefits. In addition, the grasslands developed at Lough Boora provide refuge to one of Ireland’s most endangered species, the native Grey Partridge and Lough Boora is now the only location where this species is found in Ireland. Another aspect of the Lough Boora site is the establishment of large-scale reedbed habitats at the Turraun Lagoon area.

These reed beds primarily provide important habitat but also serve as a natural water treatment mechanism for runoff from the peat. In summary, the Lough Boora project provides a hugely successful example for how NWRM can be incorporated at peatland sites (not just former industrial peat extraction sites) to achieve multiple benefits for water quality, flood prevention and increased biodiversity.

#### *3.3.2.3 Stranooden Group Water Scheme*

One of the main features of NWRM is that many of the techniques and measures utilised, may have multiple benefits, and indeed may already be in use within another context. Some examples can be found in Co. Monaghan, implemented as part of a Source Protection Project by the Stranooden Group Water Supply Scheme.

This is one of 13 schemes located in Co. Monaghan that supplies clean potable water to rural communities. It serves approximately 1,100 domestic houses and a further 400 agricultural and commercial premises. The scheme sources its water from a lake situated several kilometres south west of Ballybay named White Lough, which is part of the Dromore river system which flows west between Ballybay and Cootehill. The water is abstracted at this location and then pumped approximately 13 kilometres north to the scheme's reception reservoir at Corcaghan.

The Source Protection Project aims to develop and implement an integrated catchment management plan. The main driver is to protect the quality of the source catchment, around 125 $km^2$, from issues that could lead to poor water quality, specifically pesticides like MCPA, but also other issues such as excess nutrients, bacterial loads and organic matter.

The Project involved the identification of critical source areas (CSA's) and the development of a conceptual "Source/Pathway/Receptor" (SPR) model for the catchment. The most impacted areas also had stream walks carried out to ground truth data. Then a list of proposed mitigation measures was drawn up to address the main issues identified, but also emphasising multiple-benefits.

The river walks found that there was a significant lack of riparian buffers and fencing with significant issues with erosion as a result, particularly because of cattle access. The soil types extant in the area also indicated overland flow was the main pathway element, which in turn indicated the most appropriate measure types.

A 3-stage process was envisioned, involving communication, load reduction and physical intervention. The main physical interventions proposed were;

- Riparian buffer strips – although the GLAS requirement is for 1.5m minimum from the top of the riverbank, the Project suggested that best practice dictates that these should be wider in critical areas ("Smart Buffer" approach);
- Bank Re-profiling and/or willow spilling – some areas subject to poaching and/or erosion have been identified as suitable for these techniques;
- Development of wetlands – attenuation of phosphate by regenerating a wetland near Ballybay WWTP supplemented by willow planting would provide attenuation;
- Development of hedgerows – native hedgerows would be planted in key areas to intercept overland flow.

During 2019 and early 2020, an intensive Awareness and Media Campaign was carried out with the agricultural and wider community. To date, approximately 2,500 linear metres of buffer strips have been established, with an average width of 1.5m to 2m, with 3m to 4m buffers in critical areas. In addition, 1,640 metres of hedgerows have been planted.

It is planned to establish another 10km of fencing and hedgerows in 2020. It is planned to carry out bank re-profiling, with consultation with OPW, in suitable areas as well.

Looking forward, the Project intend to use the EPA Catchments Unit Diffuse Pollution Tool outputs to identify further sites suitable for the siting of other NWRM such as infiltration ponds or wetland areas aimed at "slowing the flow" in CSA's.

#### *3.3.2.4 GLAS scheme*

The Green Low-Carbon Agri-Environment Scheme (GLAS) is an agri-environment scheme which forms part of the Rural Development Programme 2014-2020 and follows the Rural Environmental Protection Scheme (REPS) and the Agri Environmental Options Scheme

(AEOS). GLAS aims to encourage farmers to promote biodiversity, protect water quality, and also to help combat climate change. The overall target for GLAS was to attract 50,000 farmers into the new scheme over its lifetime; to date over 48,000 herds are recorded as having successfully partaken in the scheme for payment. This has resulted in the establishment of 316 km of arable margins, 1,153 km of new hedgerow planting, 7,236 ha of minimum tillage farming, 18,665 ha of wild bird cover establishment and over 2 million cubic metres of low emission slurry spreading. **Error! Reference source not found.** below illustrates the successful implementation of arable margins coupled with low emission slurry spreading.

***Figure 3-4 Arable Margins (BSBI: Botanical Society of Britain & Ireland and Plantlife)***

Activities which are mandatory for farmers to qualify for the scheme (subject to other requirements not listed here) are almost all equivalent to a NWRM so in a sense the GLAS scheme is already incentivising NWRM in Ireland. Table 1.1 gives a comparison between GLAS scheme activities and their equivalent NWRM; with the exception of low emission spreading, all have an equivalent measure.

***Table 3-1 GLAS scheme measures compared to NWRM***

| GLAS Scheme Activity | Equivalent NWRM |
|---|---|
| Planting new hedgerows | Buffer strips and hedges |
| Arable margins | Buffer strips and hedges |
| Minimum Tillage | Low till agriculture |
| Catch Crops | Crop Rotation, Intercropping |
| Low Emission Slurry Spreading | - |
| Wild Bird Cover | Meadows and pastures |

# 4 NWRM Potential for Ireland

The purpose of this section is to identify NWRM that offer the greatest potential to achieve multiple benefits in the Irish context. NWRM that have the greatest potential for widespread adoption are those that require a low effort to implement while providing a high degree of benefits. This categorisation is done solely for the purpose of identifying measures to provide further evidence within this report and is a generalised overview. This categorisation does not rule out any NWRM for future implementation. Detailed evidence for the high potential measures is set out in Section 5.

## 4.1 Potential Matrices

Each of the NWRM examined in Section 3 of this report have been classified by their total expected ‘Benefit’ and ‘Effort’ of implementation.

The ‘Benefit’ of implementation is the total expected benefit across all their main functions, particularly water quality improvement, flood risk reduction, and habitat creation. Where a measure is likely to be highly beneficial for any function it has been classified as ‘High Benefit’.

The ‘Effort’ of implementation is a combination of the total economic cost and the difficulty of implementation. The total economic cost of a measure is the total economic cost to all stakeholders, be they implementing bodies or landowners. The difficulty of implementation represents the difficulty in overcoming all other barriers to implement a specific measure.

It should be noted that measures that require a high effort of implementation also have potential for implementation where there is an implementation mechanism to overcome the high effort e.g. OPW Flood Relief Schemes, provided that the benefits can justify the level of effort. Also, where there is potential for the widespread implementation of a specific measure, their total benefits may be greatly increased, e.g. Urban Forest Parks.

Potential matrices for each of the settings are shown in Figure 4-1 below with the measures showing greatest potential highlighted in blue.

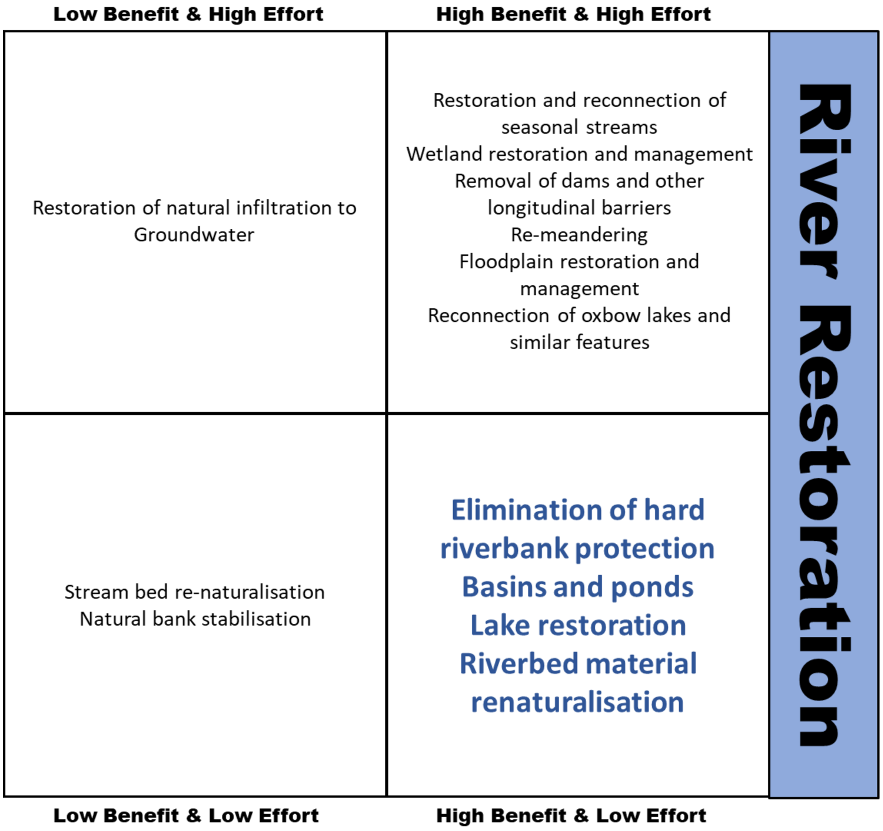



***Figure 4-1 NWRM potential matrices for each setting***


*Figure 4-1 NWRM potential matrices for each setting (cont.)*

| Low Benefit & High Effort | High Benefit & High Effort | |
|---|---|---|
| Green Roofs | Infiltration Basins<br>Detention Basins<br>Retention Ponds | **Urban** |
| Permeable surfaces<br>Rain Gardens<br>Infiltration Trenches<br>Rainwater Harvesting | **Channels and rills**<br>**Swales**<br>**Filter Strips**<br>**Soakaways** | |
| **Low Benefit & Low Effort** | **High Benefit & Low Effort** | |

| Low Benefit & High Effort | High Benefit & High Effort | |
|---|---|---|
| | Spagnum inoculation<br>Bunding<br>Drain blocking (upland areas) | **Peat** |
| | **Clearance of inappropriate vegetation on peatlands**<br>**Wetland lakes**<br>**Artificial wetlands**<br>**Land re-profiling**<br>**Drain blocking (lowland)** | |
| **Low Benefit & Low Effort** | **High Benefit & Low Effort** | |

***Figure 4-1 NWRM potential matrices for each setting (cont.)***

## 4.2 High potential measures for Ireland

The individualised potential matrices allow a setting by setting examination of measures that have the greatest benefit with the least effort. The cumulative list of measures scored under the assessment criteria were then ranked allowing the highest potential measures to be identified:

- Re-wetting drained organic lands
- Sediment capture ponds
- Basins and ponds
- Wetland restoration/rehabilitation and management
- Floodplain restoration and management
- Re-meandering
- Wetland lakes
- Detention basins
- Retention ponds
- Infiltration basins
- Removal of dams and other longitudinal barriers
- Buffer strips & hedges
- Forest riparian buffers
- Artificial wetlands
- Engineered ditches
- Enhanced Peatland Rehabilitation

It became clear that many of these measures are similar in terms of their underlying principle or corresponding benefit and this list could therefore be further condensed within grouped headings. The final list of prioritised NWRM for Ireland is therefore as follows:

- Re-wetting organic soils/ Enhanced Peatland Rehabilitation
- Engineered basins, ponds & ditches
- Floodplain restoration
- River re-meandering
- Removal of dams and other longitudinal barriers
- Buffer strips & riparian margins
- Wetlands

Each of the grouped measures listed above has been reviewed in more detail to provide a sufficient evidence base for stakeholders to ascertain the key benefits that can be gained from their widespread implementation – see Section 5.

# 5 Detailed evidence for high opportunity measures

## 5.1 Buffer strips & riparian margins

Both the agricultural measure “Buffer Strips & Hedges” and the forestry measure “Forest Riparian Buffers” are similar, both in their underlying concept and the associated benefits, and have therefore been grouped together for this review. This measure can also be considered in the urban environment.

Forest riparian woodland involves planting native woodland within the riparian zone (i.e. lands extending up to 20m either side of a watercourse). Historic afforestation included planting non-native trees (mainly conifers) into riparian zones and even up to the edge of the watercourse. Forestation practices have now evolved, and all new planting includes mandatory water setbacks which vary in width depending on the slope and soil type. In addition, all new planting requires a minimum of 15% broadleaf species to be included which is targeted at setback margins. All existing trees and scrub are retained. The Land Types for Afforestation is a plant species based scoring system which ensures no new planting occurs on certain peat soils. Riparian woodland has the effect of slowing and holding back flood flows in small to medium events as well reducing sediment delivery and bankside erosion (Environment Agency, 2018). In the Irish context riparian buffers can include setbacks without trees in coniferous plantations. Treed riparian buffers are not solely limited to areas of afforestation but can be located in urban, agricultural and wetland areas (EU NWRM, 2015).

In the agricultural setting, buffer strips & hedges are areas of natural vegetation cover (grass, bushes or trees) at the margin of fields (pasture), arable land and watercourses (riparian zones) – see Figure 5-1. Vegetation within these buffer strips can vary from grass to a combination of grass, trees, and shrubs. Buffer strips differ from riparian buffers as they can be sited away from waterbodies including field margins, headlands or even within fields (i.e. hedges planted across long steep slopes); ***buffer strips are not always linear (i.e. can be areas or plots) and do not always contain trees*** (EU NWRM, 2015). As is the case for forest riparian buffers, buffer strips and hedges are not exclusive to agriculture settings and can be cited in urban and wetland areas and are often utilised along transport infrastructure corridors. An EPA funded research project entitled “SMARTER_BufferZ” is currently investigating optimal targeting and management of riparian buffers for the effective management of water quality in Irish rivers. It is anticipated that this project will provide recommendations and tools to assist in the optimum use of this measure.

Figure 5-2 below provides a graphical illustration of the efficacy of this measure under the 5 key assessment headings.

Key benefits from this measure include:

- Slows runoff;
- Reduce erosion/sediment delivery;
- Filters nutrients;
- Increased biodiversity.

***Figure 5-1 Arable Margins (BSBI: Botanical Society of Britain & Ireland and Plantlife)***

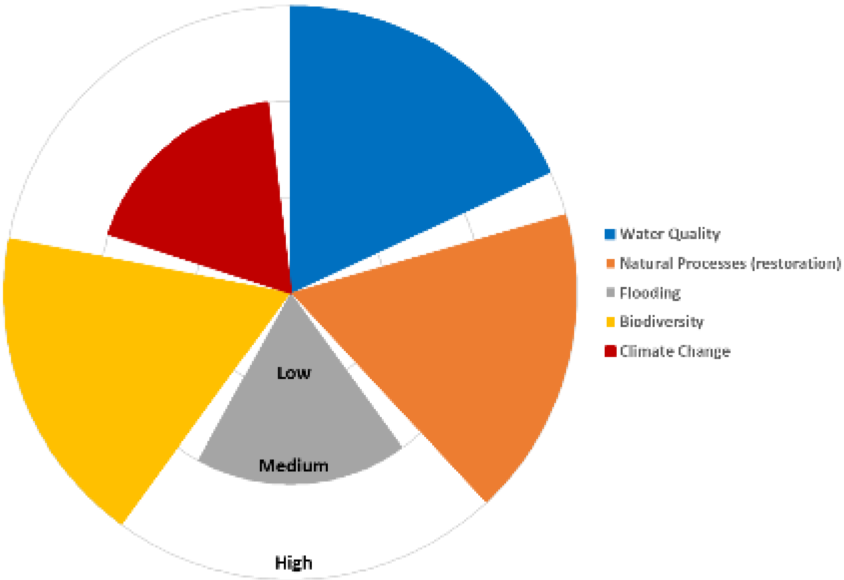



***Figure 5-2 Graphic illustrating benefits associated with buffer strips & riparian margins***

It has been reported that poor and damaged soils (particularly exposed broken soils) due to intensive agricultural practices can potentially mobilise high sediment and organic matter loads to surface waters including nutrients and other pollutants (Environment Agency, 2018). Sedimentation, eutrophication and pathogenic contamination are the resultant significant issues causing deterioration within our waterbodies. Buffer strips have been shown to be extremely beneficial in the removal of such loads to surface water with 5m buffers in hilly areas reducing phosphorous by 42–96%, nitrogen by 27–81%, organic matter by 83–90% and suspended sediment (SS) by 55–97% (Somma, 2013). Reductions observed are lower in less undulating landscapes but this can be offset by increasing the width of the buffer up to 6m – it must be noted that many of the studies referenced within the EU study reported that buffers of <1 – 2m are virtually ineffective for water quality enhancement. Forest riparian buffers are reported as removing up to 20% of nitrates whilst also reducing phosphorous and sediment loads (up to 4.8 tonnes of sediment per hectare per year (Environment Agency, 2018). Riparian buffers can also reduce metals in runoff in urban settings with copper, lead and zinc pollutants in wetlands that develop in the riparian zone (Environment Agency, 2018). The impacts of agricultural and riparian buffers on flood flows are less certain with the available case studies located in warmer climates which may not be comparable to Ireland, however runoff reductions of 20 – 50% have been reported (EU NWRM, 2015).

Both riparian and agricultural buffers provide habitat and refuge for wildlife increasing biodiversity. Buffer strips managed for biodiversity have been shown to double the number of invertebrates compared with normal cropped margins in the associated waterbody. These measures also have an important role to play in climate regulation with $CO_2$ absorption through both increased biomass and reducing losses from soils (DAFM, 2016), however no quantifiable reduction figures are available in the Irish context.

## 5.2 Engineered basins, ponds & ditches

A number of NWRM fall under a broad heading of engineered basins/ponds and whilst they vary slightly in their design and construction they all achieve similar outcomes and have similar benefits, these measures are:

- Sediment capture ponds;
- Basins and ponds;
- Detention Basins;
- Retention Ponds;
- Infiltration basins;
- Engineered Ditches.

Engineered basins and ponds are small water bodies storing surface run-off temporality before discharging at a controlled rate to a receiving watercourse – see Figure 5-4. Detention and infiltration basins differ from 'wet' ponds in that they are dry in dry weather flow conditions. Detention basins then allow stored water to drain down to an outfall whereas infiltration basins drain through the soil to groundwater. Wet ponds (e.g. retention ponds, flood storage reservoirs, shallow impoundments, sediment capture ponds etc.) are designed to permanently contain water, and have capacity to hold additional water during rainfall events. Engineered ditches are a variation on sediment capture ponds but are linear features. They are constructed by re-engineering traditional drainage ditches with dams/flow control structures to create a series of linear ponds. All of these NWRM are primarily focused at controlling the peak runoff from the areas draining to them whilst also allowing for the settlement of sediment and other pollutants. Figure 5-3 below provides a graphical illustration of the efficacy of this measure under the 5 key assessment headings.

Key benefits from this measure include:

- Store/Slows runoff;
- Water storage;
- Flood risk reduction;
- Intercept pollution pathways;
- Reduce erosion and/or sediment delivery;
- Increase infiltration and/or groundwater recharge;
- Features intended to be both wet and dry can offer additional water quality improvements.

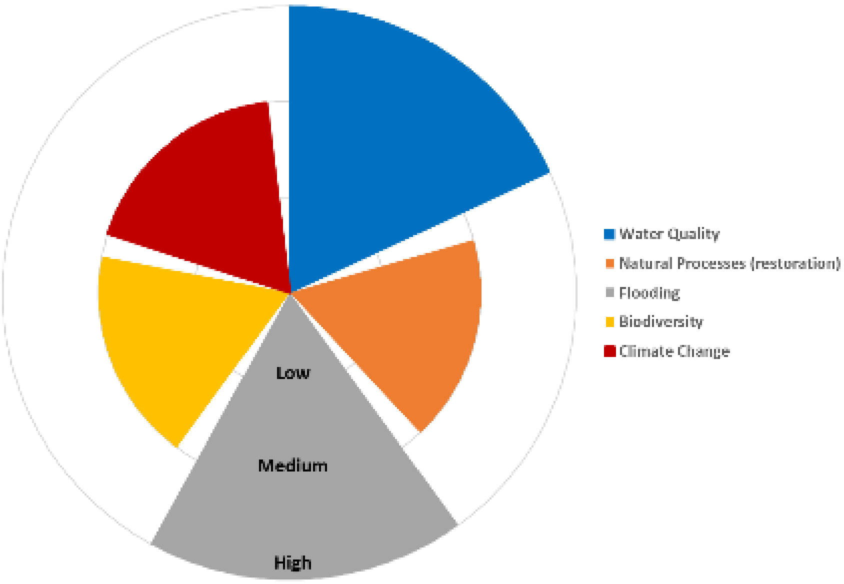



***Figure 5-3 Graphic illustrating benefits associated with basins & ponds***

Engineered basins/ponds have been found to slow, store and filter water, reducing flood risk locally for small events and disrupting and attenuating overland flow. Locally these features can provide effective flood benefit (e.g. small urban development sites) up to the 100 year storm event (CIRIA, 2015) but at the catchment scale these features are only effective with large scale implementation throughout the landscape, i.e. providing a network of measures (Environment Agency, 2018). However, the effectiveness of these features for larger storm events (> 10 - 50 year events) at the catchment scale is reported to be minimal as they can be filled with water. Ponds are effective at removing suspended sediment (SS) and other pollutants thus reducing water quality impacts on watercourses.

At the catchment scale whereby, a network of features is installed, removal rates of 49% for SS and 18% for Nitrates, 33% for Phosphorus and >50% for metals was reported (TII, 2014; Environment Agency, 2018). At the site scale CIRIA (2015) have reported dry basins to have removal rates of >50% for SS and metals (Cu, NI, Zn) with wet ponds removing up to 80% of SS and >50% for metals. A study by Bruen et. al. (2006) showed that constructed wetlands (which are very similar to some forms of engineered wet ponds) receiving road drainage removed up to 94% of the SS, 67% of the total Phosphate, 91% of total Zinc, 67% of total Cadmium, 60% of total Lead and 78% of total Copper. At the catchment scale and in rural settings, farm ponds are suggested as a possible flood control measure for overland flow which also provides water quality benefits however there is limited literature available to quantify their impacts although their contribution to biodiversity and habitat creation is acknowledged (Environment Agency, 2018). Ponds/basins can also contribute to climate regulation with organic carbon stored in pond sediment; permanent ponds with extensive natural vegetation were found to contain approximately 10% organic carbon (Environment Agency, 2018).

***Figure 5-4 A sustainable drainage system (SUDS) pond beside the new Glenmill housing development at Darnley Mains, UK (https://www.geograph.org.uk/photo/5274370)***

Engineered ditches (equivalent to peak flow control structures within the EU NWRM study) are designed to reduce flow velocities in networks of traditional agricultural or forestry drainage ditches. Whilst this measure is essentially a variation of ponds and basins as described above, additional information is provided here given the linear nature of their construction. The principle is to re-engineer existing ditch cross-sectional areas to incorporate flow control structures and, where practical, widen and flatten the ditch to further reduce flow velocities (Environment Agency, 2012). Flow control structures are designed to retard flow during storm events thereby contributing to sediment control and a reduction in the size of flood peaks – see Figure 5-5. Numerous variations of this principle have been trialled including: willow hurdles, sediment traps, sedge wetlands, willow wetlands, check dams, bunds with orifice outlets and wooden leaky barriers (Quinn et. al., 2007). Engineered ditches will have a limited lifespan before maintenance is required as sediment will eventually accumulate upstream of the flow barriers. Many of these methods have been trialled at the Nafferton Farm study led by researchers from Newcastle University and have shown this measure to be very effective at removal of sediment, nutrients and in dampening the peak discharge to watercourses (Quinn et. al., 2007). A similar study led by the University of Leeds was also undertaken at Allerton Farm and showed similar improvements can be achieved. Given the vast network of drainage ditches present across the country, this measure has the potential to provide enormous benefit if rolled out nationally in a targeted manner.

***Figure 5-5 Leaky barrier installed in a farm ditch (Quinn et. at., 2007).***

## 5.3 Floodplain restoration and management

A floodplain is an area of land that borders and interacts with the river channel, playing a vital role in the health of river systems. If the floodplain is fully connected to the river channel, this will allow for the transfer and retention of water. It will also allow for sediment and organic matter to be retained/deposited on the land which can aid river water quality but also supply nutrients to the land. Furthermore, floodplains provide habitat and refuge.

Floodplains have been impacted and degraded by hydromorphological pressures, land use changes and flood defence. Quite often the lateral connectivity between the river channel and the floodplain has been cut off by, for example, embankments, flood walls, bank protection, drainage or, completely removed by urban development. Measures to restore floodplains can include: modification of the channel, e.g. raising of artificially lowered riverbed levels; removal of embankments or other structures impeding connectivity; removing legacy sediment; new/modification of agricultural practices; afforestation; plantation of native grasses, shrubs and trees; creation of grassy basins and swales' wetland creation; invasive species removal and; riparian buffer installation and development (EU NWRM, 2015)

Figure 5-6 illustrates the benefits associated with floodplain restoration and management. Key benefits include:

- Store/Slows runoff;
- Store/slow river water;
- Flood risk reduction;
- Improve water quality;
- Improve hydromorphological conditions;
- Erosion/sediment control;
- Reduce erosion and/or sediment delivery;
- Improve soils;
- Increase infiltration and/or groundwater/aquifer recharge;
- Groundwater/aquifer recharge;
- Create riparian/terrestrial habitats;
- Biodiversity preservation.

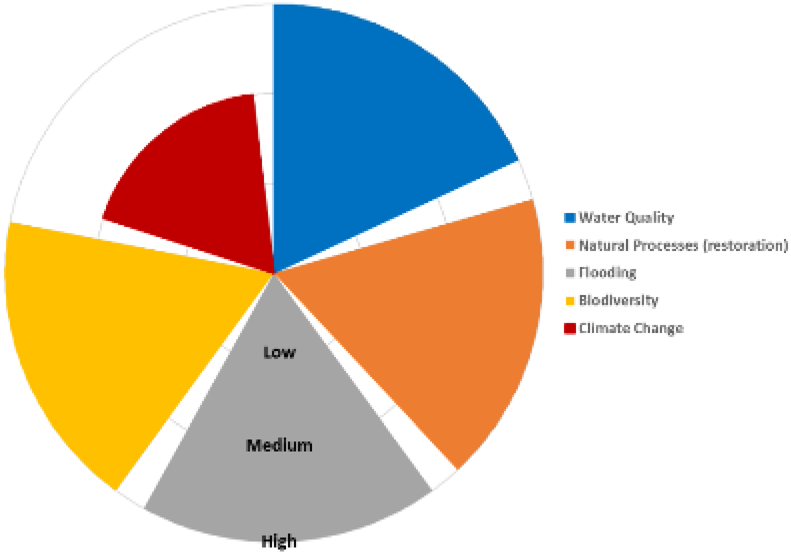



***Figure 5-6 Benefits associated with floodplain restoration and management.***

This measure can be carried out for any river type, as long as a natural floodplain (current or former) is present. Benefits accrued will depend on the river morphology and it may take time for floodplain connectivity to become fully established. It is important to note that the more restricted the river channel is, in terms of development on the floodplain, the higher the costs to implement measures. Effectiveness of measures are site specific and detailed assessments are required during the design of such measures.

- Removal of embankments on the River Glaven in the UK has led to restored connectivity with the floodplain (*i.e.* ***inundation at high level flows***, (>1.7$m^3s^{-1}$)) (Clilverd et al., 2013; 2015). As channel capacity for flows had reduced by 60%, this encouraged overbank flooding onto the floodplain, despite the fact the river bed had been lowered in the past. Other findings included ***high groundwater levels***, ***greater subsurface storage,*** a more ***natural flood pulsed hydrological regime*** (*i.e.* regular short duration inundation of the floodplain) and ***habitat creation. Ecological potential increased*** from Moderate to Good. While there was also inundation of the riparian area during low magnitude events, there was limited flood peak reduction (≤5%) due to the length of channel restored (400m) and the limited improvements to drainage. [EA WWNP]
- Acreman et al. (2003) and Williams et al. (2012) found that removal of embankments on the River Cherwell, a 910$km^2$ tributary of the River Thames in the UK, ***reduced the flood peak*** by 10-15% approximately, as ***floodplain water storage*** increased to 0.5 – 1.6m. William et al. (2012) did note however that the measures for this particular site were less likely to attenuate low frequency high return period flood events. [EA WWNP]
- A noted above, sediment storage on the floodplain can reduce sediment within the river channel and removal of nutrients. For instance, floodplain reconnection in one European study lead to an ***increase in sediment storage*** (189 tonnes per year) on the floodplain, with sediment bound phosphorus estimated at 770kg a year (Kronvang et al., 1998). However, a number of studies have highlighted that restored floodplains can act as a source of nutrient pollution (notably phosphorous) during flood events (Knowles et al., 2012; Surridge et al., 2012). [EA WWNP]
- Modelling for a scheme constructed within the Chelmer Valley Local Reserve (UK) indicated that the lowering of embankments and berm creation could lead to ***reduced flood depths*** of up to 0.3m in some locations during a 10% AEP (annual exceedance

probability) event and 0.15m during a 1% AEP event. The work was carried out along 2km of river channel. [EA WWNP]

- The habitat creation focused Mill Brook project in Cheshire (UK) consisted of floodplain excavation, lowering embankments and leaky dams along 230m of river channel. On completion, 1.5ha of ***priority reedbed and wet grassland habitat*** was created. These measures also appeared to have ***increased upstream floodwater storage*** (~1000m$^3$) ***and flood peak attenuation –*** see Figure 5-7***.*** [EA WWNP]
- In some cases, restoration of the channel is required in order to ensure connectivity with the floodplain. Modelling highlighted that peak flows were not reduced in the Thur river (France) after floodplain restoration due to the presence of a deep river channel (Kreiss et al., 2005). [EA WWNP]

***Figure 5-7 Floodplain restoration (pre-construction, during construction and completion) as part of the Mill Brook project (UK) (Source: amended from Environment Agency for EA WWNP case studies)***

## 5.4 Re-meandering

River re-meandering involves re-naturalising the channel planform, or pattern, of a river. It involves creating a new meandering (or winding) course, if suitable for the system, or reconnecting cut-off meanders (due to man-made interventions rather than natural migration) – see Figure 5-9 and Figure 5-10. This can lead to an increase in the length of the river channel, therefore slowing down the river flow and increasing storage capacity. The restored river channel creates new flow conditions and very often also has a positive impact on sedimentation and biodiversity, providing habitats for a wide range of aquatic and land species of plants and animals – see Figure 5-8 for graphic of key benefits (EU NWRM, 2015).

Key benefits include:

- Store/slow river water;
- Flood risk reduction;
- Prevent surface water status deterioration;
- Erosion/sediment control;
- Reduce erosion and/or sediment delivery;
- Take adequate and co-ordinated measures to reduce flood risks;
- Create aquatic/riparian habitats.

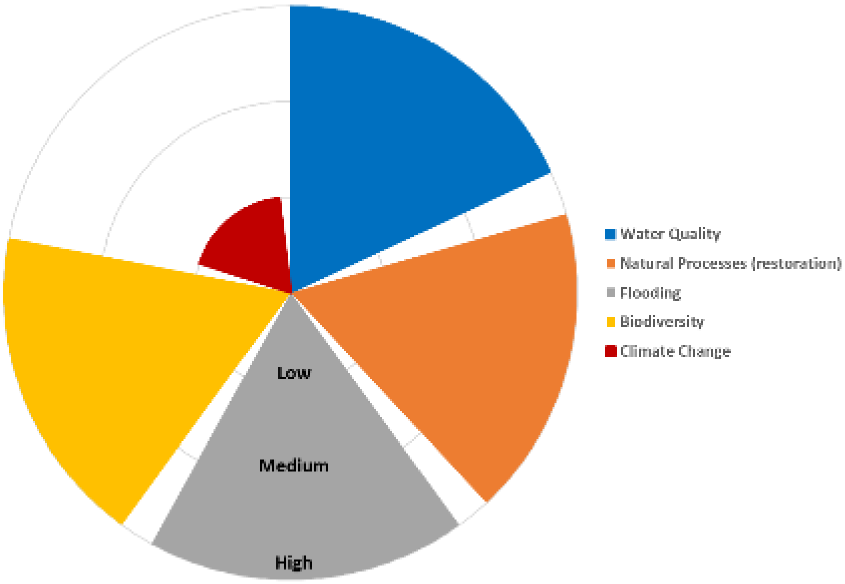



***Figure 5-8 Benefits categorised by level of significance for river re-meandering***

This measure is river type dependant – only meanders should be constructed/recreated if a naturally meandering system exists. If not, this can lead to further issues, creating an unsustainable river system.

- Measures implemented in the New Forest (UK), such as re-meandering, adding large wood, and reducing channel capacity and restoring wetlands and riparian forest, have resulted in greater floodplain connectivity, increasing the frequency and duration of floodplain inundation (25km2 catchment, Sear et al (2006)). A total length of 10km of river channel was restored resulting in 21% reduction in flood peak magnitude and a 33% increase in flood peak travel time for flows that were less than 1 m3s-1. In terms of biodiversity, 604ha of forest and wetland habitat was restored. [EA WWNP]
- Restoring meanders along a 1km reach in the US resulted in the reduction of flood peaks (with 2- to 50-year recurrence interval flows) by less than 1% (Sholtes and Doyle, 2011). [EA WWNP]
- The same study noted that spatial scale influences how effective measures are. While their study focused on a 1km reach within a 17km2 catchment, Liu et al. (2004) observed an average reduction of peak flows of 14% when re-meandering (and other

flow resistance measures) was implemented in a 400km2 catchment as part of the Alzette river restoration project. [EA WWNP]

- The Alzette river restoration project in Luxemburg consisted of re-meandering, increasing the base level of the river, widening of the riverbed, reconnection of the river to existing ponds and creation of a new pond. These measures lead to improved water storage contributing to a 15-minute delay of the peak flow. The maximal flow duration was reduced from 42 to 24 minutes. [nwrm.eu]
- Re-meandering measures have been observed to reduce nutrient levels (notably nitrogen and phosphorous) through sediment deposition, retention and purification (Hoffman et al. 2011, Shrestha et al., 2012). The latter study combined this measure with other floodplain restoration measures and observed phosphate retention was between 0.13kg and 10kg per hectare per year and nitrogen removal between 52kg and 337kg per hectare per year. [EA WWNP]
- River restoration was carried out within the suburbs of Dublin on the River Tolka and included measures such as re-meandering, pond creation, fisheries enhancement (introduction of spawning gravels and excavation of pools) and soil improvements to the floodplain. An increase in biodiversity has been observed with fish returning to this section of river and vegetation colonising the floodplain (Addy et al., 2014).

***Figure 5-9 Re-meandering by the Eddleston Water Project (UK) (Source: amended from Tweed Forum for EA WWNP)***


***Figure 5-10 Remeandering carried out by the Esk Rivers and Fisheries Trust on the Rottal Burn (South Esk) (Source: SEPA (before and during) and Kenny MacDougall/Fraser Murdoch (after), amended for SEPA Natural Flood Management Handbook – See the River Restoration C***

## 5.5 Removal of dams and other longitudinal barriers

Artificial barriers such as dams, weirs, culverts and sluices can impact the movement of water, sediment and biota along the channel. Removal of such barriers, along with restoring the slope and the longitudinal profile of the river, allows the re-establishment of fluvial dynamics, as well as sedimentary and ecological connectivity. With regard to flood mitigation, barriers have often been seen as a flood protection measure but there may be situations that the presence of barriers exacerbate flooding. Furthermore, if dams and weirs are not maintained or are compromised, removal can reduce potential flood risk (EU NWRM, 2015).

Figure 5-11 illustrates the benefits associated with barrier removal. Key benefits include:

- Improve hydromorphological conditions;
- Improve fish migration and reproduction;
- Create aquatic/riparian habitat;
- Biodiversity preservation;

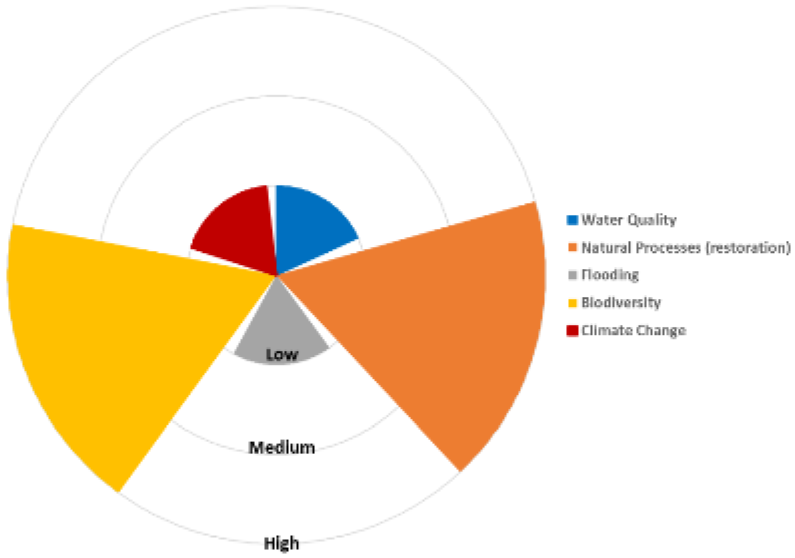



***Figure 5-11 Benefits associated with removal of dams and other longitudinal barriers***

This measure can be carried out in any river type where there are artificial barriers. However, consideration needs to be given to issues such as the potential spread of invasive species.

- The opening of 70m culverts along a 300m section of the Ravensbourne river (UK) has lead to increased channel length by 12.5%, ***re-establishment of morphological processes***, ***increase in morphological diversity***, ***reconnection to the floodplain*** (reducing flood risk downstream), ***improvement in ecology*** (i.e. increase in invertebrate taxa along the restored stretch). (https://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/1.6_Ravensbourne.pdf).
- The LIFE project, Conservation of Atlantic Salmon in Scotland (CASS), consisted of a number of measures including the removal of 25 artificial obstacles from the Spey, Dee, Moriston, Oykel, Tay and Bladnoch rivers. This resulted in ***improving fish migration*** – approximately 150km of habitat is now accessible to fish. (http://wiki.reformrivers.eu/index.php/Conservation_of_Atlantic_Salmon_in_Scotland_(LIFE_04/NAT/GB/000250)).
- IFI and OPW have completed a number of fish barrier improvement works, typically by partial removal of the structure or improving the fish passage characteristics, allowing more natural fish migration and natural processes.

## 5.6 Wetlands

NWRM that fall under this category include:

- Wetland restoration/rehabilitation and management;
- Artificial wetlands;
- Wetland lakes.

Wetlands provide a transition zone between aquatic and terrestrial ecosystems and include peatland, marsh, swamp, reedbed, heath, wet woodland, wet grassland or fen type habitats. They are an important component of the catchment as they provide many functions including water (and nutrient) retention, water purification, habitat creation/maintenance and carbon sequestration. However, wetlands have been impacted by various pressures such as drainage, peat harvesting, land use changes and development.

Restoration or rehabilitation of these features can involve: drain blocking, reversal of gravity drainage, removal of pumped drainage, the creation of peat berms and bunds above the natural surface level to maximise the peat surface area being rewetted, re-establishment or creation of riparian and wetland habitats; removal of embankments or other structures impeding connectivity between the river and wetland; changes in land use practices; creation of artificial wetlands and/or wetland lakes.

With regard to the measures considering artificial features, artificial wetlands and lakes involve the construction of engineered ponds or low-lying areas that mimic naturally occurring wetlands. They are usually constructed by creating shallow ponds and/or depressions in the land and controlling inflows/outflows to create a permanently wet area. This area can vary in depth. These areas are then filled with wetland plants which are carefully chosen to suit the habitat involved. The design needs to take account of the site's hydrology, landscape and functional ecology. Artificial wetlands have the potential to provide suitable equivalent habitat and refuge to natural or restored wetlands. Wetland lakes also have the potential to be stocked with fish, promoting biodiversity and providing an amenity, such as angling, to the area. The key benefits of these types of measures lie in increased biodiversity, sediment removal, water quality improvement and flood prevention.

Figure 5-12 illustrates the benefits associated with wetland creation and restoration/ rehabilitation. Key benefits include:

- Store/Reduce/Slows runoff;
- Absorb and/or retain CO2;
- Reduce erosion/sediment delivery;
- Filters and retains nutrients;
- Better protection for ecosystems and more use of Green Infrastructure;
- Increased biodiversity;
- Prevention of biodiversity loss;
- Create aquatic/riparian habitat.

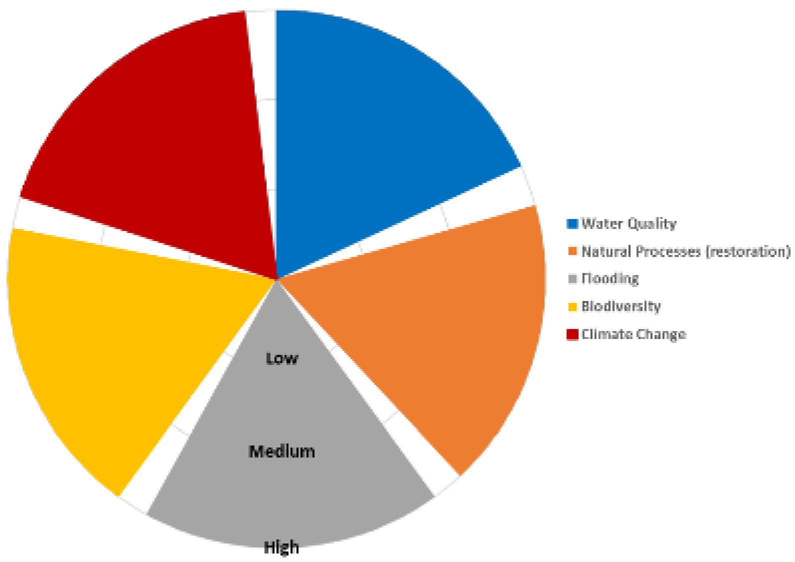



***Figure 5-12 Benefits associated with wetland creation and restoration/rehabilitation***

Depending on hydrological and landscape conditions, these measures can be implemented in current or former (degraded) wetlands. Effectiveness of measures are site specific and detailed assessments are required during the design of such measures.

- Conserving or constructing wetland areas to act as a buffer between pasture and river courses allows the wetland to intercept water and pollutants, as the following examples illustrate.
- Diversion of ditch to a linear wetland area resulted in an 80% ***reduction in phosphorous*** delivered directly to a river water course in Devon (UK). In terms of ***fine sediment delivery***, suspended sediment concentrations were also found to be reduced (Rivers Trust; https://www.theriverstrust.org/media/2017/04/Pinpoint-42.0-Managing-wetlands-Wetlands-for-water-quality.pdf).
- Ockenden et al. (2014) observed positive impacts of small field wetlands, occupying less than 0.1% of the catchment area, constructed along runoff pathways (*i.e.* either hollows of hillslopes or corners of fields) in both Cumbria and Leicestershire (UK). ***Interception of nutrients and sediment*** varied depending on soil type. Within a three-year study, an average of 0.8 t $ha^{-1}$ $yr^{-1}$ of sediment and 0.3-3 kg $ha^{-1}$ $yr^{-1}$ of phosphorous accumulated at a sandy site, 0.3 t $ha^{-1}$ $yr^{-1}$ of sediment and 0.01-0.5 kg $ha^{-1}$ $yr^{-1}$ of phosphorous within a silty site and 0.04 t $ha^{-1}$ $yr^{-1}$ sediment and 0.006-0.1kg $ha^{-1}$ $yr^{-1}$ of phosphorous at a clay site. Timing of rainfall (*i.e*. higher level of sediment transported during intense rainfall events, especially if there was bare soil or poor crop cover). Furthermore, ***accumulation of carbon*** ranged between 26kg to 2800kg (0.1-100kg C $ha^{-1}$ $yr^{-1}$).
- An Irish study looked at 44 constructed wetlands operated by local authorities (Hickey et al., 2018). It found that integrated constructed wetlands performed well in ***retaining nutrients and suspended solids***, when design guidelines were adhered to, compared to other constructed wetland types such as constructed wetlands with secondary free surface flow, tertiary horizontal subsurface flow or hybrid systems.
- As part of an Irish project assessing the impact of road drainage, one site involved the monitoring of run off from the M7 motorway (Monasterevin Bypass) to a constructed wetland along the River Barrow (Figure 5-13). The particular wetland was 20m long and 14m wide, with a maximum depth of 0.6m and longitudinal slope of 1%. Within the wetland itself, appropriate wetland species were planted (reeds (*Phragmites australis*) and bulrushes (*Typha latifolia*)). It was observed that there was a ***reduction in peak flow*** by 96% for certain storm events, while there was a ***reduction in overall run-off volume*** flowing to the river (*i.e.* 94%). With regard to ***water quality improvements***, the wetland appeared to neutralise the acidic discharge from the road run-off yet the wetland discharged warmer water to the river (increase by ~$1^{O}$). Suspended solids were retained by the wetland (82-94%), as was total phosphate (64-67%). Removal of metals varied as the wetland became more established- zinc removal 80-91%, 64-67% cadium, 16-60% total lead and 32-78% copper. This artificial wetland also ***provided habitat*** to a wide range of species (Bruen et al., 2006).
- A Finnish study looked at the effectiveness of forest wetlands as a NWRM. It found that an urban forest wetland in a small 1-2$km^2$ catchment ***reduced mean peak flows*** by 47%, with a ***risk in downstream flooding also reduced***. In terms of ***water quality improvements***, there was a reduction in nitrogen concentrations by 15%, turbidity by 8% and dissolved oxygen significantly increased (177%). [nwrm.eu]
- The Exmoor Mires peatland restoration partnership in the UK is a project running between 2010-2020 that involves restoring 3000ha of peatland by blocking ditches with peat and wood. So far, this has led to an ***increase in water storage*** (*i.e.* average increase of 2.65cm in water table levels across the area), 33% ***reduction in storm flow*** leaving the sites, increase in base flow levels and 50% ***reduction in total carbon yield***. So far, 31% of the peatland has been restored to their ***ecohydrological function*** (River Restoration Centre: https://www.therrc.co.uk/sites/default/files/projects/36_exmoor.pdf).

- In terms of ***climate change mitigation***, wetland restoration of Amalva mire and reduced emissions from the Amalvas polder in Lithuania are expected to significantly reduce greenhouse gas emissions from the current estimate of 10000-15000 t of CO2 equivalent/year. [nwrm.eu]
- An industrial cutaway bog within the West of Ireland (Ballacorrick, Mayo) was rewetted, resulting in a high water level throughout the site and extensive regrowth of vascular and moss vegetation. A 12-month study noted that ***carbon*** was ***sequestered*** at an average of 279+/-246g $Cm^{-2}y^{-1}$, while $N_20$ emissions were negligible. It was noted that such results can vary over time, particularly as vegetation establishes (Wilson et al., 2007).


***Figure 5-13 Constructed wetland, reducing the impact of runoff from the M7 motorway to the River Barrow (Source: Bruen et al., 2006)***

## 5.7 Re-wetting organic soils

Drain blocking and other measures (including bunding etc.) can be used to re-wet drained organic soils to restore the high water table necessary for natural wetland conditions to be restored. This measure is primarily aimed at marginal farm lands located on cutover peat but is also applied for enhanced rehabilitation of cutover peatlands. Rehabilitation of cutover peat involves stabilisation and water retention – in many instances it will not be possible to restore cutover peatlands to its natural function. The key benefits of this measure lie is $CO_2$ sequestration for climate change adaption and water quality improvements, however multiple other benefits also accrue including slowing and reducing runoff with associated flooding benefits and increased biodiversity – see Figure 5-14 below for graphical illustration of the efficacy of this measure under the 5 key assessment headings.

Key benefits from this measure include:

- Absorb and/or retain CO2;
- Store/slow runoff;
- Intercept pollution pathways;
- Reduce erosion and/or sediment delivery;

– Flood risk reduction;
– Prevention of biodiversity loss.

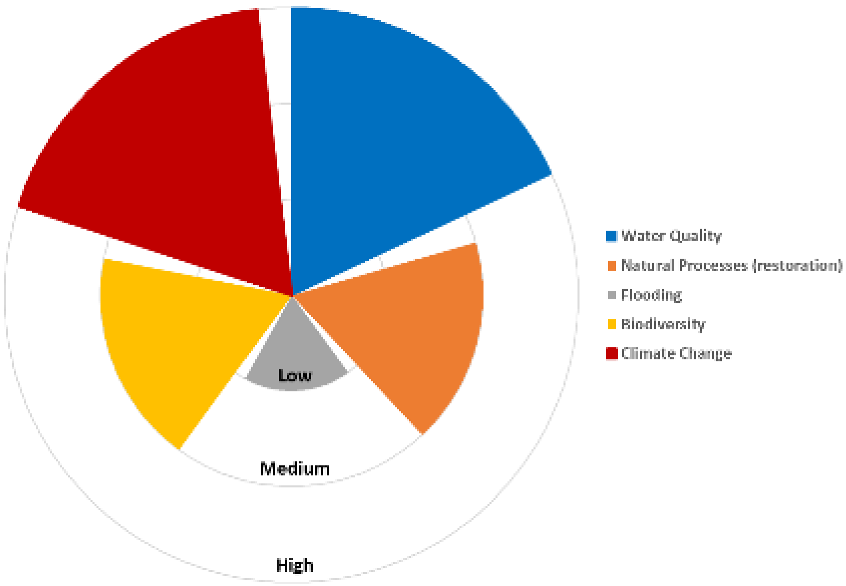



***Figure 5-14 Graphic illustrating benefits associated with re-wetting organic soils***

The National Park and Wildlife service (NPWS) has prepared guidance on the restoration of raised bogs in Ireland – "*Best practice in raised bog restoration in Ireland*" – and many of the types of activities described within this guidance are relevant for rewetting organic soils, and specifically drain blocking activities. The goal of this measures is to restore the maximum seasonal fluctuation in the water table within these organic soils to < 20cm (see Figure 5-15 below) which practically means a water table of no greater than 10cm below the surface. These works can be complicated by the presence of subsurface drainage which would also need to be intercepted and blocked as part of such works.

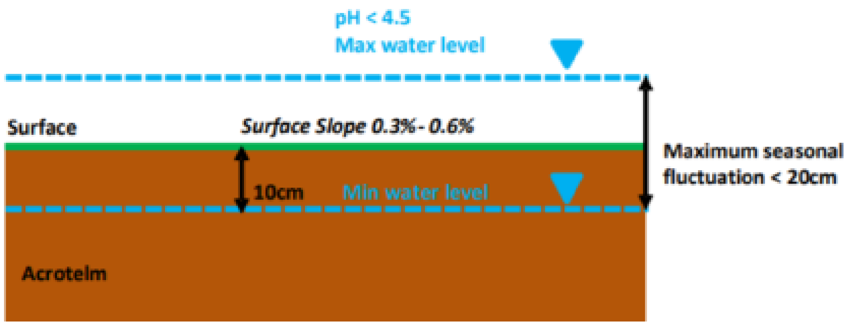



***Figure 5-15 Conditions required to maintain or restore good quality ARB habitat (NPWS, 2017)***

A study in the Netherlands which examined the impacts of intensively managed grassland on peat soil for water quality found that the associated drainage through these organic soils facilitated higher transportation of nutrients (N & P) to adjacent surface waters. The study found that raising groundwater levels by 20 cm suppressed this form nutrient loading to surface water by more than 30% (van Beek et al., 2007). Similarly, a German study also found clear evidence indicating that long-term drainage of grasslands on peat has increased the concentrations of dissolved organic carbon (DOC), ammonium, nitrate and dissolved organic nitrogen (DON) compared to the near-natural site in downstream water bodies (Frank et cl., 2014).

Re-wetting organic soils has been identified as a key measure which can assist in combatting the impacts of climate change by maximising the potential of peat as a carbon sink by both: halting the release of carbon associated with drainage activities and creating the correct environment for active peat growth for further carbon capture and storage. There have been numerous studies which have demonstrated the water cycling requirements for carbon sequestration in peat and therefore the potential impacts for climate change from this measure are significant (Hilbert et al., 2000; Frolking et al., 2010). Undisturbed peatlands have been reported to accumulate carbon from the air at a rate of up to 0.7 tonnes per hectare per year (Pearce, 1994).

An added benefit from implementing this measure is the associated benefits for biodiversity. Biodiversity benefits are mainly related to less intensive farming activities on such lands (due to wet conditions) and/or complete changes in land use in these locations. Blocking surface and subsurface drains on these organic soils also has added benefits in relation to flooding. Slowing the flow and runoff may reduce the peak discharge to the downstream waterbody and water retained within the organic soil itself may also reduce the overall volume of runoff, again potentially with positive benefits for flooding downstream (Lundin et al., 2017).

Targeting this measure to areas where other restoration/rehabilitation activities are taking place (such as raised bog restoration projects) would further enhance the multiple benefits that can be achieved across a broader spectrum. Historically, drainage of organic soils took place in lands adjoining raised bogs and indeed these lands are often located in areas of cutover bog that have been reclaimed for agricultural purposes. These lands are typically located in lowland areas of the country in the midlands and west and typically fall within arterial drainage schemes.

It must be noted that the impacts of this measure on the land owner need to be fully assessed i.e. loss of productivity and finacial implications. In addition, depending on the location, this measure could be difficult to achieve and sites will need to be carefully identified.

## Appendix 1 – Peatland NWRM

– *Description of peatland NWRM following the format of the EU NWRM project and using the list of benefits (and associate coding) set out in the project report.*

**P01 – Drain blocking**
Drain blocking on high or cutover bogs typically involves using peat or plastic dams to block the drain and restore the high watertable which is necessary for bog growth. The process typically involves clearing the drain, adding a 'key' in the side of the drain to ensure a tight seal before blocking with peat taken from a nearby 'borrow pit'. Alternatively, plastic sheet piling can be used whereby it is inserted into the drain and pushed down into the peat to create a seal as above. The key benefits of drain blocking lie in preventing/slowing runoff from peatland areas (with associated sediment/nutrient/COD benefits for water quality) increased biodiversity, sediment removal, water quality improvement and flood prevention.

*Possible benefits:*
BP1 - Store runoff
BP2 - Slow runoff
BP8 - Reduce pollutant sources
BP9 - Intercept pollution pathways
BP10 - Reduce erosion and/or sediment delivery
ES7 - Flood risk reduction
ES8 - Erosion/sediment control
PO7 - Prevent surface water status deterioration
PO9 - Take adequate and co-ordinated measures to reduce flood risks
PO14 - Prevention of biodiversity loss
ES4 - Biodiversity preservation
PO10 - Protection of important habitats
BP14 - Create terrestrial habitats
BP17 - Absorb and/or retain CO2
ES5 - Climate change adaptation and mitigation

**P02 – Artificial wetlands**
Artificial wetlands are engineered ponds or low-lying areas that mimic naturally occurring wetlands. They are usually constructed by creating shallow ponds and/or depressions in the land and controlling inflows/outflows to create a permanently wet area. These areas are then filled with wetland plants which are carefully chosen to suit the habitat involved. The design needs to take account of the site's hydrology, landscape and functional ecology. Artificial wetlands have the potential to provide suitable equivalent habitat to natural or restored wetlands. The key benefits of artificial wetlands lie in increased biodiversity, sediment removal, water quality improvement and flood prevention.

*Possible benefits:*
BP1 - Store runoff
BP2 - Slow runoff
ES1 - Water storage
ES11 - Aesthetic/cultural value
BP8 - Reduce pollutant sources
BP9 - Intercept pollution pathways
BP10 - Reduce erosion and/or sediment delivery
ES7 - Flood risk reduction
ES8 - Erosion/sediment control
PO7 - Prevent surface water status deterioration
PO9 - Take adequate and co-ordinated measures to reduce flood risks
PO14 - Prevention of biodiversity loss
ES4 - Biodiversity preservation
PO10 - Protection of important habitats
BP14 - Create terrestrial habitats
BP17 - Absorb and/or retain CO2
ES5 - Climate change adaptation and mitigation

**P03 – Wetland lakes**
Artificial wetland lakes are engineered lakes constructed by creating depressions in the land and controlling inflows/outflows to create a permanently wet area which can vary in depth. Wetland plants can be added to area of the artificial waterbody and islands incorporated to the provide refuges for birds and aquatic mammals. These lakes can be stocked with fish for biodiversity or to create an amenity for anglers. The key benefits of artificial wetland lakes lie in increased biodiversity, sediment removal, water quality improvement and flood prevention.

*Possible benefits:*
BP1 - Store runoff
BP2 - Slow runoff
ES1 - Water storage
ES11 - Aesthetic/cultural value
BP8 - Reduce pollutant sources
BP9 - Intercept pollution pathways
BP10 - Reduce erosion and/or sediment delivery
ES7 - Flood risk reduction
ES8 - Erosion/sediment control
PO7 - Prevent surface water status deterioration
PO9 - Take adequate and co-ordinated measures to reduce flood risks
PO14 - Prevention of biodiversity loss
ES4 - Biodiversity preservation
PO10 - Protection of important habitats
BP14 - Create terrestrial habitats
BP17 - Absorb and/or retain $CO_2$
ES5 - Climate change adaptation and mitigation

**P04 – Bunding**
There are two forms of bunding which can be carried out: marginal bunding and bunding on high bog. Marginal bunds are constructed on cutover areas at the margins surrounding high bog. The aim of these embankments is to retain a shallow area of water behind it to promote establishment of peat-forming vegetation on cutover areas (i.e. Sphagnum regeneration). This measure is best suited to locations where the cutover is extremely flat, there is contributing flow from nearby high bog, peat conditions are suitable to prevent significant vertical losses of water through the peat and there is an adequate marginal drain in place behind the proposed bund location. Bunding on high bog is essentially the same approach except water is retained by creating a long linear embankment on the high bog surface, or much larger peat bunds constructed on or close to the margins. This measure is typically carried out along with P01 to re-wet raised/blanket bogs and restore wet peatland conditions.

*Possible benefits:*
BP1 - Store runoff
BP2 - Slow runoff
ES1 - Water storage
BP9 - Intercept pollution pathways
BP10 - Reduce erosion and/or sediment delivery
ES7 - Flood risk reduction
ES8 - Erosion/sediment control
PO7 - Prevent surface water status deterioration
PO9 - Take adequate and co-ordinated measures to reduce flood risks
BP14 - Create terrestrial habitats

**P05 – Spagnum Inoculation**

Inoculation with Sphagnum is a method of raised bog restoration/rehabilitation for re-establishing peat-forming vegetation in areas where the surface vegetation has been removed or significantly degraded. The process involves preparing the raised bog by creating a flat surface, Sphagnum moss is then harvested from a donor peatland site, and spread across the prepared surface which is then protected and federalised to promote growth. Key to the success of this approach is the existence of suitable hydrological conditions for Sphagnum to survive prior to inoculation.

*Possible benefits:*
BP1 - Store runoff
BP2 - Slow runoff
ES4 - Biodiversity preservation
PO10 - Protection of important habitats
BP14 - Create terrestrial habitats
PO14 - Prevention of biodiversity loss
ES1 - Water storage
BP10 - Reduce erosion and/or sediment delivery
ES8 - Erosion/sediment control
PO7 - Prevent surface water status deterioration
BP17 - Absorb and/or retain CO2
ES5 - Climate change adaptation and mitigation

**P06 – Land reprofiling**

Excavation and re-profiling can be used as a peatland restoration/rehabilitation measure on high or cutover bog, to create more suitable topography and hydrological conditions for peat-forming habitats. This measure is typically utilised in combination with drain blocking and wetland creation as part of an integrated peatland restoration/rehabilitation approach.

*Possible benefits:*
BP1 - Store runoff
BP2 - Slow runoff
ES1 - Water storage
BP10 - Reduce erosion and/or sediment delivery
ES7 - Flood risk reduction
ES8 - Erosion/sediment control
PO7 - Prevent surface water status deterioration
PO9 - Take adequate and co-ordinated measures to reduce flood risks
PO14 - Prevention of biodiversity loss
ES4 - Biodiversity preservation
PO10 - Protection of important habitats
BP14 - Create terrestrial habitats
BP17 - Absorb and/or retain CO2
ES5 - Climate change adaptation and mitigation

**P07 – Clearance of inappropriate vegetation on peatlands**

This measure involves the felling/removal of inappropriate conifer plantations in order to increase the area of blanket bog cover; felling of naturally regenerated conifers from open bog can also be carried out. . Note that if such work is carried out, care will be required to avoid impacting connecting water bodies. The removal of trees/scrub other than conifers which have naturally regenerated can have the benefit of stopping the spread of  species inappropriate to a peat setting or problematic native tree species which have significant impacts on raised bog habitats by increasing interception and evapotranspiration rates. This measure is typically carried out along with P01 to re-wet raised/blanket bogs and restore wet peatland conditions.

*Possible benefits:*
BP2 - Slow runoff
BP10 - Reduce erosion and/or sediment delivery
ES7 - Flood risk reduction
ES8 - Erosion/sediment control
PO7 - Prevent surface water status deterioration
PO9 - Take adequate and co-ordinated measures to reduce flood risks
PO14 - Prevention of biodiversity loss
ES4 - Biodiversity preservation
PO10 - Protection of important habitats
BP14 - Create terrestrial habitats
BP17 - Absorb and/or retain $CO_2$
ES5 - Climate change adaptation and mitigation

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