This Project is funded by the European Union

Water and Environment Support in the ENI Southern Neighbourhood region

Activity No: N-W-IL-2

Storm Water Management and Natural Water Retention Measures / D1.1 Technical Report

Version	Document Title	Author	Review and Clearance
v.1	Technical Report	Demetrios Zarris	05.05.2020

WATER AND ENVIRONMENT SUPPORT IN THE ENI SOUTHERN NEIGHBOURHOOD REGION

The "Water and Environment Support (WES) in the ENI Neighborhood South Region" project is a regional technical support project funded by the European Neighbourhood Instrument (ENI South). WES aims to protect the natural ressources in the Mediterranean context and to improve the management of scarce water resources in the region. WES mainly aims to solve the problems linked to the pollution prevention and the rational use of water.

WES builds on previous similar regional projects funded by the European Union (Horizon 2020 CB/MEP, SWIM SM, SWIM-H2020 SM) and strives to create a supportive environment and increase capacity all stakeholders in the partner countries (PCs).

The WES Project Countries are Algeria, Egypt, Israel, Jordan, Lebanon, Morocco, Libya, Palestine, Syria and Tunisia. However, in order to ensure the coherence and effectiveness of EU funding or to promote regional cooperation, the eligibility of specific actions can be extended to neighboring countries in the Southern Neighborhood region.

DISCLAIMER:

This publication was produced with the financial support of the European Union. Its contents are the sole responsibility of the WES Project and do not necessarily reflect the views of the European Union.

To ensure the visibility of the EC and the project, please follow the EU visibility guidelines as described here https://ec.europa.eu/international-partnerships/comm-visibility-requirements_en.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

NWRM	**Natural Water Retention Measures**
SuDS	Sustainable Drainage Systems
WFD	Water Framework Directive
EA	European Union Environment Agency
DTI	UK's Department of Trade and Industry
PoM	Program of Measures

1 BACKGROUND INFORMATION

The State of Israel is characterized by a very small and narrow territory with extremely dense populated areas, especially along the shore of the Mediterranean Sea, as a conscience an accelerated process of increasing urbanization is taking place. This process is accompanied by a **reduction of recharge** to the groundwater sources and an **increase in storm water flows**. The loss of water yields to groundwater as a result of lack of natural infiltration areas caused by heavy urbanization and the runoff is estimated in tens of millions of cubic meters per year for the entire Coastal aquifer.

Management of **surface runoff in areas designated for <u>construction</u>** has in recent years been seen as an important planning goal for achieving **three main objectives**:

1. To **prevent the loss of surface runoff resulting from sealed** areas by infiltrating these runoff water and to contribute to the water resources, both in quantitative and quality ways.
2. To **reduce the storm water flows that reach the urban and regional drainage systems**, thereby creating an opportunity to reduce the total volume (and the costs) to be treated and maintained by the municipal infrastructures.
3. To **reduce pollution** in streams, and coastal and marine pollution from the urban runoff's dissolved and suspended pollutants and solid waste (mainly plastics)

Storm water management has many secondary goals such as environmental and landscape contribution, erosion prevention and pollution prevention. Several ministries and planning committees at the regional and national levels have been working in recent years to promote guidelines and regulations that require the implementation of storm water management considerations at all planning levels. Over the past decade, a number of **urban runoff management guides** have been written and in these days a **more updated guide is being prepared**. **However, the State of Israel does not have an accepted practice for the conservation and management of the urban runoff. In 2010 the Israeli Water Authority has issued regulations to promote the capture of flood water and their infiltration into the water sources**.

The main focus of applying NWRM is to enhance the retention capacity of aquifers, soil, and aquatic and water dependent ecosystems with a view to improve their status. The application of NWRM supports green infrastructure, improves the quantitative status of water bodies as such, and reduces the vulnerability to floods and droughts. It positively affects the chemical and ecological status of water bodies by restoring natural functioning of ecosystems and the services they provide. The restored ecosystems contribute both to climate change adaptation and mitigation.

As defined in the EU policy document on NWRM, NWRM

- Retain water (runoff or river flows) beyond the existing capacity of systems, releasing it at a controlled rate, or infiltrating it to groundwater;
- Use the retention capacity of soils and of aquatic ecosystems to provide other environmental and well-being improvements, such as water quality, biodiversity, amenity value or resilience and adaptation to climate change impacts;
- Are usually applied at relatively 'small scale', in comparison to the size of the water catchment or territory in which they are implemented;

- Emulate a natural process, although are not always 'natural' features themselves (as clearly illustrated by green roofs).

While the knowledge base on the effectiveness, applicability, costs and benefits of NWRM is growing, further research and results are needed to fully demonstrate their potential. The activity falls under Topic 2: "Water Efficiency Gains at Decentralised Level" and subtopic 3.3: "Non-Conventional Water Resources - Water retention" and shall be implemented in line with the EU position on the Middle East Peace Process. To this effect, all NWRM proposed under this activity should not trigger any conflict/dispute on shared water resources between the parties.

1.1 DEFINITION OF NATURAL WATER RETENTION MEASURES

According to the definition given by the EU (European Commission. 2014. EU Policy Document on Natural Water Retention Measures, Drafting team of the WFD CIS Working Group Programme of Measures (WG PoM)), the 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 natural means and processes. Their main focus is to enhance, as well as preserve, the water retention capacity of aquifers, soil, and ecosystems with a view to improving their status. NWRM have the potential to provide multiple benefits, including the reduction of risk of floods and droughts, water quality improvement, groundwater recharge and habitat improvement. The application of NWRM supports green infrastructure, improves or preserves the quantitative status of surface water and groundwater bodies and can positively affect the chemical and ecological status of water bodies by restoring or enhancing natural functioning of ecosystems and the services they provide. The preserved or restored ecosystems can contribute both to climate change adaptation and mitigation.

The definition of NWRM appeals both to a single purpose (safeguarding, enhancing or restoring the water storage potential) and also to a particular set of means (using natural processes). The actual distinctive character of NWRM has to do with the latter.

TABLE 1-1: ILLUSTRATING THE DIVERSITY OF MEASURES CLASSIFIED AS NWRM

Type	Class	Non-exhaustive list of examples
Direct modification in ecosystems	Hydro-morphology (Rivers, Lakes, Aquifers, connected wetlands)	Restoration and maintenance of rivers, lakes, aquifers and connected wetlands; Reconnection and restoration of floodplains and disconnected meanders, elimination of riverbank protection
Change & adaptation in land-use & water management practice	Agriculture	Restoration and maintenance of meadows, pastures, buffer strips and shelter belts; soil conservation practices (crop rotation, intercropping, conservation tillage...), green cover, mulching.
	Forestry and Pastures	Afforestation of upstream catchments; targeted planting for "catching" precipitation; Continuous cover forestry; maintenance of riparian buffers; urban forests; Land-use conversion for water quality improvements.

Urban development	Green roofs, rainwater harvesting, permeable paving, swales, soakaways, infiltration trenches, rain gardens, detention basins, retention ponds, urban channel restoration.

NWRM is used as a new overarching term to group measures that retain water using natural means and processes, while at the same time having the potential to provide multiple benefits to other sectors. Yet, NWRM are not something new: they encompass approaches that are partly overlapping or follow similar concepts and objectives such as *Room for the River*, *Ecosystem-based Adaptation*, *Natural Flood Risk Management* or *Green Infrastructure*. NWRM are considered to be complementary to grey infrastructure such as dikes, concrete reservoirs or wastewater treatment plants. In addition, grey infrastructure may support the implementation of NWRM, if the natural water retention process cannot be guaranteed by natural processes alone. Even though it is expected that NWRM can mitigate the extent and intensity of the negative impacts of grey infrastructure on ecosystems, NWRM cannot always be considered as cure-all measures.

NWRM can address major causes of not achieving good water status and major threats to biodiversity, mainly by natural flow regulation and natural water treatment. Natural flow regulation can lead to a reduction in the risk of floods in wet conditions and better water replenishment of groundwater and surface water bodies in dry conditions. Through dilution and the natural water filtering function, some NWRM also provide natural water treatment. NWRM can either restore the natural functions or actively preserve functional habitats such as intact floodplain wetlands. They can thus be applied to enlarge the area and functioning of aquatic, terrestrial, urban and coastal ecosystems. In agricultural and grassland ecosystems, NWRM can contribute to reversing biodiversity loss by creating small landscape elements such as buffer strips, small pools or wetlands. In the urban environment, NWRM can mitigate the impact of intense rainfall and heat waves and improve the quality of stormwater discharging into the receiving water bodies. Forest NWRM have the potential to ensure soil protection, water quality and improve water retention. Urban NWRM (e.g. Sustainable Urban Drainage Systems, SUDS) have the potential to improve water quantity and water quality in urban environment. In view of the increasing impact of climate change, NWRM are nature-based solutions that can address climate change adaptation, future natural hazards, and mitigation by facilitating natural carbon sequestration and storage.

Furthermore, NWRM can also be used - when integrated in land use planning and as part of green infrastructure - to address habitat fragmentation and lack of connectivity that are major drivers for the loss of biodiversity. Besides the enhancement of biodiversity and the provisioning of ecosystem services, NWRM can also provide benefits to society, namely jobs, green growth, improvement of health and quality of life, cooperation and innovation and promotion of diversification of the economy.

A growing evidence base, including from the NWRM pilot project, is providing better insights on the performance of NWRM. Many knowledge gaps however remain, in particular on the conditions under which NWRM perform best and how they are best combined with other measures, as well as where they might be cost-effective. One important knowledge gap relates to the effectiveness of NWRM when it comes to the **scale and location of deployment**. Implementation of NWRM is known to be effective and to deliver more easily measurable benefits at the local scale, whereas less evidence is available on the multiple benefits and win-win situations of NWRM at a larger, river basin scale and across sectors, despite the fact that benefits are expected to be more significant. This can depend on the location of the NWRM within the river basin (e.g. upstream or downstream), the area taken by NWRM, the combination with other measures and the type of extreme weather events (e.g. return period, intensity, extent). NWRM can for example **be effective for frequent, lower peak floods**, but may be **less effective for more severe floods**. Another knowledge gap are the potential trade-offs that NWRM might have on local flood risk, economic activity or environment. Hence, expert advice is needed to ensure that NWRM are implemented in appropriate locations and for contexts in which they can be effective.

1.2 NWRM AND TRADITIONAL DESIGN CONCEPTS

In the current period of financial and economic crisis with strong competition over public budget (including within the environmental sector), allocating public funds for supporting the implementation of measures that contribute simultaneously to the achievement of many policy goals (including FD, WFD, Habitats Directive, climate change policies) is likely to be very appealing to policy makers. Therefore, the multiple benefits NWRM can deliver are the primary justification for choosing and implementing NWRM as compared to grey infrastructure measures. NWRM can be considered as complementary measures to grey infrastructure measures. While NWRM cannot fully replace grey infrastructure, NWRM can reduce the need for grey infrastructure and in addition reduce, to some extent, the negative impact of grey infrastructure.

NWRM can address several policy objectives at the same time (e.g. water management and biodiversity related ones). Typically, in the planning process, NWRM are evaluated for their cost-effectiveness to achieve a single policy goal (e.g. flood risk reduction). However, the potentially high costs of land consolidation and difficulties in quantifying the benefits can bring NWRM down in the cost-effectiveness priority list. The latter often results in the non-selection of NWRM, despite other benefits they are expected to provide. The latter argument is valid in densely populated and highly productive agricultural areas, where land is scarce.

There are perceptions about what NWRM can or cannot deliver. Advocates of NWRM will stress that they are more cost-effective solutions than grey infrastructure. However, cost-effectiveness is not a permanent feature of NWRM as it is context, measure and policy specific. And NWRM are not always cheaper than grey infrastructure. When land prices are high, NWRM can be, or at least appear to be, expensive options! Furthermore, NWRM cannot address all policy challenges: for example, they are likely to have only a marginal role in addressing extreme flood events in large densely populated catchments with lots of existing development on the floodplain.

However, perceptions exist also about what grey infrastructure and traditional approaches to water management can deliver. People favouring grey infrastructure will stress their effectiveness in contributing to set policy objectives. However, there is a risk that their negative direct and indirect environmental impacts are hidden, and that the opportunities lost due to the multiple benefits of NWRM not being delivered are not considered. In addition, grey infrastructure implementation costs can be significantly higher than costs estimated in ex-ante appraisals, with potentially significant impacts on public budgets and reduced cost-effectiveness when compared to the costs anticipated at the design stage.

1.3 DESIGN CONCEPTS FOR NWRM IMPLEMENTATION

Making the most of NWRM is not just about looking for and selecting a new type of measure. It is a change in the philosophy of management and planning that takes account of the following key principles:

- Principle 1 - Giving priority to nature-based solutions.
- Principle 2 - Joint accounting for the potential multiple benefits of measures.
- Principle 3 - Capturing all opportunities favouring policy integration and simultaneous contributions to the objectives of different policies.
- Principle 4 - Thinking of a bundle of measures from the outset, which can include both NWRM and grey infrastructure measures.

It requires careful adaptation in the different steps of any planning process being carried out at a given geographical scale so that the opportunities offered by NWRM are adequately considered and taken advantage of while accounting for their limitations.

1.4 COMPATIBILITY WITH THE TERMS OF REFERENCE

This report is compiled with full compatibility with the requirements in the Terms of Reference (ToR) specifically with the TASK 1 ” Review of Best Management Practices (BMP) and Natural Water Retention Measures (NWRM) for storm water management, aquifer recharge, debris retention transported by runoff, direct use in agriculture etc. and holding a workshop”. It is stated that “Prepare the first deliverable documenting the BMPs and NWRM (for storm water management, aquifer recharge (quantity and quality), aquifer recharge, debris retention transported by runoff, direct use in agriculture) and case studies demonstrating the application of selected best practices.”

It is also stated that “Not all NWRMs are applicable everywhere, therefore a screening procedure will be performed in order to further take into consideration those measures that are applicable in arid or semiarid areas and with restricted area availability”. The NWRMs presented hereafter are the outcome of a screening procedure rejecting those who are solely or mainly applicable to other regions of the world with completely different climatic characteristics. The criteria taken under consideration has to do with rainfall regimes, average temperatures, types of agricultural practices, prevailing types of vegetation, etc.

2 LIST OF NATURAL WATER RETENTION MEASURES

In this Chapter, all the NWRMs available to the scientific community are going to be listed. These measures are categorized according to the field of the application that each measure is going to be implemented.

A total number of four different ensembles of measures are listed, which are the following:

1. Urban Runoff.
2. Hydromorphology.
3. Forestry.
4. Agriculture.

It is obvious that all measures are interrelated and there are no strict borders among categories of measures. For instance, planting trees in urban areas may be included in the Forestry category as well as in the Urban Runoff category. These four categories are also contained in the hydrologic circle and the exchange between the water and sediment nexus that are equally important.

In the following paragraphs, a vast number of measures in all 4 categories are listed and analyzed describing the pros and cons and their effectiveness to the attenuation of flood peaks and reduction of flood volumes.

Most of the measures listed below have been transferred from the European NWRM Platform (http://nwrm.eu/). The current platform gathers information on NWRM at EU level.

2.1 URBAN RUNOFF

The world's population nowadays is concentrated in urban areas. This change in demography has brought land-use and land-cover changes that have several documented effects on stream flow. The most consistent effect is an increase in impervious surfaces within urban catchments, which alters the hydrology and geomorphology of streams. In addition to imperviousness, runoff from urbanized surfaces as well as municipal and industrial discharges results in increasing floods in urbanized areas as it is decreasing riverbed capacity for flow. Rainwater management should be considered as a sustainable strategy for reconstruction of rural and urban settlements from the aspects of environmental management and social criteria.

NWRMs for urban areas play the role to decrease the adverse effects of urbanization on the environment by retaining as mush flow as possible in the urban catchment. The possible measures for urban areas are numerous (see also FIGURE 2-1). The number of each measure shown in the figure is explained in the associated paragraph with the same number.

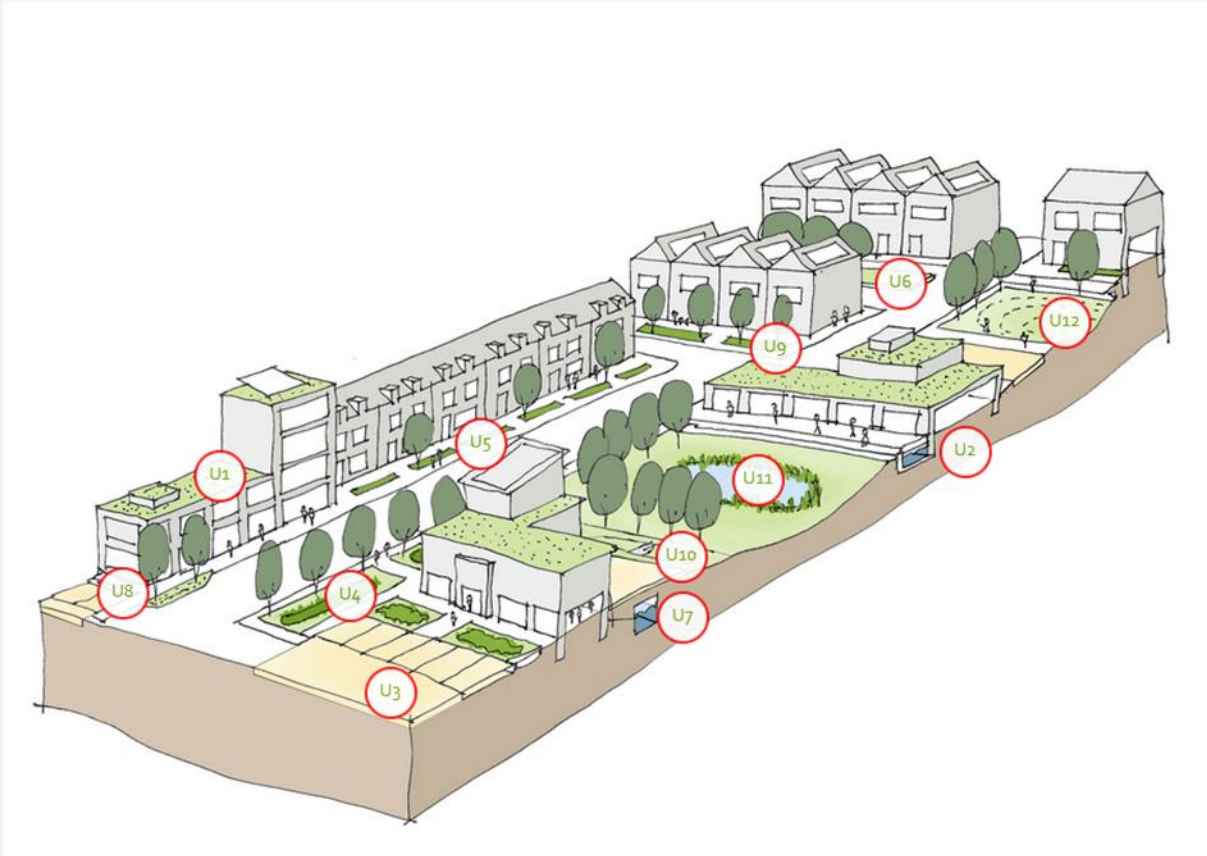

FIGURE 2-1: SCHEMATIC DIAGRAM OF URBAN RUNOFF NWRMS.

2.1.1 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.

A typical structure for a green roof includes a surface vegetation layer underlain by a substrate (growth medium), geotextile filter layer, and an aggregate or geo-composite drainage layer. The green roof materials are underlain by a waterproof membrane, with an additional layer of insulation between that and the roof itself. Green roofs are designed to intercept rainfall, which is slowed as it flows through the vegetation and a drainage layer, mimicking the predevelopment state of the building footprint. Some of the rainwater is stored in the drainage layer and taken up by the vegetation, with the remainder discharged from the roof in the normal way (via gutters and downpipes). Flow rates from the green roof are reduced and attenuated compared to a normal roof, and the total volumes discharged from the roof are also reduced. Green roofs therefore intercept rainfall at source and provide the first component of a SuDS management train.

FIGURE 2-2: ILLUSTRATION OF GREEN ROOFS

Green Roofs are applicable to all types of buildings, subject to the design and function requirements of the roof. Green roofs can be grown on any pitch of roof, including vertical walls, although roofs with a pitch greater than 1 in 3 may require additional support and may have other specific design requirements. With respect to CORINE Level 2 land uses, green roofs are applicable to:

- Urban Fabric
- Industrial/Commercial/Transport Units

According to the applicability on Mediterranean type climates, potential restrictions relating to high temperatures and dry weather, which provides challenges for vegetation maintenance, although these can potentially be overcome through irrigation (preferably using water stored from runoff from the green roof) and careful choice of drought tolerant vegetation.

2.1.1.1 Impacts on Runoff / Peak Flows

Green roofs are most effective for frequent, less extreme rainfall events, and a good design would typically capture all rainfall from a two - year event, without overflow from the roof. For larger rainfall events with a return period greater than two years, there will be some overflow, although the green roof will provide some benefit. A higher volume of rainwater can be stored if a layer of porous material is included. For intense, in extreme rainfall events (e.g. the 100 year event) the hydraulic performance of the roof is likely to be similar to a normal roof (CIRIA, 2007).

Quantification of the effectiveness of green roofs at attenuation and peak flow reduction has shown widely varying values, with a literature review by Blanc et al (2012) finding values varying from 5% up to 95% reduction in runoff compared to a hard roof surface. Oberndorfer et al (2007) found a similarly wide range in their literature review, from 25-100% rainfall retention. Overall, it is generally accepted that green roofs are effective, particularly for smaller events, but the wide range of reported effectiveness is a result of variables including substrate type and depth, antecedent conditions, season, and rainfall intensity and volume.

Runoff is decreased by the simultaneous increase of the actual evapotranspiration. Increased evapotranspiration occurs because of introduction of vegetation to an otherwise hard surface. Evapotranspiration is likely to be more significant where the substrate soil is thicker.

Green roofs can provide some water quality benefits, through filtration, adsorption, biodegradation and uptake by plants. However this is only effective in terms of improvements to the quality of the rainwater and atmospheric deposits, since green roofs intercept rain directly prior to runoff. They can also be designed to take runoff from adjacent (non-green roofs), which will increase the overall effectiveness at pollutant reduction. They are effective in removal of suspended solids, and fairly effective for heavy metals (CIRIA, 2007).

2.1.1.2 Impacts on the Urban Environment

Green roofs have aesthetic and biodiversity benefits, through introducing vegetation to what would otherwise be a hard surface with no biodiversity interest. The level of biodiversity interest will depend on the size of the greenroof, whether it is extensive or intensive, and on the type of vegetation.

When widespread across an urban area, green roofs may contribute to improvements to air quality, lower air temperatures and higher humidity levels in urban areas, thus assisting with climate regulation. When only used on a small scale, a contribution towards these impacts will still be made, but will have only a low impact individually. Green roofs with deeper substrate are more effective. Lower level green roofs (i.e. not high-rise) are more likely to have a positive influence on the heat island effect. Oberndorferet al (2007) discuss effects of green roofs on temperature, both to outside air temperatures in urban areas, as well as the insulating effect inside the building. They refer to Bass et al (2003), who modelled the influence of 50% green roof coverage in the city of Toronto, and found temperature reductions of up to 2ºC. Cooling effects in the building occur due to a combination of substrate thickness and evapotranspiration.

Green roofs introduce vegetation to areas of otherwise hardstanding. Although the diversity of the vegetation may be low (for extensive green roofs) or managed (for intensive green roofs) this nevertheless provides an improvement over a hard roof. Green roofs contribute to climate change adaptation and mitigation through: temperature regulation, potential carbon sequestration (in some circumstances) and management of urban flood risk. As discussed above, their effectiveness at providing these benefits depends on the design (particularly substrate thickness) and over what area they are implemented.

2.1.2 RAINWATER HARVESTING

Rainwater harvesting involves collecting and storing rainwater at source for subsequent use, for example, using water butts or larger storage tanks. Water butts are the most widely applied and simple rainwater harvesting technique, collecting rainwater runoff from roofs via a connection to the roof down-pipe. They are primarily designed for small scale use such as in household gardens, although a range of non-potable uses is possible. 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 cases of summer, convective storms that may produce flooding, rainwater harvesting can jointly act as “yield – demand” effect.

Rainwater harvesting is generally implemented on a small scale (CIRIA (2007) suggests 2 m^3 as an average attenuation volume for an individual house). As such the dimensions of the contributing drainage area may be that of a household roof, but it could also be a larger area such as a car park. Most rainwater collection tanks are manufactured from plastics, but other materials could be used if they are protected against the corrosive effects of the stored water and any disinfectants used. The storage of rainwater does not have to be in a traditional tank, e.g. the void space in sub-base material of a permeable paving system or within geo-cellular modular units can also be used.

CIRIA (2009) identify that rainwater harvesting is most likely to be of use for runoff control where "yield is greater than demand". This is likely to be relevant to the Mediterranean region but should be determined on a site-specific basis depending on design (dimensions) and intended use of the water. In warmer climates, particularly the Mediterranean region, there could potentially be potential public health concerns if storage is not fully contained and protected, e.g. mosquitoes. Nevertheless, rainwater harvesting is of value to this region.

FIGURE 2-3: RAINWATER HARVESTING TECHNIQUES

2.1.2.1 Impacts on Runoff / Peak Flows

Rainwater harvesting stores runoff for local use, with the potential therefore to reduce both the rate and total volume of runoff. However, the actual effectiveness of rainwater harvesting is highly dependent on whether the system is specifically designed for runoff storage or whether the primary aim is water storage. Unless space is specifically allocated for runoff storage, then there may be insufficient space to provide benefit. This may vary with region, season and the use of the water, for example Blanc et al (2012) note that in the UK, water harvested for irrigation is unlikely to be used in winter, so storage will remain full, leaving no space for runoff storage. In relation to this, CIRIA (2009) identify that rainwater harvesting is most likely to be of use for runoff control where "yield is greater than demand". CIRIA (2007) conclude that rainwater harvesting for runoff control is likely to be more effective for larger tanks than individual water butts.

Water quality improvements can be achieved prior to use by filtration or other treatment, as required, but the basic process of harvesting will have little influence on water quality.

2.1.2.2 Impacts on the Urban Environment

Rainwater harvesting can contribute to climate change adaptation through providing a contribution to sustainable water supply.

2.1.3 PERMEABLE PAVEMENTS

Permeable pavement 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. It can be used in most ground conditions and can be sited on waste, uncontrolled or non-engineered fill, providing the degree of compaction of the foundation material is high enough to prevent significant differential settlement. A liner may be required where infiltration is not appropriate, or where soil integrity would be compromised.

CIRIA (2007) and the "Centre des recherches routières" (Road Research Centre) of Brussels (2008) describes three different types of porous/permeable pavements:

- All rainfall passes through sub-structure and in to soils beneath, with (normally) no surface discharge (i.e. fully infiltrating).
- Perforated pipes lie between the sub-base and underlying sub-soil, to convey rainfall that exceeds the capacity of the sub-soil to a receiving drainage system (i.e. partially infiltrating).
- Perforated pipes lie beneath the sub-base, over an impermeable membrane, so all rainfall, after filtering through the sub-base, is conveyed to the receiving drainage system (i.e. no infiltration).

All types provide attenuation of rainfall, and potentially can also store runoff from surrounding areas, if designed and sized appropriately. Types A and B provide infiltration to underlying groundwater, thereby contributing to increased groundwater levels and/or flows, and hence potentially to baseflow. Type C does not interact with groundwater, but stores rainfall (and potentially runoff) and releases it at a controlled rate, hence still contributes to regulating the rate of rainfall-runoff.

For instance, four different types of permeable pavements are currently used in Germany. The first type consists of concrete pavers with wide joints or apertures to infiltrate the water underground. Pavers with canals on their sides are especially interesting (see FIGURE 2-4a). The joints of these pavers are filled with a permeable mineral material that allows fast water movement. Because of these canals, the pavers need only narrow joints. This feature allows them to be used, for example, around supermarkets with shopping trolleys. Such pavements look very much like traditional pavements.

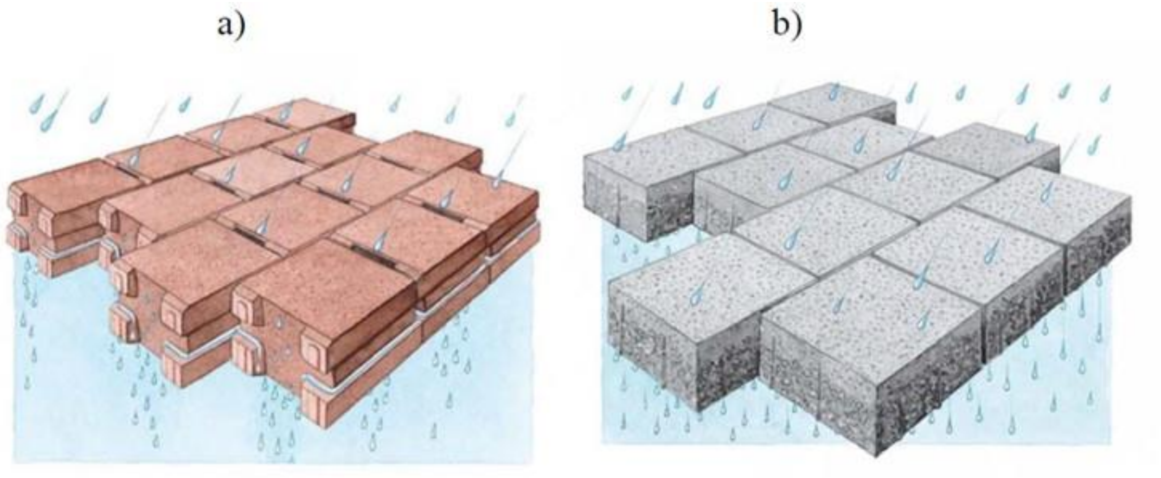

FIGURE 2-4: SYSTEMS OF PERMEABLE PAVEMENTS: A) PAVERS WITH CANALS AND B) POROUS PAVERS

High pollution retention capacities can be achieved with paving-stones made of special porous concrete (Dierkes 1999). The system consists of a porous paver with two layers (see FIGURE 2-4b). The top, fine layer acts as a filter for pollutants. The high porosity provides good infiltration and air exchange with the underlying soil. Particulate matter from rain, the atmosphere and vehicles are trapped in the upper 2 cm of the paver and can be removed by cleaning.

The third system consists of porous paving-stones with greened apertures. This system is suitable for all areas, where a natural look is desired. The small apertures of 3 cm x 3 cm are filled with a specific substrate that stores water, so that the grass does not dry out during rain-free periods. The open structure of the pavers prevents over-heating of the pavement, so the grass has ideal living conditions (see FIGURE 2-5a).

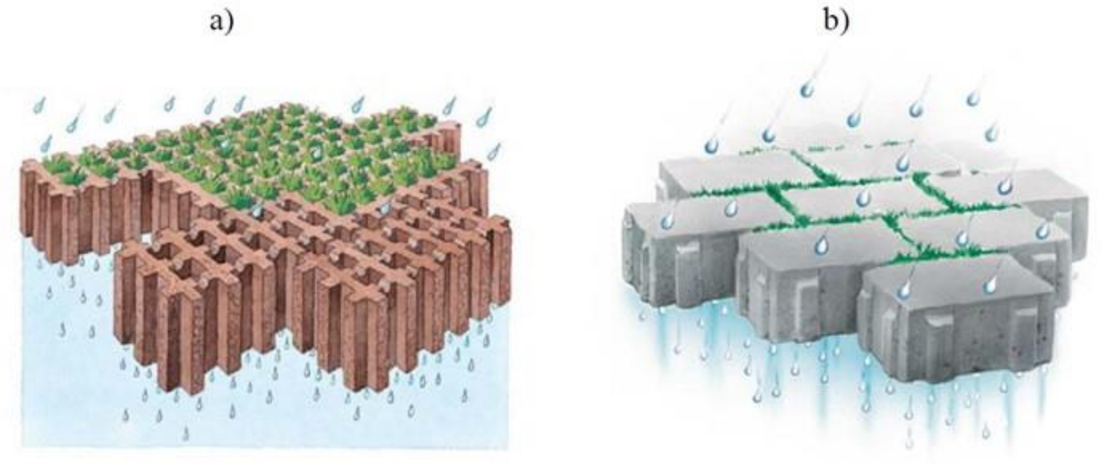

FIGURE 2-5: SYSTEMS OF GREENED PERMEABLE PAVERS, A) SMALL APERTURES, B) WIDE JOINTS

The last presented system comprises concrete pavers that are made with spacers, which provide larger gaps between each paver when laid in position. These joints are filled with a substrate that stores the rainwater and nourishes the grass during dry periods (see FIGURE 2-5b).

Permeable pavements must have a high pollution retention capacity and must be cleaned from time to time. Results of a research project concerning pollutant behaviour and cleaning are outlined below.

2.1.3.1 Impacts on Runoff / Peak Flows

Permeable paving stores rainfall-runoff in the sub-baseand either releases it at a controlled rate, or infiltrates to groundwater. Blanc et al (2012) carried out a literature review of the effectiveness of permeable paving for runoff reduction and found variable results in different situations. Values for runoff reduction varied between 10%-100%, while peak flow reductions of between12-90% were reported. Effectiveness can decrease significantly over time without sediment management Blanc et al (2012) cite Ilgen (2007), who found new permeable paving to reduce runoff by 98%, while clogged systems achieved only 29-48% reduction. This does not necessarily preclude adequate long-term performance if systems are designed with the expectation of a reduction in effectiveness over time.

The main considerations are sub-surface permeability, groundwater level and contamination of soils or aquifers. Where the soil or geology has low permeability, groundwater levels are high (e.g. less than 1m below the ground surface), or underlying substrate is contaminated, infiltration is generally not recommended. The effects of water storage on the structural capacity of the underlying soils must also be assessed carefully and slopes and collection systems used to manage the risks associated with ponding water. Any permeable pavement will need to be able to capture the required design storm event and discharge it in a controlled manner to the sub-grade or drainage system, while providing sufficient structural resistance to withstand loadings imposed by vehicles above. However, in Mediterranean type catchments, the aquifer level is frequently rather deep, thus allowing for infiltration.

2.1.3.2 Impacts on the Urban Environment

By helping to limit urban runoff and flooding, permeable paving provides a contribution to adaptation to the higher intensity storm events expected due to climate change.

Dierkes et al., (2002) have tested four different types of concrete pavers, a paver with open joints, a porous paving-stone, a paver with large greened apertures and a porous paver with greened apertures for their retention capability of dissolved heavy metals (see FIGURE 2-6). Because the pavement is the first filter for runoff, it is of special interest. The tests were carried out with intermittent rain events at an intensity of 144 mm/h. The high intensity should simulate a worst case scenario. The rigs were charged with synthetic rainwater containing mean concentrations of 180 µg/l Pb, 470 µg/l Cu, 660 µg/l Zn and 30 µg/l Cd and pH was at 4.9. According to the concentrations in the synthetic runoff and in the seepage a mass balance for the metals was calculated. Figure 4 shows the loads of metals for one square-metre over a period of 50 years. The left columns show the total input mass of metals and the right columns show the mass of metals that left the different types of permeable pavements. There are big differences in the ability of the pavers and joint fillings to trap heavy metals. Most metals in seepage were found where the infiltration was carried out only through the joints. Blocks with greened areas seem to trap the metals very effectively. Lead and copper were retained more effectively than zinc and cadmium.

In conclusion, paving-stones of porous concrete and paving-systems with greened apertures show the highest pollution retention capacities. Pavements with large joints or apertures for infiltration must have a suitable joint-filling, otherwise pollutants can pass through the pavement and get easily into the underground.

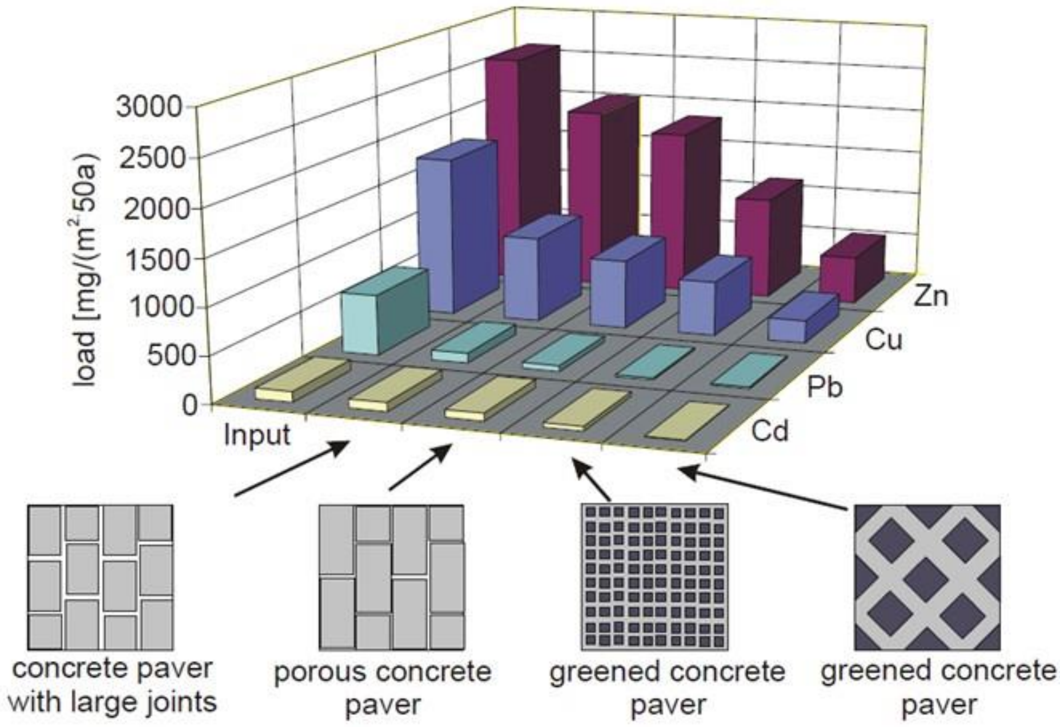

FIGURE 2-6: HEAVY METALS RETENTION OF FOUR DIFFERENT PERMEABLE PAVEMENTS

Permeable pavements show very high efficiency in being able to trap dissolved heavy metals in runoff. The pavement itself is responsible for much of the retention. Most metals are precipitated in the upper 2 cm of the porous concrete (Dierkes et al. 1999). But the pH in effluent shows, that the buffer capacities of concrete are very high, so that heavy metals do not occur predominantly in dissolved form.

2.1.4 SWALES

Swales are broad, shallow, linear vegetated channels which can store or convey surface water (reducing runoff rates and volumes) and remove pollutants. Swales are grassed waterways with side slopes flatter than 3:1 (horizontal : vertical), and top width to depth ratios of approximately 6:1 or greater. They can be used as conveyance features to pass the runoff to the next stage of the SuDS treatment train and can be designed to promote infiltration where soil and groundwater conditions allow. Three kinds of swale give different surface water management capabilities:

- **Standard conveyance swale:** Generally used to convey runoff from the drainage catchment to another stage of a SuDS train. They may be lined or un-lined, depending on the suitability for infiltration.
- **Enhanced dry swale:** Includes an underdrain filter bed of soil beneath the vegetated conveyance channel to accommodate extra treatment and conveyance capacity above that of the standard swale. The underdrain leaves the main channel dry except for larger runoff events and will prevent channels becoming waterlogged where the swale is situated on gentler slopes. A lining can also be incorporated into the underdrain if infiltration to underlying ground is not appropriate.

- **Wet swale:** Where prolonged treatment processes are required for the storm runoff, the swale's conveyance channel can be encouraged to maintain marshy conditions by using liners to control infiltration, or by siting in an area with high water table.

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. As a result, 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.

Swales are applicable to a wide range of situations. They are typically located next to roads, where they replace conventional gullies and drainage pipe systems, but examples can also be seen of swales being located in landscaped areas, adjacent to car parks, alongside fields, and in other open spaces. They are ideal for use as drainage systems on industrial sites because any pollution that occurs is visible and can be dealt with before it causes damage to the receiving watercourse.

Swales are potentially applicable to all artificial surfaces, particularly since the swale type can be adapted to be suitable to the local conditions (e.g. water table depth and suitability for infiltration). Swales are most effective when receiving runoff from impermeable or low permeability surfaces, which is most effective in the context of artificial surfaces (including artificial surfaces in agricultural, forest and semi-natural areas), but can also be appropriate where there is runoff from low-permeability surfaces in other areas (e.g. compacted soils, farm tracks, etc), and can be used to manage runoff from fields (Environment Agency, 2012).

FIGURE 2-7: A TYPICAL MANIFESTATION OF A SWALE

Goal of the design is to determine the retention volume of the swale. The hydraulic conductivity of the soil should not be smaller than 10^{-6} m/s. The required area is approximately 15 m^2 per 100 m^2 of connected impervious area. The depth of the swales should be less than 0.3 m (Dierkes et al., 2002).

2.1.4.1 Impacts on Runoff / Peak Flows

Swales are intended to slow and store runoff (Certu,2008). CIRIA (2007) states that the capacity of a swale should be designed to attenuate and treat a rain event with a 10 –30 year return period, although there is potential for runoff rate control up to a 1 in 100 year event (Blanc et al, 2012). Blanc et al

(2012) carried out a literature review of the hydrological effectiveness of swales. They found that while the literature almost invariably reports some level of effectiveness, the efficiency of swales is highly dependent on good design and catchment/local landscaping characteristics. The literature they reviewed showed significant variations in the runoff reduction achieved from swales, but in general more than 50% reduction in mean runoff. In terms of reduction in peak runoff rates, Sniffer (2004) found reductions of peak flow of 52% and 65% in two swales in Scotland.

The reduction of runoff is attributed also to the increase of evapotranspiration. The rate of evapotranspiration will depend on the swale dimensions, residence time and type of vegetation (being higher with dense vegetation and relatively low velocities).

2.1.4.2 Impacts on the Urban Environment

Where infiltration can occur, the potential for pollution to groundwater needs to be considered. However, CIRIA (2009) concluded that “the potential for contamination of groundwater from SuDS schemes appears to be low, except from industrial areas. The potential for serious pollution is associated with accidents rather than the continuous background pollution from these areas”. This conclusion drew on relatively recent work by SNIFFER (2008) that found “the vast majority of heavy metals, PAHs and petroleum hydrocarbons are retained in the top 10 cm of soil” based on bare-soil lysimeter tests, and noted that the addition of a vegetative layer would allow further uptake of pollutants. However, it is clearly important to consider the risks of pollution to groundwater on a site-specific basis in light of the wider water management, activities occurring within the drainage area of the measure and groundwater sensitivity (depth, soil permeability). Creating green areas reduces hard surfaces and leads to reduced surface leaching of pollutant sources.

By creating green areas within the urban landscape where there would otherwise be hard surfaces, swales provide a contribution to biodiversity preservation. The extent to which this benefit is provided depends on the soil moisture and choice of vegetation. Even when their individual contributions are minor, their potential for contributing to networks of vegetated areas and green corridors can make them an important element in biodiversity preservation in urban landscapes.

Swales provide a ‘green’ alternative to conventional drains. They should be planted with native vegetation to be most effective in enhancing biodiversity. They can be incorporated as an element in a network of green areas, thereby creating green corridors, which are important for the provision of terrestrial habitat.

2.1.5 CHANNELS AND RILLS

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

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 NWRMs 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.

2.1.5.1 Impacts on Runoff / Peak Flows

Channels and rills provide a small amount of storage and help to control the rate of runoff. They can be flexibly designed to accommodate and control flow as necessary, according to the local requirements. Planting in channels and rills can help to slow the rate of runoff.

The rate of actual evapotranspiration will depend on dimensions, residence time and type of vegetation. With dense vegetation and relatively low velocities, evapotranspiration can substantially increase. However, if channels and rills are designed only to convey water, with a very low residence time, evapotranspiration will not be significant. Channels and rills may be combined with small ponds that will significantly increase the rate of infiltration and evapotranspiration.

2.1.5.2 Impacts on the Urban Environment

If planted, channels and rills introduce vegetation where there would otherwise be hard surfaces only. The extent to which biodiversity benefit is provided depends on the soil moisture and choice of vegetation. Even when their individual contributions are minor, their potential for contributing to networks of vegetated areas and green corridors can make them a useful element in biodiversity preservation in urban landscapes.

Channels and rills may be planted. Depending on vegetation density and how widespread they are, they can contribute to creating “cool islands” in urban landscapes (as a result of evapotranspiration, water supply, shadow). They can also assist, if vegetated, to a small increase of CO_2 absorption.

In some cases, channels and rills can be attractively designed into urban landscapes, thereby providing aesthetic value. Using such channels and rills is a communication tool for promoting sustainable water management. Keeping water on show (rather than hiding it in traditional drainage systems) helps to raise people’s awareness and knowledge. This is particularly the case where the detail and value of MWRM is communicated to the public, for example by installing information panels.

2.1.6 FILTER (BUFFER) STRIPS

Filter strips are uniformly graded, gently sloping, vegetated strips of land that provide opportunities for slow conveyance and (commonly) infiltration. They are designed to accept runoff as overland sheet flow from upstream development and often lie between a hard-surfaced area and a receiving stream, surface water collection, treatment, or disposal system. They are 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.

Filter strips can serve as a buffer between incompatible land uses and can provide locations for groundwater recharge in areas with pervious soils. Filter strips are often integrated into the surrounding land use, for example public open space or road verges. Local wild grass and flower species can be introduced for visual interest and to provide a wildlife habitat.

Filter strips are potentially applicable to all artificial surfaces (car parks, road surfaces, etc.), or as a boundary between an artificial surface and other land use. They can also be used to agricultural areas, for example, to a field, or to artificial surfaces in agricultural areas such as farmyards.

FIGURE 2-8: MANIFESTATION OF A FILTER STRIP.

2.1.6.1 Impacts on Runoff / Peak Flows

Sediment deposition is the primary aim of filter strips, achieved by capture of sediment in vegetation at low flow velocities. Due to their rough surface (as a result of dense vegetation cover), filter strips will provide some slowing of runoff(mainly for smaller rainfall events), but this may be relatively minor since there is no storage capacity as such. The rate of evapotranspiration will depend on dimensions, residence time and type of vegetation. With dense vegetation and relatively low velocities, evapotranspiration is substantially increased, particularly if trees are planted. They are designed to be permeable, although due to the low residence time there is likely to be relatively little infiltration.

2.1.6.2 Impacts on the Urban Environment

Filter strips introduce permanent vegetation to what may otherwise have been an artificial surface or arable land. The diversity of the vegetation is limited by the function it must perform, and is normally predominantly grasses, but native and wild flowers can be added for increased diversity. Nevertheless, a large variety of trees, shrubs and plants are suited for filter strips. Filter strips should be planted with native vegetation to be most effective in enhancing biodiversity. They can be incorporated as an element in a network of green areas, and to create green corridors, which are important for the provision of terrestrial habitat.

By creating green areas within the urban landscape where there would otherwise be hard surfaces (or, for example, permanent native vegetation in an arable area) filter strips provide a contribution to biodiversity preservation. Although the diversity of the vegetation is generally relatively low, this nevertheless provides an improvement over traditional drainage and urban land cover. Development of biodiversity depends on soil moisture and choice of vegetation. The extent to which this benefit is provided depends on the soil moisture and choice of vegetation. Even when their individual contributions are minor, their potential for contributing to networks of vegetated areas and green corridors can make them an important element in biodiversity preservation in urban landscapes.

2.1.7 SOAKAWAYS

Soakaways are buried chambers that store surface water and allow it to infiltrate 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.

As a sub-surface infiltration device, a soakaway requires no net land take. They can be built in many shapes and can often be accommodated within high-density urban developments and can also be retrofitted. Soakaways are easy to integrate into a site but offer very little amenity or biodiversity value as they are underground features and water should not appear on the surface.

Soakaways are potentially applicable to all artificial surfaces, subject to consideration of the suitability of underlying soils and geology to infiltrate water and consideration of the potential to mobilise contamination or act as a vector for poor quality water to enter groundwater. They are most effective when receiving runoff from impermeable surfaces (urban areas) and providing retention to allow water to infiltrate. They are less likely to be applicable to other low-permeability surfaces such as field runoff since high sediment loading will reduce the effectiveness of the soakaway. However, soakaways can be used with pre-treatment to reduce sediment loading and may be applicable for artificial surfaces in agricultural areas, such as farmyards.


FIGURE 2-9: MANIFESTATION OF SOAKAWAYS.

2.1.7.1 Impacts on Runoff / Peak Flows

Soakaways are generally designed to collect and infiltrate runoff from a small area such as an individual house or car-parking area. Although multiple soakaways can be connected to serve a larger drainage area, it is unlikely to exceed 0.1 km^2 and designed to capture and infiltrate runoff up to the 1 in 30 year event (CIRIA, 2007).

2.1.7.2 Impacts on the Urban Environment

Soakaways store runoff and infiltrate it to groundwater. Through this impact, they enhance the potential of the landscape to store water during floods and make this water available for other purposes (e.g. recharge to groundwater, offering soil moisture to support terrestrial ecology).

2.1.8 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).

Infiltration trenches reduce runoff rates and volumes and can help replenish groundwater and preserve base flow in rivers. They treat runoff by filtration through the substrate in the trench and subsequently through soil. They are effective at removing pollutants and sediment through physical filtration, adsorption onto the material in the trench, or biochemical reactions in the fill or soil. However they are not intended to function as sediment traps and must always be designed with an effective pre-treatment system where sediment loading is high (e.g. filter strip). Unless very effective pre-treatment is included in the design, they are best located adjacent to impermeable surfaces such as car parks or roads/highways where there levels of particulates in the runoff are low. They work best as part of a larger sustainable drainage treatment train. Infiltration trenches are easy to integrate into a site and can be used for draining residential and non-residential runoff. Due to their narrow shape, they can be adapted to different sites, and can be easily retrofitted into the margin, perimeter or other unused areas of developed sites. Infiltration trenches are also ideal for use around playing fields, recreational areas or public open space. They can be effectively incorporated into the landscape and designed to require minimal land take.

Infiltration trenches are most effective when receiving runoff from impermeable surfaces and providing retention to allow water to infiltrate. They are less likely to be applicable to other low-permeability surfaces such as field runoff, since high sediment loading will reduce the effectiveness of the trench. However, infiltration trenches can be used with pre-treatment to reduce sediment loading, and may be applicable for artificial surfaces in agricultural areas, such as farmyards and roads. They are generally designed to collect and infiltrate runoff from a small area such as a carpark. Environment Agency (2012) suggest a maximum contributing area of 0.2 km^2.

2.1.8.1 Impacts on Runoff / Peak Flows

Blanc et al (2012) conclude that infiltration trenches are effective for runoff reduction for up to 1 in 30 year events. This corresponds to CIRIA (2007) recommendation of designing trenches to accept a 1 in 10 or 1 in 30 year event. The trench design must take in to account the infiltration rate of the underlying soil, to ensure effective operation.Blanc et al (2012) found in their review of literature that antecedent conditions can have a significant influence on performance. In addition, effectiveness can reduce significantly over time if high levels of sediment can enter the trench: effective pre-treatment must be included if significant sediment loaded is expected in runoff.

EA (2012) carried out a literature review of evidence of pollution removal and found reductions, based on only two infiltration trench studies of:

- 50-99% suspended solids reduction;
- 15-75% reduction in total phosphorus;
- 50-80% reduction in nitrogen;

Infiltration trenches can provide full infiltration from hard areas that would otherwise runoff to sewers or surface water. As a result they provide a significant, although localised, contribution to groundwater recharge.

2.1.8.2 Impacts on the Urban Environment

Infiltration trenches provide a contribution to reducing urban diffuse pollution, through reducing total runoff, as well as (often in combination with pre-treatment) preventing/reducing infiltration of pollutants to groundwater. There is some risk of the introduction of pollutants to groundwater, but in general, CIRIA (2009) concludes that this risk is low, providing these measures are not used to drain pollution hot-spots.

2.1.9 RAINGARDENS

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). They 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. These components may include:

- Grass filter strips to reduce incoming runoff flow velocities and to filter particulates. For example, these may be used at the base of roof drainage downspouts to slow and filter roof runoff as it enters the rain garden.
- Ponding areas for temporary storage of surface water prior to evaporation, infiltration or plant uptake. These areas will also promote additional settling of particulates.
- Organic/mulch areas for filtration and to create an environment conducive to the growth of micro-organisms that degrade hydrocarbons and organic matter. These may be particularly effective where rain gardens are used to treat excess highway runoff.
- Planting soil, for filtration and as a planting medium. The clay component of the soil can provide good adsorption for hydrocarbons, heavy metals and nutrients.
- Woody and herbaceous plants to intercept rainfall and encourage evaporation. Planting will also protect the mulch layer from erosion and provide vegetative uptake of pollutants.
- Sand beds to provide good drainage and aerobic conditions for the planting soil. Infiltration through the sand bed also provides a final treatment to runoff.

The filtered runoff is then either collected and returned to the conveyance system (using an underdrain) or, if site conditions allow, infiltrated into the surrounding ground. They aim to capture and treat stormwater runoff from frequent rainfall events, while excess runoff from extreme events is passed on to other drainage features as part of a SuDS 'train'. Rain gardens should be planted up with native vegetation that is happy with occasional inundations. Rain gardens are applicable to most types of development and can be used in both residential and non-residential areas. They can have a flexible layout and should be planned as landscaping features, enhancing the amenity value.

Individual components of rain gardens are designed only to capture runoff from a small surface area, for example a roof or car park or an office complex or shopping centre. In combination, a suite of rain gardens may capture total runoff from a larger area.

FIGURE 2-10: A TYPICAL MANIFESTATIONS OF A RAINGARDEN

2.1.9.1 Impacts on Runoff / Peak Flows

Blanc et al (2012) conclude that infiltration trenches are effective for runoff reduction for up to 1 in 30 year period storms.

2.1.9.2 Impacts on the Urban Environment

Infiltration trenches provide a contribution to reducing urban diffuse pollution, through reducing total runoff, as well as (often in combination with pre-treatment) preventing/reducing infiltration of pollutants.

2.1.10 UNDERGROUND INFILTRATION TRENCHES

An infiltration trench is actually a pit in the ground with various dimensions that is filled with drainage gravel. Water is stored within the gravel porosity and eventually infiltrates into the groundwater aquifer. With facilities situated underground, infiltration is provided by a permeable artificially-constructed gravel filter trench, which is covered by shallow soil or by pavements. The pore volume of the gravel allows for substantial storage capacity. When retention is the main purpose of the trench, runoff is either infiltrated from the reservoir into the underlying and surrounding soil or is collected by perforated pipes and routed to a throttled outflow facility. Surface trenches accept diffuse runoff directly from adjacent areas after it has been filtered by a grass buffer. Underground trenches require installation of special inlets to prevent coarse sediments and oil/grease from clogging the reservoir.

There are two types of infiltration trenches according to the way that runoff is guided to them.

A. Stormwater is transferred to the infiltration trench via a stormwater network that is placed beneath the roads. Just before the infiltration trench, a manhole is placed with two pipes beginning from different elevation. The first one from the lower elevation is heading towards the infiltration trench. The infiltration trench is a closed system without an outlet. When the infiltration trench is full of water, then backflow into the manhole will lead the flow to the pipe placed in the upper elevation, that leads directly to the existing stormwater network, therefore the upper pipe is behaving like an overflow structure. By this technique, the first priority is given to the pipe that leads directly to the infiltration trench and the overflow is directing to the existing stormwater network.

B. The infiltration trench is an open system with one inlet and one outlet. In every infiltration trench there is an inlet pipe and an outlet pipe with the same diameter, but the outlet pipe is placed a few centimeters lower than the inlet pipe for obvious reasons. By this technique, the infiltration trench will overflow to the downstream pipe after it gets full from stormwater and before overflowing to the ground. At the end of the storm, the volume stored in the trench will eventually infiltrate into stormwater but during the storm will have some infiltration as well which will be higher depending on the duration and the intensity of the storm.

The percolation trench should be filled with crushed stone or gravel. This system is especially effective for soils with low hydraulic conductivity and for hot climates. Most of the runoff is infiltrated, so it is very effective in supporting groundwater recharge, for example to decrease salinity. The system can easily be combined with infiltration swales. Goal of the design is to determine the cross-section and length of the infiltration trench. The hydraulic conductivity has to be significantly larger than 10^{-6} m/s. The length of the trench and its cross-section depend strongly on each other.

2.1.10.1 Impacts on Runoff / Peak Flows

It is estimated that the effect of infiltration trenches on the reduction of runoff volumes and peaks maybe substantial, provided the length and the diameter of the pipe and the hydraulic conductivity of the surrounding geologic material.

2.1.10.2 Impacts on the Urban Environment

Infiltration trenches provide a contribution to reducing urban diffuse pollution, through reducing total runoff, as well as (often in combination with pre-treatment) preventing/reducing infiltration of pollutants.

2.1.11 INFILTRATION PIPES

Infiltration into the ground can be performed by a perforated pipe, which is covered by shallow topsoil or traffic used pavements like roads or car parks. The pipe volume gives substantial storage capacity. Pipes with different diameters can be used. Parallel pipes or star-shaped pipes can be arranged to increase the infiltration capacity. Underground pipes require installation of special inlets to prevent coarse sediments and oil/grease from clogging the soil around the pipe.

Water is induced in the perforated pipe either directly by the catchpit chambers (or manholes) or indirectly from flood runoff infiltrating through swales or trees. The principle is to use a "saw-like" pipe placement where the water energy line is determined by the level in the catchpits, as discharge inflow will be significantly more than water infiltrating to soil through the perforated pipes. In every catchpit, an overflow pipe to the nearby conventional, storm drainage is facilitated to avoid flooding form overflowing catchpits to the surface. Since the energy line between two catchpits is determined by the water level in the catchpits, then it is assumed that the perforated pipes will be under pressure, thus performing better by increasing the amount of water infiltrating from the drainage pipes to the soil.

The direction of flow in the perforated pipe is controlled by the overflow level to the conventional storm sewer network, thus assuring that the water level in the upstream catchpit will be always higher (in absolute levels) than the downstream catchpit. An illustration of the above methodology is presented in the following figure.

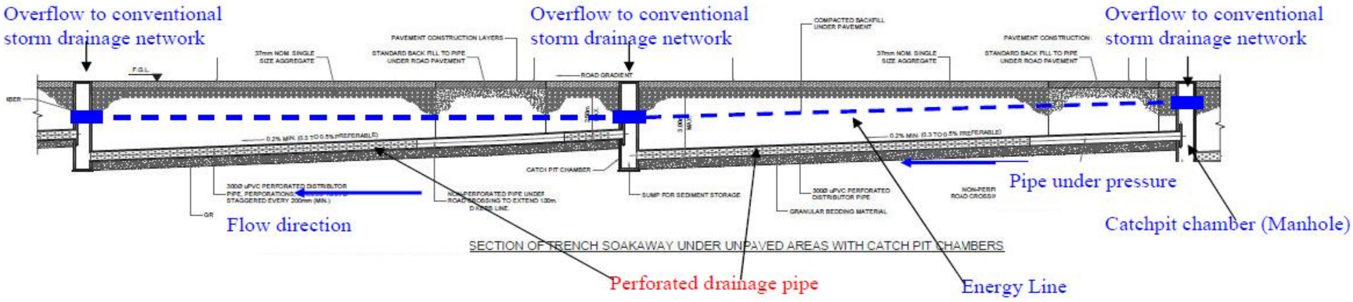

FIGURE 2-11: CONCEPT DESIGN OF AN INFILTRATION PIPE

2.1.11.1 Impacts on Runoff / Peak Flows

It is estimated that the effect of infiltration pipes on the reduction of runoff volumes and peaks maybe substantial, provided the length and the diameter of the pipe and the hydraulic conductivity of the surrounding geologic material.

2.1.11.2 Impacts on the Urban Environment

Infiltration pipes provide a contribution to reducing urban diffuse pollution, through reducing total runoff, as well as (often in combination with pre-treatment) preventing/reducing infiltration of pollutants.

2.1.12 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. They 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 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. Detention basins are most effective when receiving runoff from impermeable or low permeability surfaces. This could apply both to artificial surfaces in agricultural or forestry areas (e.g. roads or farmyards), as well as to runoff from, for example, fields with compacted soils.

Detention basins may fit better to Mediterranean type climates as for locations prone to mosquitoes because they should be designed to drain relatively quickly after an event, with the base drying out completely, therefore limiting the potential for mosquitoes to become established. A detention basin is a "inlet - outlet" system and the temporary storage must be computed in terms on inlet discharge and outlet discharge capacity characteristics. Detention basins temporarily store runoff, then releasing it at a slower rate downstream, e.g. in to a receiving watercourse. The capacity to store runoff is dependent on the design of the basin, which can be sized to accommodate any size of rainfall event. Some increased evaporation is likely to occur during storage. The rate of evapotranspiration will depend on dimensions, residence time and type of vegetation. With more vegetation and relatively low velocities, evapotranspiration is substantially increased, particularly if trees are planted.

FIGURE 2-12: ILLUSTRATION OF A DETENTION BASIN CURRENTLY EMPTY

2.1.12.1 Impacts on Runoff / Peak Flows

Temporary storage provides an attenuation of the incoming flood peak value. The attenuation depends on the volume of the storage and the residence time (proximity of outlet to inlet). Detention basins are not designed to allow infiltration to underlying soils and groundwater (instead see Infiltration basins). Although infiltration is not encouraged, some natural infiltration may occur unless the design specifically prevents it (e.g. by lining).

Detention basins can be effective at pollutant removal, particularly as a result of settling of particulate pollutants (although they are often used downstream of other source-control measures such as swales, where sediment deposition may already have occurred). Literature reviews of the effectiveness of detention basins at pollutant removal have been carried out by Environment Agency (2012) and Department of Trade and Industry (DTI) (2006). Wide ranges of effectiveness were found:

- Suspended solids reduction: EA (2012) 30-90%; DTI (2006) 61%.
- Total phosphorus reduction: EA (2012) 14-70%; DTI (2006) 19%.
- Total nitrogen reduction: EA(2012) 15-45%; DTI (2006) 31%.
- Metals: DTI (2006) 26-54%.

It is likely that achieving high effectiveness at pollutant removal will be improved by good design and adequate maintenance.

2.1.12.2 Impacts on the Urban Environment

By creating green areas within the urban landscape, detention basins may contribute to biodiversity preservation. The extent to which this benefit is provided depends on the soil moisture and choice of vegetation. Even when their individual contributions are relatively minor, their potential for contributing to networks of vegetated areas and green corridors can make them an important element in biodiversity preservation in urban landscapes. They could also provide some contribution to lowering peak temperatures in urban areas, similarly to other green spaces. Depending on vegetation density and how widespread they are, they can contribute to creating cool islands in urban landscapes (as a result of evapotranspiration, water supply, shading).

Finally, y helping to limit urban runoff and flooding, detention basins provide a contribution to adaptation to the higher intensity storm events expected due to climate change.In addition, if new vegetation is introduced, particularly woody vegetation, they may also increase carbon sequestration and help to regulate urban temperatures.

2.1.13 RETENTION PONDS

Retention ponds are ponds or pools designed with additional storage capacity to attenuate surface runoff during rainfall events more than the detention basins. 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.

Retention ponds can provide both storm water attenuation and water quality treatment by providing additional storage capacity to retain runoff and release this at a controlled rate. Ponds can be designed to control runoff from all storms by storing surface drainage and releasing it slowly once the risk of flooding has passed. Runoff from each rain event is detained and treated in the pond. The retention time and still water promotes pollutant removal through sedimentation, while aquatic vegetation and biological uptake mechanisms offer additional treatment. Retention ponds have good capacity to remove urban pollutants and improve the quality of surface runoff.

Ponds are functioning very much like an ordinary dam / reservoir and should normally contain the following zones:

- A sediment forebay (trap) or other form of upstream pre-treatment system (i.e. as part of an upstream management train of sustainable drainage components)
- A permanent pool which will remain wet throughout the year and is the main treatment zone
- A temporary storage volume for flood attenuation, created through landscaped banks to the permanent pool
- A shallow zone or aquatic bench which is a shallow area along the edge of the permanent pool to support wetland planting, providing ecology, amenity and safety benefits.

Additional pond design features should include an emergency spillway for safe overflow when storage capacity is exceeded, maintenance access, a safety bench, and appropriate landscaping. Well-designed and maintained ponds can offer aesthetic, amenity and ecological benefits to the urban landscape, particularly as part of public open spaces. They are designed to support emergent and submerged aquatic vegetation along their shoreline. They can be effectively incorporated into parks through good landscape design.

Retention ponds are applicable to all artificial surfaces, subject to land stability consideration. Lining may be required where soil contamination may influence the water quality within the pond, which may be more likely in industrial areas. They are also applicable in agricultural areas, either to receive runoff from low permeability surfaces (e.g. tracks, farmyards, etc) or as part of the agricultural landscape and / or to forest and natural areas especially upstream of a high flood risk area.

Retention ponds may not be the most desirable for warm climates (like Mediterranean climates) standing water can provide a suitable ecosystem for mosquitoes, which can be related to increased transmittance of some diseases. However, the introduction of certain type of fisheries or amphibia may consist a predator to the mosquitoes and to control their populations.


FIGURE 2-13: MANIFESTATION OF A RETENTION BASIN

2.1.13.1 Impacts on Runoff / Peak Flows

Retention ponds reduce peak runoff through storage and controlled outflow release. They must be appropriately sized to the catchment area and critical storm depth. They do not infiltrate runoff and therefore provide very little runoff volume reduction(with the exception of evaporation and evapotranspiration, which can be significant in some cases)Typically, retention ponds will be designed to attenuate runoff for events up to at least the 1 in 30 year storm for the drainage area(sometimes greater), with the excess storm volume drained within24 to 72 hours (CIRIA, 2007).

Evapotranspiration rates will depend on dimensions, residence time and type of vegetation. With dense vegetation, they are substantially increased, particularly if trees are planted.

Retention ponds can be effective at pollutant removal, particularly as a result of settling of particulate pollutants. However retention ponds, with permanent water, are likely to be less effective for removal of oils that stay on the water surface, compared to infiltration basins that dry out between events (CIRIA, 2009). Literature reviews of the effectiveness of retention ponds at pollutant removal have been carried out by Environment Agency (2012) and DTI (2006) (and probably CIRIA, 2007). Wide ranges of effectiveness were found:

- Suspended solids reduction: Environment Agency (2012) 29-91%; DTI (2006) average 55%.
- Total phosphorus reduction: Environment Agency (2012) 0-79%; DTI average 32%.
- Total nitrogen reduction: Environment Agency (2012) 0-80%; DTI average 34%.

- Metals: DTI (2006) 26-65%.

Retention ponds are highly effective at intercepting sediment loading in runoff. When designed with a sediment trap that can be easily cleared, effectiveness at sediment removal is compatible with the long-term effectiveness of the pond to attenuate runoff. Where no sediment trap is included, the gradual infilling of the pond will serve to reduce effectiveness for runoff attenuation (Environment Agency, 2012).

2.1.13.2 Impacts on the Urban Environment

Retention ponds create aquatic and riparian habitat and thereby make a significant contribution to biodiversity preservation, particularly when used in urban areas. Ponds have good potential for contributing to networks and green and/or blue corridors, which can make them an important element in biodiversity preservation in urban landscapes. By helping to limit urban runoff and flooding, retention ponds provide a contribution to adaptation to the higher storm intensity storm events expected due to climate change. In addition, if new vegetation is introduced, particularly woody vegetation, they may also increase carbon sequestration and help to regulate urban temperatures.

2.1.14 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). 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.

Infiltration basins may also act as “bioretention areas” of shallow landscaped depressions, typically under-drained and relying on engineered soils, vegetation and filtration to reduce runoff and remove pollution. They provide water quality benefits through physical filtration to remove solids/trap sediment, adsorption to the surrounding soil or biochemical degradation of pollutants. Water quality is, however, a key consideration with respect to infiltration basins as the potential for the infiltration to act as a vector for poor quality water to enter groundwater may be high. Pre-treatment may be required in certain areas before infiltration techniques are appropriate for use, for example swales or detention basins to reduce sediment loading and retain heavy metals and oils.

Infiltration basins have the potential to provide ancillary amenity benefits. They are idea 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. They increase soil moisture content and help to recharge groundwater, thereby mitigating the problems of low river flows.

Infiltration basins are potentially applicable to all artificial surfaces, subject to consideration of the suitability of underlying soils and geology to infiltrate water and consideration of the potential to mobilise contamination or act as a vector for poor quality water to enter groundwater.

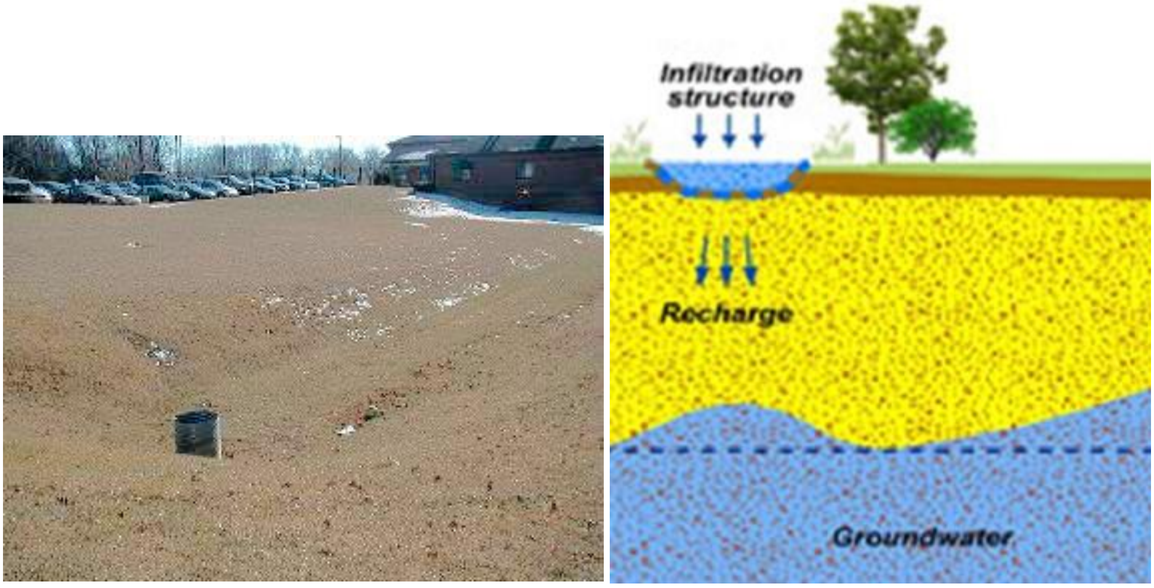

FIGURE 2-14: MANIFESTATION OF AN INFILTRATION BASIN

2.1.14.1 Impacts on Runoff / Peak Flows

Infiltration basins are designed to store runoff to be infiltrated. They are typically used to treat runoff from a small number of properties in residential areas and are effective at storing runoff from this scale of drainage area (less than 0.2 km^2). Infiltration basins are typically designed to infiltrate 50% of their storage volume within 24 hours of filling (CREW, 2012).Typically, infiltration basins are generally designed to capture and infiltrate runoff volumes for events up to the 1 in 30 year storm for the drainage area, but sometimes even for events up to 1 in 100 year storm. The effectiveness of the basin at providing this storage will depend on the condition of the underlying soil and the characteristics of the drainage area.

If designed correctly with an appropriate outfall, infiltration basins are also effective at slowing runoff for events that exceed the storage/infiltration capacity of the basin. Additional storage should be allowed above the outlet to allow for some slowing of runoff rates during larger events.

Designed to store water to be infiltrated into underlying soils and groundwater. The infiltration performance of each basin will be unique based on specific site conditions and materials. Maintaining infiltration performance is a known challenge and deterioration in performance of infiltration basins over time is common (CIRIA, 2009), although limited quantified evidence is available for this. Lindsey at al (1992) found that 67% of infiltration devices remain operating as intended 2 years after construction, with this dropping to 49% after 6 years, although this study is old and performance is likely to have improved with learning on effective construction and maintenance approaches in the intervening years.

2.1.14.2 Impacts on the Urban Environment

The potential for pollution to groundwater needs to be considered. However CIRIA (2009) concluded that “the potential for contamination of groundwater from SuDSschemes appears to be low, except from industrial areas. The potential for serious pollution is associated with accidents rather than the continuous background pollution from these areas”. This conclusion drew on recent work by SNIFFER

(2008) that found “the vast majority of heavy metals, PAHs and petroleum hydrocarbons are retained in the top 10 cm of soil” based on bare-soil lysimeter tests, and noted that the addition of a vegetative layer would allow further uptake of pollutants. However it is clearly important to consider the risks of pollution to groundwater on a site-specific basis in light of the wider water management, activities occurring within the drainage area of the measureand groundwater sensitivity (depth, soil permeability).Creating green areas reduces hard surfaces and leads to reduced surface leaching of pollutant sources.

Infiltration basins should be planted with native vegetation to be most effective in enhancing biodiversity. They can be incorporated as an element in a network of green areas, thereby creating a green corridor, which is a key issue for the provision of terrestrial habitat.

2.2 HYDROMORPHOLOGY

Mediterranean rivers have been altered by means of changing their morphology (straightening and canalisation, disconnecting channels from flood plains, occupying riparian lands, building dams, weirs, bank reinforcements, etc.) to facilitate agriculture and urbanisation, to enable energy production and protection against flooding. Also, water has been abstracted from rivers and their natural flow regime to be used as a resource for irrigation and to supply urban and industrial needs. All these human activities have damaged fluvial habitats and have had severe and significant impacts on the status of the aquatic ecosystems. These hydromorphological (HYMO) pressures are the most commonly occurring pressures in European rivers, lakes and transitional waters, affecting more than 40 % of all river and transitional water bodies.

From a holistic point of view, a typical river network directly and asymmetrically connects the upland and riparian landscape to the rest of the lowland fluvial ecosystem, estuaries and coastal systems. As headwater streams compose over two-thirds of total stream length, they have particular importance. The large-scale ecological effects of altering headwaters are amplified by land uses that alter runoff and nutrient loads to streams, and by widespread dam construction on larger rivers, which frequently isolates free-flowing upstream portions of river systems essential to sustaining aquatic biodiversity.

Often, human pressures affecting rivers do not come alone, as many elements of the riverine environment co-vary. Urban land adjoining a channel, for example, may be associated with modified water quality, altered flow regime, structural changes to the channel (e.g. channelization, bank reinforcement) and disruption of processes such as sediment supply. Concomitant ecological changes in such situations (e.g. reduced taxonomic diversity or increased decomposition rates) could be a response to any or all of the changes associated with the land use. Their effects could be additive, subtractive or multiplicative. Although multiple pressures affect rivers simultaneously and at the same time human activities stress many components of the hydrological cycle which have different time-scale responses within fluvial ecosystems, for practical reasons we have reviewed the available literature trying to distinguish single river pressures and their most direct impacts on ecosystems.

Measures that rehabilitate hydrologic connectivity among the stream network are the following as schematically described in the following figure. Most of the measures are structural and require the design and construction of works. The number of each measure shown in the figure is explained in the associated paragraph with the same number.):

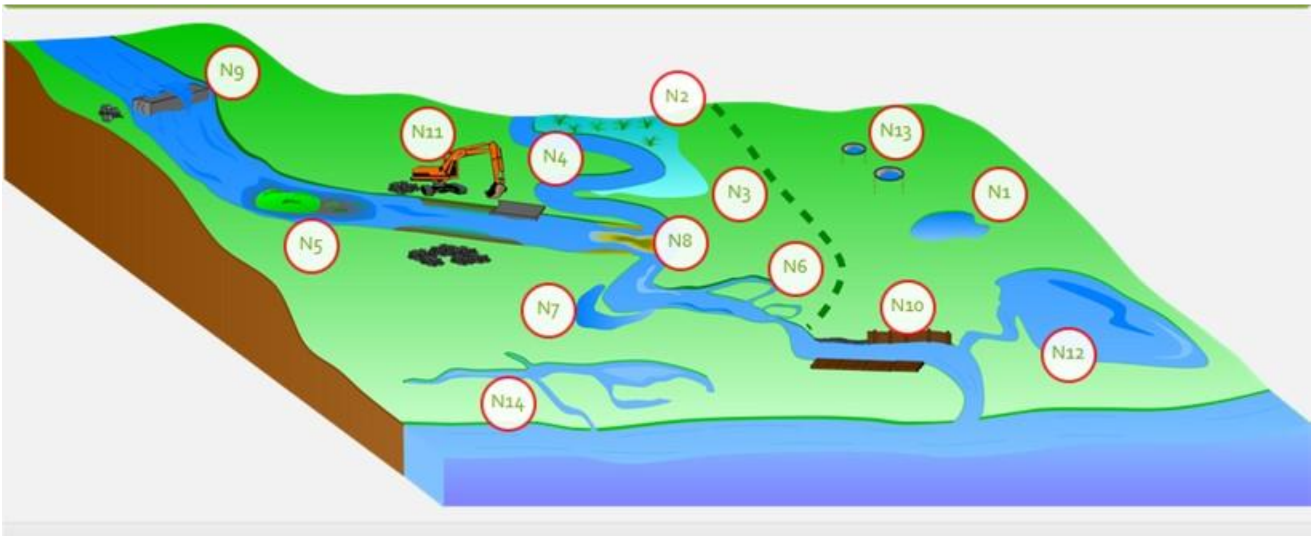

FIGURE 2-15: NWRMS INCLUDED IN THE HYDROMORPHLOGICAL CATEGORY

2.2.1 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. Basins and ponds require a large accessible area that is relatively flat and with an appropriately-sized drainage catchment. They can be installed in any type of area (urban, forest, agricultural...). Account should be taken of natural features that could be used to form the basin and/or provide additional storage areas in order to minimise the need for artificial landscaping.

Geographical implementation of basins and ponds may be limited in Mediterranean areas due to mosquitoes again like in urban areas depending the proximity to the nearest inhabited area.

2.2.1.1 Impacts on Runoff / Peak Flows

Depending on the size of the basin / pond, the attenuation of flood characteristics maybe higher or lower. Depending on the design of the basin or pond and the underlying geology and water table, this measure can increase infiltration. However in some cases, for example if the underlying geology is impermeable, or if there is a risk of contaminated runoff, then the pond or basin can be designed with an impermeable bed.

2.2.1.2 Impacts on the Environment

Due to new ecosystem, it will increase habitat diversity and thereby biodiversity, for aquatic and terrestrial species. Furthermore, an aquatic ecosystem is created with this measure and, depending on the size, could keep a valuable fish stock.

2.2.2 WETLAND RESTORATION AND MANAGEMENT

According to the Convention on Wetlands (1971), a wetland is an area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. It provides water retention, biodiversity enhancement or water quality improvement. Wetland restoration 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.

Wetlands are most frequently restored in former agricultural lands which used to be drained to increase land productivity. Wetlands are restored where forest land has been drained in the past. Wetland restoration can be implemented in all categories of forest land cover. The limiting factor might be hydrological regimes, topography etc.Wetlands are restored and maintained primarily due to high value of biological diversity. Wetland restoration measures are implemented in both land cover categories –inland and coastal wetlands. Inland wetland restoration may be implemented in the locations where peat as natural resource has been cut. Restoration of coastal meadows are driven by nature protection as well as protection measure against storm surges and sea level rise. Wetlands naturally can be located throughout river basins. The scales for restoration and maintenance measures vary, as activities can vary from constructing small urban wetlands, to wetlands in agricultural areas, to restoring wetlands at a landscape scale.

FIGURE 2-16: MANIFESTATION OF A WETLAND

2.2.2.1 Impacts on Runoff / Peak Flows

Wetlands function like natural tubs or sponges, storing water and slowly releasing it. This process supports runoff water storage capacity in the area. Although a small wetland might not store much water, a network of many small wetlands can store a large amount of water. Storage capacity depends on where (in what type of land use) and how (what elements wetland contains) a wetland is established. If the wetland is established in area with existing high water level, the additional storage capacity or runoff might be low. If a wetland is established in drained or dray area the storage capacity is higher.

Wetlands can reduce river pollution by trapping nutrients swept off agricultural land by rainfall. Most studies investigated water quality improvement, with the majority examining nutrient retention (nitrogen and phosphorus). However this depends on the wetland's size, location and the vegetation it contains

2.2.2.2 Impacts on the Environment

Wetland ecosystems hold an important part of Europe's biodiversity. They are especially important for birds, providing vital nesting and migratory flyway areas, as well as for other fauna species, such as dragonflies and amphibians. Countless specialist plants depend on wetlands. Wetlands are important bird areas, thus bird watchers are attracted to them. When implementing wetland projects, authorities often provide accompanying recreational infrastructure such as trails, towers, and recreation sites.

2.2.3 FLOODPLAIN RESTORATION AND MANAGEMENT

A floodplain is the area bordering a river that naturally provides space for the retention of flood and rainwater. Floodplain soils are generally very fertile and they have often been dried-out to be used as agricultural land. Floodplains in many places have also 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.

Restoring the floodplain roles requires measures such as:

- Modification of the channel.
- Removing of the legacy sediment.
- Creation of lakes or ponds in the floodplain.
- New/modification of agricultural practices.
- Afforestation, especially for the bank forests.
- Plantation of native grasses, shrubs and trees.
- Creation of grassy basins and swales.
- Wetland creation.
- Invasive species removal.
- Riparian buffer installation and development.

Floodplain restoration can be applied on any type of land use, as long as a (current or former) natural floodplain is present. If Artificial areas (Urban, Industrial, etc.) are located on the floodplain though, the associated cost for the measure's implementation is likely to be higher, due to land acquisition costs. These costs will also be important for agricultural areas.

2.2.3.1 Impacts on Runoff / Peak Flows

Ideally, actions for storing runoff should be conducted before it reaches the floodplainto leave space for the river floodwaters themselves. But land cover and uses are ones of main factors affecting runoff on the flood plain. The impact of floodplain restoration depends of the configuration and activities on the floodplain area. Generally the impact is very high when measures are impacting land cover and uses particularly through restoration of buffer zones and infiltration areas. Different measures targeted at floodplains can result in runoff control and appropriate land management (afforestation, installation of micro-ponds, limitation of the intensive use of the floodplain, etc.) will contribute to control runoff. Runoff reduction measures are most effective when implemented over a large proportion of the floodplain. Their efficiency is manifold for the reduction of low to medium peak flows. They are less effective for extreme flooding events in large rivers but in any case, their effectiveness always depends on the characteristics of the precipitation and the antecedent conditions. The storage of river water corresponds to the volume of water which spills into the floodplain. This is a natural function of a floodplain, hence restoration would be expected to use(and preferably maximise) this function. Breaches in the summer dikes, by-pass channels and oxbow lakes improve retention in the floodplain. The temporary retained water capacity can be increased by increasing the floodplain area, its depth and the storage time e.g. by increasing its roughness with vegetation cover.

The impact of floodplain restoration could be positive or negative regarding local conditions. Measures for floodplain restoration such as land use change from artificial or agricultural to forest or wetlands should increase evapotranspiration, having an impact on local climate conditions (could increase local humidity). Changes in land use (increase of forest and wetlands areas) and slower runoff can lead to higher discharges of water into the ground. The amount of groundwater recharge also depends on local conditions, such as geology, legacy sediment that could be impervious and the hydrological condition of the aquifer.

2.2.3.2 Impacts on the Environment

The restoration site could be planted with native grasses, shrubs, and trees. This is the first step to develop biodiversity. Environment resilience could be very important especially when the original seed bank, which has been covered by legacy sediment, is once again near the surface, and the dormant seeds begin to germinate and grow. So native flowering plants that have not been planted could appear. Creating a more natural stream channel and floodplain should also be accompanied by the immediate removal of invasive species on the site. The post-construction planting of native vegetation along the stream corridor discourages the re-establishment of invasive, non-native vegetation. Leaf litter from riparian woody plants also provides a source of food for macroinvertebrate life in the stream.

By promoting natural functioning of the aquatic ecosystem and of immediate and remote environments, floodplain restoration measures will have a positive impact on water quality, vegetation population, temperatures and habitat conditions. This will naturally be followed bya recovery of the aquatic ecosystem, and thus an increase in fish populations, a greater biodiversity and a higher natural biomass production.

2.2.4 RE-MEANDERING

A river meander is a U-form taken by the river, allowing it to decrease water velocity. In the past, rivers have been straightened by cutting off meanders. Many rivers in northern and Western Europe have been straightened and channelized to, for example, facilitate log floating and/or speed up the drainage of water and control/limit the river bed movements. Channelizing was also a way to gain land for cultivation. 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.

Re-meandering should only be conducted on a meander alluvial system (past or present).The definition of the fluvial style is essential to consider if re-meandering is applicable or not. So it is not suitable for rivers in braids, in alternating patches or anastomoses. Re-meandering a river is not creating meanders to control floods. On a river that never had meanders, this kind of modification shows that it may increase the risk of flood events. This type of action in wetlands has to be carefully considered, as it should not perturb their ecological functioning.

2.2.4.1 Impacts on Runoff / Peak Flows

By expanding the functional river area, re-meandering allows a slowing of runoff on the shores of rivers, therefore allowing increased storage, especially if the vegetation cover and the associated soil properties are prone to favour this storage. Furthermore, the increase of the stream length and reconnection of old meanders increase the storage capacity of the river as well as slows down flow velocities by increasing channel length. Meanders create wet environments supporting infiltration and ground water recharge. By modifying land cover and sometimes removing legacy sediment, re-meandering can change soil capacity retention.

2.2.4.2 Impacts on the Environment

Re-meandering provides habitat for species such as aquatic plants, otter, salmon, insects and birds, fish, macroinvertebrates, macrophytes and phytoplankton, and kingfishers. The existence of hydraulic annexes, quiet water areas or wet lowlands that can be created by the dynamics of meandering, improves the preservation and resilience of ecological communities and habitats. The modification of the erosion process also affects the quality and habitat diversity of benthic fauna and fish, as well as riparian species. The first positive impacts of re-meandering habitat, fauna and flora are visible after about two years, including riparian forest.

Knowing that animals, especially birds choose their breeding grounds on the basis of the appearance and structure of the environment, the diversity and complexity of the meandering vegetation mosaic should reflect on those animal populations. The bird populations characterizing the meandering sector are close to those of the great marshlands, calm water surfaces and reedbeds. Several years are needed to see appearing various types of vegetation in the river functional area.

2.2.5 STREAM BED RE-NATURALIZATION

Streambed (or riverbed) represents the cross section of the river, including each riverbank. 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 in removing some concrete or invert constructions in the riverbed and on riverbanks, then replacing them with vegetation structures, in order to avoid these damages and restore biodiversity.

The re-naturalization of river beds and banks could have a high impact on the erosion process. Stabilisation techniques are among the main measures to be implemented. The maximum impact is reached when the stabilisation technique restores the vegetation cover and the naturalness of the banks. Most of the time, techniques use plants for bank stabilization. According to their degree of complexity, these techniques can be grouped into two categories:

- Bank re-naturalization.
- Plant engineering (or bioengineering).

Bank re-naturalization is a stabilisation technique used to correct mild erosion problems and that does not require a high degree of expertise to be implemented. Plant engineering is defined as the techniques combining the principles of ecology and engineering to design and implement slope, bank and bank stabilisation works, using plants as raw materials for making vegetable frames.

2.2.5.1 Impacts on Runoff / Peak Flows

By diversifying the channel width and depth, this measure can increase the water storage capacity of the river as well as minimize flow velocity due to the increase of hydraulic roughness. The re-naturalization of the river bed restores the connectivity between the stream and the accompanying groundwater, therefore increasing stream-subsurface water exchanges.

By restoring the natural design of the river bed and banks, the measure contributes to intercepting pollution pathways through the filtration and auto-purification capacities of the vegetation.

2.2.5.2 Impacts on the Urban Environment

The re-naturalization of the river bed and banks promote the heterogeneity of the habitats The impact of the measures is highest in low water period as it allows maintaining a baseflow necessary for aquatic life which protects habitats from drying out. In addition to the natural modification in the riverine habitats resulting from therein stated river dynamics, human intervention further could help in accelerating habitat restoration by the application of targeted gravel extraction to mimic natural habitat mosaics while avoiding excessive accumulation of sediment. This exploitation could clearly be motivated by a biodiversity restoration objective but could be designed so as to accommodate sustained, but re-oriented economic activities while abiding by safety rules and regulations. Hydrogeomorphic processes within alluvial river systems create, maintain and degrade riparian habitat. The dynamic interactions between water, sediment, aquatic–terrestrial landforms and biotic elements control the functional processes and biodiversity.

2.2.6 RESTORATION AND RECONNECTION OF SEASONAL STREAMS

Seasonal streams or intermittent streams are rivers for which surface water ceases to flow at some point in space and time. They comprise a large proportion of the global river network and are characterized by dynamic exchanges between terrestrial and aquatic habitats. These habitats support aquatic, semi-aquatic, and terrestrial biota. Seasonal streams provide essential ecosystem services to society, including flood control and irrigation. The abundance and distribution of seasonal streams, and their natural intermittent flow regimes, are being altered by climate change, water abstraction and inter-basin transfers. 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 consists in, therefore favouring 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.

In a watershed context, landscape hydrologic connectivity refers to the maintenance of natural hydraulic connections of surface and subsurface flow between source, headwater, or contributing areas and downstream/down gradient receiving waters. This connectivity could be restored by:

- Decreasing human pressures.
- Restoring river bed as buffer zones.
- Protecting banks and the vegetation.
- Protecting the flow channel itself.

2.2.6.1 Impacts on Runoff / Peak Flows

As seasonal streams are often located in river basin heads, they often play the role of buffer zones for permanent systems downstream by providing a river bed aiming at slowing runoff flows. This measure can help slowing the river flow by temporarily diverting a part of the flow on these tributaries. Indeed, flow takes longer to reach the main channel because seasonal streams provide additional storage before water reaches the main channel. Infiltration of stream flow occurs into the unconsolidated alluvium forming channel boundaries. Nevertheless, groundwater recharge in ephemeral stream channels is effective and increased by their reconnection with the main river. It can be significant in some years and negligible in others. It is due to the high variability of precipitations which has a direct impact on runoff flows and flood intensity.

2.2.6.2 Impacts on the Environment

It should be firstly mentioned that the creation of aquatic and riparian habitats is closely linked to the duration of water flow. Additionally, to changes in channel form and sediment yield, the geomorphic response to anthropogenic disturbance can also have significant consequences for riparian ecosystems and water supplies. As streams become entrenched, formerly rich biological communities on the flood plain can become hydrologically disconnected from ephemeral stream flow and transform into dry terraces. Additionally, as channels become narrower and unconsolidated alluvial bed material is removed, there is less capacity to absorb passing flows and for vegetation to establish. Vegetation structure and diversity determine wildlife species diversity and abundance, and if a portion of habitat on which a species depends is damaged or destroyed, the breeding population of that species could be lost. The riparian environments created by ephemeral and intermittent streams, especially when they are reconnected with the main stream, provide and maintain important habitat for wildlife, and are responsible for much of the biotic diversity.

By storing large quantities of water, limiting flood intensity and playing an essential role in the river basin functioning, restoration and reconnection of seasonal streams can be important to support climate change adaptation for downstream system.

2.2.7 RECONNECTION OF OXBOW LAKES AND SIMILAR FEATURES

An oxbow lake is an ancient meander that was cut off from the river, thus creating a small lake with a U form. 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 a better water retention during floods.

2.2.7.1 Impacts on Runoff / Peak Flows

An ox-bow lake, even if disconnected, can accumulate surface runoff from adjacent lands. However, its reconnection to riverbed, therefore increasing the river length, can largely increase its capacity in this aspect. In some cases the runoff from adjacent lands is the main source of water inflow, e.g. in cases where the main river became deeper due to the bottom erosion. Moreover, oxbow lakes can play the role of buffer zones for permanent systems downstream by providing a river bed aiming at slowing runoff flows.

Reconnected oxbows and side arms may fill in and retain water from the main river. Depending on the outflow (with sluice facility), this storage capacity could be controlled. Indeed, as it increases the length of the river this measure helps increasing the storage of river waters

2.2.7.2 Impacts on the Environment

Oxbow lakes and re-connected side arms play important role, creating habitat diversity within the same river section. Often these habitats are used for spawning places by fish and other aquatic groups. Increased retention volumes for peak flows and improved water storage in the river system in droughts can participate to climate change adaptation and mitigation.

2.2.8 RIVERBED MATERIAL RENATURALIZATION

Riverbed material represents the sediment eroded upstream, transported by the river and deposited on the river floor. It can be composed of coarse and/or fine material. Its re-naturalization consists in recovering the nature-like structure and composition of the bed load, in particular the equilibrium between coarse and fine sediment. In case of 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 of 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.

2.2.8.1 Impacts on Runoff / Peak Flows

Since it increases the total water storage capacity of the river and its floodplain, this measure improves flood risk reduction.

2.2.8.2 Impacts on the Environment

The main gains of the environment is the aquatic ecosystem improvement due to continuity between water and floodplain, provision of spawning grounds for fish, and the diversification of the river bed and the river depth, which offer new aquatic habitats.

2.2.9 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 consists in destroying all the 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.

The review of the case studies shows that this measure is applied predominantly for small and medium sized rivers. In the case of bigger sized rivers, appropriate management of the dam can re-establish part of the functions targeted by this measure without removing the dam. The renewable energy production, as well as the multi functionality of big dams is also an argument that can prevent the measure to be taken.

2.2.9.1 Impacts on Runoff / Peak Flows

The measure results in restoration of the natural pattern of erosion, sediment transport and deposition. It may result in increased erosion and sediment delivery downstream. Whether these impacts are positive or negative is a subject of site specific assessment and may vary depending on the scale (distance upstream and downstream) that are considered.

2.2.9.2 Impacts on the Environment

Restored aquatic habitats and river continuity result in increased diversity of fish and other aquatic communities.

2.2.10 NATURAL BANK STABILISATION

Riverbank represents both natural and artificial terrain following the river flow. In the past, lots of 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 renaturalisation consists in recovering its ecological components, thus reversing such damages and especially allowing bank to be stabilized, as well as rivers to move more freely. Nature-based solutions such as bioengineering are preferable, but civil engineering has to be used in case of strong hydrological constraints.

2.2.10.1 Impacts on Runoff / Peak Flows

The vegetation covering the banks can help storing runoff as it intercepts and infiltrates some of the rainfall together with the minimization of flow velocities and the increase of the storage of the cross section.

2.2.10.2 Impacts on the Environment

By slowing down the flow and giving back its natural features to the river, this measure creates aquatic habitats. There is currently little empirical evidence that bank stabilisation techniques directly benefit phytoplankton, macrophytes, benthic invertebrates and fish. However, the techniques can lead to the development of improved bank habitats, which are likely to be beneficial for macrophytes and benthic invertebrates. There is little evidence to suggest that phytoplankton benefit from bank rehabilitation, although the provision of high quality bank habitats and improved in-channel conditions may lead to improvements in phytoplankton habitat. Furthermore, evidence suggests that although fish populations increase when bank habitats are improved, they do not necessarily reach levels observed in natural, unmodified banks.

2.2.11 ELIMINATION 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. Eliminating it consists in removing some parts of the bank protection, especially the inert one, in order to enhance lateral connections of the river, diversify flows (depth, substrate, and speed) and habitats, but also cap floods in the mainstream. It is a prerequisite for many other measures like re-meandering or widening, as well as initiating later channel migration and dynamics.

This kind of bank removal can especially be applied and will be very efficient in impounded large gravel bed rivers, where gravel bars are drowned and shallow low-velocity habitats are virtually absent. In these impounded rivers, spawning and nursery habitats like shallow near-bank gravel bars, side channels, and backwaters are often the bottleneck for stream-type specific fish species. River banks have been heavily fixed and the potential for river restoration is limited due to uses like navigation, hydropower or flood protection and mitigation measures are restricted to the river banks.

2.2.11.1 Impacts on Runoff / Peak Flows

As this measure allows lateral connection between the river and the floodplain, it can participate to store part of the runoff or decrease flow velocity and increase in stream storage. Finally, as the river water can go more easily to the floodplain, and in case vegetation is present in this floodplain, infiltration and/or groundwater recharge can be enhanced.

2.2.11.2 Impacts on the Urban Environment

This measure favours aquatic ecosystem improvement due to continuity between water and floodplain and also because the majority of fish species need slow and warm waters. Re-opened river banks provide spawning grounds for fish.

2.2.12 LAKE RESTORATION

A Lake is a water retention facility. It can store water (for flood control) and provide water for many purposes such as water supply, irrigation, fisheries, tourism, etc. In addition, it serves as a sink for carbon storage and provides important habitats for numerous species of plants and animals, including waders. In the past, lakes have sometimes been drained to free the land for agriculture purposes, or have simply not been maintained and have silted up. Restoring lakes consists in enhancing their structure and functioning where they have been drained in former times.

2.2.12.1 Impacts on Runoff / Peak Flows

This measure, by enhancing the lake structure (size) and functioning, in particular by cleaning out the accumulated sediment, can increase its capacity for storing runoff. The runoff storage is equal to the total volume of the lake minus the volume already occupied by water.

2.2.12.2 Impacts on the Environment

Lake and surrounding restoration could have an impact on the riparian vegetation by rebuilding or creating natural environment for riparian species. The creation of riparian habitat could be made directly by artificial facilities or indirectly by favouring the riparian vegetation development and conservation or rehabilitation of banks.

2.2.13 RESTORATION OF NATURAL INFILTRATION TO GROUNDWATER

Groundwater is the part of infiltrated water which composes the water resource for population and human activities. 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:

- Surface structures to facilitate/augment recharge (such as soakaways and infiltration basins);
- Subsurface indirect recharge – infiltration capacity is enhanced through wells drilled within the unsaturated zone; and
- Subsurface direct recharge – infiltration and recharge of the groundwater aquifer is accomplished through wells reaching the saturated zone.

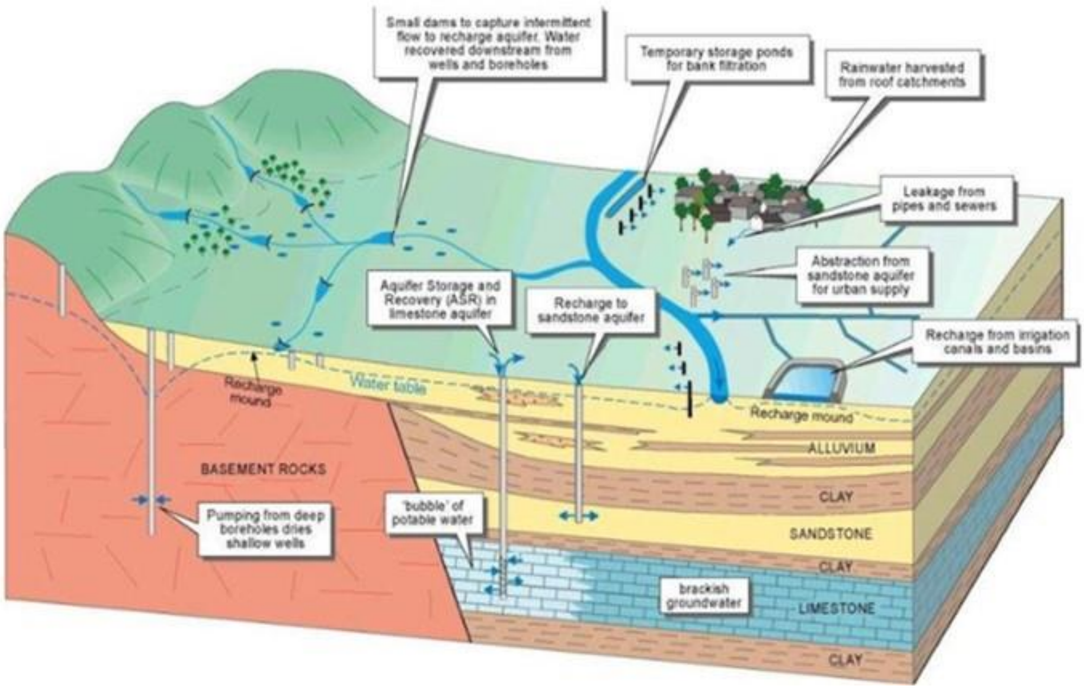

FIGURE 2-17: SCHEMATIC REPRESENTATION OF ARTIFICIAL RECHARGE SYSTEMS.

2.2.13.1 Impacts on Runoff / Peak Flows

This measure, by enhancing infiltration into deep soil, especially with shallow wells, can increase its capacity for storing runoff. Rain falling on the landscape may flow quickly over soil or rock surfaces as runoff to stream channels. Alternately, some water may flow more slowly downslope toward streams within the soil. Some may percolate downward through pores in soil and fractures in rock to reach the top of the saturated zone (often called the water table). Below the saturated zone, it flows much more slowly as groundwater. Therefore increasing recharge to groundwater reduces the amount of water available for rapid surface runoff and increases availability of groundwater for baseflow.

The measures can favor intercepting and infiltrating pollutants, but this represent a risk of introducing pollutants to groundwater, particularly when injecting directly in to an aquifer, by bypassing natural near-surface filtration, or by using contaminated water that would not normally infiltrate.

2.2.13.2 Impacts on the Environment

Groundwater resources and their long-term replenishment are controlled by long-term climate conditions. Climate change will therefore have a great impact on groundwater resources. Groundwater has to be used and managed in a sustainable way in order to maintain its buffer and contingency supply capabilities as well as adequate water quality for human consumption, also under predicted climate changes. Land use planning has to consider groundwater resources as a precious and finite resource, and take all possible measures to protect groundwater resources and their recharge mechanisms in the long run. Groundwater can act as strategic reserves during excessive drought periods.

2.3 FORESTRY

The volume of water retained by forests can depend on characteristics such as forest cover area, the length of vegetation growing season, tree composition and tree density, as well as the age and the number of layers of vegetation cover. Water retention by forests affects the amount and timing of the water delivered to streams and groundwater by increasing and maintaining infiltration and storage capacity of the soil. Forests can soak up excess rainwater, preventing run-offs and damage from flooding. By releasing water in the dry season, forests can also help provide clean water and mitigate the effects of droughts.

Irrespective of the extent of the basin's forest cover, water retention is typically about 25% greater in summer time than in winter time and that coniferous forests in general retain 10% more water than broadleaved forests or mixed forests. In general, forests in Alpine and Continental regions have the highest water-retention potentials, while Atlantic and Mediterranean regions register lower water-retention potentials.

The possible measures for Forestry are numerous (see also FIGURE 2-18). The number of each measure shown in the figure is explained in the associated paragraph with the same number. Most of the measures listed below require some construction effort.

FIGURE 2-18: NWRMS LISTED AS FORESTRY SECTOR.

2.3.1 FOREST RIPARIAN BUFFERS

Riparian buffers are treed areas alongside streams and other water bodies. While most commonly associated with set asides following forest harvest, riparian buffers can also be found in urban, agricultural and wetland areas. By preserving a relatively undisturbed area adjacent to open water, riparian buffers can serve a number of 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.

In a forestry context, riparian buffers are areas of land adjacent to streams, rivers or lakes which are not disturbed during forest harvesting. The width of the buffer may vary between very narrow (2m) to 50m+ although a 10 m buffer is mandated in many jurisdictions. The width of the buffer may also be determined according to length or size of watercourse or waterbody. Typically the width varies between 10 and 50m, based on national guidelines and regulations.

Riparian buffers are most effective at a small spatial scale and are typically seen in headwater areas, where the local effects of sediment and nutrient retention are most pronounced. The impact of riparian buffers on surface water quality declines with increasing upstream area but there are not likely to be any circumstances under which riparian forest buffers are an ecosystem disservice. Riparian forest buffers slow the velocity of overland flow. This contributes to sediment and nutrient retention and will potentially moderate the size of flood peaks. There is some evidence that riparian buffers can also increase rates of infiltration. Riparian buffers also protect stream habitats and increase recreational value of the area.

FIGURE 2-19: MANIFESTATION OF FOREST RIPARIAN BUFFERS.

2.3.1.1 Impacts on Runoff / Peak Flows

Forest riparian buffers have limited ability to slow runoff, primarily due to their relatively small breadth. Because of their rougher ground surface, forest cover can slow runoff more effectively than bare ground. Deadwood from forested banks may decrease stream velocity. During overbank flooding also riparian vegetation may potentially slow the flows.

When operating properly, forest riparian buffers can significantly reduce nitrogen (N) leaching following forest clearcut and have the potential to contribute to denitrification of runoff from adjacent agricultural areas. Well-functioning forest riparian buffers can also intercept pollutant runoff including sediments, particulate matter and phosphorus associated with overland flow events in agricultural or clearcut areas. Forest riparian zones may also helpto decrease sediment runoff after forest ditching and ditch network maintenance works.

2.3.1.2 Impacts on the Environment

forest riparian buffers can contribute to the creation of aquatic habitat, both by moderating the stream temperature regime and by acting as a source of coarse woody debris which can provide additional structure to aquatic habitats. Wood is important for diversification of habitats, providing shelter from predators and stream current and storage of fine sediment that may provide important spawning substrate to some species. Wood may also serve as food source.

Riparian forest buffers provide organic food to aquatic fauna and are important energy source for aquatic food chain. Riparian forest buffers directly influence most important factors for the survival of salmonid species: lower water temperature, create habitat structure, provide food and control sediment flux.

2.3.2 MAINTENANCE OF FOREST COVER IN HEADWATER AREAS

Headwaters are the source areas for rivers and streams, crucial for sustaining the structure, function, productivity and complexity of downstream ecosystems. They are vital to hydrologic cycling as they are one of the main areas where precipitation contributes to surface and groundwater. Headwaters are typically less intensively used than downstream areas. In many headwater areas, extensive agriculture, forests or other semi-natural land cover types predominate. 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 provisioning. 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.

This measure is applicable throughout the mountainous areas of the Mediterranean. Afforestation of headwater catchments these areas may be an effective tool for controlling landslides. Ideally, afforestation will be conducted using native species which are known to be robust to the potential effects of a changing climate. Afforestation of headwaters can have beneficial effects on water quality and flood control in downstream locations. Afforestation of headwater areas for water retention should be performed in light of local conditions and local hydrological issues, as decrease of water yield after afforestation due to increased evapotranspiration has been reported in dry mountain areas.

2.3.2.1 Impacts on Runoff / Peak Flows

Because of their greater infiltration capacity when compared to many arable, pasture or urban soils, forest soils can have a significant capacity to store excess precipitation and limit or prevent runoff. Furthermore, because of their greater surface roughness, and high water holding capacity, forest soils can act to slow runoff in much the same way as a sponge can store water and slow the rate at which water travels. When compared to non-forest land cover types, forests often have higher rates of evapotranspiration and canopy interception. Thus, headwater forest areas are able to reduce the absolute volume of water which may eventually contribute to runoff by returning a greater fraction of precipitation to the atmosphere, thereby increasing precipitation recycling.

2.3.2.2 Impacts on the Environment

Preservation of existing headwater forest catchments has a direct positive impact on biodiversity preservation, as these areas are often biodiversity hotspots. When afforestation of headwater catchments uses indigenous or local species, there is a considerable potential for biodiversity preservation. Indigenous or local forests can be important habitats for many species including plants, animals and insects.

The carbon sequestration potential of growing forests can offer significant climate change mitigation possibilities. Biomass harvesting from forest catchments may also contribute to climate change mitigation by substitution of fossil fuel energy sources. Biomass harvesting has, however, to be balanced against other ecosystem services.

2.3.3 AFFORESTATION OF RESERVOIR CATCHMENTS

Planting trees in reservoir catchments can have both negative and positive effects. . Afforestation of previously bare or heavily eroded areas can control soil erosion, thereby extending the life of the reservoir and improving water quality. Water quality can also be improved if precipitation is able to infiltrate into forest soils before flowing to the reservoir. These potential improvements in water quality need to be balanced against the possibility that less precipitation will be available for reservoir recharge due to the potentially greater interception and evapotranspiration associated with forests. Studies have indicated decrease of water yield after afforestation of the catchment and with the increase of forest age. Forests in reservoir catchments should typically not be managed for timber production, but maintained in as close to a natural state as possible as the fertilization and ground disturbance associated with intensive forest management can have negative impacts on reservoir water quality. Increased acidification and eutrophication after afforestation with conifer species have also been reported. Use of long-lived native deciduous tree species for afforestation instead of fast growing conifers or eucalypts is likely to bring enhanced biodiversity benefits while minimizing water loss.

Afforestation stabilizes land surfaces and improve infiltration, but it will often lead to lower water yields because of greater interception and evapotranspiration. Afforestation using native deciduous species is likely to be more beneficial than conifers and the balance of evidence suggests that intensive forestry should be avoided.

2.3.3.1 Impacts on Runoff / Peak Flows

Forest covered catchments and associated reservoirs can increase evapotranspiration (ET) rates above background levels. Forests often have higher ET rates than pasture or arable agriculture. Evaporation from reservoir surfaces can be considerable, especially in drier regions. Afforested reservoir catchments can reduce erosion and / or sediment delivery in two ways. Forests are efficient at retaining sediment and decrease the kinetic energy of the throughflow rainfall. Erosion rates will be lowest from natural or close-to-natural forests but may, on the other hand, substantially increase in poorly managed plantations.

2.3.3.2 Impacts on the Environment

Afforestation of reservoir catchments using endemic or indigenous tree species will create terrestrial habitats (this is also possible with non-endemic species). Afforestation for intensive biomass production is not recommended as UK experiences have shown that this can result in excessive sediment and nutrient leakage to the reservoir. Afforestation of reservoir catchments will increase carbon sequestration as a result of increased vegetation growth Reservoirs themselves can contribute to carbon sequestration through sedimentation of dissolved organic carbon which enters in runoff from the surrounding catchment.

2.3.4 TARGETED PLANTING FOR 'CATCHING' PRECIPITATION

There is some evidence to suggest that loss of tree cover on Mediterranean hill slopes has altered weather patterns, which in turn have altered precipitation amount and timing. Modelling results suggest that Mediterranean precipitation regimes are very sensitive to variations in air temperature and moisture. Land use change and associated deforestation may have led to changes from and open monsoon-type regime with frequent summer storms over inland mountains to a regime dominated by closed vertical atmospheric recirculation where feedback mechanisms suppress storms over the coastal mountains and lead to increased summer time sea surface warming. This warming leads to torrential rains in autumn and winter. These rains can occur across the Mediterranean basin. This can be exacerbated by greenhouse heating associated with air pollutants. Targeted afforestation in some parts of the Mediterranean may be one means of combating drought and desertification. However, caution should be taken when choosing areas for afforestation to avoid possible adverse effects, as there is some evidence that afforestation in dry environments, especially in mountainous areas, may decrease water yield and cause water deficit in the downstream rivers. Local tree species should be used to reduce risks to biodiversity.

Evidence from modelling studies suggests that targeted planting to affect precipitation patterns in the Mediterranean basin only works at a very large spatial scale. Millán and colleagues have assembled a considerable body of evidence about the long term effects of deforestation on regional weather patterns which suggest that changes in land use and land management have caused observed changes in regional weather and droughts.

Targeted planting for precipitation capture is only likely to provide benefits in the Mediterranean region. Millán et al. (2005) suggest that deforestation may have altered the precipitation regime in parts of the Mediterranean region with a reduction in summer storms and an increase in autumn/winter precipitation.

2.3.4.1 Impacts on Runoff / Peak Flows

Tree cover can improve soil structure through increased accumulation of organic matter from leaf litter and improvements to soil permeability. Improved soil structure can lead to greater infiltration, higher rates of groundwater recharge and increased soil water retention. The main way in which targeted planting for catching precipitation is proposed to increase groundwater recharge is through enhanced precipitation where greater amounts of rainfall are available to infiltrate and to maintain groundwater and soil water levels.

2.3.4.2 Impacts on the Environment

Afforestation of areas previously deforested using native or indigenous species has the potential to preserve or improve biodiversity by providing habitat types used by endemic species. The key purpose of targeted planting for catching precipitation is reversal of local or regional climate change induced by land use change. If successful, this measure will largely mitigate the negative effects of deforestation on Mediterranean summer precipitation regimes.

2.3.5 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. Poorly designed or poorly implemented stream crossings can have numerous negative effects on the aquatic environment including increased sediment mobilization and changes in flow patterns. For example, flooding upstream of the road crossing can occur when the bridge or culvert is unable to transport a sufficient volume of water. Such floods can also wash out bridges or stream crossings, leading to increased costs for the road owner and downstream sediment pollution. Increased sediment mobilization results in loss of aquatic habitat and may extirpate threatened species including freshwater pearl mussel as well as destroying spawning habitat.

2.3.5.1 Impacts on Runoff / Peak Flows

Properly designed forest roads and stream crossings will have a minor effect on slowing or storing runoff. Poorly designed roads and stream crossings can negatively affect river flow dynamics in the forest landscape by speeding up or excessively slowing flows. When forest roads (or any non-paved road) run across contour lines, they have the potential to channelize and speedup runoff. This can then mobilize excessive quantities of sediment, leading to downstream water pollution and in the worst case, destroying the road itself.

Properly designed stream crossings will not slow the flow or store the flow. Stream crossings that are too small for stream flow can store and slow river water, but this is a negative effect as it will lead to upstream flooding and potentially catastrophic downstream flooding if the stream crossing is washed out.

2.3.5.2 Impacts on the Environment

Properly designed stream crossings usually do not create aquatic habitat *per se* but instead prevent its destruction. Properly designed stream crossings which do not impede the movement of fish and aquatic invertebrates are vital for ensuring aquatic habitat connectivity. Sediment mobilization associated with poorly designed roads and stream crossings has the potential to smother fish spawning beds and habitat of red list species such as freshwater pearl mussel. Smothering of aquatic habitat is especially problematic as a single terrestrial sediment mobilization event has the potential to render aquatic habitats unusable for many years. Larger bridges and crossings, on the other hand, may create specific conditions for aquatic fauna and thus in some cases contribute to creation of aquatic habitat.

2.3.6 SEDIMENT CAPTURE PONDS (CHECKDAMS)

Sediment capture ponds are engineered ponds placed in networks of forest ditches to slow the velocity of water and cause the deposition of suspended materials. Sediment capture ponds are most useful for managing the effects of ditch construction and maintenance, road work and final feeling. While used primarily in forests, sediment capture ponds may be a useful temporary measure for preserving water quality in and around construction sites or mines. They may also be useful for capturing sediment in agricultural runoff. Sediment capture ponds have a limited lifespan, depending on how much suspended material is in the inflowing water. However, ponds can be maintained by removal of accumulated sediment. As most water protection methods, sediment capture ponds function well during base and moderate flow events. Catchment area, hydraulic properties of streams, 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 this and also many other measures.

While sediment capture ponds are only effective when they have a small upstream drainage area, their beneficial effects for the aquatic environment can be seen in much larger catchments. The dense network of forest streams in which sediment capture ponds are typically placed means that each pond drains a relatively small area, but that there is close correlation between the number of ponds and the strength of floods in bigger catchment systems downstream.

FIGURE 2-20: MANIFESTATION OF A SEDIMENT CAPTURE DAM.

2.3.6.1 Impacts on Runoff / Peak Flows

The sediment capturing ability of ponds is based on a slowing of water velocity. Thus, this measure will have a localized ability to slow runoff. Multiple ponds distributed across the forest landscape might have a significant ability to slow runoff during drier periods but will probably have limited effectiveness during spring snowmelt. It is questionable whether or not it is appropriate to state that sediment capture ponds store or slow river water as their use is limited to stream networks and potentially headwater streams. However, within these smaller watercourses, sediment capture ponds will both store water and slow the flow velocities.

Much of the water pollution in managed forests is associated with particulate matter. Suspended sediment can be a major water pollutant, as can phosphorus and heavy metals transported with suspended material. By slowing water velocity in forest streams, sediment capture ponds can help to reduce pollutant sources in the managed forest landscape.

2.3.6.2 Impacts on the Environment

While the primary purpose of sediment capture ponds is not the creation of aquatic habitat, some additional habitat will be created but it will be gradually lost as the pond is filled with sediment. Sediment capture ponds have a much stronger effect of preserving downstream aquatic habitat by preventing sediment pollution which can lead to smothering of spawning beds or eutrophication.

2.3.7 COARSE WOODY DEBRIS

Coarse woody debris in stream channels has multiple ecological and hydrologic benefits. 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 deployed with varying degrees of naturalness. At one extreme, coarse woody debris can be used to form coffer or placer dams which effectively limit water flow. At the other extreme, natural deadfall coarse woody debris is found when riparian trees are allowed to fall naturally into streams. Coarse woody debris will generally slow water flow velocity and can reduce the peak of flood hydrographs. 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.

2.3.7.1 Impacts on Runoff / Peak Flows

Coarse woody debris will slow the flow of small streams and rivers. When flow velocities are slowed, there will be a greater storage of water in stream channels. However, the storage benefits are limited compared to the benefits associated with slowing of river water. It is not rare the cases where a sudden break-up of the debris structure during flood events may enhance flooding downstream.

2.3.7.2 Impacts on the Environment

Coarse woody debris increases the structural complexity of stream channels. This greater structural complexity creates additional aquatic habitat. The additional aquatic habitat associated with the debris in rivers and lakes can be important for both fish and aquatic invertebrates.

2.3.8 URBAN FOREST PARKS

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

Urban forest parks are a subclass of CORINE artificial non-vegetated urban areas. Unlike many artificial surfaces (such as paved areas), urban forest parks are able to deliver significant NWRM and ancillary benefits.

2.3.8.1 Impacts on Runoff / Peak Flows

Because of the greater infiltration capacity of soils under forests compared to soils underneath agricultural or impermeable urban land cover, urban forest parks can have a significant ability to store runoff. This may be especially valuable for buffering inputs of summer rainfall as the soil capacity to store runoff will depend on antecedent moisture conditions and drier soils will have greater moisture holding capacity. Forests can also have a higher precipitation interception capacity than other vegetation types, meaning a greater fraction of the incoming precipitation is returned to the atmosphere. Urban forest parks have a moderate ability to slow runoff. Soils under forests generally are more textured with a higher porosity and organic matter content than soils underlying other land cover types. These features increase the infiltration and water holding capacity of soils, thereby slowing runoff.

Forest soils have an ability to reduce atmospheric and aquatic pollutant sources. The beneficial effects of forests on urban air quality are well established and forests can also facilitate improvements in surface water and groundwater quality. Forests typically receive less fertilizer inputs than grass lawns, which can reduce nutrient leakage and pollution of surface water and groundwater.

2.3.8.2 Impacts on the Environment

Urban forest parks have a high potential to create important terrestrial habitat for plants and animals. If urban forests are created using native or indigenous species, there can be significant biodiversity benefits. Urban forest parks have a high capacity to absorb and retain CO_2. The growing trees in an urban forest park will take up CO_2 from the atmosphere. Unlike other managed forests, harvesting of trees in urban forest parks is typically limited, resulting in a greater long-term CO2sequestration potential. The uptake of CO_2 by the growing forest also contributes to an increase in soil organic matter, which is another reservoir for forest carbon sequestration.

2.3.9 TREES IN URBAN AREAS

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. The area around urban trees may also have greater infiltration capacity than the impermeable surfaces often found in urban areas. Trees also transpire, which dries the soil and gives greater capacity for rainfall storage.

As with urban forest parks, it is difficult to place urban trees into a catchment context. The benefits of urban trees are extremely local. Hydrological benefits are related to increased interception and evapotranspiration. Urban trees can also play an important role in moderating local microclimate and can contribute to groundwater recharge. Urban trees can also be very important for increasing biodiversity in urban areas. The biophysical impacts of individual trees are generally low but as these impacts occur over a very small area, they can be locally important.

2.3.9.1 Impacts on Runoff / Peak Flows

Because the area around urban trees is often more permeable than areas further away, urban trees have a moderate potential to store runoff. The runoff storage effect is likely to be extremely limited and localized for each tree but groups of trees or small urban forest parks could have a demonstrable effect on storing runoff in urban areas. Individual trees will have a real but limited ability to slow runoff in urban areas. The rougher, more permeable soils where urban trees are planted can slow runoff when compared to impermeable surface such as pavement.

2.3.9.2 Impacts on the Environment

Trees in urban areas have a high potential to create terrestrial habitat. Studies have shown that trees in urban areas can be biodiversity hotspots with more bird species than empty areas. Trees in urban areas can contribute to reductions in peak temperature at ground level. Because trees have a higher albedo than many urban surfaces, they reflect instead of absorbing heat. The evapotranspiration from trees also contributes to local cooling.

Trees in urban areas have a high climate change adaptation and mitigation potential. While individual trees do not sequester large amounts of carbon, when sequestration is summed across a city, the effect can be considerable. Trees in urban areas can also contribute to climate change mitigation as they can limit peak temperatures at ground level. Trees also reduce wind speed and have potential to moderate temperature by offering shade from sunlight and shield from cold winter breezes.

2.3.10 PEAK FLOW CONTROL STRUCTURES

Peak flow control structures are designed to reduce flow velocities in networks of forest streams and/or overland flow in slopes. Peak flow control structures are engineered ponds or small ditches designed to limit the rate at which water flows out of a catchment. 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.

2.3.10.1 Impacts on Runoff / Peak Flows

Peak flow control structures are primarily designed to slow and store runoff during high flow periods as well as to minimize flow velocities. Because peak flow control structures will store and slow water, they have some limited potential to increase infiltration and groundwater recharge. Increased infiltration because of slower water flows can also have some benefits for soil water retention.

2.3.10.2 Impacts on the Environment

Prevention of sediment loss can contribute to preservation of fish stocks and maintain spawning sites.

2.4 AGRICULTURE

There is substantial evidence that modern land-use management practices have enhanced surface runoff generation at the local scale, frequently creating impacts through "muddy floods". Such local impacts can be avoided or mitigated through the adoption of better land management practices and/or small scale surface runoff control measures. There is little evidence that local scale changes in runoff generation propagate downstream to create impacts at the larger catchment scale. This does not imply that impacts do not exist, but the very few studies in which evidence has been sought have not produced any conclusive findings.

The possible measures for Forestry are numerous (see also FIGURE 2-18). The number of each measure shown in the figure is explained in the associated paragraph with the same number. Most of the measures listed below require a shift of the agricultural management.

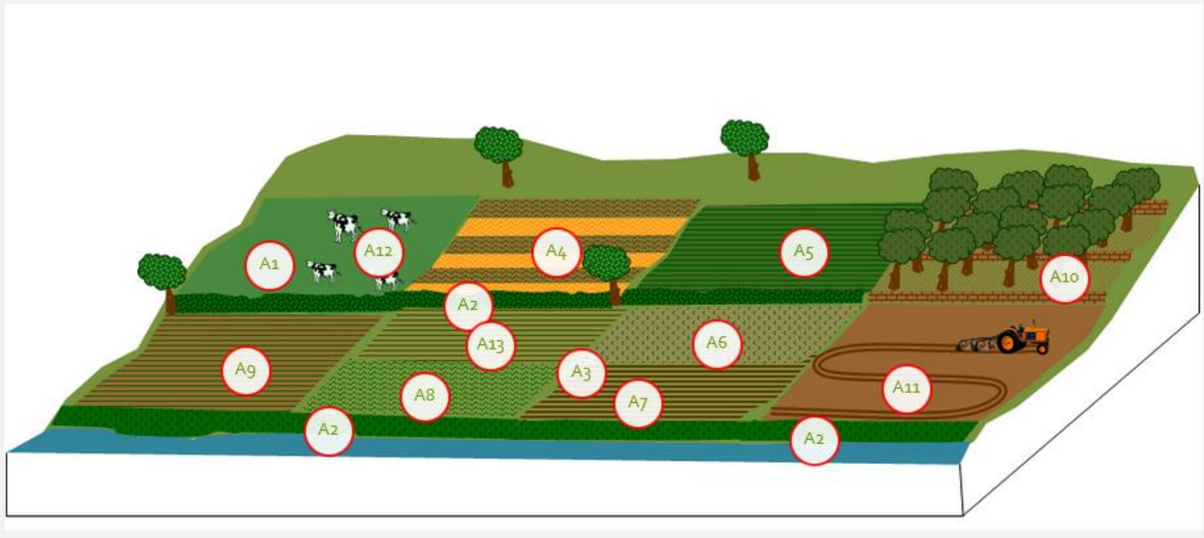

FIGURE 2-21: NWRMS LISTED IN THE AFRICULTURAL SECTOR

2.4.1 MEADOWS AND PASTURES

Meadows are areas or fields whose main vegetation is grass, or other non-woody plants, used for mowing and haying. Pastures are grassed or wooded areas, moorland or heathland, generally used for grazing. Due to their rooted soils and their permanent cover, meadows and pastures provide 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. Soil cover is maintained at all times with rooted vegetation, this reduces the surface flow of water and allows greater infiltration to the soil. Rates of soil erosion are considerably lower than arable land with potential benefits for water quality.

2.4.1.1 Impacts on Runoff / Peak Flows

BIO Intelligence Service (2014) report that a study in Catalonia (Spain) found that run off was 1884 m3/ha for arable land compared to between 643 to 962m3/ha for grassland, i.e. reductions of between 49% and 66%. Kedziora (2010) reports on the impacts of different land management practices in the Wielkopolska region of Poland. Run-off was lower for meadows versus arable land:

- Dry year (627mm precipitation): 0mm for meadows versus 108mm.
- Normal year (749mm precipitation): 155mm for meadows versus 233mm, i.e. 33% lower.
- Wet year (936mm precipitation): 271mm for meadows versus 351mm, i.e. 23% lower.

Improved soil structure, for example through grass root systems, can increase infiltration rates. However, meadows and pastures are susceptible to compaction and poaching from machinery and livestock; although these management factors interact with soil type/texture and climactic conditions to influence compaction.

2.4.1.2 Impacts on the Environment

Well managed grassland can contribute towards climate change mitigation through higher carbon storage.

2.4.2 MEADOWS AND PASTURES

Buffer strips are areas of natural vegetation cover (grass, bushes or trees) at the margin of fields, arable land, transport infrastructures and water courses. They can have several different configurations of vegetation found on them varying from simply grass to combinations of grass, trees, and shrubs. Due to their permanent vegetation, buffer strips offer good conditions for effective water infiltration and slowing surface flow; they therefore promote the natural retention of water. They can also significantly reduce the amount of suspended solids, nitrates and phosphates originating from agricultural run-off. Buffer strips can be sited in riparian zones, or away from water bodies as field margins, headlands or within fields (e.g. beetle banks). 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.

2.4.2.1 Impacts on Runoff / Peak Flows

Borin et al (2010) report on a study in Padova, Italy, in which a 6m wider buffer strip of trees and shrubs reduced runoff by 78% compared to no buffer strip, this was equivalent to a runoff depth of 231mm over 5 years. CORPEN (2007) report that a 10m buffer strip can reduce runoff by at least 50%.

JRC (2013) report the following impacts on runoff of 5m buffer strips:

- 15-20% P reduction (10% for pastures)

In hilly areas these impacts are:

- 42-96% P reduction.
- 27-81% N reduction.
- 83-90% organic matter.

Borin et al (2010) report on a study in Padova, Italy, in which a 6m wider buffer strip of trees and shrubs reduced pollutant loads:

- 74% total N reduction
- 80% total P reduction (soluble P concentrations were unmodified)

Buffer strips provide both covering vegetation and can trap/filter sediments from surface flow. JRC (2013) report that a 5m buffer strip in a ‘hilly area’ reduced sediment by 55-97%. Borin et al (2010) report that a 6m buffer strip reduced total suspended solids by 94%.

2.4.2.2 Impacts on the Environment

Buffer strips take land out of production but can provide a number of benefits to adjacent crops, e.g. habitats for pollinators and pest predators; slowing runoff; reducing wind and water erosion. Buffer strips can be managed (cutting regimes etc.) to directly provide habitats for a range of plant and animal species. They also have a role in providing habitat connectivity.

2.4.3 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. It gives various benefits to the soil. A traditional element of crop rotation is the replenishment of nitrogen through the use of green manure in sequence with cereals and other crops. Crop rotation also mitigates the build-up of pathogens and pests that often occurs when one species is continuously cropped. However, as crop rotation has been traditionally practiced for agronomic reasons rather than to achieve environmental and water objectives, new practices may be required to ensure water retention benefits can be achieved.

Crop rotation is widely undertaken in most of the EU-27 regions, as the EU-27 average of crop rotation implementation out of total arable land is approximately 86% (BIO Intelligence Service with support from Hydrologic, 2014). Under Mediterranean climate (Spain, Italy, South of France, Greece and Cyprus), rotations can include permanent culture (olives, fruits), legumes, beans, alfalfa and maize(BIO Intelligence Service with support from Hydrologic, 2014).

2.4.3.1 Impacts on Runoff / Peak Flows

Carefully designed crop rotation scan reduce the period of time that soil is left bare or fallow. This may lead to increased infiltration and runoff reduction (BIO Intelligence Service, 2014).

Crop rotation can improve fertilization efficiency by several means: making mineral elements available for following crops, increasing humus rate in the soil, increasing organic concentration in the soil etc. A study conducted by Arvalis and GNIS (Cavaillès, 2009) in France showed that introducing a different crop before wheat could lead to decreased Nitrate inputs (or N losses) in wheat production for the sameyield objective: From wheat-wheat to:

- wheat-legume -20 to -40 kgN/ha,
- rapeseed-wheat: -20 to -40kgN/ha,
- sunflower-wheat: 0 to +30kgN/ha,
- alfalfa-wheat: -25 to -40 kgN/ha first year, -45 to -60 kgN/ha second year,
- purple clover-wheat: -20 to -40 kgN/ha firstyear, -60 to -90 kgN/ha second year.

Crop rotation is also efficient in managing grass cover. By limiting adventitious flora, it can lead to decrease pesticides use.

2.4.3.2 Impacts on the Environment

Bio Intelligence Service (2010) note that the impact of crop rotation on biodiversity (soil and above ground) is complex and relies on the choice of crops used and management actions. Harmful inputs may be reduced, but field operations and soil disturbance may be damaging. Maintaining a heterogeneous habitat may be beneficial.

2.4.4 STRIP CROPPING ALONG CONTOURS

Strip cropping is a method of farming used when a slope is too steep or too long, or otherwise, when one does not have an alternative method of preventing soil erosion. It alternates strips of closely sown crops such as hay, wheat, or other small grains with strips of row crops, such as corn, soybeans, cotton, or sugar beets. Strip cropping 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.

FIGURE 2-22: EXAMPLE OF STRIP CROPPING ALONG CONTOUR LINES

2.4.4.1 Impacts on Runoff / Peak Flows

Strip cropping contributes to slowing down runoff by introducing strips of row plants which absorb water more efficiently due to the use of closely sown crops in the alternating strips. Across slopes, it helps to intercept water runoff compared to up-down slope cropping. Densely vegetated strips increase surface roughness and hydraulic resistance to flow; that reduces the transport capacity of the runoff. Strip cropping greatly reduces the rate of sediment moving down the slopes (US Department of Agriculture, 1997). A strip is efficient in reducing erosion when its width is sufficient for the sediment transport capacity to be reduced to less than the sediment load being transported by the runoff. In this case, deposition happens(US Department of Agriculture, 1997).

2.4.4.2 Impacts on the Environment

Densely vegetated strips increase surface roughness and hydraulic resistance to flow; that reduces the transport capacity of the runoff. Strip cropping greatly reduces the rate of sediment moving down the slopes (US Department of Agriculture, 1997). A strip is efficient in reducing erosion when its width is sufficient for the sediment transport capacity to be reduced to less than the sediment load being transported by the runoff. In this case, deposition happens(US Department of Agriculture, 1997).

2.4.5 INTERCROPPING

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

FIGURE 2-23: EXAMPLE OF INTERCROPPED CEREALS WITH SOYBEAN

2.4.5.1 Impacts on Runoff / Peak Flows

Intercropping can slow runoff by up to 50% (Zougmore, 2000) and increased infiltration can reduce runoff by up to 4 times(OMERE, 2014).

2.4.5.2 Impacts on the Environment

Intercropping leads to a more efficient use of resources (light, water, nutrients, etc.) and an increased productivity compared with each sole crop of the mixture (Lithourgidis, 2011). Research led in Zimbabwe showed that intercropped pigeonpea or cowpea can help to maintain maize yield when maize is grown without mineral fertilizer and in sandy soils (Waddington, 2007). Intercrops happen to increase light interception, reduce evaporation and improved conservation of the soil moisture(Ghanbari, 2010). Intercropping increases biodiversity into agrosystems by providing habitats for insects and soil organisms, which increase species richness (Lithourgidis, 2011).

2.4.6 NO TILL AGRICULTURE

Tillage is a mechanical modification of the soil. 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. No-till is an agricultural technique which 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.

Use of no-till has increased in south-western Europe due to perceived environmental advantages and lower costs. Observed yields for winter-sown crops are either equal or increased for no-till compared to after ploughing. The combination of no-till and preservation of surface crop residues has improved soil and water conservation (Soane et al., 2012).Uptake of no-till in selected countries as % of arable in 2010 (Eurostat):Greece 1.9%, Spain 6.2%, Croatia 2.1%, Italy 4.1%, Cyprus 0.3%, Portugal 2.6%, Slovenia 1.5%.

2.4.7 LOW TILL AGRICULTURE

Low till agriculture, also known as conservation or reduced till applies to arable land. It consists of a combination of a crop harvest which leaves at least 30% of crop residue on the soil surface, during the critical soil erosion period and some surface work (low till). This slows water movement, which reduces the amount of soil erosion and potentially leads to greater infiltration.

2.4.7.1 Impacts on Runoff / Peak Flows

BIO Intelligence Service (2014) report on a study in Hungary where a 32% runoff reduction was achieved:

- Average runoff volumes of 172.6 m3/ha versus 453.8m3/ha in conventional plots).
- Water storage in the upper 20 cm increased by 8.8%, below 20 cm water content increased by 1.7%.

However, Bescansa et al. (2006) in a study in Northern Spain found that there is no significant different between reduced tillage and mouldboard tillage.

2.4.7.2 Impacts on the Environment

Bescansa et al (2006) report no significant difference in 5-year average barley yields for reduced tillage (4.85 t/ha) versus mouldboard tillage (4.61 t/ha), although the reduced tillage system was more efficient due to lower production costs.Schmid et al (2004) report on the impact of different reduced tillage and cover crop systems on sugar beet in Austria. Yields for the reduced tillage systems were similar with a range of 109.8 to 120.6 dt/ha compared to a range of 118.7 to 121.9 dt/ha for conventional tillage. The yields for both these treatments were below the conventional tillage without cover crop control treatment yield of 130.3 dt/ha.

2.4.8 GREEN COVER

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.

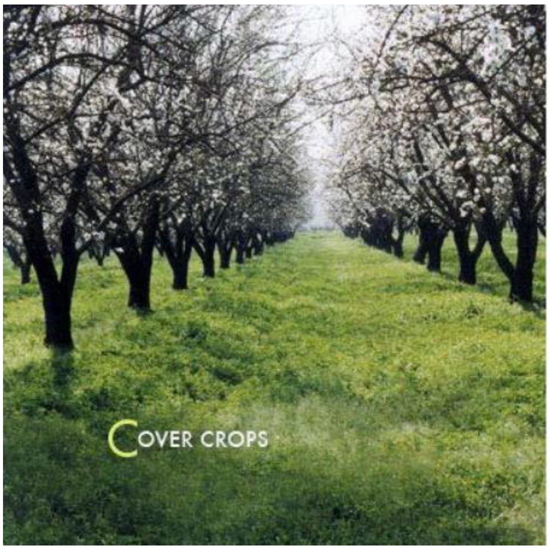

FIGURE 2-24: EXAMPLE OF AN ORCHARD WITH GREEN COVER

2.4.8.1 Impacts on Runoff / Peak Flows

Green cover prevents the soil from remaining bare during winter, thus it reduces runoff. O'Connell et al (2007) showed that green cover can reduce surface runoff up to 80%.The case study 'Cover crops and no-tillage in an olive grove (Andalusia, Spain) reports a lower runoff coefficient of 1.2% for cover crops in comparison to conventional tillage(3.1%) and considerably lower than for no tillage (11.9%). Green cover implies that the soil is not bare in winter, but covered by plants. Root systems enable infiltration, thus leads to reduce surface runoff.

2.4.8.2 Impacts on the Environment

Green cover add carbon in the soil, which contributes to improve its structure(Stella consulting , 2012). Justes et al measured that green cover could catch 300kgC/ha take up to the soil (+-150kgC/ha). Moreover, soil composition can benefit from the type of cover; catch crops, particularly legumes, assimilate nitrogen from the air which makes it available for the soil. Thus, legume green cover can helpincreasing soil fertility. Field tests led by INRA, Arvalis and the Chambre d'Agriculture in France showed that nitrogen catch in the soil can increase by 3,3 to 6% (in17 years) thanks to catch crops (+0,16tN/ha to +0,38tN/ha).(INRA, Arvalis, Chambres d'Agriculture).

Green cover contributes to preserve cultivated biodiversity and can constitute habitat for fauna. Thus it contributes to biodiversity preservation.

2.4.9 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 Early sowing of spring crops may also require different cultivation techniques (reduced tillage, controlled traffic farming) as soils are likely to be saturated before usual sowing times increasing the risk of soil compaction. Restrictions on early sowing of winter crops include the harvest date of the preceding crop (particularly root crops) which may be later in northern Europe. For both spring and winter crops, early sowing involves a number of trade-offs. For example, different pest and disease risks arise that might require changes in management.

2.4.9.1 Impacts on Runoff / Peak Flows

Early sowing can increase the level of vegetation cover which will slow run-off. Defra (2005) recommends sowing of winter cereals should be early enough to ensure 25% cover by early winter, i.e. no later than mid-late September in lowland England. For spring cereals Defra (2005) does not recommend early sowing particularly on field with high erosion risk. O'Connell et al (2007) report that winter cover crops in maize production can reduce run-off by up to 80%. The impacts of early sowing are likely to be lower as full crop establishment is not the aim and differences in crop and soil types are likely to be important.

2.4.9.2 Impacts on the Environment

Arvidssonet al (2000) report that early sown spring barley had a 1% higher yield than when sown at the conventional time. The improvement in yield was higher the earlier the time of sowing. Dejoux et al (2003) report in trials of very early sowing up to one month before normal sowing of oilseed rape in France. Yields for normal sowing were slightly lower and had a wider range than those for early sowing:

- Normal sowing: 1.1 to 4.1 t/ha
- Very early sowing: 2.3 to 4.4 t/ha

2.4.10 TRADITIONAL TERRACING

Traditional terraces consist of nearly level platforms built along contour lines of slopes, mostly sustained by stone walls, used for farming on hilly terrain. By reducing the effective slope of land, terracing can reduce erosion and surface run-off by slowing rainwater to a non-erosive velocity. This also increases the degree if infiltration and improves soil moisture. However, abandonment of traditional terracing can result in high levels of erosion and run-off due to the lack of maintenance of stone walls. Abandonment can also change the nature of local flora and fauna; this may not be beneficial, for example the spontaneous regeneration of vegetation can present a risk of wild fire spread on sloping land. This measure focuses on existing or traditional terracing as it involves less disturbance of the terrain than modern terracing such as significant levelling or cutting using heavy machinery. As the measure is highly labour intensive and costly to implement the focus of the measure would be in maintaining existing terracing rather than expansion.

Traditional terracing was developed to mitigate the high risk of soil erosion due to high intensity rainfall events in the Mediterranean region, in particular where increasing demand for agricultural products resulted in deforestation and land conversion of hillsides.

FIGURE 2-25: ILLUSTRATION OF TRADITIONAL TERRACING

2.4.10.1 Impacts on Runoff / Peak Flows

Dorren and Rey (no date) report that a study in Canada found that terracing could reduce runoff by 25% of growing season rainfall. Traditional terracing reduces also soil erosion, as the same authors report on the outcomes from a number of studies:

- Canada: soil loss reducedfrom 20 t/ha/yr to <1 t/ha/yr (~95%).
- Malaysia: soil loss reduced from 63 t/ha/yr to 1.4 t/ha/yr (~98%).

The most important erosion reducing activity was the maintenance of existing terrace walls, without this soil loss is a major risk.

2.4.10.2 Impacts on the Environment

Traditional terracing contributes to the cultural heritage and landscape character of areas where it is implemented. Abandonment may result in homogenisation of these landscapes and undesirable land use change.

2.4.11 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, compacting around 75% of the area within one season and at least the whole area by the second season. Soils don’t recover quickly, taking as much as a few years. A proper CTF system on the other hand can reduce tracking to just 15% and this is always in the same place. CTF is a tool; it does not include a prescription for tillage although most growers adopting CTF use little or none because soil structure does not need to be repaired. The permanent traffic lanes are normally parallel to each other and this is the most efficient way of achieving CTF, but the definition does not preclude tracking at an angle. The permanent traffic lanes may be cropped or non-cropped depending on a wide range of variables and local constraints.

2.4.11.1 Impacts on Runoff / Peak Flows

According to Douglas (1998), soil compaction enhances waterlogging. Chamen(2011) reviewed different literature sources and concluded that infiltration could increase by 84 to 400% in the absence of wheel compaction. Controlled traffic farming, by decreasing soil compaction, has so an effect on increasing infiltration.

2.4.11.2 Impacts on the Environment

Controlled traffic farming leads to diesel use reduction; Chamen (1993) calculated that diesel reduction was between 4.70 and 16.30 L/ha depending on soil types compared to conventional farming. The net impact on CO_2 emissions is assessed between 31.96 (sand) and 236.71 (clay) kg/ha.

2.4.12 REDUCED STOCKING DENSITY

Livestock, particularly heavy species such as cattle, can have a number of 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.

Reduced stocking density will limit soil compaction, thereby facilitating more rapid infiltration during precipitation events and potentially reducing peak flows and sediment runoff. There may also be issues due to management decisions which can increase risks due to livestock without changing stocking levels. For example increased out-wintering of cattle to avoid housing costs will exacerbate risks due to the increased vulnerability of soils during the winter months. The measure may be effectively achieved by moving grazing livestock from high risk areas or by increasing the use of housing. Whether the reduction in pressure is achieved through direct reductions in stocking density, movement from high risk areas or housing, there will be impacts on farm business in terms of direct or opportunity costs.

2.4.12.1 Impacts on Runoff / Peak Flows

Potential improvements in soil physical properties (compaction, bulk density) resulting from reduced livestock numbers could result in reduced run-off rates through both reduced surface flow (higher soil cover) and greater infiltration (Bilotta et al., 2007). Heathwaite et al (1989) found that livestock over grazing and trampling can reduce infiltration by 80%, whilst Heathwaite et al (1990) report that surface run-off can be doubled at field and hill slope scale.

2.4.12.2 Impacts on the Environment

Pollutants loads may be both reduced due to reduced livestock numbers and filtration increased due to both greater vegetation and infiltration.Bilottaet al (2008) report an increase in sediment related water quality issues with increases in stocking density, implying that these would be mitigated by reduced stocking density. However, residual phosphorus in soils continued to be released even at zero stocking density.

2.4.13 MULCHING

A mulch is a layer of material applied to the surface of an area of soil. Its purpose is any or all of the following:

- To conserve moisture.
- To improve the fertility and health of the soil.
- To reduce weed growth.
- To enhance the visual appeal of the area.

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.

FIGURE 2-26: MULCHING IN AGRICULTURE

2.4.13.1 Impacts on Runoff / Peak Flows

Jordan et al (2010) showed that in semi-arid conditions in Spain, mulching could slow runoff: in their experiments, surface runoff and runoff at the plot outlet was delayed as mulching rate increased. Organic residues in the soil surface indeed increase the hydraulic roughness and interception, which favors a higher infiltration of rain water.

3 RELATED PROJECTS

3.1 THE LAKE KARLA REHABILITATION PROJECT - REGION OF THESSALY - GREECE

The largest environmental project in the Balkans is being implemented by the Region of Thessaly at Lake Karla. This is a local development project of national importance, with multiple benefits for Thessaly, the region where the Lake is situated, and broader growth.

The major benefits expected from this project are:

- The enhancement of the water supply to the broader region of Volos with high-quality subterranean water. The replacement of the use of subterranean water of the region for irrigation with water from Lake Karla enables the utilisation of part of this water, through new boring projects, for the supply of water to the Urban Complex of Volos, which is currently facing a lack of high-quality water (the greater area of Volos is forced to meet its needs by using water containing chlorides).
- Flood protection f the low-land areas of the lake and of the city of Volos through the existing tunnel that discharges flood volumes through the tunnel to the streams of the city of Volos.
- The partial restoration of the ecosystem (which existed before the lake was drained), through the recreation of the lake and the creation of the planned wetlands and plant ecosystems around it.
- The recovery of the level of the subterranean groundwater by reducing extractions, which will be achieved by replacing the use of subterranean water for irrigation with water from the lake being created.
- The minimisation of the contribution of the Lake Karla catchment area effluents to the pollution of the Pagasetic Gulf, with the collection of effluents in the lake. Following the creation of the lake, the use of the Karla tunnel for removing water from the Karla catchment area to the Pagasetic Gulf will only take place in the case of intense of extended flooding, when the anti-flooding functioning of the artificial lake is no longer possible.
- The gradual improvement of the quality and increase of the usable quantity of surface water, through the construction of the dam and the cleaning of leachates from the irrigation of crops using natural processes (wetland for leachate cleaning).
- The improvement of soil quality. The proposed project will result in improvement of the physical and chemical properties of the soil in the broader region. More specifically:

The concentration of effluents of the closed Karla catchment area in the lake being created ensures the anti-flooding protection of lowland areas and conditions for good soil drainage, which will contribute towards improving soil quality. The reduction of groundwater pumping is expected to result in gradual eradication of the causes of the cracking and subsidence currently observed due to increased pumping throughout the region. The provision of adequate quantities of high-quality surface water for irrigation (water with low salinity and alkalinity levels) and the achievement of good drainage conditions in the region will achieve restoration of the pathogenic factors for the soil currently observed in the area around the lake being created (saline soil and, in places, alkali soil).

- The environmental upgrading of the broader region, flora and fauna, with the support of wildlife and particularly migratory avifauna.
- The effective protection of the broader region from flooding, as it is situated at point of lowest elevation in the plains of Thessaly.
- The support of (permanent and seasonal) relocation to the region. The project will contribute towards reversing the population shrinkage of the region and attracting visitors through the creation of eco-tourism and recreation projects.
- The creation of infrastructure and favourable conditions for the realisation of new activities and employment opportunities that are compatible with sustainable growth (fisheries, eco-tourism).
- The expected change to the micro-climate of the region (lower temperatures in the summer, higher temperatures in the winter).
- The upgrading of the aesthetics of the landscape.

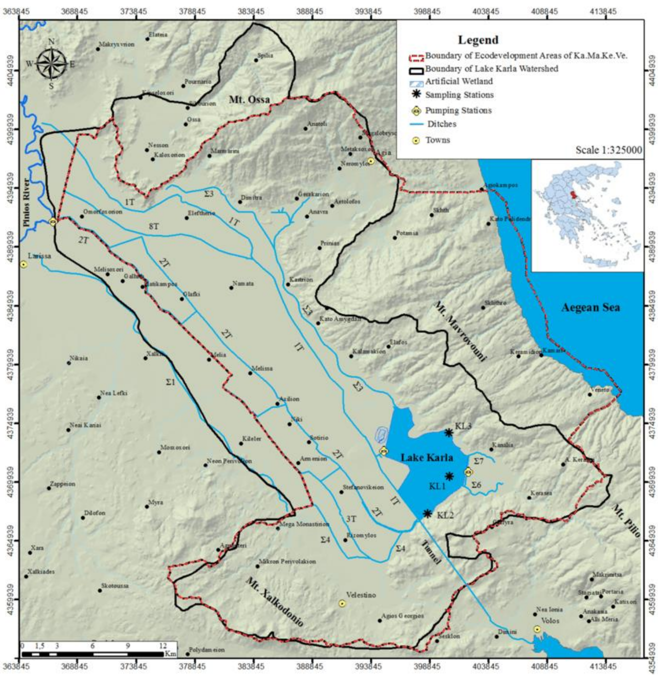

FIGURE 3-1: THE LAKE KARLA REHABILITATION PROJECT.

3.2 GERMASOGEIA RIVERBED ARTIFICIAL GROUNDWATER RECHARGE IN CYPRUS

Yermasogeia river (also known as Amathos river) crosses the premises of Germasogeia municipality, close to the city of Limassol on the south end of Cyprus. The aim of the measure implementation is to enable natural purification of water and recharge of yermasogeia aquifer, processes that were disrupted by the construction of an upstream dam. This is succeeded by gradually releasing water from the upstream dam and maintaining the high transmissivity of the riverbed.

The Germasogeia aquifer is an alluvial aquifer, consisting of loose material, which enables effective filtering of the water. It lies along the Germasogeia river valley and extends from the Germasogeia dam to the coast. It is 5.5 km long and has an area of 3 km^2. It lies under an urbanised area, the Limassol–Nicosia highway, local important roads and several main pipelines. The Germasogeia aquifer is the first aquifer in Cyprus that has been used as a natural water treatment plant, and it is currently the most intensively exploited aquifer in the country. Since 1982, the WDD in the district of Limassol has been using water from the Germasogeia dam to recharge the Germasogeia aquifer, with controlled releases on the surface of the aquifer, at four recharge points.

After natural purification, the ‘treated’ groundwater is pumped out of the aquifer through boreholes to supply domestic water to the greater Limassol area. No further water treatment is carried out except chlorination of the water tanks.

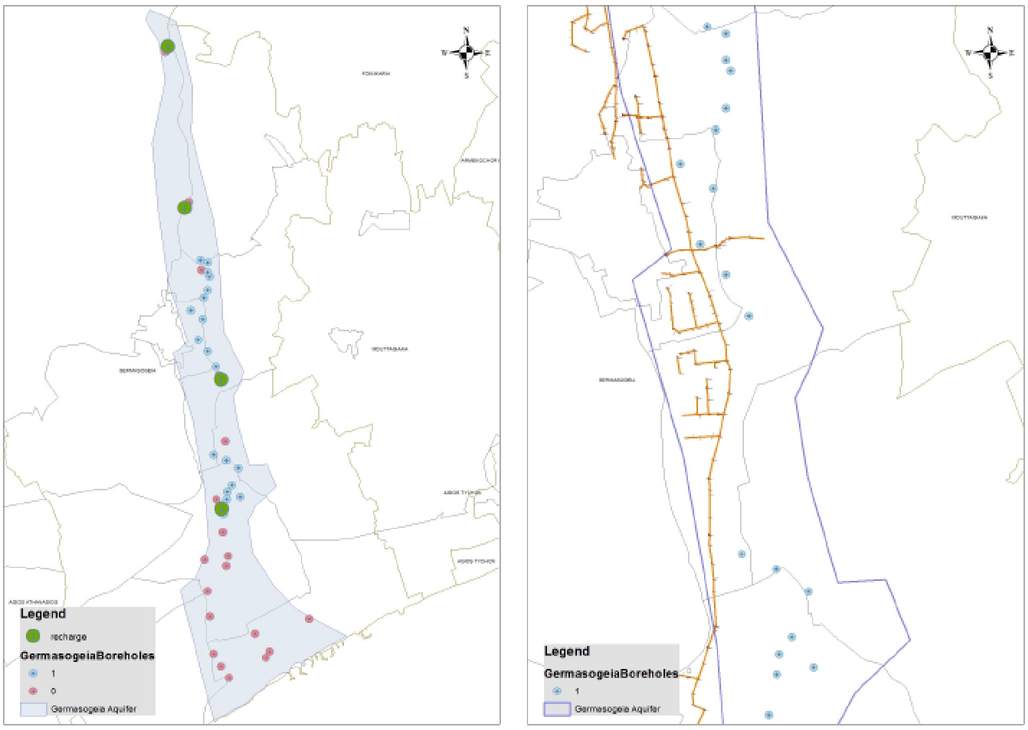

FIGURE 3-2: TOP VIEW OF THE AQUIFER. LEFT: THE RECHARGE POINTS ARE INDICATED WITH LARGE GREEN CIRCLES AND THE EXTRACTION POINTS INDICATED WITH SMALL CIRCLES. RIGHT: THE LOCATION OF THE SEWAGE SYSTEM, INDICATED WITH ORANGE (BENHAM ET AL., 2017).

3.3 EZOUSAS ARTIFICIAL GROUNDWATER RECHARGE OF TREATED EFFLUENT IN CYPRUS

The coastal part of the Ezousa riverbed aquifer, stretches up to 8 km from the coasts of Pafos district. The measure implementation concern the utilization of the local aquifer as a natural reservoir for natural filtration, storage and reuse of water, by creating and feeding infiltration ponds located in the riverbed. The water consists of tertiary treated sewage originating from the Paphos sewage treatment plant.

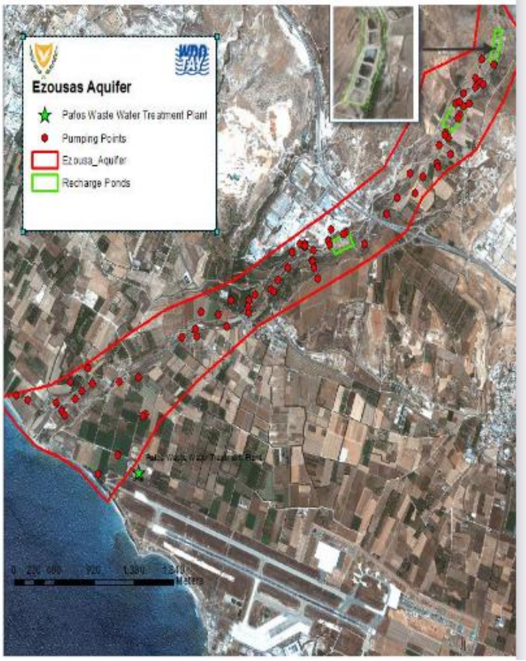

FIGURE 3-3: MAP OF EZOUSAS GROUNDWATER RECHARGE (WATER DEVELOPMENT DEPARTMENT)

The main parts of the project consists of the following:

- Tertiary disinfected treated water (4,5MCM), is pumped from the treatment plant to five shallow ponds in turns
- The water level in each pond reaches up to 0.5 m from where it slowly seeps into the ground
- Water from the aquifer is pumped from wells (20), which are located 100 m to 1000 m downstream of the recharge ponds, into a canal (open channel) at a ratio of 1:20 (aquifer water to dam water)
- The canal carries water from Asprokremmos dam to the Paphos irrigation scheme and passes across the Ezousas aquifer
- Pumping is carried out strategically so that retention time in the aquifer is maximised.

An assessment of the groundwater quality has several purposes: it ensures that when the water is used for irrigation it does not present a human health risk, nor does it affect plant growth and crop production. Additionally, it must be ensured that there are no negative impacts on the natural environment through the wastewater containing high concentrations of nutrients, toxins and pathogens. However, the recharging of treated effluent near the coast can lead to the formation of a hydraulic barrier that retards both the discharge of fresh groundwater and the ingress of saline water from the coast.

A hydrogeological investigation has been conducted to define the boundaries and hydraulic characteristics and assess the storage capacity of the Ezousas river aquifer in SW Cyprus for recharge with treated sewage effluent. It was found that the aquifer could accommodate the 5 hm^3 of recycled water produced annually from the Paphos Municipal Sewage Treatment Plant provided that the abstraction–recharge cycling was continuous.

This prevented either seepage to the sea or seawater encroachment into the aquifer. A monitoring programme, set up with a combination of piezometers and flow meters, measured the fluctuations in the seawater–freshwater interface and thus avoided abstraction of water with unacceptable salinity levels. The geological environment has been shown to exert an influence on the quality of the groundwater abstracted in terms of TDS and sulphate because of the natural solubility of the entrained gypsum and carbonate rocks that underlie the river basin upstream of the recharge sites. The water quality was tested regularly for toxicity, salinity and heavy metals, and assessed as being suitable for all crops that are traditionally planted within the Paphos irrigation area.

This study has shown that the Ezousas gravel aquifer is suitable for the storage and recycling of the treated sewage effluent from the nearby city of Paphos. Aquifer recharge with treated effluent offers an attractive option for improving the all year round reliability of the existing groundwater system while avoiding the expansion of environmentally costly and damaging infrastructure, risks to public health and seawater ingress.

3.4 DRAINAGE AND DISPOSAL SYSTEMS OF THE AREAS WEST OF THE MESSOLOGHI AND AETOLIKO LAGOONS, PREFECTURE OF WESTERN GREECE, GREECE

The main purpose of the flooding works is to minimize the outflows of the drainage pumping station D2 to the Lagoon Tholi, in order to improve the quality characteristics of this water. The need for improvement arises (a) from the sudden but temporary, significant reduction in water salinity in the estuary area, and (b) the presence of pollutants, mainly of agricultural origin (nitrogen, phosphorus) present in the drainage effluents. Both factors are aggravating for the livelihood of the fish, which are a very important financial resource for the fishermen who are active in the area but also for the economy of the wider area.

The wetland lake is located in a degraded area which is not used in agriculture due to the high salinity of the soils. The area is often flooded as its shape is an inverted cone with the deepest point in the center approximately the area intended for the creation of the wetland lake. The area is drained with a system of ditches in the form of a grid in the direction of flow either to the TVI Trench in the north or to the Central Tholis Trench in the east. It is noted that the recipient of both ditches is the Pumping Station D2. The creation of the wetland lake will eliminate all the drainage ditches, therefore the catchment area of the sewerage services of P/S D2 will be reduced by a small percentage.

The wetland lake is formed on an area of about 2800 acres, rectangular in shape in the area and is bounded between four embankments, of which two are existing and two are planned. The angles between the North and the West embankment as well as the West and South Embankment have been shaped in such a way as to avoid the creation of stagnant water sections with burdened quality elements and the water flow to be more smooth. The eastern and southern embankments are existing (at the crown of which is the asphalt road (see Photo 5) and the dirt road respectively) and border with Lagoons Tholi and Gourounopoules respectively.

Formation of the constructed wetland for the drainage (basically) and part of the sewage in the area shown in the relevant plans with a maximum area of approximately 2,811,000 m^2 (ie 2.8 km^2). The wetland will be formed on the existing terrain without any configuration except the external embankments and the internal embankment to guide the outflows of the Pumping Station D2. The lake area has a deep segment about in the middle (absolute altitude -1.50m approximately). The wetland lake is designed with a level from +0.5 (minimum overflow level) to + 0.9m (maximum operating level). The lake is formed by 2 existing embankments (east on the aforementioned asphalt road to Louros beach and south on a gravel rural road) and 2 new earthen embankments crown level + 1.5m (or + 2.0m). These are (a) the northern embankment on the TV Trench approximately 1800m long, and (b) the western embankment approximately 1650m long. The inner embankment of approximately 700m in length and a crown level of + 2.0m is formed at the end of the floodgate to guide the outflows into the wetland lake so that they "run" the maximum relative distance into the wetland lake from its entrance to its exit. These embankments will be constructed of earthworks which will come either from excavations to form ditches and culverts or from the area west of the western embankment of the wetland lake, which is not flooded by water in its current state. The embankments are constructed with slopes 3: 1 (h: v) based on the provisions of the geotechnical study. Because the ripples seem to be significant (due to the large size of the lake surface) then specific parts of the new embankments (which are facing the direction of the strongest winds blowing in the area (ie Southwest (SW) and Northeast (NE)), will be constructed with a level of +2.0m.

Formation of three islands of living and reproduction of the bird fauna in the wetland lake that lives in the area, as required by the Management Body and in excess of the Preliminary Design of the project. The islets will be made of the same material as the embankments, but with much milder slopes. The level of coronation of the islets is set at + 2.00m and with an area at their coronation equal to 50 m^2 each. The level of coronation of the islets is a requirement of the FDE as it stated that the level of coronation of the islands should be one (1) meter above the maximum water level, which is + 0.9m.

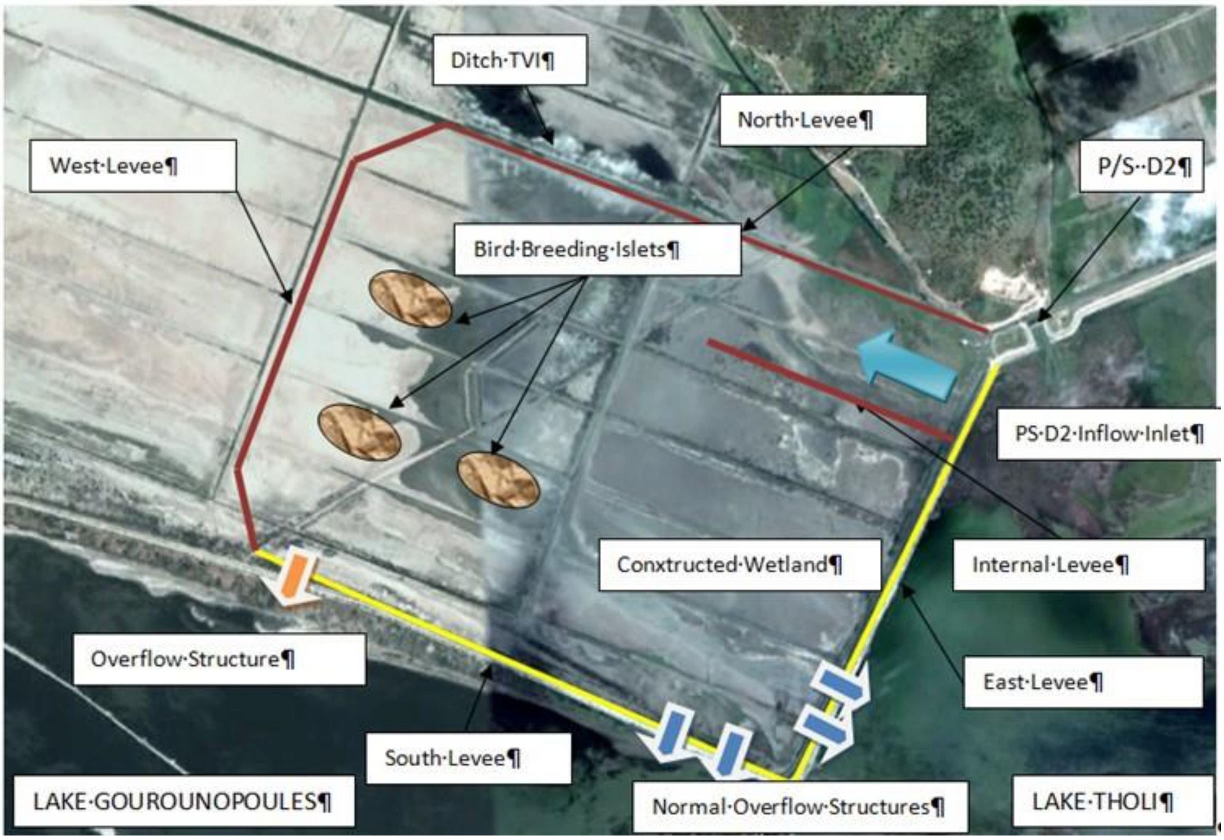

FIGURE 3-4: CONFIGURATION OF THE CONSTRUCTED WETLAND FOR THE D2 PUMPING STATION EFFLUENTS TREATMENT.

3.5 MAGLI RETENTION POND NEAR NICOSIA, CYPRUS

Lake Magli is a retention pond, near Nicosia, with an area of about 37 000 m_2 and perimeter 760 m, which is created the diversion of part of the runoff of Pediaios R. The storage volume of the pond is grossly estimated to 200,000 m^3. The diversion has been made feasible by a small, concrete, diversion dam (maximum height 1m) along the bed of the river.

The purpose of this retention pond is for flood attenuation and secondly for recreational and amenity purposes. Although the assessment of the level of flood attenuation and the decrease of flood risk of Nicosia City, that is situated further downstream of the pond, cannot be quantified in practice, however it is estimated that its role can be significant when some conditions are met.

In any case, the pond gives a very nice view of the area that increases significantly the aesthetics and the value of the neighboring properties.

FIGURE 3-5: AERIUAL VIEW OF MAGLI RETENTUION POND

FIGURE 3-6: VIEW OF THE DIVERSION DAM AND THE INLET OF THE PIPES TO THE RETENTION POND

Further upstream on the Pediaios R., several retention ponds have been constructed to exploit the stored water for irrigation purposes. These retention ponds have been constructed very close to the river bed providing space for runoff storage and flood peak attenuation downstream.

FIGURE 3-7: AERIAL VIEW OF A ENSEMBE OF RETENTION PONDS FOR IRRIGATION PURPOSES