- FORESEE -

Future proofing strategies FOr RESilient transport networks against Extreme Events

– Deliverable *3.1*–

Assessment of traditional solutions in drainage and sustainable drainage systems in linear infrastructures

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LIST OF ABBREVIATIONS AND ACRONYMS

BMP	Best Management Practice
CAME	Correct-adapt-maintain-explore
CWA	Clean Water Act
FAWMA	Flood and Water Management Act
FORESEE	Future proofing strategies For Resilient transport networks against Extreme Events
IPPC	Integrated Pollution Prevention and Control
LCC	Life cycle cost
LID	Low Impact Development
LIUDD	Low Impact Urban Design and Development
PPP	Public-private-partnership
PFZ	Preferential Flood Zone
SAB	Sustainable approval body
SDS	Sustainable drainage systems
SUDS	Sustainable urban drainage systems
SWOT	Strengths, weaknesses, opportunities, threats
USACE	United States Army Corps of Engineers
WEWS	Water Environment and Water Services Act
WFD	Water Framework Directive
WSUD	Water Sensitive Urban Design

1 EXECUTIVE SUMMARY

This document comprises the analysis of existing frameworks of sustainable drainage systems along with a multi objective analysis in order to detect the application possibilities of these systems in transport infrastructures. In order to achieve this goal, several tasks have been carried out, which are outlined below

Firstly, two preliminary sections have been included, in which the definition of some of the most relevant concepts are defined.

Then, in section 3, the water management framework has been defined. This framework includes the definition of basic concepts such as hydrology or hydrologic engineering together with the analysis of the most representative prescription in the field of water management in Europe and other parts of the world. This analysis emphasizes the inclusion of the concept of sustainability in water management.

Section 4 proposes a general definition of existing and conventional drainage systems for both roads and railway as an introduction to the new concepts.

Requirements in drainage due to changes in climate and land use are analysed in section 5, in which the current and foreseen situations are explained along with the issues associated with these facts.

Section 6 comprises a general analysis of the sustainable drainage systems including approaches, principles, techniques, experiences, and criteria for designing and maintenance.

Finally, in section 7 a comprehensive analysis of sustainable drainage systems oriented to its application in linear infrastructures is presented. This analysis comprises different approaches such as SWOT and CAME analysis.

To facilitate and provide a synthetic analysis of existing drainage systems, an appendix has been included. This appendix collates a number of summary sheets in which all the existing information for every system has been collected (applications, design, maintenance criteria, draws, and so on). Moreover, these sheets have been used as the basis for the multi-criteria analysis.

2 INTRODUCTION

2.1 GENERAL

Drainage systems represent a number of techniques and elements which are installed in different locations with the goal of moving liquids, mainly water, from where they are not required for disposal in appropriate locations. They are crucial for the proper maintenance and performance of the transport infrastructures, ensuring security and safety, and providing an adequate level of service for users.

Historically, in the field of transport infrastructures, drainage systems have been classified into two main typologies: surface drainage elements, and underground drainage systems. This classification is mainly based on the location of the elements and on the principles of hydraulic operation. In this regard, the analysis of the drainage should be done taking into consideration both systems individually, despite the close relationship existing between them.

Other possible classification for drainage systems can be done in base of the transport infrastructure for which is designed. In this way, roads and railways represent the main linear infrastructures in which the drainage systems play a major role. A first glance of both typologies of infrastructure will lead to think that drainage systems should have in common many features. However, a deeper analysis shows some noticeable differences which should be taken into consideration in any research about drainage.

Recently, the rise of a number of ecological concerns particularly related to climate change and the sustainability of the infrastructures have made new concepts related to the concept of sustainable engineering. This is a concept that meets different approaches such as waste reduction, water management, materials management, pollution prevention, product enhancements, or environment management.

It is in this environment that the concept of Sustainable Drainage System has appeared. This is an idea that could be considered as a departure from the traditional approach to draining sites. This concept has a number of key principals to mimic natural drainage such as storing runoff and releasing it slowly, harvesting and using the rain close to where if falls or allowing water to soak into the ground infiltration (Susdrain, 2019).

First attempts of installing these systems of drainage were located in urban areas due to some particular issues related to urbanisation such as high concentration of pollution, rapid run-off, or lack of infiltration due to the existence of non-permeable pavements. However, its application to other environments is still in a preliminary stage.

This document includes an exhaustive assessment from different approaches for the sustainable drainage systems in order to detect the advantages, drawbacks, restrictions, compatibilities or applicability of this new concept of drainage.

2.2 CONCEPTS

2.2.1 Definition of sustainability

Sustainability is defined in the Oxford dictionary as

"The ability to be maintained at a certain rate or level"

and

"Avoidance of the depletion of natural resources in order to maintain an ecological balance"

In this document, **sustainability** is defined as the capacity of a system to ensure the long-term availability without negatively affecting the environment in which is located.

Drainage systems are designed for ensuring their availability in single episodes of rainfall, offering a good performance of their capacity.

2.2.2 Definition of drainage

Drainage is defined in the Oxford dictionary as

"The action or process of draining something"

and

"A system of drains"

In this document, **drainage** is defined as the set of processes and elements designed to ensure the suitable drainage of water in linear infrastructures such as roads and railways.

2.2.3 Definition of system

System is defined in the Oxford dictionary as

"A set of things working together as parts of a mechanism or an interconnecting network; a complex whole"

and

"A set of principles and procedures according to which something is done; an organized scheme or method"

In this document, **system** is defined as a set of procedures and devices, working together to ensure a common goal.

3 WATER MANAGEMENT

3.1 APPROACH

Water is one of the natural resources intimately linked to life. All human activities are linked to the use of water. This is the case of domestic, agricultural, livestock, industrial or recreational aspects.

Since ancient times, water has been a source of food and a means of transport. As water control is fundamental to human life, cities and societies grow and disappear in accordance with their successes and failures in water management. In the present time economies of countries are increasingly dependent on each other, therefore we have to look at water, a scarce and vital resource, as a planetary resource. From its importance and scarcity arises the need to plan its use.

The UN has warned that we can no longer treat our water resources as if they were inexhaustible, because it has been shown that they are not. In fact, it is enough to look at the following figures: 1.1 billion people do not have access to quality drinking water; 2.5 billion people lack proper sanitation; 3.5 million people die each year from diseases related to the consumption of contaminated water (La Información).

The progressive decrease of water has affected the supply of the population, already 20% of the population lacks necessary water, and it is expected that by 2025 this figure will increase to 30%. There are four main reasons for this lack:

- Inefficiency of its use.
- Degradation due to pollution.
- Excessive exploitation of groundwater.
- Increased demand to meet human, industrial and agricultural needs

In this regard, the study, analysis and management of water requires several disciplines that form different approaches (technical, social, environmental, economic) could solve all these issues, ensuring availability for human uses and environmental protection.

In the field of civil engineering, particularly for the transport networks, the main problems are related to the need of drainage the water from precipitation, ensuring the proper performance of the infrastructure. This approach requires, on one hand, the analysis, and study of the precipitation phenomena and the circulation of the water in the ground. On the other hand, it claims the conversion of precipitation in amount of flow, needed to design and build the adequate drainage infrastructures to ensure the level of service of the transport infrastructures.

This fact requires the engagement of two science disciplines: hydrology and hydrological engineering. Both disciplines will be developed in the following sections along with some of the most recent incorporated applications in civil engineering.

3.2 HYDROLOGY

3.2.1 Introduction

According to the dictionary, hydrology is defined as the study or the branch of science which studies the distribution, conservation, use, distribution, and circulation of water on and below the earth's surface and in the atmosphere.

Regarding the scope and application of hydrology there are three main issues which hydrology deals with:

- Measure, register and publication of data
- Analysis of data to develop and improve the fundamental theories.
- Application of these theories and data to the real problems.

In terms of the hydrologic cycle, hydrology's scope can be defined as the phase of the hydrologic cycle from the rainfall to the evaporation or return of water to the sea. The other phases are studied by other sciences such as oceanography or meteorology. Hydrology also includes in its scope water of internal origin which are part of the available hydric resources on the Earth.

Hydrology requires the support of other basic sciences such as physics, chemistry, biology, geology, fluids mechanics, maths, or statistics.

3.2.2 Hydrologic cycle

The hydrologic system describes the water circulation in the atmosphere, soil, and subsoil in different phases. It is considered a closed cycle, not having a beginning or an end. That means that to describe the cycle is possible to start in any phase, for instance the rainfall or precipitation.

Precipitation is a phenomenon in which the existing water in the atmosphere as steam condenses, passing into the liquid phase (rainfall) or into the solid phase (snow, ice). Part of this water never reaches the soil, evaporating, either through the atmosphere or from a fraction of rainfall retained in the vegetation due to a phenomenon called interception. From the water which reaches the ground, the fraction that falls on non-pervious surfaces or saturated soils, runs superficially through the streams, rivers, and oceans. On the other hand, the fraction that falls in pervious surfaces drains through the ground. Moreover, another fraction of water could be kept retained in ground depressions, which traditionally is named as depression storages. This fraction could evaporate or infiltrate depending of the permeability of the ground. Other fractions of water from precipitation could directly fall in water bodies such as lakes, reservoirs, or oceans.

The water which falls in the snow state, stays retained for a time in that state until the environment temperature makes possible its melting, from what it continues the same path that the water which falls in liquid phase, even though a little fraction could evaporate through the phenomenon of sublimation.

The infiltrated water goes through an area of the soil non-saturated before achieving the saturated area. The vegetation takes water from subsoils from both areas, evaporating in a process named evapotranspiration. The water which circulated through non-saturated soils is called subsurface flow and the water which goes through saturated soils is called underground flow. Part of both flows could join to water flows later, in spring or fountains. Other part of the subsurface flow could become an underground flow. On the other hand, the underground flow could lead to the ocean or infiltrates deeper layers through the process called percolation.

All the water which is in contact with the atmosphere, either in surface or in water bodies such as rivers, lakes or oceans, is subjected to evaporation. Due to this process, the steam is again available in the atmosphere to, subsequently, become in precipitation. All this process is shown in the following figure (Figure 1).

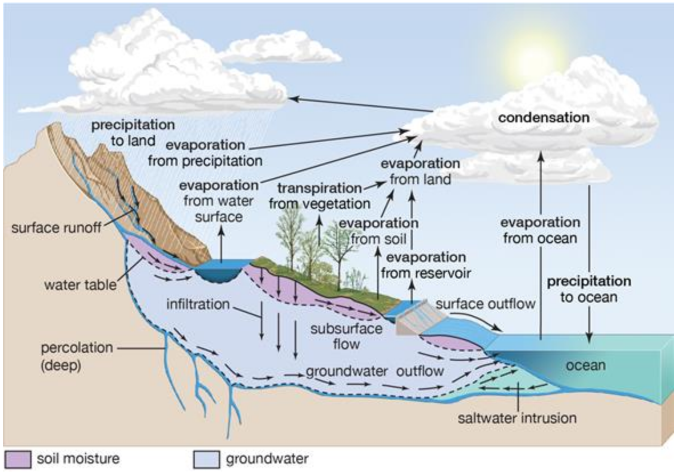


Figure 1. The hydrologic cycle (Encyclopedia Britannica, Inc., 2015)

At global scale, the amount of water in each phase of the hydrologic cycle is relatively constant. However, the analysis of a certain limited space, i.e. a basin, shows notably changes during periods not much longer. The study and analysis of these variations are one of the objectives of hydrology. In the Table 1 is collected the estimated amount of water on the Earth depending on the source and distinguishing between salty and fresh water.

Table 1. Estimation of global quantities of water (UNESCO, 1978)

	Salty water (km^3)	Fresh water (km^3)	Salt water %	Fresh water %
Oceans	1.338.000.000		96,5	
Underground fresh water		10.530.000		0,76
Underground salt water	12.870.000		0,929	
Humidity in soil		16.500		0,0012
Polar ice		24.023.500		1,73
Nonpolar ice and snow		340.600		0,0246
Fresh water lakes		91.000		0,0066
Salt water lakes	85.400		0,0062	
Reservoirs		11.470		0,0008
Rivers		2.120		0,0002
Biological water		1.120		0,0001
Atmospheric water		12.900		0,0009
Amount of salt water	1.350.955.400		97,5	
Amount of fresh water		35.029.210		2,53
Amount of water	1.385.984.610			

3.3 HYDROLOGIC ENGINEERING

Because of the study of the hydrologic cycle, it has been proven that the amount of water could vary in wide ranges, during the different stages of the cycle. This situation necessitates that hydrological engineering correct this variability in order to increase the availability of the resource.

On the one hand, water management aims to guarantee the availability of water when the user requires, such as droughts or in places where the water is a scarce resource, making reservoirs, water or irrigation channels, pipelines, or irrigation areas. On the other, water management leads to protect the catastrophic effects of floods, defining flooding areas and making drainage and protection work in both rural and urban areas.

Traditionally, water management has tackled the problem of availability of water from two different approaches: water as a resource and water as a risk, which will be analysed in the following sections.

3.3.1 Water as a resource

When the water is considered as a resource, one needs to know the amount available in the basin under study. The available sources of water can be divided into surface waters: rivers, lakes, reservoirs; and underground waters: groundwater and springs.

Main difference between both groups is the speed of movement of water. This speed can be several times higher magnitude orders in the case of surface waters. This difference keeps the water flowing much time after an event as a rain or the snowmelt since it comes from the groundwater. This fact means the groundwater could be considered as underground reservoirs.

In order to know the available amount of water in a basin, a water balance mush be calculated. This balance consists in accounting all the water inlets and outlets in the basin. The continuity and conservation equation lead to the following expression:

$$water\ inlets = water\ outlets\ \pm variatios\ in\ the\ storage$$

If, in this expression the terms are replaced for the hydrological cycle processes results in:

$$precipitation = evapotranspiration + surface\ runoff + underground\ runoff \\ \pm variations\ in\ the\ storage$$

Taking into account the above for long periods (e.g.: a year), the variations in the storage could be considered negligible, the above expression results in:

$$precipitation = evapotranspiration + surface\ runoff + underground\ runoff$$

Precipitation and evapotranspiration are almost constant processes which are extremely difficult to change in a basin, apart from modifying drastically the use of the land. As a result, the availability of water every year will be the difference between the precipitation and the evapotranspiration.

In case of extracting from the basin an amount of water equal to the average between the difference between the precipitation and the evapotranspiration, the resources are exploited.

Otherwise, if the extraction is greater than this difference, the water reserves are exploited and hence, the resources are overexploited.

Annual fluctuations could be cushioned by building reservoirs and storage facilities, or even wells for the extractions of groundwater in the case of combined (surface and groundwater) exploitation systems.

Nowadays, different simulation models are used to simulate the water processes in order to study and analyse the availability of the resource. These models can be classified into two different categories:

- Simulation models whose target is the simulation of the hydrological cycle and the analyse of availability of water during the different phases taking into account the existing exploitation systems
- Optimisation models whose target is to optimise the availability of the resource by defining different strategies in the exploitation systems.

3.3.2 Water as a risk

The consideration of water as a risk firstly deals with the estimation of the flood flows for every episode of occurrence and subsequently the design of the required hydraulic works preventing damage or drainage systems to avoid the potential material, or even human, losses.

Due to the time scale of the flood flows (hours, days); the amount of water potentially evaporated is negligible. Moreover, the speed of circulation of groundwater is so low that can be ignored. These facts lead to the following expression:

$$precipitation = surface\ runoff + losses\ in\ the\ precipitation$$

In this expression, losses in the precipitation collect the water that has not become surface runoff due to some phenomena such as evaporation, interception, storage in wetlands or infiltration as the most usual.

In order to ease the analysis of the areas where the water could represent a risk in case of floods, main prescriptions have developed a number of concepts that allow the zoning and definition of areas where certain level of precipitation could result in damage.

One of the most usual concept related to this fact, is the Preferential Flow Zone (PFZ) which are well defined in Spanish regulation for public domain of water (Gobierno de España, 1986). In this regulation, the PFZ is defined as the overlapping area where the flood flows are preferentially concentrated during a precipitation and the area where the flood flows with a return period of 100 years can cause severe damages.

In addition, in order to apply the above definition, severe damages are defined as follows:

a) Height of water will be up to 1 m
b) Speed of water will be up to 1 m/s
c) The product of height and speed will be up to 0.5 m^2/s.

Moreover, the flood flows preferentially concentrated means those flows which causes an over-elevation of the height of the water of 0.3 m over the elevation of the same flood flow taking into account the whole floodplain, 0.1 m in urban areas or 0.5 m in rural areas.

Commonly, hydrological engineering makes use of different computer tools[1] in terms of simulation software which are able to simulate the flow due to a precipitation event. The models are extremely powerful. However, the adequate use of these ones requires a large number of parameters, usually named descriptors of the basin, which determination is quite difficult. The correct choice of these parameters will be crucial for a suitable simulation and reliable determination of flood flows.

There are a large number of different computer programs, particularly developed for this purpose. Among others, it is remarkable HEC-HMS (hydrologic modelling system), developed in the Hydrological Engineering Centre of the United States Army Corps of Engineers (USACE) since it allows the simulations of most of the processes associated to the hydrological engineering.

Complementarily, other generation of computer programs allows the determination of the flood area associated to the flood flows and the height of the water for any kind of channels or riverbeds. Within this group, HEC-RAS (river analysis system), also developed by the USACE, stands out as one of the most used.

3.4 INTERNATIONAL PRESCRIPTIONS IN SUSTAINABLE WATER MANAGEMENT

3.4.1 Europe

Water management in Europe is essentially regulated by the EU Directive 2000/60/EC of the Water Framework Directive (WFD) (European Parliament and the Council , 2000). WFD is established as the need to reformulate in a single legal text the framework for the protection of continental water bodies, transition water bodies, coastal water bodies, and groundwater. Moreover, it establishes a common framework of water management in order to enhance the quality of water bodies.

In this regard, the Water Framework Directive deals with:

- Establishing a holistic approach to manage the water environment, based on river basins, integrating water quantity with quality considerations
- Establishing quality objectives for all water bodies in order to achieve good status
- Establishing a quality classification system for surface water that includes chemical, hydromorphological and ecological parameters
- Establishing a quality classification system for groundwater status and a requirement for the quality of groundwater not result in any significant damage to terrestrial ecosystems
- Establishing statutory controls in relation to pollution of water bodies from point and diffuse sources
- Preventing deterioration in the status of water bodies
- Promoting sustainable water use based on long-term protection of water resources
- Achieving environmental objectives in a cost-effective way.

Regarding flood management, the Flood Risk Management Directive (European Parliament and the Council, 2007) published in 2007, proposed a new management approach in which different stakeholders had a better collaboration between themselves and contribution from public were incorporated in the management processes.

[1] HEC-HMS, HEC-RAS, WMS, MODFLOW, SWAT.

Directive established a roadmap towards the new flood risk management. This roadmap included a preliminary assessment of flood risk by 2011, development of flood risk maps by 2013, and flood risk management plans by 2015.

3.4.2 UK

England and Wales regulate the water Management by the Flood and Water Management Act (FAWMA) (British Parliament, 2010). This Act collected in a single text the provisions from the European Water Framework (European Parliament and the Council , 2000) and the Flood Risk Management Directive (European Parliament and the Council, 2007).

FAWMA introduced a new approach in the water management in which concepts such as flood risk management or sustainability were defined. Regarding this latter, the Act established the creation of a sustainable drainage approving body (SAB). This organism promotes the use of SDS and has the responsibility for the approval of drainage systems in new developments. Moreover, the use of SDS in certain cases such as major development of more than 10 dwellings or equivalent non-residential developments will be mandatory.

At local planning level, national policy encourages the use of SDS by guidance to local authorities on what can be built where. The goal of this planning framework is to achieve multiple benefits by the use of these technologies.

3.4.3 Scotland

In Scotland, policy in terms of water management is regulated by the Water Environment and Water Services Act 2003 (WEWS) (Scottish Parliament, 2003). This Act includes the provisions for implementing the European Directives, particularly the European Water Framework Directive.

In terms of sustainable drainage systems, this Act introduces the regime of responsibilities. In this regard, Scottish Water will be the responsible for run-off from roofs and any paved ground surface within the property boundary. In addition, WEWS established the use obligatory in cases of surface water drainage from all new developments. For that, the Scottish Water's specifications in the manual 'Sewers for Scotland 3er Edition' (Scottish Water, 2015) must be applied.

Moreover, the Flood Risk Management Act published in 2009, introduced the approaches established in the Flood Risk Management Directive (European Parliament and the Council, 2007). Some of the novelties of this Act are a new framework for coordination and cooperation between organisations involved in flood management or new methods to enable stakeholders and the public to contribute to manage flood risk.

3.4.4 Germany

German planning for water management is based on measures to reduce the impact of the loss of permeability in the soils through the imposition of limits in the construction activities and the obligation of reserve some parts of the land to drainage facilities.

The German Edification Code establishes in its article 9 the structure of the roads, vegetation on both sides of the roads, and the adoption of ecological designs to foster the storm water retention uses.

3.4.5 Netherlands

The policy in storm water management has four main pillars: the prevention of the pollution in the storm water by arrangements of control at source, the collection, and storage of storm water, the deployment of separating networks of drainage and the equilibrium of all these considerations at a local level.

The Dutch law in matter of waters establishes the obligation at a local level to apply an efficient collection and efficiency treatment of the run-off. This treatment includes at least: storage, conveyance, effective use, or discharge, before or after the treatment, in the soil or in the surface water, together with its conveyance to a treatment plant.

On the other side, following the Law of Environmental Management (Netherlands Government, 2002), local council can apply specific rules about the discharge of storm water. For instance, the City Council could force to the landowner apply water management techniques regarding the storm water of its property, providing a deadline to disconnect this water from the sewerage network. Moreover, according to this Law, City Councils must develop a local sewerage plan in which the procedures to collect and manage the water from run-off are included. However, alternatives solutions are allowed if they get the same result.

3.4.6 France

In France, the approval of acts *Grenelle I* and *Grenelle II* introduced the concept of sustainability in the economic development of the country (Benoit, 2012). For the land management and sustainable development, these laws deal with the prevention of natural risks, energy management, energy efficiency, and reduction of emissions.

Complementary, in terms of water, these regulations consider financial and tax actions, such as an annual tax for the storm water management. On the other side, the Water Act and water environment Act of 2006 allow the City Councils to establish a local tax for the management of storm water (0,20 €/m2). In addition, this regulation allowed a credit line to finance recuperation of storm water and their domestic use as watering or washing.

3.4.7 Spain

Spanish regulations in matter of water management is mainly regulated through the Spanish Water Act TRL 1/2001 (Gobierno de España, 2001) which collects the regulations of the use of water, establishing basic standards for the protection of inland, coastal and transitional waters and the state competence in water planning. This regulation included the precepts developed in the Water Framework Directive 2000/60 (European Parliament and the Council , 2000).

According to this regulation, a number of different planning such as the Spanish National Hydrological Plan was developed. This plan was approved in the Spanish Law 10/2001 (Gobierno de España, 2001) and bring about important measures such as the promotion of new technologies in water management like desalination or water reuse. Moreover, it has boosted the renovation of some existing prescriptions in order to encourage the use of best practices to limit the contribution of rainwater to collectors.

Regarding sustainable systems, the approval of the RD 638/2016 that modifies Public Water Domain Prescription 849/1986 introduced and promoted the concept of sustainability in drainage actions, by the introduction of the following paragraph into its articulates:

"New developments, industrial estates and urban developments in general, must introduce sustainable drainage systems, such as permeable surfaces, so that any increase in the risk of flooding is mitigated. To this end, the urban development file must include a hydrological-hydraulic study that justifies it".

Moreover, some regional and local prescriptions in terms of the use of sustainable systems can be found. In this regard, Madrid City Council, the publication of the new "Ordinances for the efficient use of water" and the manual of "Best Practices in Architecture and Urbanism", or Barcelona City Council with its recommendations for the implementation of sustainable systems in the Special Sewage Plan Barcelona, represent the best examples of regulation and promotion of these technologies at local level.

3.4.8 USA and Australia

In the United States, as in many other places, water management legislation includes different issues such as drainage or flood management for many years.

However, in the 1970s, the problem of diffuse pollution was recognized, and in 1987, this problem was reflected in the Clean Water Act (CWA) (United States Congress, 1987).which led to specific action programs to solve this problem.

The progressive awareness during the last two decades of the need to improve water quality led to the emergence of the concept of Best Management Practices (BMPs). Since the development of BMPs, several states and local governments have adopted a large number of laws, regulations, and ordinances to promote them or force their use. A similar process took place in Australia in the late 1990s, with its own regulations, legislation and design manuals.

3.4.9 Colombia

Constitution of Colombia recognises in its article 80, the use and management of natural resources under the principles of sustainable development, protection, or restoration. This fact is reflected in the different decrees and laws which developed this article. In terms of water management, different laws establish the framework of management at the different levels under the above principles.

At city level, it is possible to find some relevant decrees in which the promotion of sustainable drainage system is included. For instance, the water regulations of Bogotá establishes the development of a Sustainable Rainfall Drainage system with a number of general objectives such as reduce the flood events, recovery the capacity of infiltration, improve the quality of water or increase the number of green spaces. All these objectives match with the SDS principles which are defined in the same regulation.

Good examples of the application of this regulation can be found in different urban planning such as POZ Norte (see section 6.4.2).

4 TRADITIONAL DRAINAGE SYSTEMS IN LINEAR INFRASTRUCTURES

4.1 INTRODUCTION

This chapter comprises the definition of the main conventional drainage systems used in linear infrastructure both roads and railway lines. These elements are considered crucial for the good performance of the transport system, ensuring an adequate level of service and safety.

The assessment and analysis of the drainage can be divided into:

- Surface Drainage, refers to the water flowing on the surface, both from the road/railway and from the adjacent areas.
- Groundwater Drainage refers to the flow of groundwater.

4.2 SURFACE DRAINAGE SYSTEMS

4.2.1 Introduction

Surface drainage comprises a set of different elements which can be clustered between themselves to form a complete network. Regardless the type of element, the general approach of surface drainage has a number of common objectives, among which the following stand out:

a) The collection of water (rain or thaw) from the platform and its margins, through channels, ditches and their drains.
b) The evacuation of collected water, possibly through manholes and longitudinal collectors, to natural channels, to sewerage systems or to the water table, either directly or through transverse drainage works or open-cast or buried pipes.
c) Restoration of the continuity of the natural channels intercepted by the road, by means of their possible conditioning and the construction of transversal drainage works.

Therefore, regarding the surface drainage, three main aspects of design are of interest:

- Rapid evacuation of water falling on the roadway or flowing from the environment
- Clearance of rivers and watercourses
- Restoration of intercepted courses

To solve this problem, two phases are required:

1. Determine the flow of water to be considered for the design: Hydrology.
2. Design the drainage element to drain water: Hydraulics.

The Hydrology determines the flow to be drained by a surface drainage element, while the Hydraulic aims to design these elements in such a way that there is no damage or harm to traffic, adjacent areas, or people.

4.2.2 Classification

Minor surface drainage system elements operation mode is based on conveying surface run-off and subsurface moisture away from the pavement. During their normal operation must be ensured that it does not impinge on the users or close areas. Usually drainage systems consist of a number of discrete interconnected elements such as:

- Kerbs
- Channels
- Pits and inlets
- Underground pipe networks
- Surface channels (cut-off drains, table drains)
- Retention, detention, sedimentation, or infiltration facilities.

On the other hand, major drainage system elements are only used when the capacity of the minor drainage system is exceeded. This implies that when the major system is called into use, there will be some disruption to the level of service provided by the road and to the adjacent communities. Among others, it is remarkable:

- Roadways
- Designated surface channels
- Some retention and detention facilities

The following section includes a more detailed definition of some of the most relevant surface drainage elements.

4.2.2.1 Table drains

Table drains are surface drainage elements which are usually located along the outer edge of shoulder in cuts, and besides roads or streets. They collect water from the pavement, shoulders, and cuts batter and convey it to a suitable turnout, watercourse, or culvert.

Base of table drains will be installed at least 150 mm below the bottom of the pavement to protect the structural stability of the pavement composition. Where subsurface drains discharge into a table drain, the base depth should be deep enough to allow the subsurface water to drain away. Depth of the drain will also depend on the design capacity required to drain the design stormwater flow. Some prescriptions (e.g.: Spanish IC-5.2 Drainage Instructions for Roads) establish the requirement of a minimum distance of 5 cm between the maximum water level in table drains or culverts and the pavement.

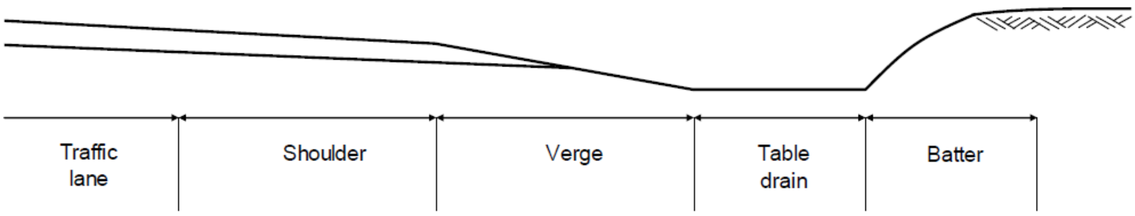


Figure 2. Section of table drain

In cases of constructing table drains as a source of borrow material, it is needed to take into account that the water cannot be ponded in order to avoid damages to road formation. To solve these issues, a more restrictive depth between road pavement and base of the table drain will be established.

In longitudinal profile, the minimum slope is 0.5%. Slope more than 1% might need scour protection such as a concrete or vegetative coverage.

4.2.2.2 Kerbs

Kerbs or curbs are particular cases of table drains usually installed in streets, urban roads, or bridges where the lack of space or the existing buildings can result in issues for the installation of other drainage linear systems.

Their use is highly suggested in cases where:

- Limit the width of cut to the available right-of-way
- Restrict the amount of cut in order to balance earthwork quantities
- Protect the formation against scour on steep grades

The use of concrete or asphalt concrete kerbs at the edge of roads and embankments is also common, particularly in cases where the material of embankment could be easily eroded by flow off the pavement or if, for a property protection it is necessary to restrict run-off to particular locations.

Kerbs can be different configuration in function of the hydraulic profile and their position to the road. In this regard, national prescriptions present different designs for every country. For instance, Figure 3 shows the common profiles according to the Australian drainage for road prescriptions.

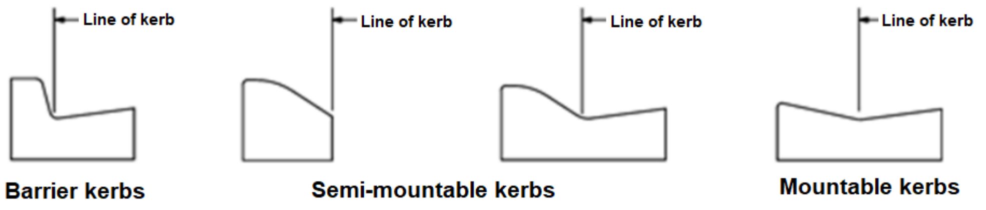


Figure 3 Some usual kerb profiles or sections (Queensland Government. Deparment of Main Roads, 2009)

One of the most important considerations at the time of designing this type of drainage element is the fact that kerbs must be connected to drainage inlets that convey the run-off to other drainage elements such as pipes or culverts avoiding the appearance of puddles in lanes or shoulders.

4.2.2.3 Gutters or side ditches

Gutter or side ditches are linear and surface elements with a shape of continuous trench which objective is to convey the water as a channel in laminar regimen. Gutters are installed at both sides of roads and streets next to the shoulders. They collect road water and lead it onward to outlet ditches. This fact is especially important when road is in cut otherwise if the road is on a high embankment, side ditches are not always necessary and their need has to be evaluated case by case.

Different typologies of gutter can be found in roads and streets. Main classifications are related to the possibility or not, to be lined. Depending on the geometry, sections can be distinguished between triangular or trapezoidal.

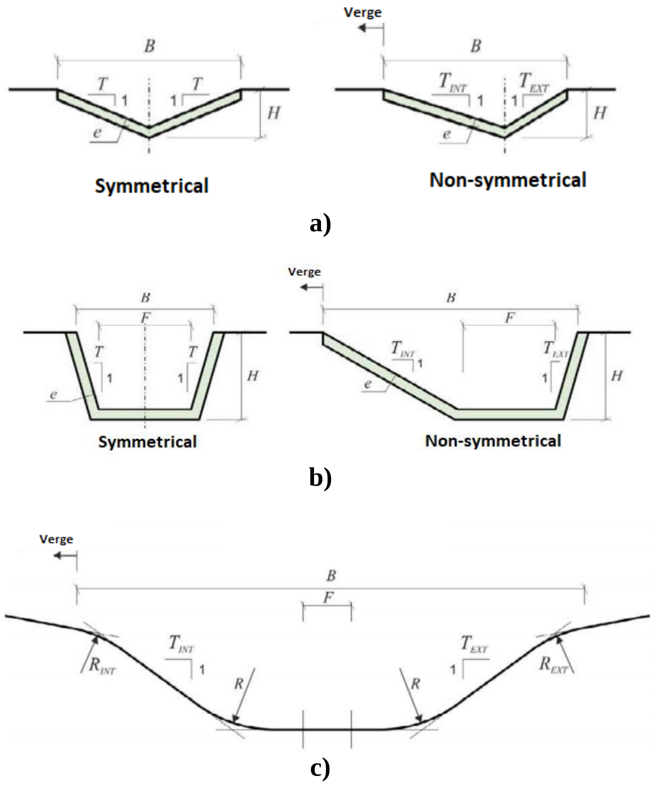


Figure 4. Some types of side ditches: a) triangular ditch; b) trapezoidal ditch; c) non-lined ditch

The lining in gutter is highly suggested in some specific cases such as:

- Water speed in the side ditch exceeds the maximum permissible velocity for this type of drainage element according the national prescriptions.
- Longitudinal slope exceeds 3%
- Longitudinal slope lower than 1%
- Additional protection for aquifers and underground water will be required.

Moreover, the installation of energy dissipation devices in gutters is suggested in cases where the longitudinal slopes will exceed 7% in order to avoid scour. These structures can be tackled from different approaches such as techniques for increase the roughness or the construction of rungs along the side ditch.

The use of non-lined ditch covered by grass is widely applied in some areas of Northern and Central Europe. In this case, it is needed to take into consideration some specific issues regarding the annual average of rainfall and possibility of scour. Generally, this typology is suggested for annual average of rainfall higher than 600 mm and longitudinal slopes lower than 4%.

4.2.2.4 Batter drains or chutes

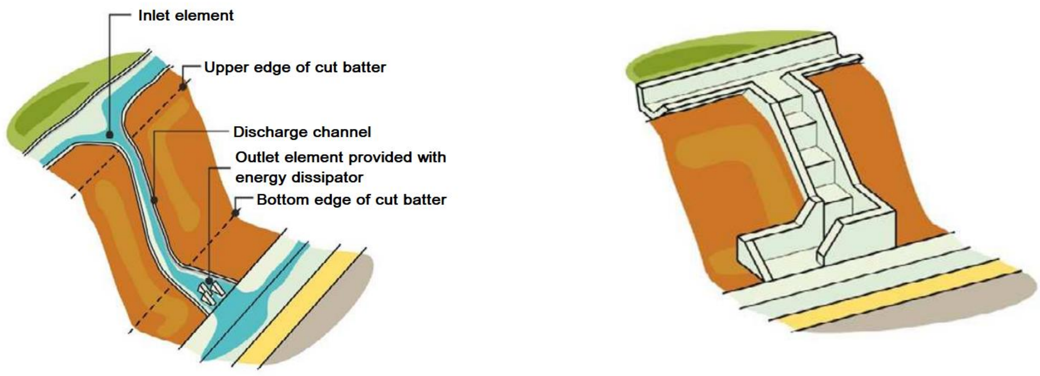
Batter drains or chutes are linear and surface drainage element, located in the cut batter (slope of the walls) besides of the roads or in the walls of the embankments to convey smalls flows directly down, in different water regimes.

Batter drains collect the water from catch drains, in case of cuts or the water from the road platform in case of roads and convey to a major drainage element such as gutters, culverts, or pipes.

Geometrically, batter drains consist of a lined channel which collects water in certain points from catch drains, table drains or directly from watersheds, to convey the water into low levels where it is possible to install an energy dissipator.

Three main parts can be distinguished in a cutter drain:

- Inlet element, which must be located above the edge of cut batter and with geometry shape which allows the collection of run-off or water from other drainage element.
- Discharge channel, located in the maximum steep line and have the required elements to avoid the loss of water
- Outlet element, to evacuate the water into a major drainage element such as natural channel, concrete pit or to an underground system. Usually, some form of energy dissipation and scour protection will be required.



a)

b)

Figure 3. Examples of different typologies of cutter drains: a) lined batter drain; b) batter drain with energy dissipators in the channel (Ministerio de Fomento, 2016)

Regarding the typologies, two main systems are found in the construction works: open batter drains and piped chutes. For open batter drains, any necessary changes of direction must be achieved before the water reaches critical velocity if overshooting and scouring want to be avoided.

On the other hand, although pipes chutes are more expensive than open ones, the former are not susceptible to be overtopped and scoured, and do not constitute an obstacle within the clear zone. Some specific materials are used to install pipes chutes such as polyethylene because of their good properties in terms of abrasion resistance.

4.2.2.5 Catch drains

Catch drains, also known as cut-off drains, are a type of surface drainage in which the run-off from the top of cut batter are collected before it falls, preventing batter from damage, erosion or scouring.

The location of catch drains is on the top of the cut batter at 1or 2 meter from the edge in a way that allows the collection of the water from run-off.

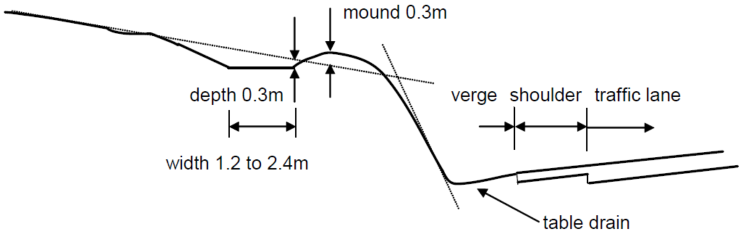


Figure 5. Section of catch drains

Catch drains are particularly suggested in the construction of any cut batter excepting some specific cases. These cases, in which the catch drains are not needed, are presented in some national prescriptions as, once more, the Spanish normative '5.2-IC Drainage Instructions for Roads' (Ministerio de Fomento, 2016). Some of these exceptions are:

- Slope in the natural ground in opposite direction to the slope.
- Small size of the hydraulic basin or small damage of run-off.
- Reduced dimensions of cut batter or favourable lithological features.

Generally, the construction of catch drains is done before the excavation of the cuts. Moreover, the longitudinal profile should be carefully levelled in order to avoid low points, or in case that these points will unavoidable, to install batter drains to convey water to culverts or gutters.

Slopes can be moderately steep in catch drains what results in high speed of the water flows. This fact leads to raise the issue of installing energy dissipators to avoid major damages in the drainage system. Moreover, it is possible to deal with the possibility of installing energy dissipators in the drainage points, such as at the end of the batter drains, as is said in the previous section.

Drainage point of catch drain can be designed to pour the water into a:

- Gutter
- Natural watercourse
- Culverts
- Batter drain

4.2.2.6 Drainage inlets

Drainage inlets are drainage elements which are designed to collect water flows from run-off from the road platform, pavement, or from other drainage element such as a side ditch or table drains, to convey and pour into drainage pits.

Different types of drainage inlets can be designed depending on their relative location regarding the water flow or the operation mode. In this way, according to its location a possible classification will distinguish between continuous or isolated inlets. On the other hand, according to performance criteria it is possible identify continuous inlets or isolated ones.

Moreover, this type of drainage element could be built on site or be built by the use of prefab elements made of concrete, metal, polymers, or ceramics.

As said before, location of inlets is closely related to ensure a suitable drainage of flows from platforms and pavements. From a hydraulics approach, the more adequate configuration is the longitudinal inlet in which the water from gutter or table drains is collected. In this configuration, the most usual location is in both sides of the platform.

4.2.2.7 Drainage pits

Drainage pits are drainage elements which connect pipes and surface drainage element such as gutters or inlets, guaranteeing the adequate connection between these element avoiding losses. This fact allows the connection of different element in a continuous mesh or network of drainage.

Regarding the material of construction, this type of drainage element is usually made of concrete, metal, polymers, or combinations of these materials. About the operation mode, the inputs of water in pits are normally in form of pouring to, subsequently, conveyance the water flow to the drainage pipes or culverts in laminar regimen.

Location of drainage pits will depend on the geometry of the drainage pipes or culverts at which are connected.

4.2.2.8 Drainage pipes

Drainage pipes are linear drainage elements, in which the regimen of water flow is laminar. Although, drainage pipes are generally underground, they are considered surface drainage elements since they are directly connected to surface drainage elements and the operation mode.

As drainage pits, drainage pipes are usually compound of prefab pipes made of concrete, metal, polymers, or combinations of these materials, with special joints which allow some relative movement between pieces.

Drainage pipes can be installed in different places, usually in both sides of the road in trenches between drainage pits. Moreover, sometimes they are installed crosswise in order to drain water from one side to another one. Slopes will vary between 0,5% to 4% in order to ease the flow, with a maximum distance between inlets or pits according to the need of maintenance and inspection.

Regarding the final point of drainage, drainage pipes could be connected to different elements such as:

- A culvert
- Other major drainage elements such as retention basins or wetlands
- Connection to a urban drainage network

The use of drainage pipes is mainly focused on the collection and conveyance of the run-off from the platform and other drainage elements under the road due to a lack of capacity in the rest of drainage systems or the need of crossing the road. Previously, water flows must be collected by drainage pits or drainage inlets.

4.2.2.9 Culverts

Cross drainage in linear infrastructure is solved by means of large diameter pipes or box culverts, collectively known as culverts. The purpose of culverts is to prevent flooding, to minimize erosion, and to provide pathways for a run-off, so culverts are located under roadway or railway.

Materials for culvert construction are usually based on the materials such as steel, concrete, or polyethylene which improves the quality of it.

As to the design and construction, culverts should be design correctly for water flows that includes the most unfavourable event of rainfall in a period of return which will depend on the national prescription to apply. They must be located at the most favourable point to drain, allowing water, and wildlife to travel without interruptions avoiding the interruption of natural flow upstream.

4.3 UNDERGROUND DRAINAGE SYSTEMS

4.3.1 Introduction

The humidity of the formation layers of a road or a railway is one of the factors that influences the most its structural behaviour. An increase in pavement level normally leads to a significant reduction in its bearing capacity and may give rise to physical and chemical phenomena (collapse, expansiveness, dissolution, and so on) detrimental to its behaviour and to the durability of the platform as a whole.

In case of increases in the water content of the pavement layers, a reduction in the capacity of the substrate and an increase in the degree of deterioration appear. Moreover, dynamic actions by traffic loads cause abrupt loss of cohesion in saturated layers in case of the absence of movement of water between pores or fine when there is a possibility of interstitial movement of water.

The only solution is the installation of a good underground drainage system. Following section includes the definition of the most relevant underground drainage system installed both roads and railways.

4.3.2 Classification

4.3.2.1 Draining ditches

Draining ditches are ditches filling with granular materials such as gravel or coarse sand, lined with a geotextile, and isolated from the surface waters. They are devices especially designed to collect and conveyance water from critical areas of the road to other major draining elements.

The goal of draining ditches is to protect the different layers of pavement, base, and subbase from the horizontal infiltration, by conveyance the water which could have be infiltrated, and to decline the level of the water table and to drain slopes and earthworks on general.

The operation mode of these devices is based on the movement of water through the ditch on its lateral walls. Water infiltrates through the filling materials to the bottom and drain on it or in the draining pipe.

In case of installation of draining ditches to decline the level of water table, main prescriptions suggest the performance of a previous geological study in which a number of tests should be determined in order to know the permeability rates of existing soils.

Different types of draining ditches can be identified. Main difference between themselves are the presence or not of a draining tube on the bottom of the ditch. If pipes are not installed, the bottom of the ditch is totally filled with granular material. These materials should comply a number of restrictions in terms of permeability and voids in order to ensure a good permeability rate which allows the infiltration and movement of water.

Draining ditches can drain water in other draining elements such as wells or sewers, or in other cases, drain directly to the bed of a stream or a river.

4.3.2.2 Drainage walls

Drainage walls and drainage sheets are deep ditches with a width no higher than 25 cm, usually installed on the edge of the pavement or base and subbase, including a geotextile and a draining core. These types of elements habitually drain into a sewer.

Main types of drainage walls include two typologies:

- In situ, in which the draining core is compound of granular material such as gravel or coarse sand.
- Prefab, in which the draining core is built in an industrial process.

Location of drainage wall is habitually on one side of the road or the way. However, they can be also installed close to the pavement layers. In this case, the waterproofing should be especially considered and ensured.

Maintenance requirements of drainage walls are quite strict, higher than other similar systems. The construction project should justify the use of these elements, including characteristics and location, and justifying the choice of this element. Moreover, cleaning and maintenance task should be included.

A draining pipe is installed at the bottom of the wall in order to collect water from draining core. The diameter should be higher than 100 mm, ensuring the correct drain of infiltration.

4.3.2.1 Draining pipes

Draining pipes are perforated pipes, surrounded by a filling draining material such as gravel or coarse sand or geotextile.

The goal of this element is the collection of water from the water table or infiltration and conveyance to another drainage element.

Pipes are designed with a minimum diameter of 150 mm taken into account maintenance and cleaning tasks.

4.3.2.2 Horizontal drains

Horizontal drains are long perforated pipes which are installed in slopes, fillings, or earthworks in general in order to drain the groundwater.

These types of elements are usually installed in a horizontal position, made of PVC, with diameter around from 30 to 50 mm, an inclination of approximately 5/10º with respect to the horizontal to allow the drainage of the tubes. In galleries or other uses, other inclinations are arranged, even vertically.

The aim is to decrease the water table or drain the slope in order to reduce the interstitial pressures that are presence on the surface slip potentials. This fact leads to an increase in the resistance of the terrain and in a reduction in the weight of the slope.

Water collected from horizontal drains should be adequate conveyance, to not affect slopes or pavements, by other drainage elements such as gutters or table drains.

4.3.2.3 Herringbone drains

In case of installation of a network of drains, or draining ditches, the most habitual design is the herringbone drain. This is a kind of design, in which a number of pipes are connected in a tree structure to a central main central pipe.

This solution is widely applied in large areas where different needs of draining. Moreover, its construction requirements, herringbone drains does not require as much depth for excavated drains compared to other option, make this system more popular than other which demand more sophisticated construction processes.

4.3.2.4 Sewers

Sewers are large buried pipes which are connected to other drainage elements such as wells or draining pipes. This type of element is not specific for transport infrastructure but also is frequently found in the drainage network of cities, industrial areas, or wherever large water flows to drain is required.

Sewers are elements specifically designed to conveyance large amount of water to a drain point such as a bed of a river or stream, the sea, or to a sewage treatment plant.

When the possible filtrations from the collector could affect materials susceptible to water, the project will define complementary prescriptions to guarantee their water tightness in some way such as sealing of joints, limed tubes and so on.

4.3.2.5 Waterproof sheets

Sometimes, it is necessary to avoid the infiltration of water in certain areas of fillings or natural soils, in which the presence of water could be result in failures or landslides. To do that, the use of synthetic waterproof sheets is a usual solution.

This type of sheets must carry out a number of chemical and mechanics requirements related to durability, stability, permeability, and strength in order to ensure a good performance during its service life. Nacional prescriptions include thresholds and values to comply with these requirements.

In the project location, construction and overlapping details should be included to ensure the waterproof of the area of installation.

4.3.2.6 Filter and draining materials

Filter more frequently used are the local fillings and geotextiles. Both elements should comply the requirements demanded in the different prescriptions in order to satisfy the rate of permeability, voids, and durability.

Between local fillings, gravel, or coarse arena are the materials habitually included in the drainage projects. Complementary, additional prescriptions can be demanded, especially for geotextile, in order to avoid issues such as impact strength or clogging.

4.3.2.7 Drainage galleries

Drainage galleries are horizontal or almost horizontal galleries, excavated in the natural ground which include collection and drain elements.

The objective of drainage galleries is to improve the stabilisation of cuts and natural slopes, by draining the ground water, decline the level of water table and decrease the interstitial pressures in soils.

The project must define, according to the geological and geotechnical characteristics of the slope, sections, layout, support system, and construction process.

Depending on the characteristics of soils, the wall of galleries could be required different types of support and classing where appropriate with the enough permeability rates. In order to achieve the adequate permeability different possibilities can be considered such as hollow, discontinuities, or perforation in the walls to allow the flow the water into the gallery. To drain the water different drainage elements are installed such as horizontal drains.

Inspection of drainage galleries is mandatory and in order to allow it, geometry, dimensions and pedestrian access should be considered in the design. A concrete slab, with certain slope, will be built at the bottom of the gallery in order to allow the passing of inspector and facilitates the drain of water.

The access to the drainage galleries will be closed by a door or a fence in order to avoid intrusions of animals or vandals.

4.3.2.8 Wells

Wells are vertical boreholes, whether lined or not, designed to reduce the level of water table either by draining or by pumping.

They are infrequent drainage elements, which require a good prior knowledge of the hydrogeology of the area, particularly drainage conditions, permeability of soils, geotechnics and so on.

Drainage wells must be designed in such a way that they prevent the flow of water towards the element to be protected. The depth, separation, diameter, and flow in them will depend on the hydrogeological characteristics of the area to be drained. To ensure a good design, a number of previous tests should be carried out whenever possible. In case of as a contrast of hypotheses, or when the performance of such tests is, not feasible, theoretical formulas should be used.

If dimensions make it possible, the possibility of inspection of wells should be taken into consideration. In this case, the bottom of the well will include a concrete slab of 50 cm of thickness. Moreover, connection with other drainage elements such as other wells, pipes, or drainage galleries should be reinforced with concrete.

Regarding the line, wells are usually lined with perforated pipes, filling the gap between the soil and the pipe with granular material such as gravel.

In order to improve the drain, the connection between other wells or other elements such as drainage galleries can be defined in the project.

5 NEW PARADIGM IN THE DRAINAGE APPROACH

5.1 INTRODUCTION

The current paradigm of drainage and water management infrastructure is clearly unsustainable due to several factors. The ongoing situation is characterised for the breakage of the natural water cycle intercepted by different infrastructures such as roads or railways including urbanised areas, lack of connection between water basins and high impervious surfaces. All these facts reduce dramatically the groundwater recharge and increase the level of run-off, unsustainable use of water resources or low underground conveyance drainage of storm water providing marginal protection against flooding (Novotny, 2008).

All these facts together with the climate change, lead to the need of propose a new paradigm in the traditional drainage approach in which the current principles will be updated with data from the new regimen of rainfall or changes in the land uses. Complementary, a number of issues such as social, economic, or environmental matters should be integrated in the process of decision.

5.1 DISCUSSION

In the specific case of transport infrastructures, it is needed to analyse other considerations that take into account the special features of these types of infrastructures such as lifespan, investment, costs of maintenance, vulnerability, or criticality. Among others, it is highlighted that:

- Existing drainage systems are designed to deal with the weather conditions for a specific area. This fact, in an environment where the weather conditions are changing, and generally becoming more extreme, due to the climate change, could result in drainage systems which are designed for the past climate conditions but not for the current situation or future situations.

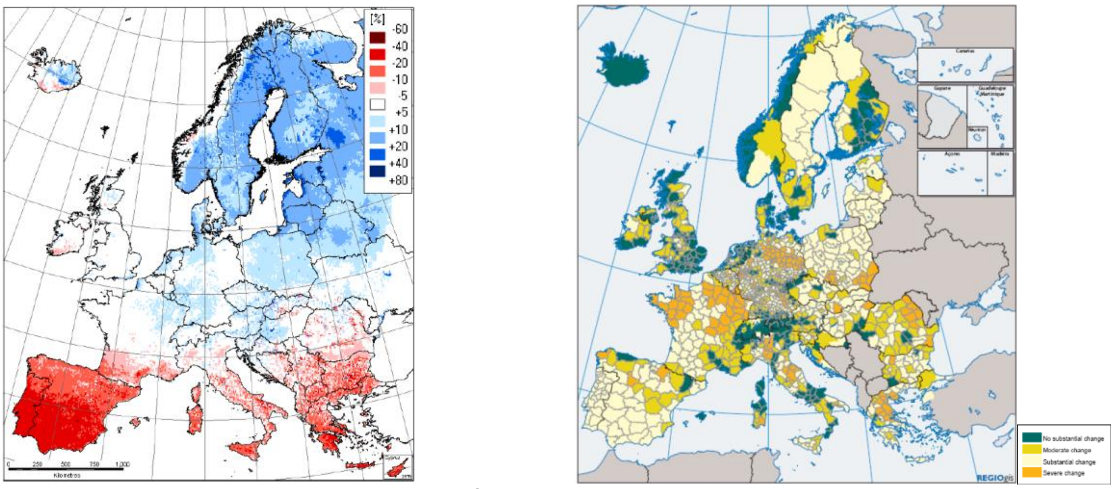
- Increase in the traffic, population, urbanisation of large areas, affect the number of events causing damages, more people will be affected and are vulnerable to natural phenomena, such as heavy rainfall events, storms, floods, etc. Urbanisation is also a major issue as the drainage system might have been built for areas in which the impervious surface areas were fewer and smaller than nowadays.

In particular, the extreme weather events which are expected to increase in number and intensity in Europe because of climate change are droughts and heat waves, especially in the south of Europe, storms, extreme precipitation and resulting floods. Even in some areas with a decrease in average temperature, a large increase in the intensity of rainfall events is expected (IPCC, 2007).

In some of the different models, it is shown that annual mean temperature in Europe is likely to increase more than the global mean temperature. In several projected scenarios, present a range of increase in the temperature between 1º to 5ºC. This increase is not homogeneous between the regions, with large differences between the South of Europe and the countries of the North of Europe (see Figure 6).

Regarding the rainfalls, the patterns of behaviour are similar. Annual average precipitations in the northern and central Europe will increase. On the other hand, the rainfalls in southern

Europe will experience notably changes not only in decreases in the order or 30-45% (Figure 6) but also in the annual rainfall distribution, concentrating the majority of precipitation in short periods during the winter.



a) Projected changes in average yearly rainfall **b) Change in extreme temperature and precipitation**

Figure 6. Expected changes in the weather in the different regions of Europe (Directorate General for Regional Policy, 2009)

This fact will lead to redesign the concept of the existing drainage networks considering all these changes since the current systems are not resilient to large or extreme precipitation events.

In this environment, the proper term for defining this process of redesign is the concept of adaptation. This term could be defined as 'an adjustment in the natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities associated with climate change' (IPCC, 2007). The objective of adaptation is to reduce vulnerability to climate change and variability, thus decreasing the economic and social costs of climate change. Adaptation action can take the form of policies, practices, and projects (European Environment Agency, 2007).

Drainage system practices should be integrated this concept during all the different stages of their life cycle, not only in the design but also in the exploitation and maintenance, in order to increase the level of reliability against the challenges that represent the climate change.

In order to achieve this target, different techniques of Environmental Governance have been come up in different parts of the world which try to deploy a new approach in the drainage project that overcome some of the problems raised with climate change and ensure an environment-friendly framework.

These techniques, with different terminology (i.e. Best Management Practices, Sustainable Drainage Systems, Water Sensitive Design, and so on) have in common a number of principles among which are, the respect of the natural hydrological cycle, promotion of biodiversity, improvements in the air and water quality or creation of green areas.

One of the most important features of these systems is the capacity of adaptation to changeable scenarios. Because of all of them are designed based on the hypothesis of simulate the natural cycle of water, recovering the capacity of infiltration of soils, their potentialities in a scenario where the vulnerability (Figure 7) is increasingly raised due to climate change, make their use highly suggested.

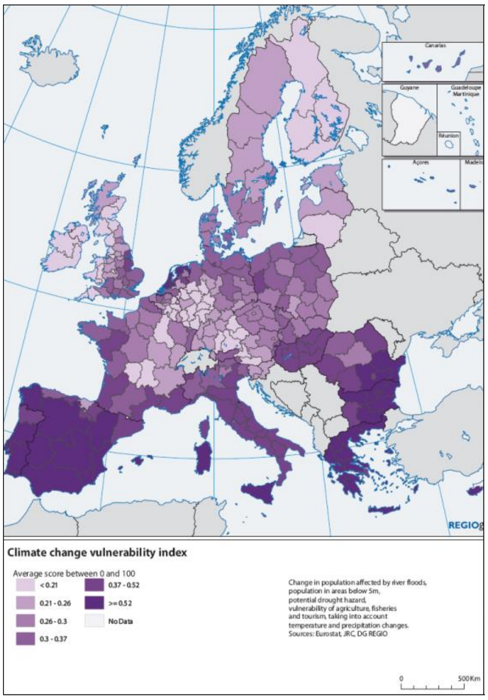


Figure 7. Climate change vulnerability index in European Regions (Directorate General for Regional Policy, 2009)

5.2 EFFECTS AND CONSIDERATIONS

Drainage solutions in linear transport infrastructures must deal with several considerations, which have strong effects on the performance of the transport system. These considerations include not only technical approaches but also economic, social and effects on the environment. All of them, along with the climate change approach should be analysed to obtain a clear vision about the needs and requirements to be met by the new drainage approach.

In economic terms, some specific issues will raise, which has been tackled to ensure the level of performance and safety. Some of the most relevant are described as follows:

- The size of current drainage infrastructures should be enlarged in order to be able to manage higher amount of water due to the irregularities in the rainfall regime because of the climate change
- An irregular and changeable regime of rainfall, with alternating droughts and floods will result in a great deterioration of large drainage infrastructures. This fact leads to an increase in the maintenance tasks.
- The increase in the events of floods will raise the damages in infrastructure which in turn, will lead to more frequently refurbishment or renewal actions.

Regarding the effects on the natural environment, the installation of traditional drainage systems has strong effects not only at the location of installation but also in the surrounding area due to a number of considerations associated to these elements. Some of the most representative effects are listed below:

- Complete fracture of the natural water cycle together with disappearance of natural purification mechanisms and infiltration in the soil.
- Increased physical, chemical and thermal pollution in natural ecosystems receiving water
- Barrier effect between habitats or biological communities.
- Increased erosion of riverbeds with loss of riverbank ecosystems and decrease in biodiversity.

Moreover, social effects should be considered. To the existing drawbacks related to the installation of conventional drainage systems, new disadvantages and restrictions will appear due to the changes in the climate and rainfall distribution. In addition, other major issues such as the lack of hydric resources should be included in these considerations.

Among others, some of the most remarkable facts which should be considered in the drainage project are:

- Lack of safety for transport infrastructures users in case of heavy rainfalls.
- Discomfort and loss of service in the infrastructures that can reach the total close of the infrastructure.
- Lack of aesthetics
- Loss of the value of rainwater that can be collected and used in other non-potable uses.

5.3 REQUIREMENTS

The new drainage approach should comply with a number of requirements in order to achieve a real transition from the current systems towards the new approach based on concepts of sustainability, efficiency, and safety.

Based on the considerations defined in the previous section, achieve the concept of sustainability will require the inclusion of a set of procedures, techniques, and systems which will give as a result a better use of natural resources and a reduction of impacts on the environment.

In terms of drainage, sustainability will require a comprehensive framework, which includes urban planning, design, operation, and maintenance. This framework should deal with some specific issues already mentioned in previous sections. This includes:

- Flood risk management
- Nonpoint source pollution control
- Improvement in the quality of water
- Mitigation of climate change effects
- Promotion of biodiversity
- Increase in the quality of life of citizens
- Increase in the level of safety

As mentioned above, sustainable drainage systems will play a major role within this new approach for drainage, not only in urban areas where they are significantly spread, but also in other fields such as the transport infrastructures.

The following sections study and go further into the analysis of the characteristics and feasibility of this bundle of techniques in its application to the transport linear infrastructures such as roads and railways.

6 SUSTAINABLE DRAINAGE SYSTEMS

6.1 INTRODUCTION

Some phenomena defined in the above section regarding the climate change such as flooding, rainfall variability, or droughts together with others such as urbanisation or water management have become in a challenge the drainage of infrastructures particularly due to their adverse impacts on precipitation extremes and the environment of urban areas. In this regard, Sustainable drainage systems (SDS) have gained growing public interests in the recent years, due to their positive effects on water quality and quantity issues and additional recreational amenities perceived, especially in urban environments.

Since the Brundtland report (1987), the Rio declaration, and Agenda 21, sustainable drainage systems have been highly promoted as an alternative and/or a complement to the conventional approach to address long-term sustainability in the design of infrastructures such as buildings or roads.

These agreements have been already included in the different national prescriptions and legal acts related to the water management. The best example of this fact is the Water Framework Directive (European Parliament and the Council , 2000) in which a new approach to water management in Europe is defined (see section 3.4).

6.2 APPROACH AND PRINCIPLES

As it is said above, different factors such as the climate change will increase the requirements of the existing drainage systems due to appearance of a new regime of precipitations with lower frequencies of rainfall but notably higher intensities. Moreover, other non-meteorological factors like urbanisation due to building and infrastructures have changed completely the natural cycle of water, declining the capacity of infiltration of the ground, increasing the level of run-off (see figure below).

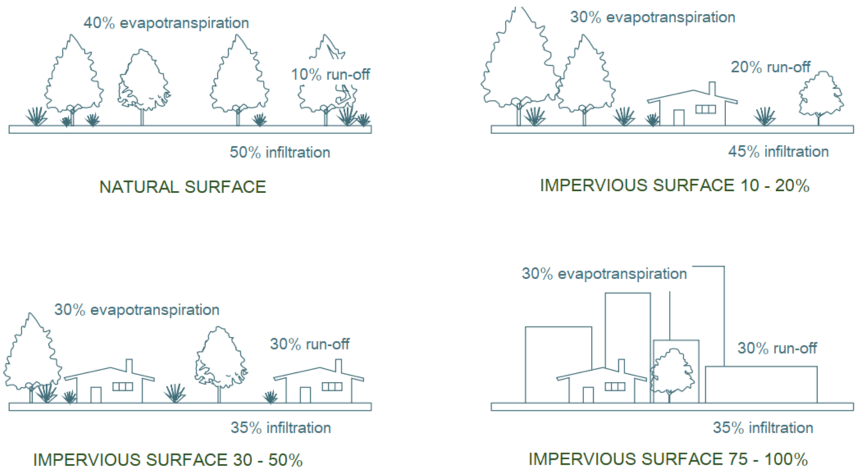


Figure 8. Changes in the water flow regarding the level of urbanisation

The clearest consequence of this fact is a high pollutant loads and an increase in the peak flows with negative impacts on the environment which are described below:

- **Flooding**: in which the conventional drainage elements are not possible because their design is based in terms of capacity. In a medium- and long-term, other approach should be considered which allow sustainable solution for the problem.
- **Non-point source pollution:** the increase of impervious surfaces leads to a loss of quality of water from run-off due to the existence of pollutants on the surface. This fact leads to the need of installing devices which recover the quality before restoring the water into the environment.
- **Loss of natural characteristics:** urbanisation and linear infrastructures, particularly in the urban areas, has made difficult the existence of natural spaces. This fact leads to a lack of recharge of aquifers, alters the natural water cycle, and generates the heat island effect.

To deal with all these issues, appears the concept of sustainable drainage systems. Sustainable drainage systems can be defined as the set of techniques that have as objective to reproduce the natural water cycle, avoiding or mitigating some of the problems defined above and providing diverse benefits related to four main categories: water quality, water quantity, amenity, and biodiversity (Woods-Ballard, y otros, 2015)

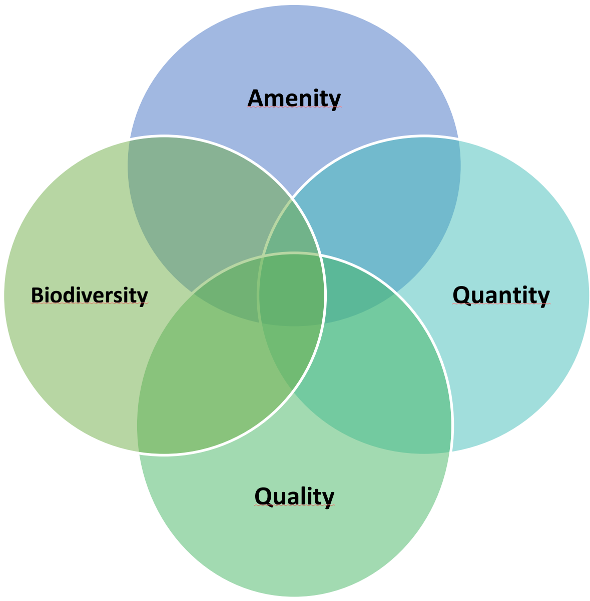


Figure 9. Sustainable drainage objectives (Woods-Ballard, y otros, 2015)

The specific purpose of SDS is to mitigate peak flow rates and reduce water pollution through infiltration, transport and retention mechanisms (Castro-Fresno D. , Andres-Valeri, Sañudo-Fontaneda, & Rodriguez-Hernandez, 2013), enabling the promotion of evapotranspiration, recharge of groundwater and reuse of storm water (Roy, y otros, 2008).

To achieve this purpose, sustainable drainage systems use a sequence of techniques that together form a management sequence. As surface water flows through the system, flow velocity is controlled, and pollutants are removed. The management train may include the following stages:

- **Source control methods** decrease the volume of water entering the drainage/river network by intercepting run-off water on roofs for subsequent re-use (e.g. for irrigation) or for storage and subsequent evapotranspiration (e.g. green roofs).

- **Pre-treatment steps**, such as vegetated swales (ditches) or filter trenches, remove pollutants from surface water prior to discharge to watercourses or aquifers.
- **Retention** systems delay the discharge of surface water to watercourses by providing storage within ponds, retention basins, and wetlands for example.
- **Infiltration systems**, such as infiltration trenches and soakaways mimic natural recharge, allowing water to soak into the ground.

6.3 TECHNIQUES

Nowadays, there are many different sustainable drainage systems which can be considered and a bundle of drainage techniques and devices with the same objective: allowing for runoff attenuation and mitigation, pollutants reduction and amenity construction. These techniques can be clustered into two main groups: structural measures and non-structural measures.

Regarding structural measures, they are related to absence of actions on the physical drainage elements. Their principles are focus on other aspects such as land-use planning, maintenance and cleaning tasks, education, or legislation.

On the other hand, structural measures are those which manage the run-off by the use of physical elements. These drainage elements should be designed to simulate the most natural water cycle as possible. At the time of decision, the pursued objectives are:

- Protection and maintenance of natural conditions
- Decline run-off
- Promote retention and infiltration
- Concatenate treatment to eliminate pollutants.

As follows, the Figure 10 shows the general classification for sustainable drainage systems according the main authors (Woods-Ballard, y otros, 2015).

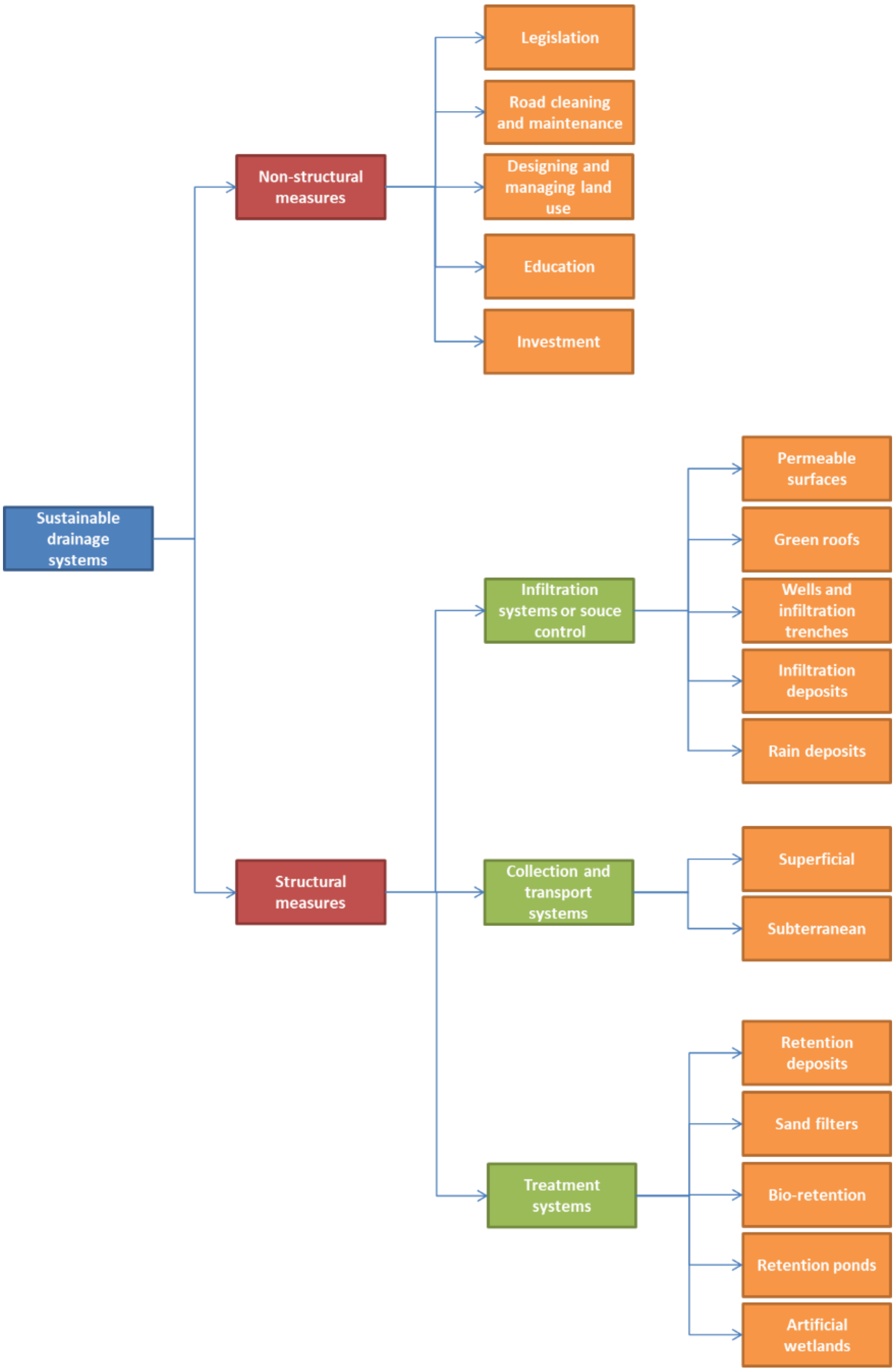


Figure 10. Classification of Sustainable Drainage Systems

6.3.1 Non-structural measures

In the field of drainage, non-structural measures are defined as decisions or planning actions that avoid the occurrence of problems associated to surface run-off by encouraging the use of sustainable drainage systems or promoting changes in the human and social behaviours. These techniques are considered non-structural measures since they do not require any works.

Although these measures could be considered less important than structural measures, the reality is both; structural and non-structural are totally complementary and must be linked in order to achieve the objectives of sustainability in the drainage field.

Within this category could be distinguished three main approaches or items: legislation, education, and investment.

6.3.1.1 Legislation

Legislation plays a crucial role in the implementation of solutions for drainage based on the concept of sustainability. Legislation could be analysed from different approaches depending of the type of action. On the first hand, legislation could be oriented to change the habits or behaviour of people and procedures in order to achieve the concept of sustainability in the use of water (intervention). On the other hand, legislation is required in terms of technical documents which encouraging and promoting the application of techniques with the adequate level of safety, quality and performance.
Regarding the legislation based on the information to the citizens and the compliment of the infractions, the intervention of public bodies are fundamental. From the legal point of view, there are, at least, five different ways of intervention in the transport infrastructures that, correctly applied, can support the implementation of sustainable drainage systems in any area (Sañudo Fontaneda, Rodriguez Hernández, & Castro Fresno, 2012).

- Regulations in environmental protection
- Preventive control
- Information
- Urban and land use planning
- Infractions

From legislation at technical level, there is still a legal void in relation to the sustainable drainage systems that prevent the application of this set of techniques. In this regard, some countries such as UK and Australia have an advantage with a number of codes that allow a complete framework of application of SDS, especially in urban areas. However, the generalisation of SDS to the rest of the transport networks is still far from being a reality and requires more efforts from the administrations, infrastructure managers, technicians, and universities.

6.3.1.2 Education and training

Regarding the education and training, it could be considered as a crucial challenge in order to reduce the diffuse pollution due to the run-off. An adequate education of the society allows the implementation of some of the new techniques and procedures along with a change in the behaviour and habits.

The citizenship should be aware of the importance of their behaviour in the correct performance of the drainage and water treatment systems. Good behaviour, mainly related to cleanliness, depends on the education and attitude of the citizens. This fact is particularly important in urban areas in which to ensure proper urban cleaning are fundamental customs such as the collection of excrement from pets, the use of litterbins for depositing any waste generated in urban traffic or not shaking domestic dust through the windows. However, good behaviour also transcends the urban sphere into the rural sphere in which the correct practices in the field of animal husbandry, agriculture, and waste management are essential to avoid phenomena related to diffuse pollution.

On the other hand, policies related to the land management and land uses are considered crucial as a non-structural measure to guarantee the good performance of the sustainable drainage techniques. A good knowledge about the soils features at a composition level and runoff level, the topography, surface and underground water streams and so on, allow a properly of distribution of the land uses depending of the features of industry, crop types, transport infrastructures or urban areas. A rational distribution of the land uses will result in a decrease in the level of runoff, and for that, in the level of pollution, allowing a better water management and use of the resources, complying the concept of sustainability.

From industry, it is crucial the role of the owners, managers, or designers of installations such as petrol stations, industrial areas, or car wrecks together with the water management administration (Sañudo Fontaneda, Rodriguez Hernández, & Castro Fresno, 2012). These installations must be equipped with hydrocarbon separators and retention basins to deal with possible accidental spills. This type of installations allows avoiding problems related to the diffuse pollution. Nevertheless, the existence of this type of measures are not enough to ensure the avoidance of the pollution but rather maintenance and control are mandatory in order to guarantee the good performance in medium-term. Moreover, there is still a large number of facts which are extremely difficult to deal with. One of the most relevant problems in the road networks is the pollution due to oil spills in roads. This represents a major problem not only at an environmental level but also at a safety level.

In the field of transport infrastructures, engineers and technicians should take into consideration in the designs a better knowledge about the hydrological processes both surface-water and groundwater, new techniques of drainage, continuity of the water cycle or inclusion of the concept of sustainability. Training the new generation of technicians and engineers in these matters and the refresher courses for experienced technicians is essential for the promotion of the new concepts that allow the transition from the traditional approaches in matter of drainage towards the concept of sustainable drainage systems.

6.3.1.3 Investment

Investment represents the third pillar of the non-structural measures. Due to its nature, drainage systems are related to the public infrastructure in this is linked to the public bodies. Different road administrations and infrastructure managers must put the required resources to implement and ease the application of the measures and techniques to achieve the concept of sustainability in the drainage systems, not only in monetary terms but also in human resources, in time and financial mechanisms.

In terms of budget, different alternatives are possible. The most direct solution is mainly based on the reserve of items of the annual public budget dedicated to the implementation of public works in terms of drainage which includes innovative solutions for drainage. These budget items could be associated to the items dedicated to Public Works or being included in specialised items dedicated to Research. However, there are other possible solutions such as the possibility of collaboration between private companies and public bodies through the public-private-partnership (PPP) in which by public contract new and innovative solutions could be tested and the financial risks of the public bodies are notably reduced, boosting innovative initiatives in this sector.

Human resources, from public administrations, private companies, and specially universities, represent other needed of investment, to ease the implementation of the concept of sustainability in the drainage systems. As it identified above, the lack of normative, regulations and technical documents are the most relevant weak points at the time of achieving the definitive implementation of this kind of solutions not only in urban areas but also in linear infrastructures such as roads and rail. To overcome this situation, technical guidelines and more research must be developed. Consequently, a numbers or technicians, researchers and professionals must be involved in the development of these technical documents that ensure the correct design and maintenance, minimising the risk and increasing the quality. Public administration at any level: national, regional and local should be involved in the process of elaboration of these technical guidelines so only with their support the implementation of this technology will result in a successfully way.

Nowadays, public bodies are using new procedures or means for boosting or pushing plans or programs. One of these new trends is by using financial mechanism in terms of reduction of taxes, tax allowances, or tax benefits. These types of mechanism could be successful in the process of implementing sustainable drainage systems not only in public infrastructures but also in residential areas, private industries, or private infrastructures, encouraging, and stimulating its use. This idea is closely linked to the fact of paying taxes for a high-quality water for uses that no requires such quality (e.g. watering, cleaning, bathrooms). Use of renewed water from SDS for those uses could result in important save of money and water resources, restricting the use of high-quality water only for human consumption.

6.3.2 Structural measures

Below is a description and general definition of each of the main sustainable drainage systems. Moreover, technical analysis and requirements can be found in the catalogue of sustainable system collected in the annex of this document.

6.3.2.1 Source control

Permeable surface

Porous or permeable pavements are surfaces that at the same time can be used by pedestrians or traffic road, allowing the water infiltration, with the possibility of recharging aquifers or being storage in other layers for its reuse or evacuation.

The void spaces of this mixture allow rain and snowmelt to pass through to a subbase of stone aggregate that both supports the asphalt layer and provides storage for and treatment of rainfall or snowmelt.

This kind of asphalt can be an ideal Best Management Practice (BMP) in the right location. Porous pavements not only reduce peak flow of run-off but also the quality of the water is improved due to the elimination of oils, metals, or solids in suspension. The decrease in the resulted run-off also increases the security in the traffic on these kinds of surfaces since porous pavements prevent the formation of puddles that reduce the adhesion.

In order to be able to manage correctly the extreme events of rainfalls that exceeds the design period return, it is needed a perimeter spillway which will be able to absorb the exceeded water and conveyance to the conventional drainage systems or to another sustainable drainage system.

(a)

(b)

Figure 11. Examples of permeable pavements: road pavement (a) and pedestrian sidewalk (b)

There are different types of porous pavements regarding the design and construction procedure. A possible classification can be done distinguishing between continuous pavements (concrete or asphalt) and non-continuous pavements such as modular elements. The former is usually applied in road pavements while the latter is widely used in pedestrian sidewalks, car parks, or parks. Moreover, other classification systems could be applied such as classification based on the type of joints between modules or in the use of grass or aggregates to ease the absorption of water.

Nowadays, the use of porous asphalt is discouraged in areas of low temperatures and frost, which can crack these systems or in pavements with high loads of traffic. One of the main research lines in the future is to extend the use of this technology to be used in any situation regardless of traffic, vehicle loads, or weather.

Technical information about permeable surface is collected in Annex 10.1.1

Soakaways and infiltration trenches

Soakways and infiltration trenches are shallow wells and trenches filled with draining material with a high rate of voids. These structures are used to pour run-off from the non-permeable surfaces. They are designed as infiltration structures able to absorb the run-off generated by the design storm and infiltrate into the subsoil.

Main difference between soakways and infiltration trenches is geometry. Infiltration trenches are narrower and less shallow than the soakways, being more efficient from a construction point of view.

The mode of operation of these systems are based on offering an additional volume of collection and pre-storage of water to the soils that makes easier the infiltration of water from surface run-off. The amount of water will depend on several factors such as the capacity of water storage of the system but fundamentally on the potential infiltration of the soils in which it is installed.

The capacity of storage could be improved by the choice of draining materials with high rate of voids or increasing the volume of the system. Increase the rate of infiltration of the soils is another possibility by adding interfaces between soils (i.e. geotextile sheets, gravel columns).

Regarding the well performance, the existence of high rate of permeability in the soil where they are installed is crucial because the only way of drainage water these systems have, is through the infiltration into the soil. Less rate of permeability in the soils will result in problems in the close foundations due to structural instabilities during the rainfall episodes.

In terms of construction and maintenance, soakaways and infiltration trenches are simple structures, with easy procedures of construction and low maintenance costs. Moreover, at hydrology level, these types of sustainable drainage systems are extremely efficient since they collaborate in the recharge of groundwater with large water flows with a minimum land occupation.

One of the benefits of the use of sustainable drainage systems is pre-treatment of the water from run-off, allowing improvements in the level of quality and in the percentage of polluting substances prior to the reincorporation of the water into the water cycle. In this regard, soakaways and infiltration trenches improve the quality of water by the filter effect at make passing the water through the permeable layers which allow the absorption of polluting particles such as aggregates, dust, metal traces... Complementary, if the retention time in the system is long enough, biological degradation could occur, contributing to the reduction of some of the polluters.

Due to their features, easy construction, low maintenance cost and land occupation, soakaways and infiltration trenches are widely applicable to any situations. These systems are especially recommended in areas with low spaces, in particular, sport installations, recreation areas, and open public spaces, collecting the run-off from impermeable areas and allowing the infiltration. However, the capacity of soakaways or infiltration trenches for larger areas could result insufficient.

There different cases of these type of sustainable drainage system that could be found in different environment. In the following pictures, it is shown some examples.


a)


b)

Figure 12. Examples of soakaway (a) and infiltration trench (b)

Technical information about soakaways and infiltration trenches is collected in Annex 10.1.1

Infiltration basins

Infiltrations basins are depressed permeable surfaces, which constitutes surface reservoirs where the water from rainfall is concentrated and storage from medium or even larger basins, until its infiltrations in the ground.

These structures are designed to collect, storage and infiltrate gradually the run-off generated on adjacent surfaces. In this manner, surface water flow is transformed in underground flow, obtaining additional benefits such as the elimination of polluters by physical and biological processes. Among these processes are, filtration, adsorption or oxidation. Infiltration basins are especially effective in the elimination of suspended solids and heavy metals.

Regarding the geometry, the shape of these systems is irregular and easy adaptable to orography of the location. Lateral slopes must not be very steep and they should be covered by vegetation.

Figure 13. Examples of large infiltration basins (Alley, Reilly, & Franke, 2013)

One of the most useful functionalities of the infiltration basins is related with their capacity of recharging groundwater or aquifers. This is remarkable in areas where the regimen of rainfall is extremely irregular and the vegetation is scarce. In these areas, most of rainfall is loss in runoff, damaging and promoting the desertification processes of the land.

The main drawback of infiltration basins is the low speed of infiltration (only some centimetres per hour). Thereby the infiltration of large amount of water requires large surface of infiltration.

Technical information about infiltration basins is collected in Annex 10.1.1

Green roofs

Green roofs are multi-layer systems in which a vegetal covered roofs and terraces of any type of buildings. They are designed to serve a set of different purposes, among them we could highlight:

- Absorption and storage of rainfall
- Filtration of pollutants
- Providing insulation
- Creation of habitat for wildlife
- Control of air temperature and heat island effects.

There are three types of green roofs:

- Extensive, with scrub vegetation which covered the most part of the roof. This type is lighter and requires low maintenance.
- Intensive, similar to a conventional garden, supports varieties of plants, but are thicker, heavier and more expensive to maintain.
- Simple intensive, in which the vegetation is compound of grass. It is the lightest type of green roof.

Figure 14. Green roof in Warsaw University Library (www.flickr.com/photos/habitatsustentable)

The mode of operation of green roofs allows a decrease in the peak and volume of run-off, the reduction of the solids in suspension. It also permits moderate reductions in the level of heavy metal transported in the drainage networks. In terms of ecology, green roofs are interesting especially due to the oxygen produced by the vegetation.

Main drawback of green roofs is related to the notably increase in the budget of the construction, particularly in the structural design, in infrastructures with this type of drainage elements. Moreover, the maintenance costs are higher than traditional systems, since design and typology must be carefully chosen. In this regard, most relevant aspects to take into consideration are:

- Saturated weight of roof-water
- Resistant structural capacity
- Moving loads due to the maintenance tasks
- Waterproof membrane
- Plant roots

Green roof is a system for rainfall drainage particularly applicable in urban environment. Its application to transport infrastructure is not widely spread, mostly due to the lack of roofs or equivalent surfaces in this kind of structures. However, green roofs could represent a sustainable solution in some specific elements of the transport network such as rail stations, terminals, logistic centres and so on, and in general extensive infrastructures which large areas of roofs that could be exploited as massive drainage elements. Moreover, collected water from rainfall by using this type of drainage elements could be intended for some specific uses in cooling systems, watering, or restrooms.

Technical information about green roofs is collected in Annex 10.1.1

6.3.2.2 Permeable conveyance systems

Filter drains

Filter drains are continuous ditches covered of a geotextile and filled with draining materials such as rubble, stone or other void-forming media, which are used to collect and conveyance the water from rainfall. Moreover, this type of drains could be compound of a drain tube embedded in the draining filler to ease the circulation of water inwardly. They could be considered a form of soakaway.

From the quality of water point of view, this type of drainage system helps to reduce the amount of polluter in water, especially suspended solids and heavy metal.

Figure 15. Filter drains in a road (www.transportscotlalnd.gov.uk)

From the applicability approach, they are particularly recommended in soils with low rate of permeability. In addition, they are applicable in case where the infiltration of water could damage the stability of close structures since ditches conveyance the run-off downstream. One of the most common applications of this type of drainage system is in the drainage of roads, located on one side of the road.

Technical information about filter drains is collected in Annex 10.1.2

Swales

Swales are linear grass covered structures which its main function is to lead surface water overland from the drained surface to storage or discharge system.

This type of drainage element consists of a shallow (slopes 1:3 or 1:4) and relatively wide ditch which provides temporary storage for storm water and reduces peak flows. They are designed to collect and treat the water with speeds lower than 1 or 2 m/s to avoid erosion and allow the deposit the suspended particles.

There are three main typologies of swales:

- Traditional, which are covered by a layer of grass and are used to conveyance water from run-off
- Dry vegetal, which are made including a permeable filter that allows the passing of all the volume of water through the bottom of the channel. These types of swales, most part of the time, are dry.
- Wet vegetal, which retain permanently the water, so it is built in places with high water table or non-permeable soils.

Regarding the location, they usually are placed close to the source of run-off. Usually, they are installed along road and residential streets to treat the run-off from non-permeable areas such as parking slots or sidewalks. Swales can constitute networks within a development linking storage ponds and wetlands.

In order to get an adequate operation, the area covered by swales must be around 10 or 20% of the total area to drain, which has to be less than 2 ha. One of the crucial requirements in its design is to avoid the erosion. For that, longitudinal slopes must be less than 4%. If the time of retention should be increased, it is possible to build little weirs along the swales, which ensure larger retention times by the lamination of the water flow. In case of be installed in areas which high level of protection due to the existence of groundwater for human uses, it is necessary to seal the bottom of the swales, avoiding the infiltration.

Figure 16. Swale in Hackney, East London (www.ecologyconsultancy.co.uk)

Among the benefits of swales, we can list the reduction of the level of run-off and the improvement in the quality of water for the retention of suspended particles and heavy metals due to the decrease in the speed of the water flow. Other important advantage is the improvement of the biodiversity, especially in urban areas, and the quality of the air due to the presence of vegetation.

Technical information about swales is collected in Annex 10.1.2

6.3.2.1 Passive treatment

Filter strips

Filter strips are surfaces covered by vegetation in which a minimum slope makes water flow slowly from the run-off. In filter strips, water is treated by several processes including physical, chemical, and biological, ensuring the filter effect due to their vegetation covering which may vary from grass to bushes or even small wood.

Geometrically, they are wide and little steeped, located between the non-permeable surface and the area which received the run-off. Recommended dimensions to be effective should be between 5 to 15 meters wide.

Figure 17. Example of filter strips (www.sudssostenible.com)

Generally, filter strips are used as pre-treatment technique before other drainage systems. In linear infrastructures such as roads, run-off from pavement could be treated by filter strips prior to be incorporated into the general drainage network avoiding the blocked by sediment or vegetation of the general system.

Technical information about filter strips is collected in Annex 10.1.3

Detention basins

Detention basins are artificial surface depressions on the ground which are used to storage a large volume of water, reducing the risks of flood by laminating the water flow. The operation mode of detention basins is the storage of water during the rainfalls episodes and a slowly release directly to the water network the stored volume of water.

There are different typologies of detention basins depending of their characteristics. A general classification for them can be established depending on their location. According to this criterion, detention basins can be divided into surface and buried.

Surface detention basins are similar to infiltration basins but with a larger depth since in the detention basins, the reduction of water flow is given by the storage of the run-off on the surface instead of the infiltration to the sub-soil as it is done in the infiltration basins.

On the other hand, buried detention basins are usually installed when there is not availability of parcels in surface or the conditions (topography, orography) making impossible the installation on the surface. The most common materials for the construction of buried detention basins are reinforced concrete or plastic materials.

Figure 18. Example of detention basins installed in a roundabout (www.ovacen.com)

In case of surface detention basins, they could be considered as storm tanks or controlled flood-prone areas. Other condition for them is the obligation to be naturalized and integrated into the environment in which they are located. Moreover, they have to be connected to the sewerage network through a bottom drain which allows a complete emptying of the basin. The bottom drain avoids overflows of the basin and allows the availability of the whole volume of storage for the following rainfalls episodes.

Among the benefits of these types of drainage elements, it is noted the increase in the sedimentation processes that reducing the pollution, the avoiding of floods and erosion process, particularly in dry climates with irregular regimes of rainfalls.

Technical information about detention basins is collected in Annex 10.1.3

Retention ponds

Retention ponds are shallow surface reservoirs with a permanent level of water (with a depth from 1.2 to 2 m). Along with this, the main feature of retention ponds is the presence of abundant aquatic vegetation both emergent and submerged.

The design of retention ponds is based on a non-permeable bottom which allow long period of retention for the run-off (2 or 3 weeks), promoting the sedimentation and nutrient absorption by the vegetation. Although the design is based on a permanent level of water, retention ponds have an additional volume for the lamination of peak flows.

The permanent level of water forces to establish a minimum of input and output of current to renew the water and avoid a loss of quality.

Figure 19. Example of retention ponds in commercial area (www.phys.org)

From an environmental approach, retention ponds are especially remarkable due to their capacity to host different natural specimens both plants and animal life, promoting the biodiversity.

The main drawbacks related to the use of the retention ponds are the conditions during the dry season which can give as a result anaerobic conditions in the water, causing discomfort and problems due to the presence of bad smells and mosquitoes.

Technical information about detention ponds is collected in Annex 10.1.3

Wetlands

Wetlands are large shallow water surfaces with abundant vegetation as lakes and swamps. The density of vegetation is higher than retention ponds what promotes a great ecologic potential, aesthetic, educational and recreational.

In wetlands, the elimination of pollution is done by a number of biological transformations, plant absorption, sedimentation processes, and adsorption.

Figure 20. Urban wetland (www.salixrw.com)

Some of the disadvantages of wetlands are closely related to the retention ponds due to the presence of standing water, although in these systems the problem of mosquitoes can be solved by the biological control including reducing their reproduction by larval fish, or installation of nest for swallows and bats that feed on them.

Moreover, other important restriction is the fact that the urban run-off cannot directly pour into natural wetlands, but they must be conveyance to artificial wetlands.

Despite these facts, wetlands could be considered ideal systems for drainage of larger non-pervious areas, allowing the concentration of the run-off in certain areas with a better use of hydraulic resources.

Technical information about wetlands is collected in Annex 10.1.3

6.4 WORLDWIDE EXPERIENCES

Currently, the techniques of sustainable drainage system are broadly suggested and applied in many parts across the world. Despite the terminology changes depending on the regions, similar design approaches are used. Some of the terms used for these types of technologies are Low Impact Development (LID), in the USA and Canada; Sustainable Urban Drainage Systems (SUDS), in the United Kingdom; Water Sensitive Urban Design (WSUD), in Australia; and Low Impact Urban Design and Development (LIUDD), in New Zealand.

6.4.1 Europe

In Europe, different systems are spread knowns as Sustainable Drainage Systems. Most of the countries have developed literature and normative (see section 3.4) in order to promote the concept of sustainability in drainage systems, particularly in the fight against the adverse effects of the climate change.

UK is the country of Europe where the sustainable drainage systems has been implemented more successfully. This fact is given by a supportive normative and documentation related to sustainable urban drainage systems which promotes and facilitates the application of these techniques. Among these regulations, it highlights the work carried out by CIRIA as the construction industry, research, and information association. As a neutral, independent, and non-profit body, CIRIA has developed the most acknowledged guidelines about sustainable drainage system entitled 'The SuDS manual' (Woods-Ballard, Kellagher, Martin, Jefferies , Bray , & Shaffer, 2007) releasing its first version in 2007. This publication has boosted the use of these systems in urban areas mainly.

Experiences in UK are numerous and diverse. These ones include examples of the application of sustainable drainage systems in many different situations and locations.

One of the best examples of a massive installation of sustainable drainage systems can be found in the Olympic Park, located in Stratford at the east of London. This place, formerly used as industrial area, offered a great opportunity to put into practice some of the sustainable drainage system defined in the SUDS manual. Due to its features, which include lowlands and swamps, the existing of polluted soils or a number of watercourses crossing the area, along with the regeneration process to be used as the main installations of the Olympic Games of 2012, this area provided a greater opportunity to incorporate sustainable drainage systems into their general urban planning.

Drainage approach included the use of traditional drainage elements such as road gullies and kerb drainage collection systems, combined with sustainable systems. Among them, it is worth mentioning the installation of a large wetland with the objective of hosting plants and animals such as otters or grey herons. The wetlands collect run-off of paved-areas by porous asphalt strips.

Moreover, swales were included within the wetland area as conveyance devices. Swales deliver run-off from high to low level and discharge into ponds and wetlands. In addition, the installation of swales included devices to reduce the velocities of flows, avoiding other issues such as erosion.

Figure 21. Example of swale installed in the Olympic Park of Stratford

Other interesting example of the use of sustainable drainage systems in UK is the case of Bridget Joyce Square in London. This was an urban area with serious problems due to a number of facts. First, the existence of two playgrounds and a school along with a road and a parking represented a hazard for children crossing the road and make school drop-off and pick-up difficult. Secondly, a sewer catchment with large problems of capacity was installed close to the area in which hydrological models revealed the high risk of flooding.

All these facts, offered a good opportunity to deploy a comprehensive scheme of sustainable drainage systems in the area in which, by using different types of SDS, create new spaces for pedestrians, reduce the risk of flood, and improve the safety levels.

The actions were mainly focused on the installation of permeable paving, raingardens, and pond basins. The final goal of the action was the restriction of the flow to below 1 l/s, retaining more amount of flow onsite for a longer period. In this regard, these results resulted in improvements in the treatment performance at quality level (pollutants), increases in the protection to the sewer, or improvement in the quality of life by the creation of leisure safety and healthy areas.

Some of the advantages achieved and measured after the installation of the sustainable drainage system comprehensive network were:

- Reduction of the flood risk
- Flow volume into the sewer reduce by 50%
- Vegetation will lead to improvements in the quality of air, particularly in reductions of NOx and PM.
- Level of safety notably increases due to the creation of new pedestrian areas.

Figures below show some of the actions carried out in Bridget Joyce Square area.

Figure 22. Summary of the actions in terms of SUDS installed in Bridget Joyce Square (London) (www.susdrain.org)

One interesting case of study, particularly for roads, is the actions in terms of drainage carried out in the junctions 2 and 3 of the M90 road, in Dunfermline (Scotland).

The area, partially covered by vegetation, will be developed as a mixture of industrial, commercial, residential, and recreational uses. Different problems arose at the time of planning, due mainly to the existence of a river in which the quality of water and hydrological regime can be affected by the changes in the land uses. Moreover, the risk of flooding can be increased due to the velocity and volume of the run-off originated by the installation of non-pervious surfaces where natural ground previously existed.

Because of the need of tackling these issues, the use of sustainable drainage systems in the area was considered mandatory. This fact led Dunfermline to be the largest site in UK in where the sustainable drainage elements have been installed.

The actions were focus on the installation of different elements of sustainable drainage. Due to the low permeability of the area, compound mainly by clay soils, the use of infiltration methods was restricted to the installation of soakaways in some residential roads. On the other hand, drainage in roads was solved by the use of kerbs, filter drains, and swales which discharge in detention basins and wetlands. Especially remarkable is the use of detention basins in roundabout taking advantage of the spaces that did not have a specific use in the performance of drainage systems.

Figure 23. Summary of the actions in terms of SDS installed in Dunfermline (www.susdrain.org)

The main benefit of the use of sustainable drainage system in this case was related to the high costs of the installation of conventional drainage systems due to the size of area to drain. The use of traditional drainage system would entail the installation of a network of drain elements along long pipes with more than 5 km. to discharge the run-off into the Forth River. The use of SDS has represented a cheap solution together with all the advantages related to the use of these elements such as decline the impacts on the environ, promotion of the biodiversity, improvement in the water quality and creation of new leisure areas for citizens.

Apart from UK, there are other interesting examples in Europe of the use of sustainable drainage system in different environments. Among these examples, some of the best practices are found in the Scandinavian Countries.

In Malmoe, Sweden, the project Eco-city Augustenborg had as objective the gentrification of a run-down neighbourhood by using sustainable design and active community involvement.

In the field of rainwater management, the neighbourhood located in lowland and marshland area presented some typical problems of these types of areas: high risk of flooding, presence of clay soil which prevent infiltration, or potential risk of damage by run-off.

The action comprised the combined installation of green roofs, swales, ponds, basins, and permeable pavements. Different systems are structured in several stages, ensuring a comprehensive treatment of water, reducing risk of flooding and damages due to run-off.

a) Infiltration swales

b) Pond located downstream swales

Figure 24. Examples of some of the SDS techniques used in Augustenborg Eco-city (Malmoe, Sweden)

In addition, in Malmoe, it stands out the case of Fjärilsparken Eco-corridor. It consists of an open drainage corridor, developed in the suburbs of the city of Malmoe. The objective of this action was the creation of a green corridor through the urban area, to deal with the storm water from new planned developments.

Different sustainable drainage systems were implemented. The main element was the design of a huge swale with a width of 50 metres and a depth of 2 or 3 metres. The swale was designed to have a capacity of conveyance of water for a 100-years period of return. That capacity covered the most part of the extreme events of rainfall with a significant decrease in the risk of flooding and reduction of run-off in the area.

Moreover, the action included a number of complementary elements such as benches, places to meet, playgrounds, or small wooden bridges that improve the quality of life of people, creating a new green area for leisure.

Other important example of the installation of sustainable drainage systems is located in Brondby, Denmark. In this case, a combination solution compound by the construction of raingardens in the streets sides together with green roofs and raingardens in the private backyards of the houses allowed the decline in the run-off and the disconnection of downspouts from the combined sewer systems, increasing the capacity of drain water from other non-pervious areas.

a) Raingardens installed in street

b) Raingardens installed in private courtyards

Figure 25. Examples of raingardens installed in Brondby, Denmark

The Netherlands is other country where these types of technologies for increase the sustainability in the drainage has been boosted in the recent years. In this country, the issues related flooding and drainage are well known from the ancient times. For that reason, the importance of drainage system which allows a good performance, during the drainage tasks combined with a better integration in the landscape and a number of improvements in the environment, is crucial.

Good examples can be found in the city of Kampen where the development of a new residential area situated at the sea level and with a ground water level of 0,8 m below surface presented serious problems of drainage. In addition, soil conditions, mainly clay and silt with low rates of permeability, did not allow the infiltration of run-off.

A comprehensive solution which included grass swales, infiltration soakaways, and retention ponds was implemented. The result was the prevention from flooding and improvements in the quality of water due to the installation of filter at the end of the swales.

Other remarkable example of SDS in The Netherlands is located in Witteveen. In this place, the lack of spaces made impossible the installation of traditional drainage systems. This fact, along with the boundary conditions with the close presence of the river Rhine, water level 8,5 m above the sea level and sandy soils with good infiltration capacity, led to the use of sustainable drainage systems.

The planned solution consisted of a combination of different elements such as swales, pervious pavement, or infiltration ponds which achieved reduce the risk of flooding and increase the quality of the infiltrated water.

Figure 26. Examples of raingardens installed in Brondby, Denmark

In France, it is possible too to find some interesting examples of the use of SDS in different urban planning. A good example of comprehensive deployment of sustainable drainage system is the technological area *Porte des Alpes* in Lyon. In this place, a valley surrounded by mountainous orography, the drain of water constituted a major challenge. To solve the problem, different SDS were installed in order to facilitate a natural way of draining. A set of devices such as swales, filter drains, retention ponds or infiltration basins were built. Moreover, the devices are open to the public, allowing the development of different activities related to sports or leisure.

The results obtained after the installation of SDS were highly successful in terms of improvements in the quality level of life of workers and the degree of involvement of society in the urban planning.

a) b)

Figure 27. Examples of SDS installed in Porte des Alpes (Lyon, France): a) Football pitch in an infiltration basin; b) Swales

In the south of Europe is also possible to find some interesting case of study in matter of sustainable drainage systems. One of the countries of the area with more remarkable experiences is Spain. Among other actions, it stands out the Parque de las Llamas located in Santander. In this park with more than 300.000 m^2, renewed in 2008, the concept of sustainability was implemented by the use of different technologies in terms of sustainable drainage systems which allow a comprehensive network of drainage and green spaces.

The actions were focused on the installation of a large wetland in the centre of the park which allows the collection of run-off from other parts of the park, avoiding excessively run-off and erosion. The wetland was complemented by a network of swales and ponds to conveyance the water from non-pervious areas to the wetland.

In addition, experimental parking slots were built. These parking slots were built with different technologies such as porous asphalt, porous concrete, grass reinforced with concrete and plastic cells, or different geotextile (Castro-Fresno D. , Andres-Valeri, Sañudo-Fontaneda, & Rodriguez-Hernandez, 2013) in order to check and monitor the drainage capacity in real environments. The results have been more than successfully.

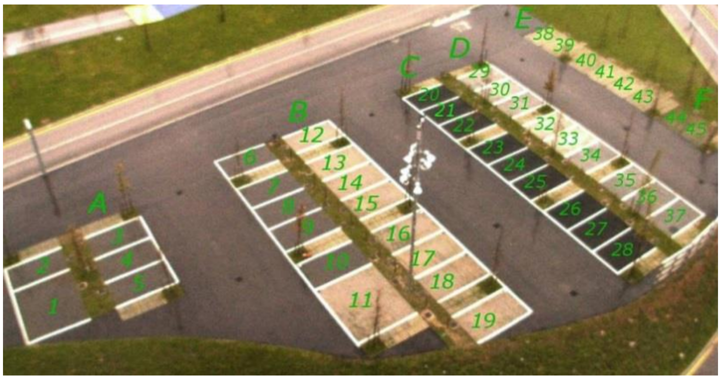


Figure 28. Parking slots in Parque de las Llamas (Santander) (Andres-Valeri, Marchioni, & Sañudo-Fontaneda, 2016)

New headquarters of bank BBVA located in the north of the city of Madrid (Spain) represents other magnificent example of the use of sustainable drainage techniques in the south of Europe. These offices have a green area of around 12.400 m^2 built in 2014 in which a comprehensive network of SDS has been installed. That network includes raingardens, walk paths built with gravel or pervious modular pavements. A network of infiltration trenches connected to soakaways allows the drainage of run-off from non-pervious areas.

Obtained results have been showed a reduction of 83% in the annual volume of water poured into the general sewer systems regarding the traditional solutions. Moreover, a number of ecological benefits have been achieved such as the creation of a microclimate or leisure areas for the employees of the bank.

Figure 29. Green area in the new BBVA HQ in Madrid (Spain) (Perales Momparer & Andres, 2016)

Especially remarkable is the case of the municipality of Benaguacil (Valencia). This municipality of 11.000 inhabitants is a clear example of good water management in terms of sustainability. During the period of 2010-2015 a series of sustainable drainage elements such as raingardens, detention ponds, or green roofs were built in different locations in order to ensure the optimal use of water from rainfall and run-off. A complete monitoring plan was deployed so as to check the benefits of the SDS network, both quality and volume of water collected. The results have showed important advantages in terms of improvements in the environment and risk of flooding reductions, especially in an area with a rainfall regime extremely irregular. This experience was awarded as Sustainable City 2015 (Ballester-Olmos y Anguis, Peris-Garcia, Soto-Fernandez, Andres-Domenech , & Escuder Bueno, 2015).

a) b)

Figure 30. Examples of SDS elements installed in Benaguacil (Spain): a) Raingardens; b) Water butts. Source: GreenBlueManagement

Other good example of comprehensive management of water in Spanish cities is found in Vitoria. This city was awarded as European Green Capital in 2012 by the European Commission (Ayuntamiento de Vitoria, 2012), after decades of promotion of sustainability policies in terms of urban planning. This recognition encouraged the compromise of the city with sustainability and boosted a planning of green urban infrastructure system in which techniques such as SDS are integrated. Among other, sustainable drainage system such as infiltration basins or raingardens were included in the urban planning.

The most remarkable action was deployed in the Gasteiz Avenue in which the permeable surface has been increased, promoting infiltration and detention by the use of pervious pavements and swales. The storage water is used for watering gardens and for the cleaning of streets.

Figure 31. Examples of SDS in Vitoria: swales and raingardens.

6.4.2 World

On the other hand, the use of sustainable drainage system is also widely spread in other countries far away from Europe. For instance, in USA is also possible to find some good examples of the use of sustainable drainage systems in different situations. In this country, objectives in the use of SDS are focus on two major issues: the lack of water for some uses such as irrigation, and the need of improvements in the quality the environment, especially in degraded and run-down urban areas.

Regarding the issue of the lack of water, use of innovative drainage systems has put their focus on the installation of devices to help the recharge of groundwater avoiding excessively run-off. Some relevant examples of the utilisation of sustainable drainage system are found in Dayton (Ohio). In this place, there is an extremely dependent of the groundwater to satisfy water needs. This fact requires ensuring the level of water table. To do that, a series of infiltration ditches and lagoons which occupy a surface of around 80.000 m^2 were deployed. These drainage system allow the periodically recharge of groundwater, satisficing and ensuring comply the water needs, reducing risk of flooding and avoiding issues of erosion.

Other remarkable case of a massive installation of sustainable drainage system to recharge groundwater is located on Long Island (New York). Main issue of this area is the lack of source of water to supply needs of people, where the only source is groundwater. To keep the adequate levels of water table, avoiding saltwater intrusion and decline the risk of flooding, a set of more than 3.000 recharge basins were constructed with a capacity of storage of more than 0,5 hm3 per day. In addition, to install these basins a number of abandoned gravel pits were used, improving the landscape, integrating, and reusing degraded installations for a given purpose.

Figure 32. Aerial picture of recharge basins (Nassau County Department of Public Works)

Regarding the improvement in the environment and the reduction of run-off, USA shows good examples of the application of sustainable drainage techniques, especially in the university field where SDS are widely spread. Some of the most notable examples are the drainage systems installed in universities which are listed below:

- University of Alabama Birmingham: green roofs
- University of Auburn: sidewalks and permeable parking slots
- University of South Alabama Mitchell centre parking: permeable parking slots
- University of California: wetlands, bioretention and raingardens.
- Sonoma State University: wetlands
- University of Delaware: green roofs in different buildings, permeable pavements, biorretention areas, and raingardens.

a) Green roof in the University of Delaware

b) Permeable pavement in parking slot in the University of South Alabama

Figure 33. Aerial picture of recharge basins (Nassau County Department of Public Works)

In USA, it is also possible to find good examples of sustainable drainage systems in the urban environment. One of the most representative cases is the Tanner Spring Park in Portland (Oregon). This is a neighbourhood surrounded by residential buildings located in the Pearl District, where originally marshlands were. All these wetlands are now channelled beneath the street surface.

Because of the lack of green spaces, due to its industrial past along with the issues related the nature of the soils and problems with flooding, a global solution has been taken. This solution included a masterplan with three types of parks in which Tanner Springs was one of them.

The planning for Tanner Springs consisted of a number of water management techniques which took into consideration local conditions. Due to the impossibility of rainwater infiltration, a number of sustainable drainage systems were installed. The systems included narrow channels and leaf-shaped glass roof to conveyance run-off. Among them, a central pond was built in the centre of the park to collect water, facilitates evaporation along with being a habitat for wildlife.

The action improved the environment of the area by the creation of a green space with natural wildlife, reductions in the risk of flooding and improvements in the microclimate through evaporation.

Figure 34. Wetland deployed in Tanner Spring Park (www.museumofthecity.org)

Australia is other country where the techniques oriented to a better and sustainable management of water have been boosted in the recent years. Many projects and initiatives have been deployed involving different stakeholders in order to extend the application of the techniques of sustainable drainage to different environments, especially urban environment and leisure areas.

In the Australian experiences in the use of sustainable water management techniques different scales has been applied. At building scale, several techniques have been used such as green roofs. Moreover, innovative approaches including the installation of wetlands and bioretention tanks on the roof or integrated in the building have been developed. Different examples in which roof water is treated in a roof garden a stored in storage tanks for it reuse in the hot water system are implemented (see figure below).

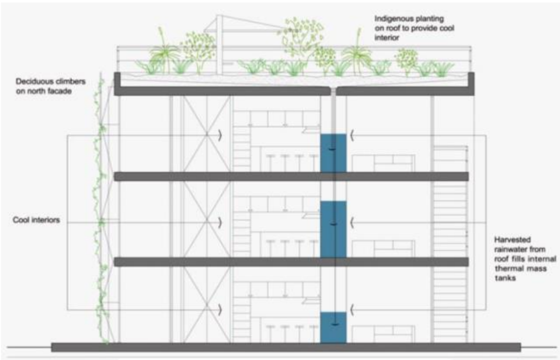


Figure 35. Integrated stormwater management system in a building (Wong, 2006)

At large scale, the use of sustainable techniques for the water management has been applied as an opportunity to integrate them into the general urban planning and within the overall landscape design. Actions have been led to the creation of green areas in which additional drainage capabilities are integrated in order to increase the storage capacity of water, reduce run-off or decline the risk of flooding. Most of the actions were deployed in urban environment, particularly installed in parks or in residential areas.

These uses include design considerations in terms of safety and aesthetic amenity. Some of the most relevant experiences of SDS in Australia are shown in the following picture (Figure 36).

a) b) c)

Figure 36. Some of the experiences in the use of SDS in Australia: a) bioretention basin in Brisbane; b) raingarden in Australand; c) Wetland in VicUrban (Wong, 2006)

In Colombia, a country where the awareness about the availability and good management of water has increasingly improved is possible to find some of the most challenge examples of the use of sustainable drainage system.

One of the better examples of the use of sustainable drainage techniques is located in the city of Bogotá. This city has suffered in the last 30 years a number of large flooding which has caused major economic losses and disturbances in the daily routine of citizens. Because of these events, different experiences have been implemented within a policy oriented to the sustainable use and smart management of the hydric resources.

First experience on the use of sustainable drainage system in Bogotá was located in the design of the sewer network, in which the agreement between the local council and the responsible of water management recognised SDS (water sensitive urban design in Australia) as a system which offers a number of benefits over the conventional drainage systems. This recognition established a basis and facilitated the development and application of this type of systems in different environments.

Urban planning *POZ Norte* is good example of a comprehensive use of sustainable water management techniques directly applied on an urban area. This area, deeply run-down, was selected as a test for the implementation of a new urban planning in which the concepts of sustainability and smart water management should play a major role in the design. As a result, several actions at different levels: roads, sidewalks, buildings, green spaces and so on, were deployed. A number of strict requirements were established, with minimum values for the percentage of permeable areas, or level of the run-off.

Some examples of the planned actions are shown in the Figure 37.

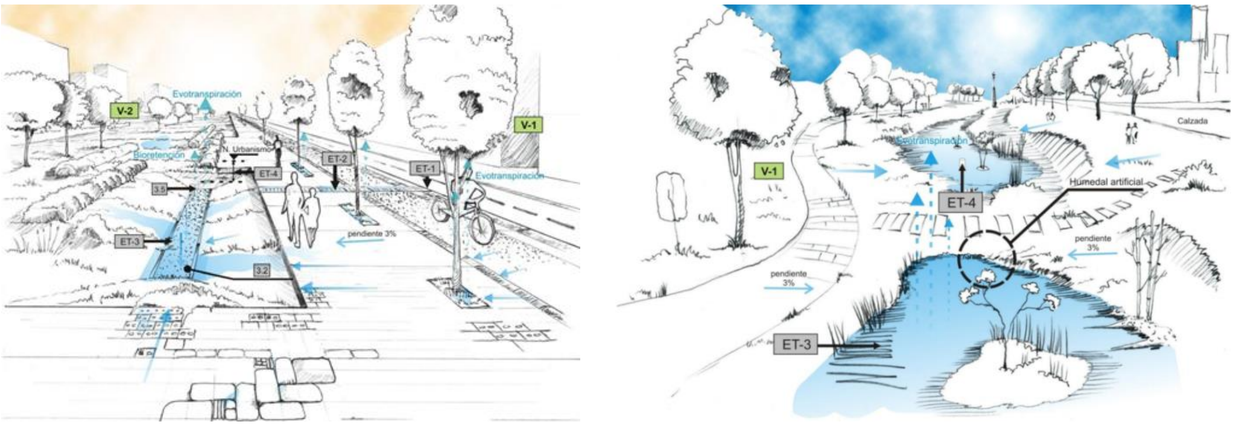


Figure 37. Examples of urban planning integrating SUDS in Bogota (Molina Leon, Gutierrez, & Salazar, 2011)

6.5 DESIGN CRITERIA

The planning and design of the sustainable drainage system is a multidisciplinary task in which different disciplines such as hydrology, hydraulics, microbiology, geotechnics, landscaping, urbanism and so on are involved. In order to arrange a framework to work in a determined area including social and environmental issues is necessary to establish a number of criteria.

The criteria could be classified in different modalities according the achieved interested. Following sections will define a common framework of the different criteria and approaches which should be considered, according the bibliography, at time of analyse the drainage systems.

6.5.1 Hydraulic performance criteria

Performance criteria can be considered crucial at the selection and design of a drainage system. These criteria usually include different approaches related to the hydraulic regime, operation mode, or capacity of drainage.

However, in case of sustainable drainage systems, performance assessment should be enlarged to evaluate additional approaches. In this regard, performance criteria must put the focus on other aspects such as the control of damage upstream and downstream, reduction of volume of run-off, reuse of resources, flood risk management, or flexibility and capacity of adaptation to existing infrastructures.

According to the existing literature (Woods-Ballard, y otros, 2015) and based on the previous precepts, a number of proposed hydraulic criteria to be included in the design process are collected in the following table.

Serviceability criteria	Indicators
Use of the run-off as a resource	A proportion of the run-off is storage to its re-use or infiltrates into the ground to increase the rivers or streams flows or recharge groundwater.
Support an efficient management of the risk of flooding	Outlets from surface waters are prioritized over the sewer outlets
Protection of morphology and ecology of the environment	Volume and pollutant loads are under control according to the regulations about the quality of water
Preservation and protection of the natural hydrologic system	Natural drainage systems are protected and improved as a part of the landscape or the surface waters.
Efficiency in the drainage	The infiltration and draining of the run-off is done by sustainable drainage system in which the performance of the system is not reduced in subsequent events.
In-situ management of risk of flooding	The overflows larger than capacity in sustainable drainage systems are channeled to and storage in identified areas of storage.
Flexibility in the design of the system to make future changes	Design of sustainable drainage systems will include the consideration of the climate change or include the elements to be easily adapted during its service life.

Table 2. Hydraulic criteria to analyse SDS

6.5.2 Serviceability and social criteria

The water management in terms of sustainable drainage systems contributes to the land uses planning promoting the health and wealth by the creation of green and leisure areas. Moreover, surface water helps to reduce the temperatures and provide habitat for plant and animal life.

On the other hand, adaptability of futures changes is one of the most important requirements to carry out by the sustainable drainage systems. Adaptability includes the capacity of deal with new rainfall regime and the possibility of being installed in existing drainage networks.

Finally, regarding the social-educative approach, sustainable drainage systems play a central role in the support of environmental education.

The following table collects the serviceability and social criteria by the definition of a number of indicators (see Table 3).

Serviceability criteria	Indicators
Maximise the functionality of drainage systems	Number, variety, and quality of additional uses for the sustainable drainage system as leisure areas, parking slots or elements for traffic management.
Safety in operation	Safety is a key design point in the sustainable drainage system
Adaptability of existing environment and future changes	Contribution of the sustainable drainage system to increase the resilience to the current and future extreme events,
Maximise the visibility and accessibility	Provides visibility and accessibility for inspection tasks
Improvement in the landscapes	Drainage system is designed to result attractive, support local heritage, improve the existing landscapes, and be integrated in the environment.
Support environmental education and social concerns	Approach to the social concerns, school participation, and education strategies and so on.

Table 3. Service criteria to analyse SDS

6.5.3 Environmental and biodiversity criteria

The benefits from creating or enhancement sustainable drainage systems are further beyond the functionality and the performance of the drainage. They provide a healthy environment that valorises the quality of life and the environment. This kind of criteria usually is linked to the serviceability criteria. In addition, the creation of these areas contributes to the promotion and support of natural habitats and biodiversity in the area where they are installed.

On the hand, in terms of environmental protection, the increase of the areas with impervious surface leads to an increase in the polluting loads. A water treatment is required in order to reduce the pollutants before restoring to the environment. In this regard, this fact should be considered a crucial criterion at the time of designing SDS.

Among others, the most relevant criteria regarding environment and biodiversity are collected in the following table.

Biodiversity and environmental criteria	Indicators
Support and protect natural habitats and environments	Extension, quality and importance of local habitats supported or improved by the design of sustainable drainage systems
Contribution to the local objectives for biodiversity	The habitats created by sustainable drainage systems comply the local strategies for biodiversity
Contribution to the connectivity of habitats	The design scheme of sustainable drainage systems is integrated and contributed to connect autochthonous habitats
Creation of sustainable and diverse environments	Resilience and diversity of the habitats created by the installation of sustainable drainage systems
Water treatment	Reduction of pollutants in the run-off

Table 4. Biodiversity criteria to analyse SDS

6.6 MAINTENANCE APPROACH

Sustainable drainage systems are based on a number of principles, already defined, including simulation of natural water cycle or promoting biodiversity and natural conditions of environment.

The achieving of these principles, together the concept of sustainability entails a design oriented towards low maintenance needs in which the good performance of the SDS will be based on the natural capacity of water streams for regenerating and adapting to changeable conditions and in which the human actions are minimised.

Usual maintenance tasks in SDS are mainly related to the conservation of plants, replacements of damaged elements, cleaning and remove debris and sediments to ensure the good performance of the system or removing blockages. These tasks are carried out periodically, or after an extreme event such as a storm or a flooding.

In this regard, at the time of analysing the different sustainable drainage is needed to identify the maintenance requirements of every system. A complete definition of the maintenance tasks has been included in the summary sheets in Appendix I in which these tasks have been classified into four main groups depending on the frequency of action: regular maintenance, occasional maintenance, remedial actions, and monitoring.

Complementary, in order to facilitate the analysis, the following table (Table 5) collects the main maintenance operations for every SDS analysed according the main authors (Graham, Day, Bray, & Mackenzie, 2012)

Maintenance operations	SDS features											
	PS	SK	IT/ FT	IB	GR	FD	SW	FS	DB	RB	WL	RG
Clear shingle perimeter and drainage layer, removing unwanted vegetation					●							
Retain dead stems in autumn as habitat for over-wintering invertebrates				●	●						●	●
Remove litter and other inorganic debris as required	●	●	●	●	●	●	●	●	●	●	●	●
Clean and refill blocks paver joints with gravel	●											
Undertake trimming, pruning or removing leaves cutting		●	●	●	●		●		●	●		●
Replace dead plants and, adjusting species mix according to local conditions				●	●		●	●				●
Mow to achieve a sward structure. Use clippings to crease habitat piles	●						●	●	●	●		●
Weed as necessary, employ a light touch	●		●	●	●							●
Remove silt		●	●	●		●	●	●	●	●		
Check inlets/outlets/sediment traps and remove blockages		●	●	●		●	●	●	●	●		●
Reinstate permeable surface by spiking or scarifying			●			●						●
Repair, create new and maintain habitat features					●		●	●			●	●
Maintain access routes to inlets/outs and other features inspection		●	●	●		●			●	●		
PS: permeable surfaces; SK: soakaways; IT/FT: infiltration/filter trenches; IB: infiltration basins; GR: green roofs; FD: filter drains; SW: swales; FS: filter strips; DB: detention basins; RB: retention basins; WL: wetlands; RG: raingardens												

Table 5. Maintenance feature in analysed SDS

7 MULTI CRITERIA ASSESSMENT

7.1 APPROACH

This chapter includes the assessment from different approaches, which will determine the feasibility of the use of sustainable drainage system and comparison between the different existing elements.

Regarding the analysis, different sections are included, in which the external and internal factors, potentialities and features are analysed. In order to obtain precise results, a series of steps have been followed. These steps represent different phases of a more complex analysis. The explanations and analyses of each of the different phases of this overall study are shown below.

7.2 SWOT ANALYSIS

SWOT analysis is a business technique for projects or ideas, in which strengths, weaknesses, opportunities for growth and improvements, and threats in terms of internal and external environment, are identified.

	Positives aspects	Negative aspects
Internal analysis	Strengths	Weaknesses
External analysis	Opportunities	Threats

Table 6. Example table of SWOT analysis

Therefore, SWOT is a kind of analysis in 4 steps which covers different approaches in a business. Every steps of the analysis is defined as follows:

- Strengths: project features which give it advantages over others
- Weaknesses: project features which can potentially place the project at a competitive disadvantage
- Opportunities: environment elements which the project can exploit for its benefit
- Threats: environment elements which can cause issues to the project

7.2.1 Strengths

Sustainable drainage systems (SDS) are based on a number of principles which provides strategic benefits over the traditional drainage systems with the objective of complementing or substituting them in some cases. These principles can be considered the strengths of SDS and among others could be noted:

- **Reduction of the risk of flooding:** one of the bases of SDS is the improvement of the performance of the drainage systems by simulating the natural water flows and increasing the permeability of the surfaces (i.e. removing non-permeable pavements or installing raingardens). These facts which result in a reduction of run-off, an increase in the capacity of drainage, and subsequent, to a reduction of the risk of flooding.
- **Simulation of natural water flows:** the simulation of natural water flows will lead to a change in the regime of hydraulic operation. This fact will result in reductions of peak flows, volume reductions, and increase in the availability of hydric resources which can be used for several uses such as aquifer recharges, watering plants, or environmental flows.

- **Creation of new green areas**: SDS are based on the use of vegetation due to its capacity of retaining the water in the soil, increasing the run-off coefficient, and reducing the times of water flow circulation in the surface. This vegetation will result in the creation of new green areas which have themselves positive aspects such as improvements in the landscapes, mitigation of 'heat island' effect, prevention of effects of global warming, or creation of new areas for leisure.
- **Environment improvements**: the use of SDS will entail some type of physical treatment for rainfall water which, depending of the type of SDS will result in removing of some pollutants such as suspended elements, nutrients, or heavy metals.

These benefits are included in the summary table of section 7.2.5.

7.2.2 Weaknesses

All bibliographical sources consulted agree in a number of weaknesses associated to the use of sustainable drainage systems. These weaknesses must be analysed in order to overcome or mitigate the negative effects on the global capacities of SDS.

After an analysis, some of the main weaknesses of SDS are listed bellows:

- **Installation costs:** despite most of SDS types are easy construction and maintenance elements, the installation costs represent a major obstacle to the generalisation of this type of drainage elements. The large number of existing drainage elements along with their interconnection to other critical elements such as the transport networks or the land take requirements of some SDS types makes the cost one of the most relevant entry barrier to the use of these types of drainage elements.
- **Lack of technical information:** the lack of technical information represents an important weakness in the use of sustainable drainage systems. Technical information can be found only for determined countries such as UK. However, most countries do not have specialised guidelines for the extension of these technologies. In the particular case of the use of SDS in roads or railway, the case is even more difficult since there are only a few technical documents at level of municipalities or regional governments.
- **Lack of experience**: the lack of experience in the installation and operation mode of SDS will result in other relevant obstacle to the use of these types of drainage elements. Due to its relatively new implementation, there is still no a larger documentation about best practices especially during maintenance operations and particularly in medium or long-term.

These weaknesses are summarised in the table of SWOT analysis (see above section 7.2.5.).

7.2.3 Opportunities

From the analysis of the external situation, a complex scenario has been revealed in which the uncertainties and changes due to several factors such as the global warming or the raise of the environmental awareness in the society will lead to the appearances of windows of opportunity to the implementation of these types of technologies.

The analysis carried out for the SDS will result in the following opportunities:

- **Global warming:** changes in the climate due to the effect of global warming will result in modifications of the duration or frequency of rainfall episodes along with changes in

other aspects such temperatures or regime of winds. All these changes will force to the implementation of extensive arrangements in existing infrastructures in order to increase the level of resilience to the new weather framework. In this regard, SDS can play a major role due to their capabilities to adapt existing infrastructure for a different hydraulic regime along with complementary benefits such as the minimisation of 'heat island' effects.
- **Environmental awareness:** the capacity of generation new green and leisure areas represents one of the most important windows of opportunity of SDS. Nowadays, the lack of leisure areas, particularly in urban environments is one of the main social demands more representative. Moreover, the raise of a social environmental awareness linked to the reduction of pollutions, that linked to the increase of the biodiversity phenomenon in the places where SDS are installed, makes the SDS an ideal system to comply environmental requirements of the society.
- **Risk management:** reductions of the risk of flooding due to the changes in the operation mode of hydraulic elements by the installation of SDS is particularly important in a society where the risk management is a must in any field of the public or private management.

The opportunities are included in the summary table of section 7.2.5.

7.2.4 Threats

In the same way as in the previous section, the external analysis has revealed a number of threats to the use of SDS. Public bodies, experts, and infrastructure managers must deal with these threats so as to be integrated in the business strategies.

Some threats have been identified in the following bullets:

- **Reluctance of public administrations:** one of the greatest obstacles when it comes to generalising the use of these systems is the reluctance of the various administrations to use them, reluctance mainly due to a lack of experience and a lack of regulations to support and facilitate their implementation.
- **Budget restrictions:** In an economic situation where the economic crisis has been overcome but the budget, restrictions are still presented in the public bodies; large investments are notably difficult to carry out. This fact is particularly remarkable in case of the installation of SDS due to the large required investments and in which alternative financial tools should be considered.

These threats are collected in the summary table of section 7.2.5.

7.2.5 Summary

The SWOT analysis can be summarized in a table such as the one shown in Table 6 in which the result of the analysis itself is summarized briefly and at a glance. This type of table is very useful for a quickly and accurately collecting SWOT results.

The following table (Table 7) collects the results from the SWOT analysis for the Sustainable Drainage Systems:

Strengths	Weaknesses
▪ S1: Reduction of risk of flooding ▪ S2: Simulation of natural water flows ▪ S3: Creation of new green areas ▪ S4: Environmental improvements	▪ W1: Installation costs ▪ W2: Lack of technical information in transport infrastructure ▪ W3: Lack of experience in designing in transport infrastructure
Opportunities	**Threats**
▪ O1: Global warming ▪ O2: Environmental awareness ▪ O3: Risk management	▪ T1: Reluctance of public administrations ▪ T2: Budget restrictions

Table 7. Summary table of SWOT analysis

7.3 CAME ANALYSIS

Closely linked to the SWOT analysis is the CAME analysis (correct-adapt-maintain-explore). This is based on the first to, based on the results of the same, establish actions and procedures to help correct weaknesses, adapt or mitigate threats, maintain strengths, and explore opportunities.

7.3.1 Correct weaknesses

Because of the SWOT analysis, the main weaknesses detected are related to, on one hand, the lack of technical information and experience in the use of SDS in transport infrastructure, and the other hand, the installation costs of this type of drainage elements. To correct these weak points, the following actions are proposed:

- **Development of specific technical documentation/guidelines** about the designing, installation, and maintenance of sustainable drainage system in transport infrastructures such as roads, railways or stations and terminals. This documentation should include all the required points to ensure the best performance of the drainage, guarantying a robust design to comply all the demanded requirements to another drainage elements. The documentation should consider different environments and situations covering as many cases of study as possible.
- **Collection and transference of information about the existing experiences in the use of sustainable drainage system in transport infrastructure** in catalogues of solutions, or celebration of conferences, congresses, or technical journals which allows the transference of information between technicians, designers, or politicians. All these events and documentation will help to put in common different approaches in the use of sustainable drainage systems in several situations, facilitating the generalisation and penetration of this type of solutions in the transport infrastructures.

- **Reduction/ adjusting of installation costs** by the optimisation in the design, operation, and maintenance tasks along with a life-cycle analysis in which the costs associated to the risk of flooding or environmental protection will be considered. Optimisation can be achieved by the increase in the information and experience in the use of SDS in linear infrastructure.

7.3.2 Adapt or mitigate threats

In the same manner as above section, the CAME analysis is based on the SWOT analysis to ease the process of making strategic decisions to adapt, fight or mitigate the threats. From the SWOT analysis, main threats related to the use of SDS in transport infrastructure are the reluctance of public administrations to include these systems in large public projects due mainly to the lack of experience, and the budget restrictions associated to the current financial situation.

To fight or mitigate these threats a number of strategies can be taken as it is pointed as follows:

- **Creation of working groups and celebration of workshops between public administrations and experts in SDS** in which different points of view will be interchanged and in which, opportunities, potentialities and the benefits of the use of SDS will be shown to public bodies in order to convince them that the implementation of these drainage solutions has strong positive effects. These effects are related not only for the improvements in the hydraulic operation mode and reductions in the risk of flooding, but also in terms of social benefits such as the creation of green areas or reduction of pollutants.
- **Performance of analyses of life cycle cost (LCC) and multi-criteria analyses** in which will be shown that the use of sustainable drainage system in transport infrastructures will result in safe of resources in a medium and long-term because of several factors such as the decrease of the risk of flooding, the reduction in the environmental integration actions or the reduction in the pollutant load of run-off which allow the optimization of the sewage treatment plants.

7.3.3 Maintain strengths

One of the most relevant points of the CAME analysis is to propose strategies to maintain the strengths detected in the SWOT analysis for the systems analysed. In this sense, the main strengths of the sustainable drainage systems are related to its capabilities to improve the hydraulic operation mode of drainage elements or to get environmental improvements.

In order to maintain, and even strengthen these strengths, a number of actions have been established, among which the following stand out:

- **Keep researching the operation hydraulic mode of SDS** in order to obtain most optimised and customised designs to a wide range of infrastructures including transport infrastructure such as roads and railways.
- **Exploring the possibilities of integration of SDS in new and potential environments** different from the current situations in order to increase the applicability of these technologies.
- **Integrated design of public spaces** in which leisure and green areas will regard additional functionalities as sustainable drainage systems and vice versa.

- **Exploring the redesign of sewage treatment plants** taking into consideration the benefits in terms of reduction of pollutant load in the run-off due to the use of sustainable drainage system.

7.3.4 Explore opportunities

The opportunities identified in the SWOT analysis make it possible to consider a number of actions that can help strengthen the SDS by taking advantage of these opportunities.

In this way, the following actions are proposed as priority ones:

- **Identification of positive specific effects** related to global warming that the use of sustainable drainage systems has on the environment where they are installed. These effects such as the mitigation of 'heat island' effect, recharge of aquifers or increase the level of humidity in the atmosphere can be evaluated and categorised into different case of study to facilities their dissemination and divulgation.
- **Integration of these technologies into the risk management strategies**, showing its capability to reduce the risks of flooding and contribution to the water management in a better way than traditional drainage systems. This fact will lead to the generalisation of these technologies in all areas where are applicable.
- **Assistance to conferences, workshops, elaboration of paper in technical journals,** or any other activity which allow the dissemination of the benefits of the use of SDS.

7.4 MULTIOBJECTIVE ANALYSIS

7.4.1 Introduction

Multi objective analysis is a technique which allows the comparison between systems that have different characteristics between themselves but have a common goal.

To perform the analysis is needed to the previous definition of the criteria which can be clustered in different categories according to their features.

In the analysis of SDS, six different categories have been defined in a way to entail a holistic analysis that take into consideration the higher number of criteria as possible. These six categories are:

- Performance
- Costs
- Pollutant removal capacity
- Maintenance
- Applicability
- Social acceptability

These categories are related to some of the design criteria, already defined in previous sections, including also other requirements such as maintenance or applicability.

During the analysis, each criterion has been assigned a weight. In this regard, the multi objective analysis of a SDS allows obtaining finally a number from 0 to 10 for each group of criterion so that different SDS can be compared themselves. Weighting has been defined based on data from summary shits (Appendix I). Appendix II collects the tables in which the system of weights and ponderation can be seen.

7.4.2 Analysis of criteria

7.4.2.1 Performance

Within the performance criteria, different approaches have been included. These approaches include criteria regarding hydraulics such as peak flow reduction or volume reduction, water quality, amenity or ecology potential according main authors (Woods-Ballard, y otros, 2015).

Performance criteria	Description
Peak flow reduction	Reduction in the peak flows pour to the conventional drainage system or natural watercourses during an extreme event of rainfall due to the storage capacity of SDS
Volume reduction	Reduction in the volume of run-off due to the storage capacity of SDS
Water quality treatment	Improvement in the quality of water restored to the natural watercourses due to the physical and chemical processes performed in the SDS
Amenity potential	Creation of leisure and green areas for social activities
Ecology potential	Promotion of flora and fauna

Table 8. Performance criteria included in multi objective analysis

Values given for every performance criteria are aligned with the scale defined in the summary sheets included in Appendix I.

7.4.2.2 Costs implications

Criteria regarding costs include a number of approaches such as land take, capital costs, or maintenance burden according to the information collected in the summary sheets of Appendix I in which this structure of costs are classified in three levels.

Cost criteria	Description
Land take	Costs of acquiring the land on which the SDS is installed
Capital costs	Costs of construction and investment of this type of elements
Maintenance burden	Costs of maintenance during the service life of the SDS

Table 9. Cost criteria included in multi objective analysis

7.4.2.3 Pollutant removal capacity

Regarding the pollutant removal capacity, the chosen criteria are related to the capacity of the SDS for removing pollutants including sediments, debris, nutrients, or heavy metals.

Pollutant removal capacity criteria	Description
Total suspended soils	Capacity of SDS for reducing the amount of sediments and debris in the run-off
Nutrients	Capacity of SDS for reducing the load of nutrients and other organic substances in the run-off
Heavy metals	Capacity of SDS for reducing the load of heavy metals in the run-off

Table 10. Pollutant removal capacity criteria included in multi objective analysis

Given values for every criterion are based on the information collected in the summary sheets of Appendix I, in which the capacity are graduated in three levels.

7.4.2.4 Maintenance

For the analysis of needs of maintenance, the tasks required for every system collected in the Table 5 have been used as criteria of comparison between the different sustainable drainage systems.

Given values have been consisted of determining if the task is required for the analysed SDS or not.

7.4.2.5 Applicability

To analyse the potential uses of SDS in different environments, a number of several infrastructures has been defined. Based on these infrastructures and the information collected in the summary sheets of Appendix I, applicability criterion are based on the possibility of installation the analysed the SDS in the given infrastructure (see appendix II).

7.4.2.6 Social acceptability

Social acceptability criteria include a large number of different criteria from many points of view collecting from many authors, such as health, public opinion, aesthetics, integration, research, economy, or employment (see following table).

Based on information collected for every SDS, different criterion has been considered in the analysis to obtain finally an aggregate index.

Social criteria	Description
Health	Effects on the human being's physical and mental state due to accidental causes (Li, Hui, Xu, & Li, 2012), long-term diseases (Chow, Hernandez, Bhagat, & McNally, 2014) or exposure to source of pollution (Jeon, 2010)
Public opinion	Perception of the community with respect to the general acceptance of the project, unease or satisfaction with the construction or the operation of the infrastructure (Dasgupta & Tam, 2005)
Aesthetic and degradation	Infrastructure design fits with the harmony of the surrounding and public sensitivity (Balali, Mottaghi, Shoghli, & Golabchi, 2014)

Social criteria	Description
Safety of the environment	All physical risks and implications of criminality for the local population (Bonsall & Kelly , 2005)
Integration with existing infrastructures	Capacity of adaption to existing drainage systems, urban planning and existing linear infrastructures
Research, development and innovation (R+D+I)	Promotion of technological development in the infrastructure project to generate social contributions (Institute for Sustainable Infrastructure, 2015)
Land use	Efficiency and effect of the changes of ground use in the community for the development of the infrastructure (Thomopoulos & Grant-Muller, 2013)
Distribution of production benefits	Equity in the distribution of the contributions and costs of the infrastructure among the local and regional populations (van de Walle, 2002)
Economy and local development	Improvements or harm to local business (Kucukvar, Gumus, Egilmez, & Tatari, 2014) Alteration of the operational costs of the users of the infrastructure (Koo, Ariaratnam, & Kavazanjian, 2008)
Employment	Aspects related to the number of work opportunities associated directly and indirectly to the development of an infrastructure (Labuschagne & Brent, 2006)
User-oriented design	Design of infrastructures being compatible with the needs of a context (Valdés-Vasquez & Klotz, 2013)

Table 11. Social criteria

7.4.3 Summary

In this section, a summary of the obtained results from the multi criteria assessment, for every one of the sustainable drainage systems analysed, is collected. For that purpose, a number of polygonal charts have been developed. Within every polygonal chart, the different criterion for the sustainable drainage systems along with its value has been showed (see appendix II). It entails a polygonal chart for every sustainable system which is recast in three different figures if systems are grouped depending on their main aim. This fact will allow the visualisation and comparison between the different systems in order to determine the best and worst capabilities for the selected criteria. The identification and comparison between themselves will ease the selection process in order to include SDS in the design and re-design of transport infrastructures.

7.4.3.1 Source control systems

For the first group of sustainable drainage systems corresponding to the source control systems, results of the multi criteria analysis for the six different approaches, is collected in the following figure (Figure 38).

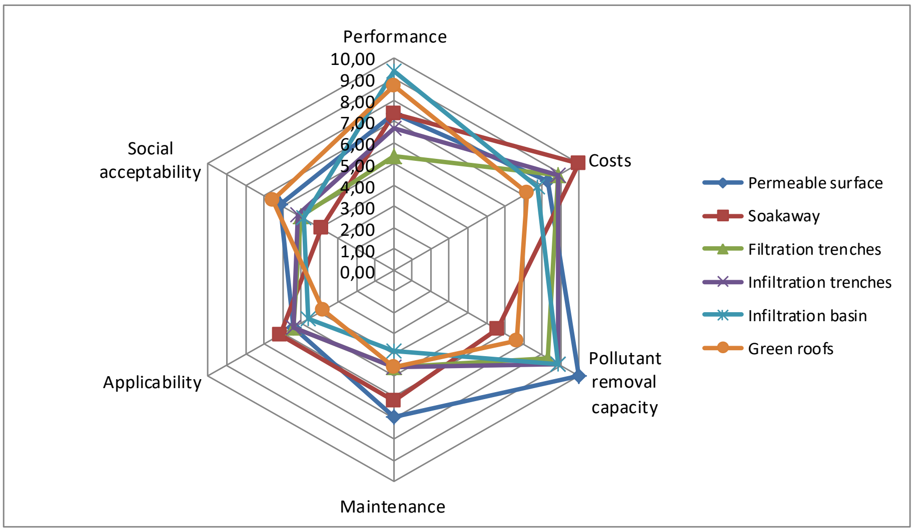


Figure 38. Multi criteria results for source control systems

The analysis of the figure leads to the ascertainment that six different source control systems presents some slightly differences regarding the proposed indicators. Firstly, regarding the performance, the SDS which presents a better behaviour are the infiltration basins. This fact is based on the good capabilities of infiltration basins in terms of volume reduction of run-off, water quality treatment, or ecology potential. On the other hand, filtration trenches present the worst result due mainly to the low score obtained for volume reduction or amenity potential.

Concerning costs, in spite of what one might think, green roofs has resulted in the lowest cost systems. This fact is based on the absence of costs of land taking due to its installation on existing roofs or its maintenance needs which can be covered by existing maintenance staff in buildings. In contrast, soakaways represent the most expensive SDS because of the costs of land taking, maintenance needs, or capital costs.

In regard to pollutants removal capacity, it highlights permeable surface as the most efficient system, due to its good performance in terms of removal capacity for suspended soils, nutrients, and heavy metal. However, soakaway has revealed as the worst system due to its poor performance for removal nutrients.

Other key indicators present contradictory results. For maintenance needs, the best system is permeable surface due, mainly, to the low number of required maintenance operation, focused on the major seasonal actions in terms of brushing or vacuuming if necessary. In terms of applicability, soakways has resulted the system which can be used in a large number of different situations (i.e. residential areas or roads) closely followed by the rest of systems. Finally, in terms of social acceptability, it highlights green roofs as the best system because of it good performance in urban and polluted areas as an element that can contributes to improve the air quality or environment conditions.

Detailed score index and polygonal charts for every source control system are collected in the Appendix II.

7.4.3.2 Permeable conveyance systems

The results of the assessment for the second group of sustainable drainage systems corresponding to the permeable conveyance systems, is showed in Figure 38.

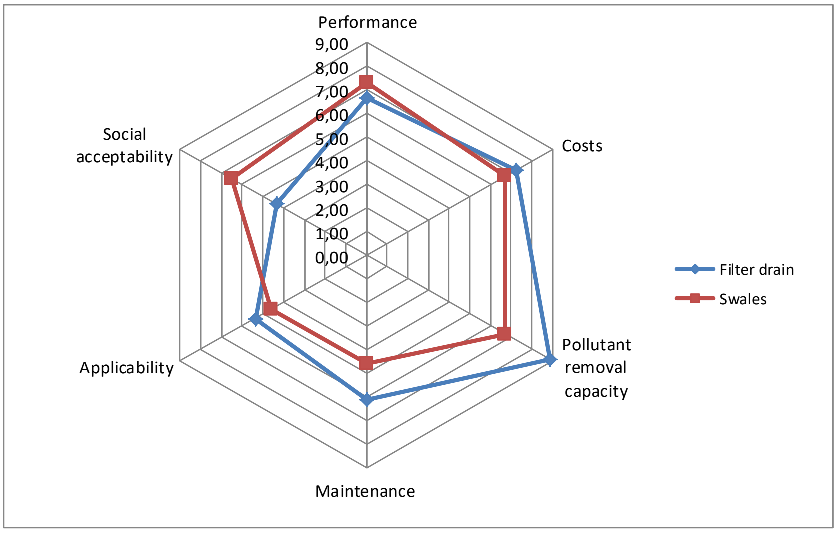


Figure 39. Multi criteria results for permeable conveyance systems

A closer look of the figure reveals that filter drains presents better results for cost, pollutant removal capacity, maintenance needs and applicability. On the contrary, swales have better score in terms of social acceptability and performance.

Main differences between both systems are found in social acceptability in which the features of swales are notably higher than filter drain or in pollutant removal in which filter drain has better capabilities. Social acceptability of swales is due to the good performance of these systems in terms of aesthetics, integration with existing infrastructure or user-oriented design by taking advantage of existing traditional gutters to become in swales. Regarding pollutant removal capacity, the higher score of filter drain is given by its better performance for removal suspended soils, nutrients or heavy metals.

Detailed score index and polygonal charts for every permeable conveyance system are collected in the Appendix II.

7.4.3.3 Passive treatment

Regarding passive treatments, results obtained in the assessment of passive treatments are shown in the following picture (Figure 40).

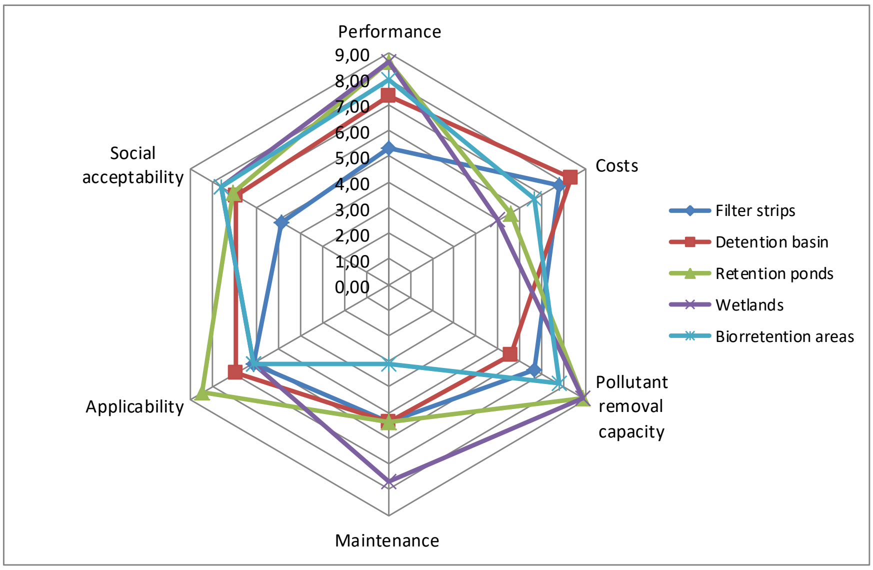


Figure 40. Multi criteria results for passive treatments

First analysis reveals the good behaviour of all systems in terms of performance, for which the score of all of them are close to the maximum value except filter strips. Regarding costs, some notably differences appear due mainly to capital costs associated to every system. The rest of cost structure is similar because of large land take of this type of SDS.

In relation to the pollutant removal capacity, some slightly differences can be identified. Wetlands and retention ponds present the best results based on their good capacity for removing suspended soils and heavy metals. On the other hand, detention basins have poor results in this term since is the system with low rates of removal capacity for every one of the analysed pollutants.

From the maintenance need perspective, biorentention areas have the lowest score of all passive treatment. The fact of this kind of passive treatment is mainly installed in urban areas where the maintenance requirements are significantly higher than in rural areas is the key factor of this result. On the opposite, wetlands show the best performance for maintenance needs because of the processes and water operation mode in this type of SDS tries to simulate the natural water cycle.

For the rest of criterion the results are uneven. In case of applicability, retention ponds result in the system which allows more possibilities at being a drainage system that can be installed in different environment such as any type of roads or linear transport infrastructures along with the possibility of being installed in other facilities such as terminals or industrial and commercial areas.

From the point of view of social acceptability the difference between passive treatments are minor, with filter strips as the lowest score system.

Detailed score index and polygonal charts for every passive treatment system are collected in the Appendix II.

7.4.3.1 Relevance index

In order to determine a key indicator which allows a direct comparison between all the analysed systems from a global point of view, a relevance complex index has been defined. This relevance index is compound by the linear composition of scores of every considered criterion offering an overall parameter to compare under the same requirements different systems. To do that, the same weight for every criterion has been considered. This fact will lead to consider the equal importance which has been change if necessary.

The following pictures (Figure 41, Figure 42, Figure 43) show the obtained results for every group of sustainable drainage systems assessed: source control systems, permeable conveyance systems, and passive treatments.

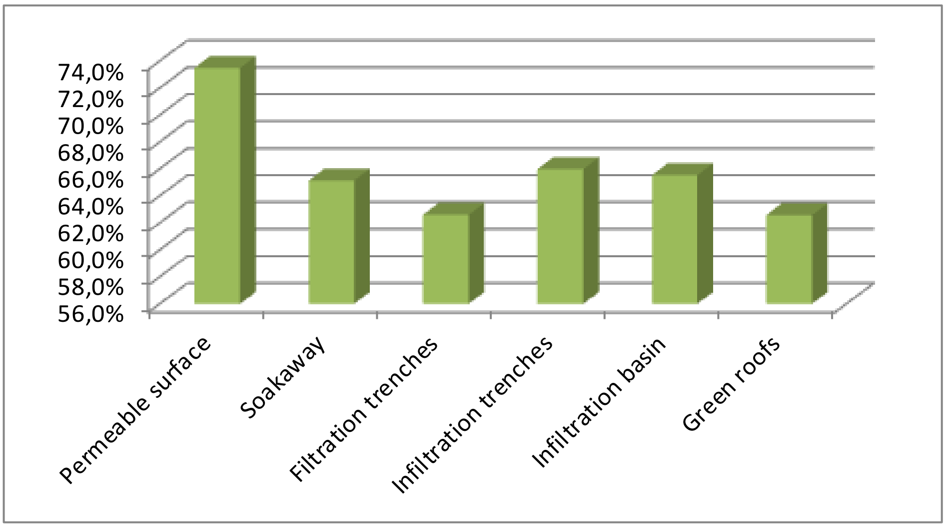


Figure 41. Comparison between source control systems

The analysis of the relevance index for source control systems reveals that the system which achieves the higher score is the permeable surfaces. On the other hand, filtration trenches and green roofs offer less performance than the rest of source control systems. Soakaways, infiltration trenches and infiltration basins compound a central group with intermediate features.

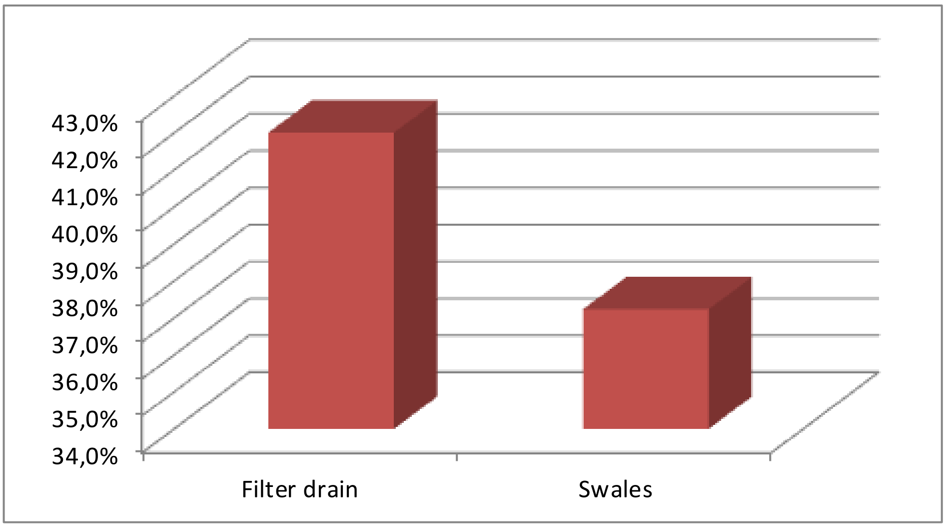


Figure 42. Comparison between permeable conveyance systems

In case of permeable conveyance systems, the direct comparison between filter drain and swales shows that the former has slightly better performances that the latter.

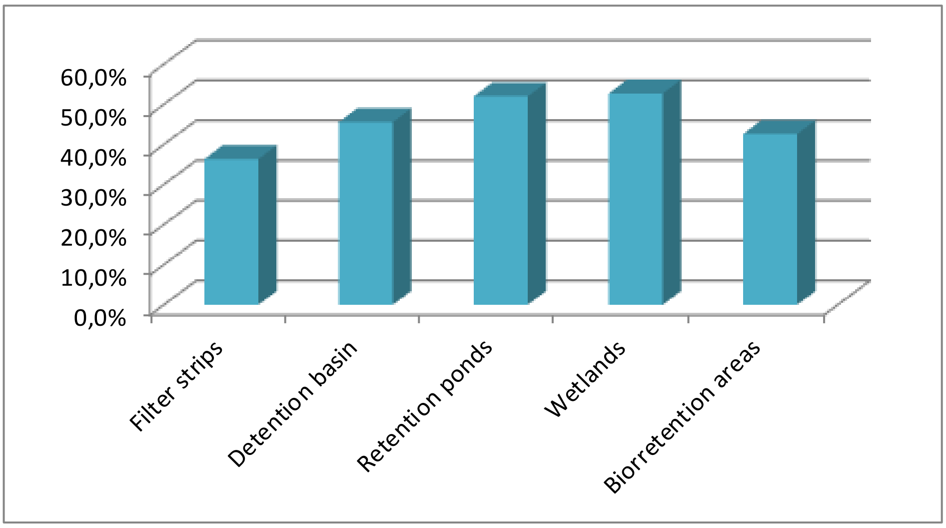


Figure 43. Comparison between passive treatments

Passive treatments look similar performance, highlighting retention ponds and wetlands as the systems with the highest scores.

8 CONCLUSIONS

This document comprises a review and assessment of sustainable drainage systems from different approaches which include water management, legislation, experiences, design, and maintenance.

The analysis of the current situation has revealed a complex framework in which different factors such as urbanisation, economic development, environment protection, or global warming, makes necessary a change in the drainage approach.

Sustainable drainage systems are a set of techniques, elements, and procedures which can deal with this complex situation, offering an ideal solution, easily adaptable to a changing environment.

Experiences in the use of these techniques are widely used in urban areas. However, their application in linear infrastructures such as roads or railways is still incipient.

Within this document, the review of existing experiences, legislation, and benefits has provided a clear vision about the potential of the use of sustainable drainage systems in linear infrastructures. This potential is mainly based on the benefits of these techniques which can provide solution from the hydraulics, pollutant reduction, or promotion of biodiversity at the same time. All these advantages, linked to the adaptive capacity to existing infrastructures, strongly suggest the application of these elements in the drainage networks of roads and railways.

Regarding the application of SDS as a whole, and in the transport infrastructures in particular, the lack of official prescriptions or specific guidelines has been detected as one of the most important entry barriers. Although there are a large number of scientific papers, the lack of official guidelines makes the Public Administrations reluctant to include these kinds of solutions in engineering work contracts.

In order to facilitate and increase the knowledge about sustainable drainage systems, a number of technical summary sheets have been drafted, in which the main characteristics at different levels, including design schemes, design requirements, or maintenance procedures are included. These summary sheets represent the first step towards comprehensive guidelines for the use of sustainable drainage systems in linear transport infrastructures.

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10 ANNEXES

APPENDIX I. CATALOGUE OF SUSTAINABLE DRAINAGE SYSTEMS

Source control systems

01	SC	PERMEABLE SURFACE OR PAVEMENTS

Description

Permeable surface or pavements are multi-layered surfaces which allow the infiltration of water through their surface or their gaps. At the same time, they provide a pavement for pedestrian or vehicular traffic.

Objectives

- Retaining rainfall water to increase the concentration time and decrease the volume of run-off
- Infiltration of rainfall water to reduce the volume of run-off and recharge aquifers
- Depuration of rainfall water, removing sediments and pollutants
- Reusing of rainfall water to generate more available hydric resources

Types

- Modular permeable pavements
- Geocells permeable pavements
- Continuous permeable pavements

Applications

- Light vehicles parking slots
- Open urban areas: parks, leisure areas, pedestrian areas
- Access roads/links
- Roads/street 250 – 10.000 veh./day

Why are used?

- Capacity of removing some pollutant from rainfall water
- Removing of waterlogging and ice sheets in areas where temperatures are low
- Easy construction
- High adaptability and suitable installation in high density development

Design criteria

- Water table level at least 1 metre under the surface to avoid pollution
- Slopes between 2 to 5%
- Surfaces permeable not larger than 4 ha.
- Joints between cobbles could be filled with ground, gravel, or vegetation.
- Filter gravel layer of subbase calculated for an intensity of rainfall of a period of return of 2 years
- Clay content less than 30% in different layers
- Geotextile clogging is recommended as filter and restrengthening system
- Drainage depends on capacity of storage of subbase

Performance

Peak flow reduction	Good
Volume reduction	Good
Water quality treatment	Good
Amenity potential	Poor
Ecology potential	Poor

Maintenance requirements

Regular maintenance	Brushing and vacuuming	Three times/ year at end of winter, mid-summer, after autumn leaf fall or as required
Occasional maintenance	Stabilise and mow contributing and adjacent areas	As required
Remedial actions	Remediate any landscaping which through vegetation maintenance or soil slip has been raise to within 50 mm of the level of the paving	As required
	Remedial work to any depressions, rutting and cracked or broken blocks considered detrimental to the structural performance or a hazard to users	As required
	Rehabilitation of surface and upper sub-structure	As required
Monitoring	Initial inspection	Monthly
	Inspection of weed growth	Four times per year
	Inspection of silt accumulation rates	Annually
	Monitor inspection chambers	Annually

Advantages

- Increase the available hydric resources
- Recharge of aquifers and reusing of water if non-pervious layer are installed.
- Low cost of construction and maintenance (not in case of continuous pavements)
- Long service life in case of modular and geocells pavements
- Good retrofit capability

Restrictions and drawbacks

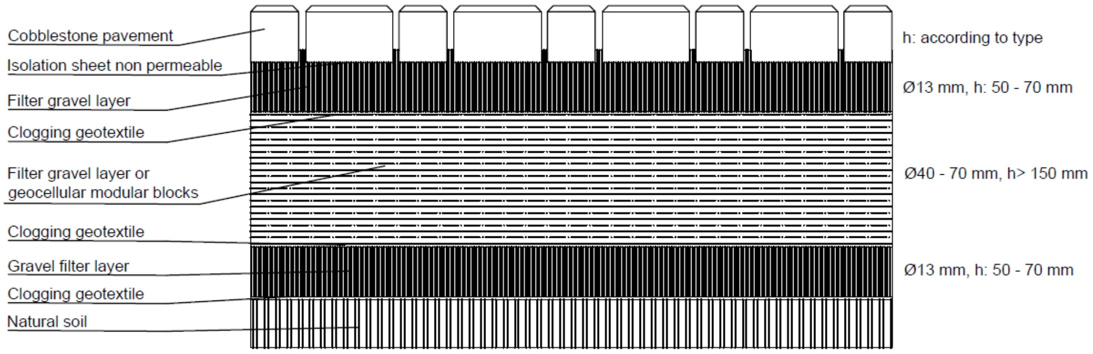
- Not suggested in cases where large sediment loads may be poured or carried onto the surface
- Not suggested in highways or roads with high volume of traffic or high rate of heavy vehicles
- Risk of clogging and weed growth if maintenance is not appropriate.

Cost implications

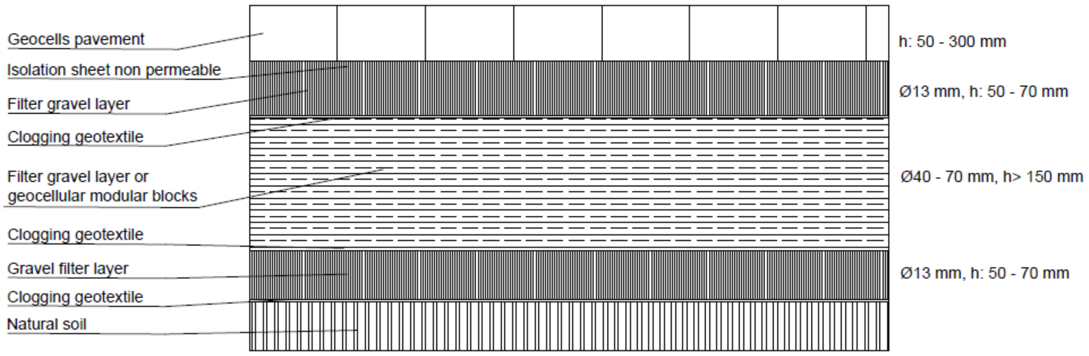
Pollutant removal

01	SC	PERMEABLE SURFACE OR PAVEMENTS	
Land take	Low	Total suspended soils	High
Capital costs	Medium	Nutrients	High
Maintenance burden	Low – Medium (continuous pavement)	Heavy metals	High

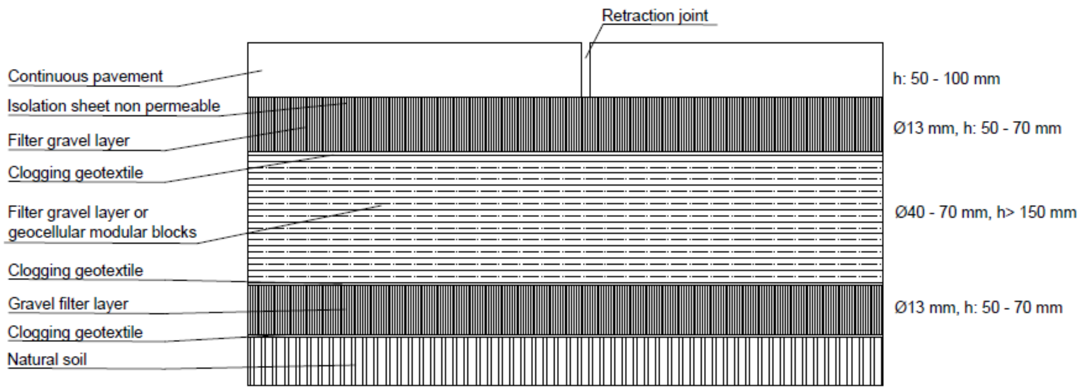
Design scheme



Modular permeable pavements



Geocells permeable pavements



Continuous permeable pavements

02	SC	SOAKAWAY

Description

Excavations (square or circular), filling with granular or synthetic material. Designed to collect run-off from large impermeable surfaces, storage, purify, and infiltrate in the subsoil, recharging the aquifers.

Objectives

- Retaining rainfall to increase the concentration time of rain
- Infiltration of rainfall water to reduce the volume of run-off and recharge aquifers
- Depuration of water from rainfall, removing sediments and debris
- Reusing rainfall to increase the availability of hydric resources

Applications

- Single house
- Residential areas
- Commercial areas
- Park areas
- Roads/highways

Why are used?

- Capability of removing some pollutants from rainfall water
- High adaptability to different environments could be used in reduced areas and urban environment with high dense of population
- Use as an auxiliary drainage system in large areas
- Easy maintenance and construction
- Environmentally friendly, help to recharge of aquifers

Design criteria

- Water speed low enough to ensure an adequate water quality.
- Estimated depth around 1 to 3 metres
- Depth larger than 4 m will require environmental specifications
- Estimated diameters around 1 to 2.4 metres
- Suggested using of clogging geotextile to avoid clogging or failures in the system
- Not suggested to install in filling soils in order to avoid loss of support capacity
- Minimum distance of 3-5 meter from foundations of close structures (bridges, buildings…)
- Minimum distance of 1 meter from the high water table level
- Fill material > 30% voids
- Fill material could be replaced by geocellular units
- Capacity estimated for return periods for storm estimated of 30 years
- Time of emptying around 24 hours.
- Impermeable surfaces to collect run-off less than 0.5 ha.

Performance

Peak flow reduction	Good
Volume reduction	Good
Water quality treatment	Good
Amenity potential	Poor
Ecology potential	Poor

Maintenance requirements

Regular maintenance	Removing of sediments and debris from pre-treatment devices	Annually
	Inspection of tubes and chamber	Annually
	Cleaning of gutters and filters	Annually
	Trimming of close roots	As required
Occasional maintenance	-	-
Remedial actions	Replace or clean void fill	As required
	Replacement of clogged geotextile	As required
Monitoring	Inspection of silt traps	Monthly during the first year, then annually
	Checking of correct performance of emptying	Annually

Advantages

- Minimal land take
- Groundwater recharge
- Good volume reduction and peak flow attenuation
- Good social acceptability
- Easy to build and operate
- Easy retrofit
- Can be grouped and linked together in order to increase the capacity of storage

Restrictions and drawbacks

- Not great capacity
- Not suitable for poor draining soils
- Pre-treatment for removing sediments and debris is required
- Not suggested in polluted soils
- Increase risk of groundwater pollution
- Attraction of roots of plants which could affect close foundations

Cost implications

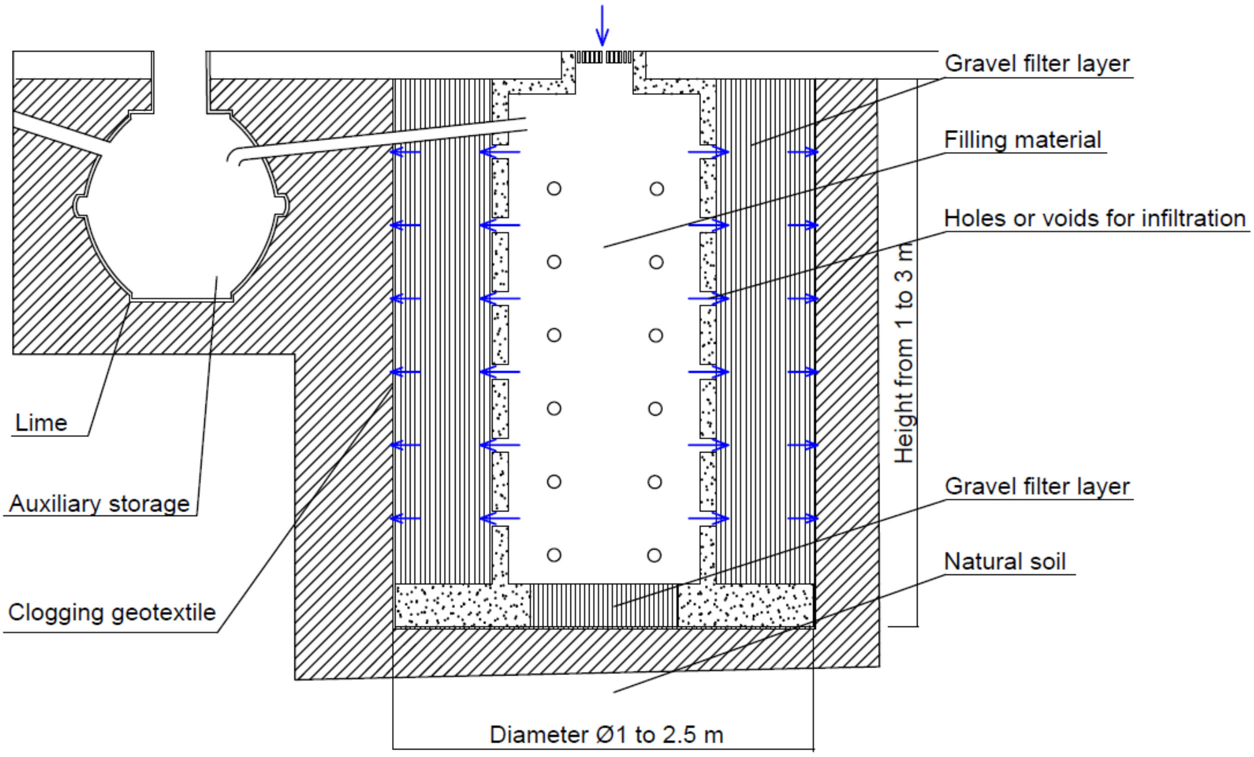
Land take	Low
Capital costs	Low
Maintenance burden	Low

Pollutant removal

Total suspended soils	Medium
Nutrients	Low
Heavy metals	Medium

Scheme design

02	SC	SOAKAWAY



03	SC	TRENCHES

Description

Shallow and linear excavations filled with rubble or stone to provide treatment and temporary storage of run-off before either infiltration, conveyance to downstream drainage systems or infiltrate directly into the subsoil.

Objectives

- Retaining the rainfall water to increase the concentration time of rain
- Infiltration of rainfall water to reduce the volume of run-off and recharge aquifers
- Reusing of rainfall water to generate more available hydric resources

Types

- Infiltration trenches (IT)
- Filtration/filter trenches (FT) to convey water to drainage system

Applications

- Trunk roads
- Distributor roads
- General access roads
- Industrial access roads
- Roads/street 250 – 10.000 veh./day
- Residential areas
- Industrial areas
- Perimeters of parking areas

Why are used?

- Capability of removing some pollutants from the rainfall water
- Environmentally-friendly due to their capacity of recharge aquifers
- High capacity of integration into the landscape both urban and rural
- Capacity of substitution some of the traditional drainage systems
- Low cost of construction and maintenance
- Easy access

Design criteria

- Shallow of excavations between 1 and 2 metres
- Width will depend on area of collection run-off
- Distance between the bottom of excavation and table water level must be larger than 1 m.
- Slope of excavation between 2 and 5%.
- Area of collection run-off not larger than 2 ha.
- Capacity of drainage of ,at least , 50% of water collected during 24 hours
- They should be filled with granular material with diameters of 40-60 mm.
- Not suggested in soils with lime or clay.
- Geotechnical deep study is mandatory due to the possibility of changes in the chemical structure of soils.
- Minimum porosity of 30% for filled material
- Storage of water based on void ration of filter media
- Infiltration rate of surrounding soils requires to be determined for infiltration trenches
- Percolation through media using Darcy's Law
- Pre-treatment is required
- Distance between trenches and foundations, more than 3 metres.
- Plumb systems could be installed when the performance of trenches is not adequate.

Performance

Peak flow reduction	Medium
Volume reduction	Poor (FT) Good (IT)
Water quality treatment	Good
Amenity potential	Poor
Ecology potential	Poor

Maintenance requirements

Regular maintenance	Litter and debris removal from trench surface	Monthly
	Removal and washing of exposed stones on the trench surface	Annual
	Trimming of any roots	Annual
	Remove weeds on the trench surface	Monthly
Occasional maintenance	Removal of sediment from pre-treatment devices	Six monthly
	Remove tree roots or trees close to the trench	As required
	Remove surface geotextile and replace	Five yearly
Remedial actions	Clear perforated pipework of blockages	As required
	Rehabilitate infiltration	As required
	Replace geotextiles and clean and replace filter media if clogging	As required
	Excavate trench walls to expose clean soil	As required
	Inspect inlets, outlets and inspection points for blockages	Monthly
Monitoring	Inspect pre-treatment systems, inlets, trench… for silt accumulation	Half yearly

Advantages

- Recharge of aquifers increase the hydric resources

Restrictions and drawbacks

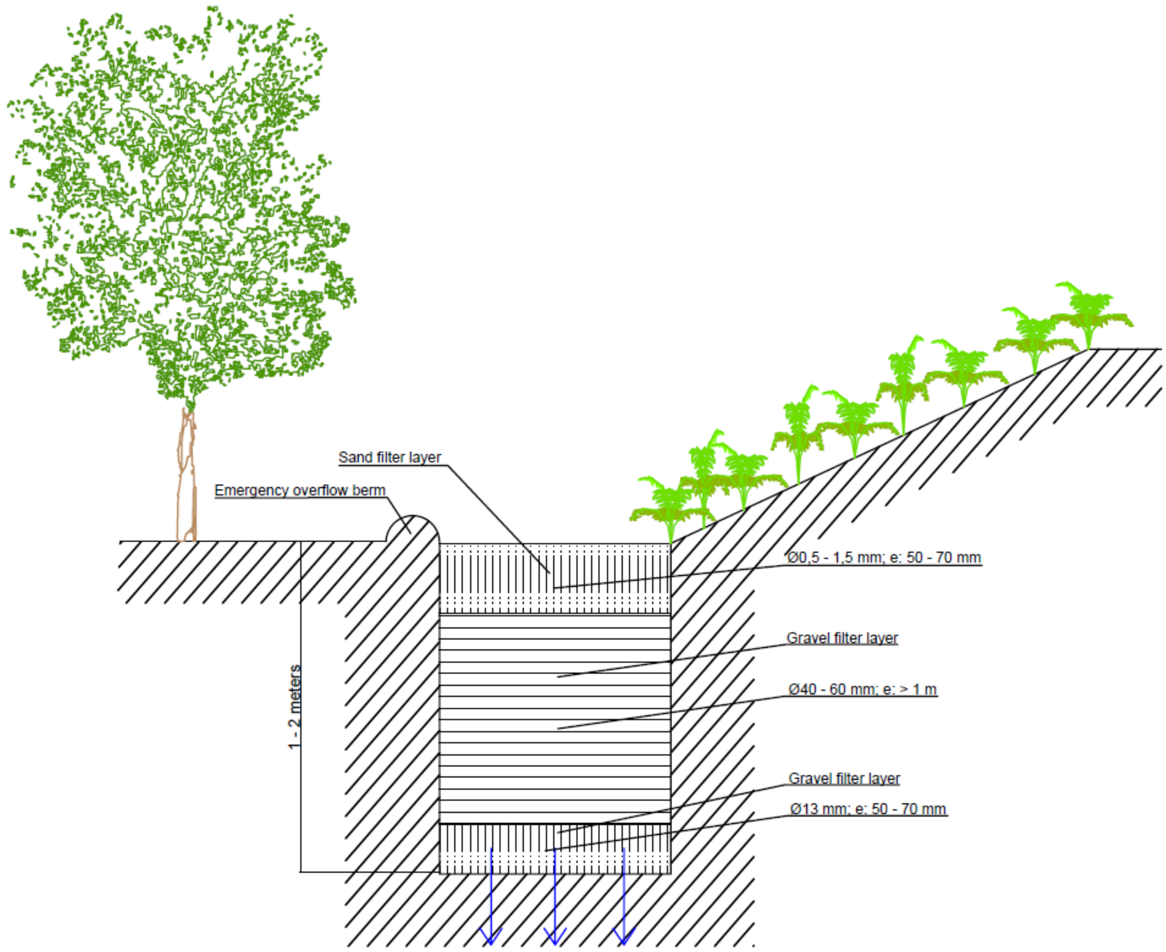
- Pre-treatment features required to prevent clogging

03	SC	TRENCHES

· Notable reductions both run-off rates and volumes · Infiltration reduction in the pollutant load · Easily incorporated to site landscaping · Good fitting with roads · Low costs of construction and maintenance	· Should not be used where large sediment loads may be deposited on the paved surface · Access points are required to clean periodically debris and vegetation · High costs of replacement of filter material

Cost implications		**Pollutant removal**	
Land take	Low	Total suspended soils	High
Capital costs	Low	Nutrients	Low/medium
Maintenance burden	Medium	Heavy metals	High

Scheme design



04	SC	INFILTRATION BASINS

Description

Infiltration basins are vegetated depressions formed naturally or artificially that are designed to retain surface water runoff and allow in to infiltrate into the ground

Objectives

- Retaining rainfall to increase the concentration time of rain
- Infiltration of rainfall water to reduce the volume of run-off and recharge aquifers
- Depuration of water from rainfall, removing sediments and pollutants
- Reusing rainfall to increase the availability of hydric resources

Types

- Parking slots
- Open space

Applications

- Trunk roads
- Distributor roads
- General access roads
- Industrial access roads
- Roads/street 250 – 10.000 veh./day
- Car parking
- Railway lines

Why are used?

- Good capability to remove the pollutants from water
- Significant reductions in the volume of run-off, reducing the risk of flooding
- Provide larger capacity of storage than soakaways or trenches
- Flexible design
- Low cost of construction and maintenance
- Easy access and installation

Design criteria

- Based on site investigation data with infiltration potential of underlying soils
- Maximum side slopes 1:4
- Basin half drain down time in 24 hours
- Maximum storage depth 0.8 m
- Complete drain down in less than 72 hours to prevent emergence of nuisance insects
- Area of drainage not larger than 10 ha.
- Distance to water table level not less than 1.2

Performance

Peak flow reduction	Medium
Volume reduction	Good
Water quality treatment	Good
Amenity potential	Good
Ecology potential	Good

Maintenance requirements

Regular maintenance	Litter, debris and trash removal	Monthly
	Grass cutting – landscaped areas and access routes	Monthly
	Grass cutting- meadow grass and around basin	Half yearly
	Manage other vegetation and remove nuisance plants	Monthly
Occasional maintenance	Replace clogged material	As required
	Seed periodically areas with poor vegetation	Annually
	Prune and trim trees	Annually
	Remove sediment from pre-treatment systems	As required
Remedial actions	Repair of erosion or other damages	As required
	Manage and repair landscaping	As required
	Rehabilitate infiltration surface	As required
	Re-level uneven surfaces and reinstate design levels	As required
Monitoring	Inspection inlets, outlets, structures or pipework	Monthly
	Inspection of silt accumulation	Half yearly
	Inspection of surfaces for compaction and ponding	Monthly

Advantages

- Reduction the volume of run-off
- Contributions to groundwater recharge
- Simple and low cost construction
- Changes in performance easy to observe

Restrictions and drawbacks

- Unsuitable in areas where groundwater vulnerable
- Unsuitable where the seasonally high water is within 1 m of formation
- Land take requirements high
- Pre-treatment systems are required

Cost implications

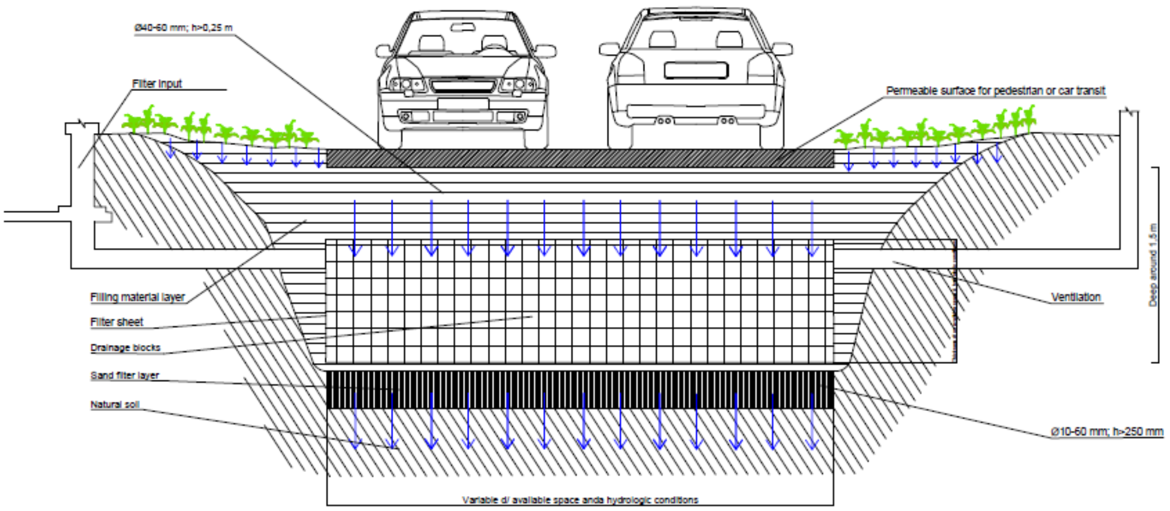
Land take	High
Capital costs	Low
Maintenance burden	Low

Pollutant removal

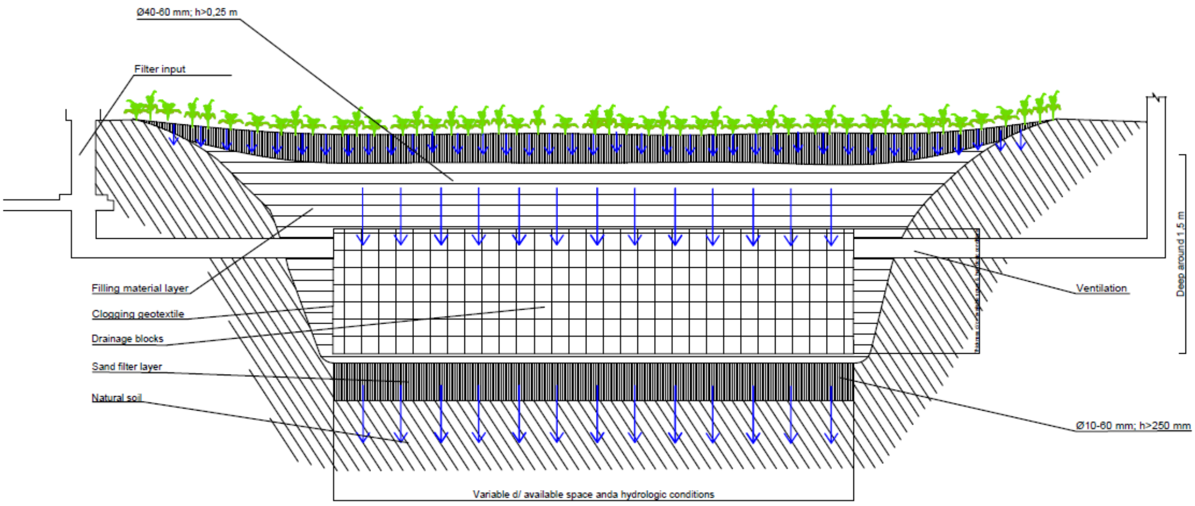
Total suspended soils	High
Nutrients	Medium
Heavy metals	High

Design scheme

04	SC	INFILTRATION BASINS



Parking slot



Open place

05	SC	GREEN ROOFS

Description

Multi-layered system that covers the roof or terrace of building or structure with vegetation over a drainage layer.

Objectives

- Retaining rainfall water to increase the concentration time and decrease the volume of run-off
- Depuration of rainfall water, removing sediments and pollutants
- Reuse of rainfall water to increase the availability of hydric resources

Applications

- Residential houses
- Buildings
- Factories
- Stations
- Terminals
- Petrol stations
- Podium structures

Why are used?

- Large capacity of removing large quantities of urban pollutants which are in the atmosphere by the vegetation, improving the quality of air.
- Larger capacity of storage that other similar systems in buildings
- No required new land take, resulting extremely suitable for renewal or refurbishment of buildings

Design criteria

- Minimum roof slope 2º
- Maximum roof slope 20º
- Anchorage required for slopes > 10º
- Additional structural strength for roof due to the hydraulic loads
- Several outlets to avoid risk of blockage
- Lightweight soil for fillings to avoid additional loads
- Overlapped geotextile at least 150 mm
- Type of vegetation depending of climate
- Non vegetated bands for fire prevention
- Perimeter strip of gravel of 400 mm wide to collect water surpluses

Performance

Peak flow reduction	Medium
Volume reduction	Medium
Water quality treatment	Good
Amenity potential	Good
Ecology potential	Good

Maintenance requirements

Regular maintenance	Irrigation during establishment of vegetation	Initially
	Remove debris and litter to prevent clogging of inlet drains	Six monthly or annual
	Replacement of dead plants	Monthly
	Remove fallen leaves and debris from plant foliage	Six monthly
	Remove nuisance and invasive vegetation	Six monthly
	Cut grass and remove clippings	Six monthly
Remedial actions	In case of erosion, stabilisation with additional soil substrate similar to original material.	As required
	Reparation of drain inlets when they were cracked or moved	As required
Monitoring	Inspection of all components including soil substrate, vegetation, drains, irrigation systems or membranes	Annually/ after severe storms
	Inspection of erosion in soils	Annually/ after severe storms
	Inspection of drain inlets to ensure good performance	Annually/ after severe storms
	Inspection of roof for evidence of leakage	Annually/ after severe storms

Advantages

- Increase the level of moisture in urban areas
- Improvements in the landscape, generating green areas
- Long useful life
- No large maintenance required.
- No land take

Restrictions and drawbacks

- Costs
- Not suggested for steep roofs
- Maintenance of roof vegetation
- High critically in case of failure of waterproof membrane.

Cost implications

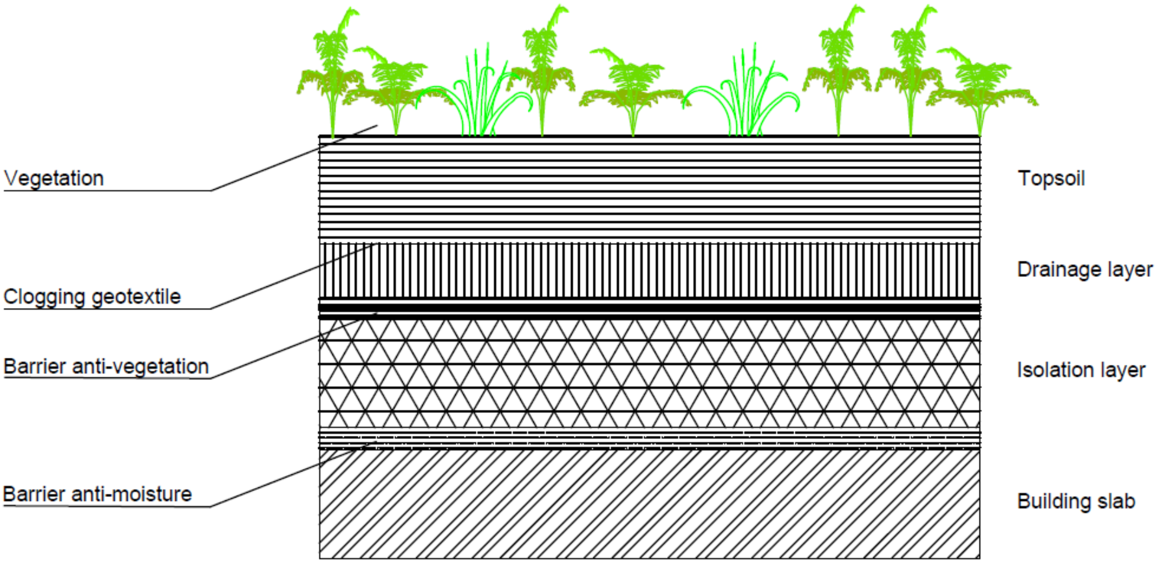
Land take	None
Capital costs	Medium-High
Maintenance burden	Medium

Pollutant removal

Total suspended soils	High
Nutrients	Low
Heavy metals	Medium

Design scheme

05	SC	GREEN ROOFS



Permeable conveyance systems

01	CS	FILTER DRAIN

Description

Roadside trenches filled with a permeable media to provide treatment and temporary storage of runoff. They are designed to collect the run-off from adjacent non-pervious areas, storage during brief periods to infiltrate into the soil or conveyance to other drainage system.

Objectives

- Retaining rainfall to increase the concentration time of rain
- Infiltration of rainfall water to reduce the volume of run-off and recharge aquifers
- Depuration of water from rainfall, removing sediments and pollutants
- Reusing rainfall to increase the availability of hydric resources

Types

- Allowing infiltration
- No infiltration allowed

Applications

- Trunk roads
- Distributor roads
- General access roads
- Industrial access roads
- Roads/street 250 – 10.000 veh./day
- Railway lines
- Perimeters of parking areas
- Residential areas

Why are used?

- Capability of removing some pollutants from the rainfall water
- High adaptability to both urban and rural landscapes because a variety of designs is possible
- Notably reduction of volume, speed and peak flow of the run-off
- Decrease the risk of flooding
- Capacity of substitution some of the traditional drainage systems
- Low cost of construction
- Easy access

Design criteria

- Depth will depend on soils, between 0.7 and 0.8 m.
- Minimum hydraulic load required of 1.2 m, 0.3 for perimeter drains
- Steep slope between 2 and 5%.
- Distance between bottom of drain and water table level larger than 1 m.
- Area of collection run-off not larger than 2 ha.
- Time of draining less than 40 hours.
- PVC pipe of 0.15 m of diameter
- Suggested use of clogging geotextile
- Minimum porosity of 40% for filled material
- Filled material could be substituted for modular blocks
- Not suggested in clay or lime soil
- Distance greater than 3 m between drains and foundations
- Design to pollution reduction of at least 75%.

Performance

Peak flow reduction	**Medium**
Volume reduction	**Good**
Water quality treatment	**Good**
Amenity potential	**Poor**
Ecology potential	**Poor**

Maintenance

Regular maintenance	Litter, debris and trash removal	Monthly
	Removal and washing of exposed stones on the surface	Annual
	Trimming roots for avoiding blockages	Annual
	Remove weeds	Monthly
Occasional maintenance	Removal of sediment	Six monthly
	Remove tree roots or trees close to the drain	As required
	Remove surface geotextile and replace or wash	Five yearly
Remedial actions	Clear perforated pipework of blockages	As required
	Rehabilitate infiltration surfaces	As required
	Replace geotextiles and clean or replace filter media if clogging	As required
	Re-excavate trench walls to expose clean soil in filtration reduces	As required
	Inspection inlets, outlets, structures or pipework for blockages	Monthly
Monitoring	Inspection of silt accumulation	Half yearly
	Inspection of surfaces for compaction and ponding	Monthly

Advantages

- Low construction costs
- Easily incorporation to existing drainage systems
- Notably reductions of volume and run-off rates
- Significant reduction of pollutants
- Good environment integration

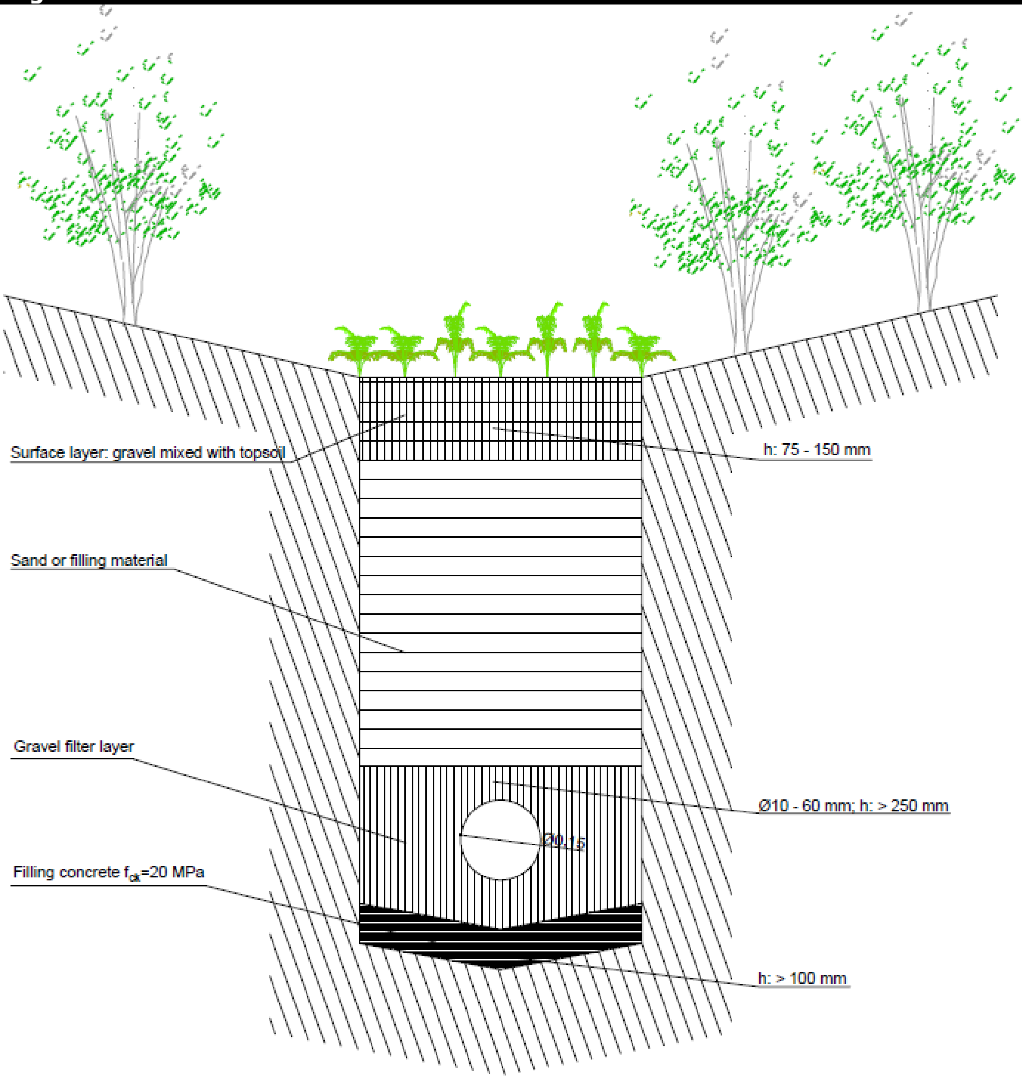
Restrictions and drawbacks

- Not suitable in steep sites
- Not suitable for draining hotspot run-off
- Not significant attenuation or reduction of extreme event flow
- Long period of water storage could be result in clogging issues
- In case of obstruction, bad smells and nitrates appearance

Cost implications		Pollutant removal	
Land take	Low	Total suspended soils	High

01	CS	FILTER DRAIN	
Capital costs	Medium	Nutrients	Medium
Maintenance burden	Medium/high	Heavy metals	High

Scheme design



02	CS	SWALES

Description

Shallow open excavations, with sloped walls and dense vegetation, particularly designed to collect run-off from adjacent non-pervious areas, depurates and infiltrates into the soil. They are usually designed smaller than filtration trenches and larger than filter drains.

Objectives

- Retaining rainfall to increase the concentration time of rain
- Infiltration of rainfall water to reduce the volume of run-off and recharge aquifers
- Depuration of water from rainfall, removing sediments and pollutants
- Reusing rainfall to increase the availability of hydric resources

Types

- Standard conveyance swales
- Dry swale
- Wet swale

Applications

- Trunk roads
- Distributor roads
- General access roads
- Industrial access roads
- Roads/street 250 – 10.000 veh./day
- Recreational areas (parks, gardens, leisure areas)
- Railway lines

Why are used?

- Good capability of removing pollutants from water rainfall due to the surface vegetation
- High adaptability to existing environments because a variety of designs is possible
- Pre-treatment system, complementary to existing drainage systems
- Notably reduction of volume, speed and peak flow of the run-off, decreasing risk flooding

Design criteria

- Storage of water based on void ration of filter media
- Infiltration rate of surrounding soils requires to be determine for infiltration trenches
- Percolation through media using Darcy's Law
- Depth between 0,55 and 0,75 metres,
- Protection distance of 0,15 m
- Minimum width 0.5 m, with distances between 2 and 3.
- Minimum length 30 m.
- Trapezoidal cross-section to ensure uniform water flow.
- Wall slopes between 25 and 35%.
- Longitudinal slopes between 2 and 4% to avoid erosion issues.
- Water flow speed between 0.3 m/s and 2 m/s
- Laminar water flow
- Minimum distance between swale and close foundation of 3 m.
- Suggest to match with existing streams water
- In polluted areas, isolation sheet is required.

Performance

Peak flow reduction	Medium
Volume reduction	Medium
Water quality treatment	Good
Amenity potential	Medium
Ecology potential	Medium

Maintenance

Regular maintenance	Litter and debris removal	Weekly
	Grass cutting	Monthly
	Manage other vegetation and remove nuisance plants	Annually
Occasional maintenance	Checking poor vegetation and control adjacent vegetation	Annually
	Re-seed areas of poor vegetation growth	Annually or as required
Remedial actions	Repair erosion or other damage	As required
	Re-level uneven surfaces	As required
	Scarify and spike topsoil layer to improve infiltration properties	As required
	Remove sediments	As required
	Remove and dispose of oils or petrol residues	As required
Monitoring	Inspection inlets, outlets and overflows for blockages	Monthly
	Inspection of infiltration surfaces to check silt accumulation	Monthly or as required

Advantages

- Low construction and maintenance costs
- Easy installation and access
- Good removal of pollutants
- Improvements in the landscape
- Maintenance can be incorporated to general road management
- Failures or blockages are visible and easy to deal with.

Restrictions and drawbacks

- Pre-treatment features required to prevent clogging
- Should not be used where large sediment loads may be deposited on the paved surface
- High land take
- High maintenance needs to avoid clogging or failures
- Not suitable for steep areas

Cost implications

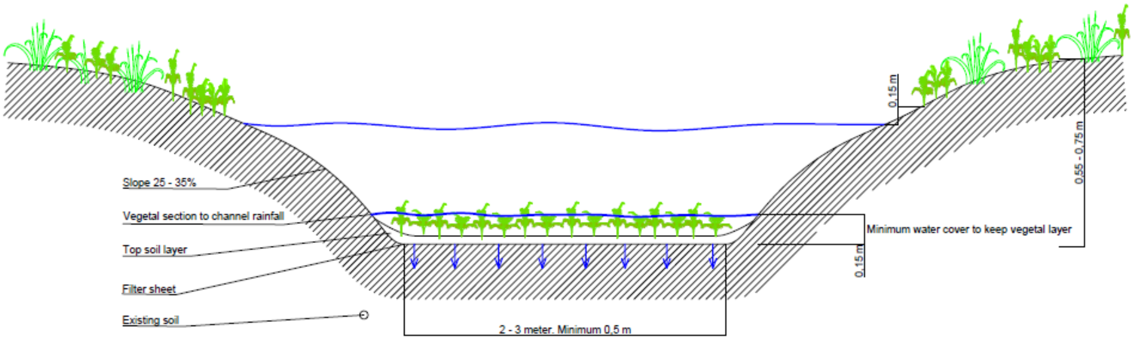
Land take	High

Pollutant removal

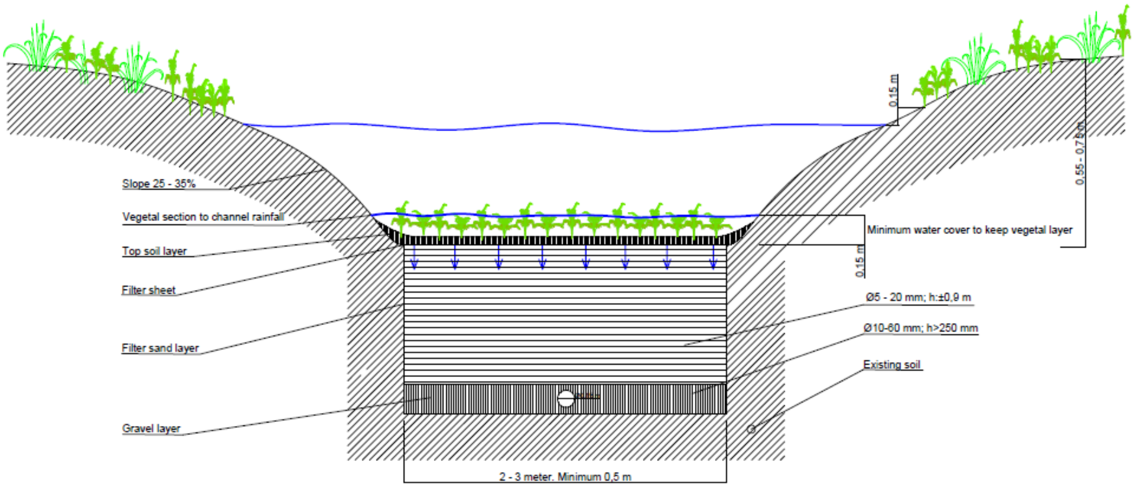
Total suspended soils	High

02	CS	SWALES	
Capital costs	Low	Nutrients	Low
Maintenance burden	Medium	Heavy metals	Medium

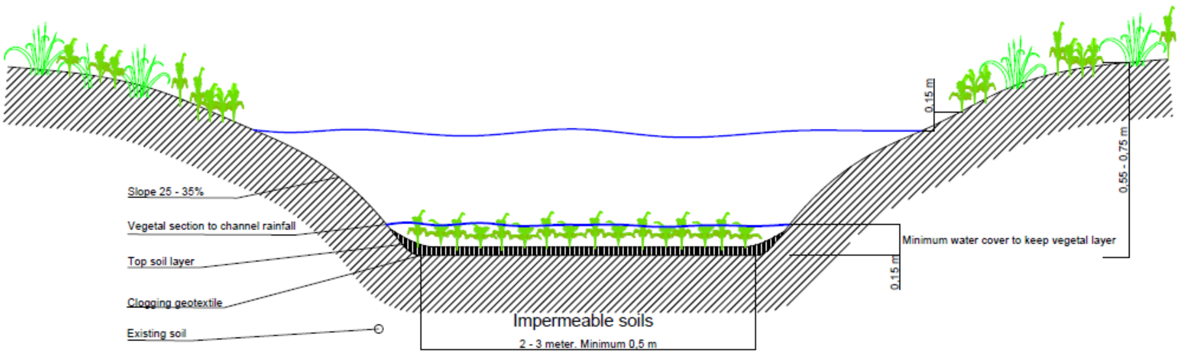
Scheme design



Standard conveyance swale



Dry swale



Wet swale

Passive treatments

01	PT	FILTER STRIPS

Description

Filter strips are strip of grass or other dense vegetation, installed in the perimeters of non-pervious areas. They receive water from adjacent non-pervious areas, treating the run-off by vegetative filtering, and promoting settlement for some pollutants.

Objectives

- Retaining rainfall to increase the concentration time of rain
- Infiltration of rainfall water to reduce the volume of run-off and recharge aquifers
- Depuration of water from rainfall, removing sediments and pollutants
- Reusing rainfall to increase the availability of hydric resources

Applications

- Trunk roads
- Distributor roads
- General access roads
- Industrial access roads
- Roads/street 250 – 10.000 veh./day
- Rural roads
- Minor access link
- Recreational areas (parks, gardens, leisure areas)
- Parking areas
- Railway lines

Why are used?

- Good capability of removing pollutants from water rainfall due to the surface vegetation
- Improvements in the landscape
- High adaptability to existing environments because a variety of designs is possible
- Pre-treatment system, complementary to existing drainage systems
- Decrease the risk of flooding

Design criteria

- Flow across the filter strip determined by Manning's formula
- Minimum residence time of 5 minutes
- Minimum width recommended of 6 m.
- Maximum width recommended of 15 m.
- Maximum length of 50 m is suggested
- Slopes between 2 to 5%.
- Water depth less than 50 mm
- Water flow speed recommend between 0.3 m/s and 1.5 m/s
- Topsoil should drain well and allow the growth of dense vegetation
- Berm material should be of sand, gravel or sandy loam to encourage grass cover
- Recommended in areas with flashing rain events

Performance

Peak flow reduction	Poor
Volume reduction	Poor
Water quality treatment	Medium
Amenity potential	Medium
Ecology potential	Medium

Maintenance

Regular maintenance	Litter and debris removal	Monthly
	Grass cutting	Monthly
	Manage other vegetation and remove nuisance plants	Monthly
Occasional maintenance	Checking poor vegetation growth	Annually
	Seed areas of poor vegetation growth	Annually
Remedial actions	Repair erosion or other damage	As required
	Re-level uneven surfaces	As required
	Scarify and spike topsoil to improve infiltration features	As required
	Removed sediments	As required
	Remove oils or petrol residues	As required
Monitoring	Inspection filter strip surface to identify failures (erosion, ponding…)	Half yearly
	Checking flow spreader and filter strip surface for even gradient	Half yearly
	Inspection of filter strip for clogging	Half yearly
	Inspection silt accumulation	Half yearly

Advantages

- Easy and low construction costs
- Increase in the evaporation and the level of moisture in urban areas
- Effective pre-treatment option
- Easily adaptable to existing infrastructures
- Aesthetic benefits due to the increase of green areas
- Good social acceptability
-

Restrictions and drawbacks

- High land take requirements
- Not suitable for treating point source flows
- Not suitable for steep sites
- Should not be used where large sediment loads may be deposited on the paved surface
- No significant attenuation or reduction of extreme event flows
- Other drainage system is required to additional treatment

Cost implications

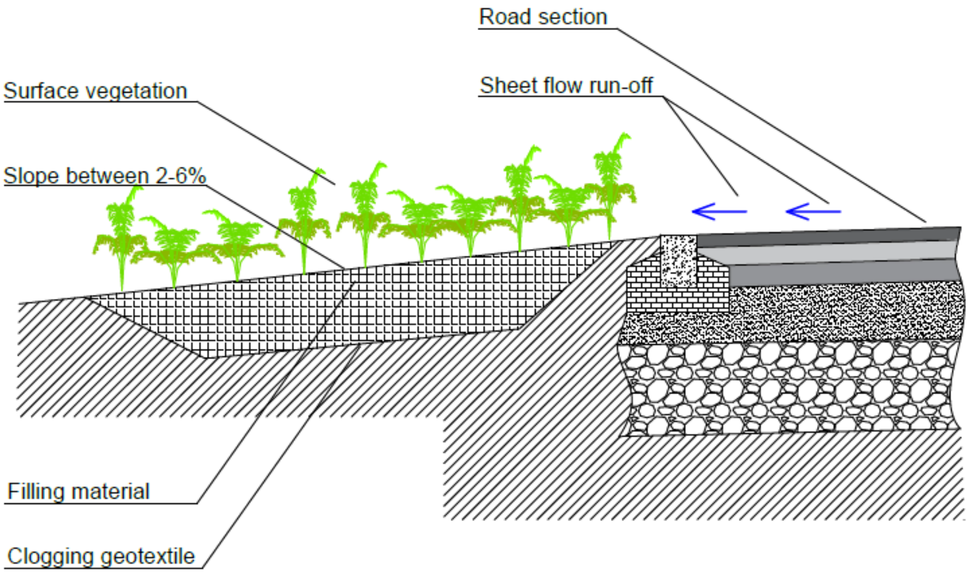
Land take	High
Capital costs	Low

Pollutant removal

Total suspended soils	High
Nutrients	Low

01	PT	FILTER STRIPS	
Maintenance burden	Low	Heavy metals	Medium

Scheme design



02	PT	DETENTION BASINS

Description

Detention basins are artificial depressions in the surface in which the water from run-off is storage, providing control over storm flows and facilitating the settlement of some pollutants.

Objectives

- Retaining rainfall to increase the concentration time of rain
- Depuration of some pollutants
- Reusing of water from rainfall

Applications

- Trunk roads
- Roundabouts
- Residential areas
- Public spaces
- As a reception element from other drainage systems

Why are used?

- Good capability of removing pollutants from water rainfall due to the surface vegetation
- High adaptability to the environment
- Providing recreational facility
- Notably capacity of storage run-off and reducing risks of flooding

Design criteria

- Maximum depth of water in the basin not larger than 3 m.
- Bottom of the basin slope no more than 1% to maximise contact of run-off with the vegetation
- Maximum side slopes of 25%
- Recommended length/width ratio between 2:1 and 5:1
- Outlets placed to maximise the flow
- Liner required to maintain the water level in a micropool
- Geomembrane required to ensure a correct isolation
- Embankment fill material should use inert natural soils avoiding leaches into the stored run-off
- Capacity of storage more than 25.000 m3 will require special requirements in terms of safety
- Planning sedimentation bay should be at least 10% or the total basin area
- In systems with multiple inlets, pre-treatment should be provided for each inlet
- Use of rip-rap or other control system is suggested, particularly in case of high risk of erosion

Performance

Peak flow reduction	Good
Volume reduction	Poor
Water quality treatment	Medium
Amenity potential	Good
Ecology potential	Medium

Maintenance

Regular maintenance	Litter and debris removal	Monthly
	Grass cutting: spillways and meadow grass around basin	Monthly/Half yearly
	Manage vegetation and remove nuisance plants	Monthly
	Tidy dead vegetation	Annually
	Remove sediments from inlet or outlets	Annually or as required
	Manage wetland plants in outlet pool	Annually
Occasional maintenance	Seed areas of poor vegetation	Annually
	Prune and trim trees and remove cuttings	Two years
	Remove sediment from forebay	Three-ten years
Remedial actions	Repair erosion and other damages	As required
	Realignment of rip-rap	As required
	Repair inlets and outlets	As required
	Re-level uneven surfaces	As required
Monitoring	Inspection of inlet, outlets for blockages	Monthly/ after large storms
	Inspection banksides, structures, pipework…	Monthly/ after large storms
	Inspection inlets and facilities for silt accumulation	Half yearly
	Checking mechanical devices	Half yearly

Advantages

- Easy designing, construction
- Can deal with a wide range of rainfall events
- Suitable where groundwater is vulnerable
- Minimising 'heat island effect' in urban areas
- Potential dual land use
- Adaptable to existing elements i.e. roundabouts
- Easy detection of failure i.e. spillages

Restrictions and drawbacks

- Little reduction in run-off volume
- Geometry is constrained by systems of inlets and outlets
- Regular maintenance is required
- Periodical renovation of water is mandatory to avoid bad smells and mosquitoes

Cost implications

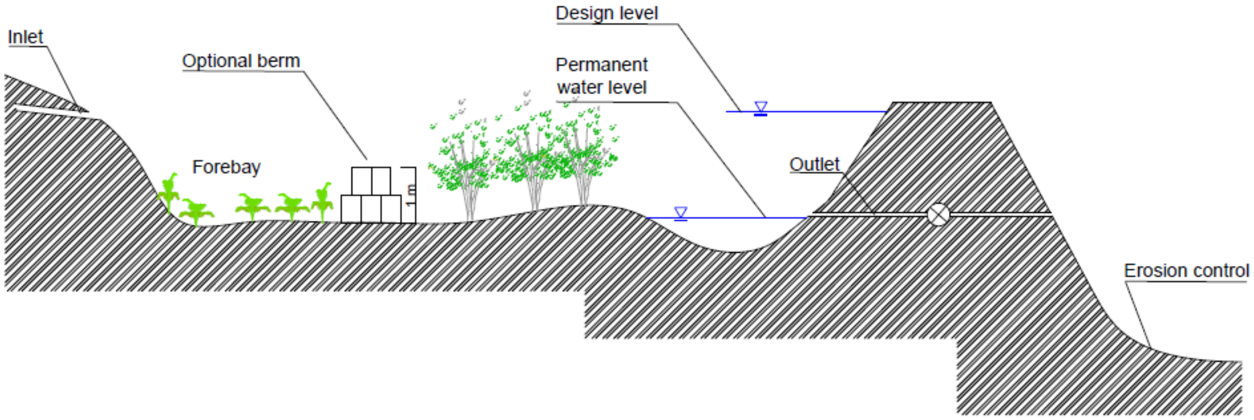
Land take	Medium-High

Pollutant removal

Total suspended soils	Medium

02	PT	DETENTION BASINS	
Capital costs	Low	Nutrients	Low
Maintenance burden	Low	Heavy metals	Medium

Scheme design



03	PT	RETENTION PONDS

Description

Shallow depression, natural or excavating, in the ground, covered by vegetation, designed to treat the rainfall water by a temporal retaining, removing pollutants, and sediments. They reduce the risk of flood, decreasing the volume of run-off and conveyance the water to other element to be reused o infiltrated.

Objectives

- Retaining rainfall to increase the concentration time of rain
- Depuration of some pollutants
- Reusing of water from rainfall

Applications

- Residential areas
- Public spaces, with easy access and level ground
- As a collection element from other drainage systems
- Close areas to terminals and stations
- Roads/streets 1.000 – 10.000 veh/d
- Trunk roads
- All distributor roads
- General access roads
- Industrial access roads
- Railway lines

Why are used

- Capability of removing some pollutants
- Notably reductions of run-off volume
- Decrease of the risk of flooding
- Optimal response to extreme rainfall events due to their large storage capacity
- Easily combinable to other drainage systems, traditional or sustainable.
- Due to its capability of retention could be used to substitute or complement traditional spillways
- Add value to close properties in the area of installation

Design criteria

- Minimum depth of water of 1.2 m
- Maximum depth of permanent water of 2 m
- Maximum side slopes of 35% (suggested between 25-30%)
- Recommended length/width ratio between 3:1 and 5:1
- Bottom slope lower than 15% to ensure low water flow speeds.
- A wedge shape design is suggested to reduce the speed of the water flow
- Areas of collection water lower than 30 ha.
- Design to store a temporal volume of water depending on the local conditions
- Time of evacuation not longer than 48 hours
- Several spillways are required to drain the excess water
- Pre-treatment for run-off not required
- Native plants are recommended to the design of topsoil to ensure the nature conservation and lower costs of maintenance

Performance

Peak flow reduction	Good
Volume reduction	Poor
Water quality treatment	Good
Amenity potential	Good
Ecology potential	Good

Maintenance

Regular maintenance	Litter and debris removal	As required
	Grass cutting in public areas and meadows grass	Monthly/ Half yearly
	Inspection vegetation in pond edge and remove nuisance plants	Monthly
	Cutting submerged and emergent aquatic plants	Annually
	Remove bank vegetation from water edge to a minimum of 1 m above water level	Annually
	Tidy and remove dead vegetation	Annually
	Remove sediment from forebay	1-5 years
	Remove sediment from one quadrant of the main body water	2-10 years
Occasional maintenance	Remove sediment from the main body of big ponds if the volume is reduce to 20%	>25 years
Remedial actions	Reparation of erosion or other damage	As required
	Aerate pond when eutrophication occurs	As required
	Realignment of rip-rap	As required
	Repair or rehabilitation of inlets and outlets	As required
Monitoring	Inspection structures if poor operation	Monthly/after large storms
	Inspection banksides, structures, pipeworks… for physical damages	Monthly/after large storms
	Inspection water body for signs of eutrophication	Monthly
	Inspection silt accumulation	Half yearly
	Check mechanical devices	Half yearly

Advantages

- High adaptability to match with existing environments

Restrictions and drawbacks

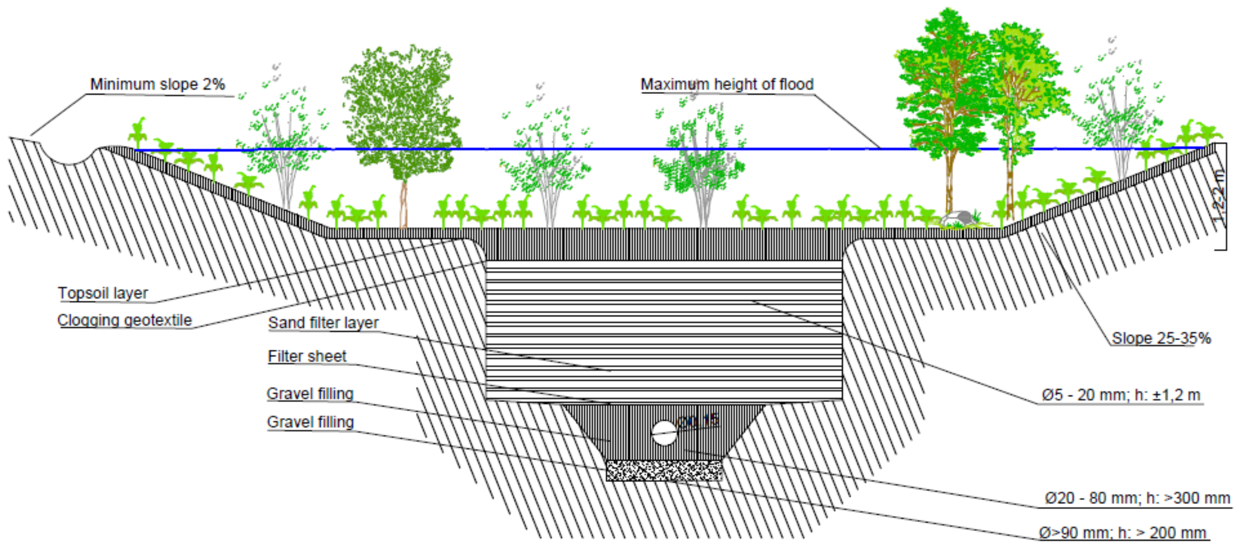
- Regular maintenance is required to ensure a good

03	PT	RETENTION PONDS

• Improvements in the landscapes due to the generation of new green and leisure spaces • Recovery of biodiversity in degrades environments • Optimal response to extreme rain events due to its large capacity of storage • Notably reduction of run-off volume • Suitable in areas with regular periods of droughts since not require a permanent sheet of water • Minimising of 'heat island effect'	performance • Anaerobic conditions can occur without regular flows • Periodical renovation of water is mandatory to avoid bad smells and mosquitoes • Not suitable in steep areas • Risk of colonisation by invasive species • High land take • Health and safety risk will lead to fence and isolate the pond

Cost implications		**Pollutant removal**	
Land take	High	Total suspended soils	High
Capital costs	Medium	Nutrients	Medium
Maintenance burden	Medium	Heavy metals	High

Scheme design



04	PT	WETLANDS

Description

Wetlands are shallow depressions, naturally or artificially formed, comprising marshy areas and shallow ponds, and are almost entirely covered with wetlands vegetation

Objectives

- Retaining rainfall to increase the concentration time of rain
- Infiltration of rainfall water to reduce the volume of run-off and recharge aquifers
- Depuration of water from rainfall removing sediments and pollutants
- Reusing rainfall to increase the availability of hydric resources

Types

- Shallow wetland
- Extended detention shallow wetland
- Pocket wetlands

Applications

- Residential areas
- Public spaces, with easy access and level ground
- As a collection element from other drainage systems
- Close areas to terminals and stations
- Roads 1.000 – 10.000 veh/d
- Trunk roads
- All distributor and general access roads
- Industrial access roads
- Railway lines

Why are used?

- Large capacity of removing large quantities of pollutants from the rainfall water (50-90%) due to the process of filtering by the vegetation
- Significant reduction in the volume of run-off, reducing the risk of flooding
- Optimal response to extreme rainfall episodes due to their large capacity of storage and infiltration
- Generation of green areas for social affairs
- Add value to close properties in the area of installation

Design criteria

- Retention time from 16 to 24 hours
- Length to width ratio 1.5:1 to 4:1
- Width greater than 5 m
- Maximum depth of 2 m.
- Distance between inlets and outlet between 0.9 and 1.5 m.
- Water flow speed around 0.1 m/s to ensure appropriate time of retaining
- High land take of around 10 ha.
- Time of evacuation of 24 hours.
- Surface area = 1% catchment area
- Continuous base flow to ensure wetlands does not dry out
- Combinations of deep and shallow areas
- Shallow side slopes
- A proper penstock system is required
- Natural and local vegetation is suggested to ensure good performance and low maintenance costs

Performance

Peak flow reduction	Good
Volume reduction	Poor
Water quality treatment	Good
Amenity potential	Good
Ecology potential	Good

Maintenance requirements

Regular maintenance	Litter/trash/debris and surface scum removal	Monthly
	Grass cutting	Monthly
	Inspection of vegetation to wetland edge and remove nuisance	Monthly
	Hand cut submerged and emergent aquatic plants	Annually
	Remove of 25% of bank vegetation from waters' edge	Annually
	Tidy all dead growth before starts of growing season	Annually
	Remove sediment from one quadrant of sediment	Annually
Occasional maintenance	Remove sediments from the main body of wetland when its volume is reduced by 20%	5-25 years
Remedial actions	Repair of erosion or other damage	As required
	Manage and repair landscaping	As required
	Supplement plants if vegetation is not established after the growing season	Single event
Monitoring	Inspection of structures	Monthly/ after large storms
	Inspection of silt accumulation	Monthly/ after large storms
	Check penstocks and other mechanical devices	Six monthly

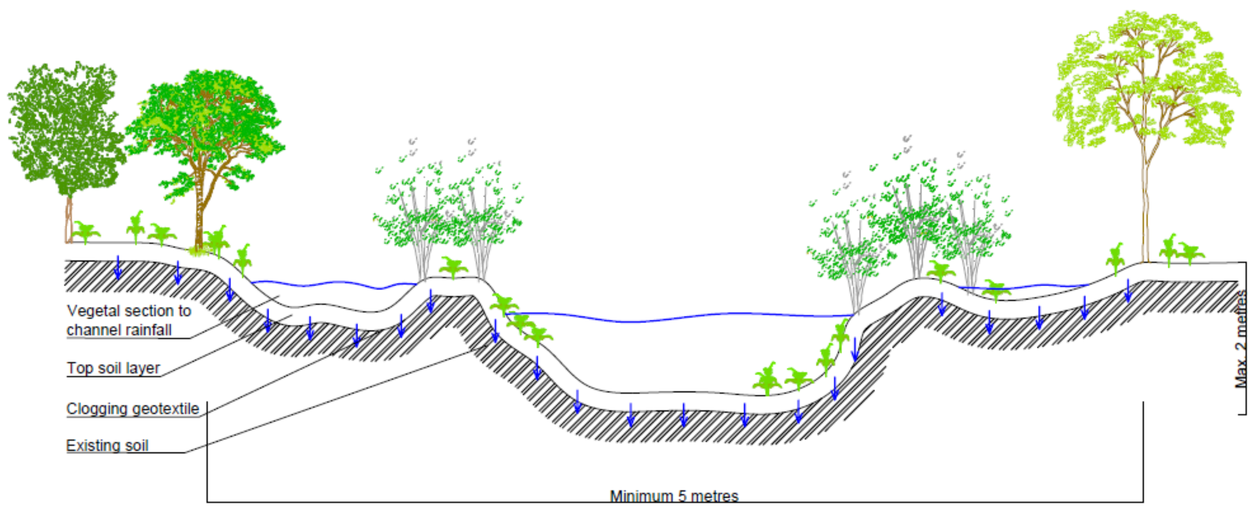
Advantages

- Large capacity for removing pollutants

Restrictions and drawbacks

- Land take requirements high

04	**PT**	**WETLANDS**	
· Good social acceptability, improvements in the landscapes · High potential ecological · Add value to local properties · Recharge of local aquifers · High adaptability to the available space		· Need impervious soils or liner · Unsuitable at grades above 5% where wetland is adjacent to the road · Not suggested in areas where the water sheet cannot be guaranteed permanently	
Cost implications		**Pollutant removal**	
Land take	High	Total suspended soils	High
Capital costs	High	Nutrients	Medium
Maintenance burden	Low-Medium	Heavy metals	High
Design scheme			



05	PT	RAINGARDEN or BIORETENTION AREA

Description

Vegetated and shallow depressions of ground with an outlet, used to reduce the volume of run-off by retaining the water during short periods of time and its subsequent infiltration.

Objectives

- Retaining rainfall to increase the concentration time of rain
- Infiltration of rainfall water to reduce the volume of run-off and recharge aquifers
- Depuration of water from rainfall removing sediments and pollutants
- Reusing rainfall to increase the availability of hydric resources

Types

- Lined
- Non-lined

Applications

- Trunk roads
- Distributor roads
- General access roads
- Industrial access roads
- Roads/street 250 – 10.000 veh./day

Why are used?

- High efficiency in removing urban pollutants during the filtering process
- Notably reductions in volume and speed of urban run-off
- Decreases in the risk of flooding
- High adaptability to existing environments
- Not high land take demanding

Design criteria

- Design will depend on the location
- Minimum width of 1.5 m.
- Ratio width/depth of 2:1
- Suggested depth for sandy subbase of 1 m.
- Suggested depth of the vegetation layer of 0.30 m.
- Height of the water sheet not exceeds 0.15 m.
- Times of evacuation of 50% of rainfall event of 24 hours and 100% of rainfall event of 48 hours.
- Applicable in levelled areas or with little steeps
- Area of installation around 5-10% of the surface of collection water
- Liner mandatory in areas where infiltration cannot be allowed due to close foundations.
- Overflow/bypass facilities for extreme events

Performance

Peak flow reduction	Medium
Volume reduction	Medium
Water quality treatment	Good
Amenity potential	Good
Ecology potential	Medium

Maintenance

Regular maintenance	Removal of litter and debris	Monthly
	Removal and replace the mulching	Annually
	Pruning and trimming of trees	Two years
	Spiking, scarifying topsoil	Three years
Occasional maintenance	Watering of plants	As required
	Weeding	As required
Remedial actions	Removal of damage or silt covered vegetation	As required
	Treatment of diseased trees	As required
	Re-seed of grass poor vegetated areas	As required
	Reinstatement of design level and restoration of infiltration systems	As required
Monitoring	Inspection of inlets, outlets for blockages	Monthly/after large storms
	Inspection of infiltration surfaces for ponding	Monthly or when required
	Inspection inlets for silt accumulation	Half yearly
	Test planting soil for pH	Annually

Advantages

- Recharge of aquifers
- High adaptability of existing environments
- High efficiency in terms of removing pollutants
- Can be planned as landscaping features
- Good retrofit capability

Restrictions and drawbacks

- Not suitable for areas with steep slopes
- Should not be used where large sediment loads may be deposited on the surface
- Periodic maintenance is required to ensure a good performance

Cost implications

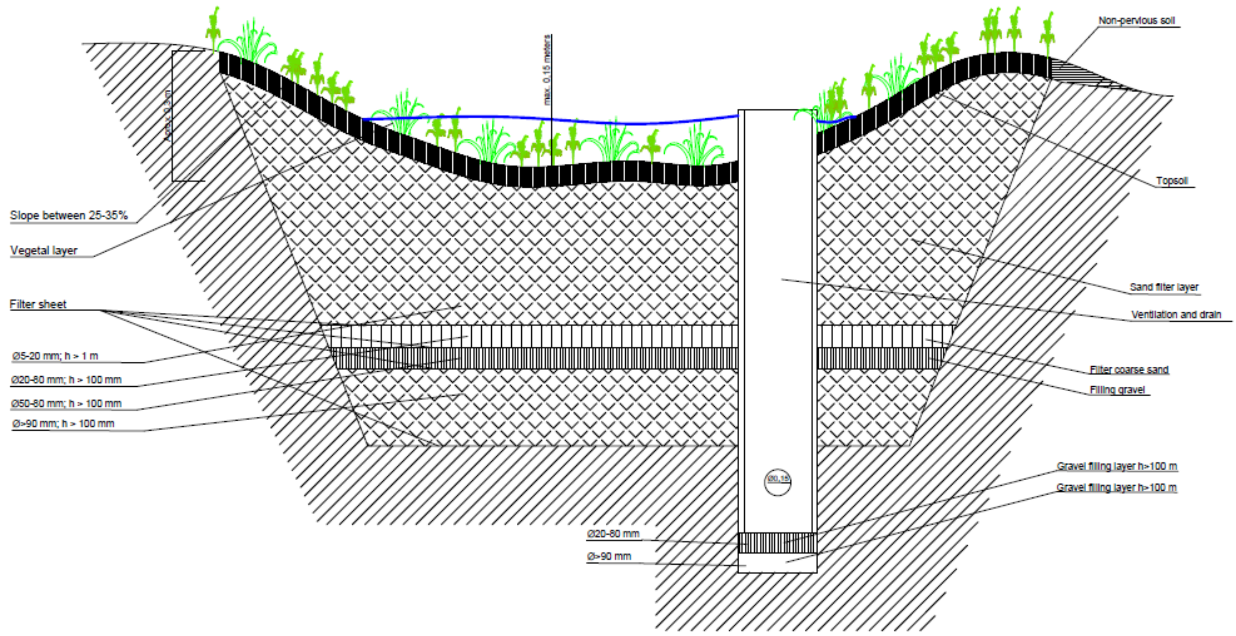
Land take	High
Capital costs	Low
Maintenance burden	Medium

Pollutant removal

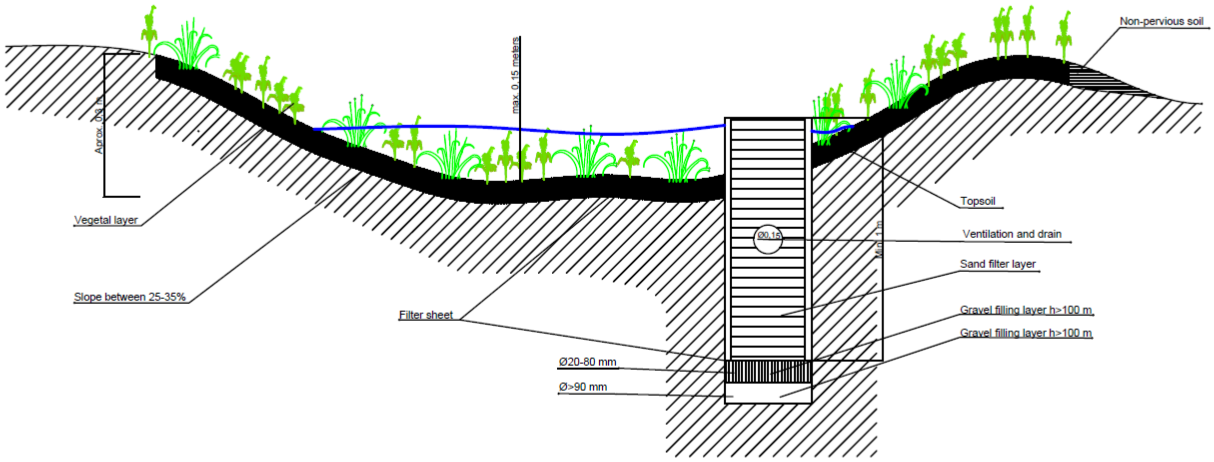
Total suspended soils	High
Nutrients	Low
Heavy metals	High

Scheme design

05	PT	RAINGARDEN or BIORETENTION AREA



Lined



Non-lined

APPENDIX II. MULTICRITERIA ASSESSMENT OF SDS

Weighting indicators for criteria

Performance

Sustainable drainage system	Performance					
	Peak flow reduction	Volume reduction	Water quality treatment	Amenity potential	Ecology potential	Aggregate index
Source control						
Permeable surface	3	3	3	1	1	**7,33**
Soakaway	3	3	3	1	1	**7,33**
Filtration trenches	2	1	3	1	1	**5,33**
Infiltration trenches	2	3	3	1	1	**6,67**
Infiltration basin	2	3	3	3	3	**9,33**
Green roofs	2	2	3	3	3	**8,67**
Permeable conveyance systems						
Filter drain	2	3	3	1	1	**6,67**
Swales	2	2	3	2	2	**7,33**
Passive treatment						
Filter strips	1	1	2	2	2	**5,33**
Detention basin	3	1	2	3	2	**7,33**
Retention ponds	3	1	3	3	3	**8,67**
Wetlands	3	1	3	3	3	**8,67**
Bioretention areas	2	2	3	3	2	**8,00**
Good = 3; Medium = 2; Poor = 1						

Table 12. Multi criteria analysis for performance criterion

Costs

Sustainable drainage system	Costs			
	Land take	Capital costs	Maintenance burden	Aggregate index
Source control				
Permeable surface	3	2	2,5	**8,33**
Soakaway	3	3	3	**10,00**
Filtration trenches	3	3	2	**8,89**
Infiltration trenches	3	3	2	**8,89**
Infiltration basin	1	3	3	**7,78**
Green roofs	3	1,5	2	**7,22**
Permeable conveyance systems				
Filter drain	3	2	1,5	**7,22**
Swales	1	3	2	**6,67**
Passive treatment				
Filter strips	1	3	3	**7,78**
Detention basin	1,5	3	3	**8,33**
Retention ponds	1	2	2	**5,56**
Wetlands	1	1	2,5	**5,00**
Bioretention areas	1	3	2	**6,67**
High = 3; Medium = 2; Low = 1				

Table 13. Multi criteria analysis for cost criterion

Pollutant removal capacity

Sustainable drainage system	Pollutant removal capacity			
	Land take	Capital costs	Maintenance burden	Aggregate index
Source control				
Permeable surface	3	3	3	**10,00**
Soakaway	2	1	2	**5,56**
Filtration trenches	3	1,5	3	**8,33**
Infiltration trenches	3	2	3	**8,89**
Infiltration basin	3	2	3	**8,89**
Green roofs	3	1	2	**6,67**
Permeable conveyance systems				
Filter drain	3	2	3	**8,89**
Swales	3	1	2	**6,67**
Passive treatment				
Filter strips	3	1	2	**6,67**
Detention basin	2	1	2	**5,56**
Retention ponds	3	2	3	**8,89**
Wetlands	3	2	3	**8,89**
Bioretention areas	3	1	3	**7,78**
High = 3; Medium = 2; Low = 1				

Table 14. Multi criteria analysis for pollutant removal capacity criterion

Maintenance needs

Sustainable drainage system	Maintenance needs													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	Aggregate index
Source control														
Permeable surface	1	1	0	0	1	1	0	0	1	1	1	1	1	**6,92**
Soakaway	1	1	0	1	0	1	1	1	0	0	1	1	0	**6,15**
Filtration trenches	1	1	0	1	0	1	1	0	0	0	0	1	0	**4,62**
Infiltration trenches	1	1	0	1	0	1	1	0	0	0	0	1	0	**4,62**
Infiltration basin	1	0	0	1	0	0	1	0	0	0	1	1	0	**3,85**
Green roofs	0	0	0	1	0	0	1	0	1	1	1	0	1	**4,62**
Permeable conveyance systems														
Filter drain	1	1	0	1	1	1	1	1	0	0	0	1	0	**6,15**
Swales	1	1	0	1	0	0	0	1	0	0	1	0	1	**4,62**
Passive treatment														
Filter strips	1	1	0	1	1	0	0	1	0	0	1	0	1	**5,38**
Detention basin	1	1	0	1	0	1	0	1	0	0	1	1	0	**5,38**
Retention ponds	1	1	0	1	0	1	0	1	0	0	1	1	0	**5,38**
Wetlands	1	0	0	1	1	1	1	1	1	1	1	0	1	**7,69**
Bio retention areas	1	0	0	1	0	0	0	0	1	0	0	0	1	**3,08**
(1) Clear shingle perimeter and drainage layer, removing unwanted vegetation; (2) Retain dead stems in autumn as habitat for over-wintering invertebrates; (3) Remove litter and other inorganic debris as required; (4) Clean and refill blocks paver joints with gravel; (5) Undertake trimming, pruning or removing leaves cutting; (6) Replace dead plants and, adjusting species mix according to local conditions; (7) Mow to achieve a sward structure. Use clippings to crease habitat piles; (8) Weed as necessary, employ a light touch; (9) Remove silt; (10) Check inlets/outlets/sediment traps and remove blockages; (11) Reinstate permeable surface by spiking or scarifying; (12) Repair, create new and maintain habitat features; (13) Maintain access routes to inlets/outs and other features inspection														

Table 15. Multi criteria analysis for maintenance needs criterion

Applicability

Sustainable drainage system	Applicability													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	Aggregate index
Source control														
Permeable surface	1	1	1	1	1	0	0	0	0	0	0	1	1	**5,38**
Soakaway	1	1	1	1	0	1	1	0	1	0	0	0	1	**6,15**
Filtration trenches	1	1	1	1	0	1	0	1	1	0	0	0	0	**5,38**
Infiltration trenches	1	1	1	1	0	1	0	1	1	0	0	0	0	**5,38**
Infiltration basin	1	1	1	1	0	0	0	1	1	0	0	0	0	**4,62**
Green roofs	0	0	0	0	0	1	1	1	0	1	1	0	0	**3,85**
Permeable conveyance systems														
Filter drain	1	1	1	1	0	1	0	1	1	0	0	0	0	**5,38**
Swales	1	1	1	0	0	0	0	1	1	0	0	1	0	**4,62**
Passive treatment														
Filter strips	1	1	1	1	1	0	0	1	1	0	0	1	0	**6,15**
Detention basin	0	1	1	0	1	1	1	0	1	1	0	1	1	**6,92**
Retention ponds	1	1	1	0	1	1	1	1	1	1	0	1	1	**8,46**
Wetlands	0	1	1	0	1	1	0	1	1	1	0	1	0	**6,15**
Bioretention areas	1	1	1	1	0	0	1	1	1	1	0	0	0	**6,15**

(1) streets; (2) access roads; (3) trunk roads ;(4) parking slots; (5) open urban areas; (6) residential areas; (7) commercial areas; (8) industrial areas; (9) railway lines; (10) terminal or stations; (11) petrol stations; (12) leisure areas; (13) roundabouts

Table 16. Multi criteria analysis for applicability criterion

Social concerns

Sustainable drainage system	Social concerns											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Aggregate index
Source control												
Permeable surface	3	2	1	3	3	2	0	2	2	1	3	**6,67**
Soakaway	2	1	1	3	1	1	0	1	2	1	1	**4,24**
Filtration trenches	1	2	2	2	2	2	1	2	1	1	2	**5,45**
Infiltration trenches	1	2	2	2,5	2	2	1	2	1	1	2	**5,61**
Infiltration basin	1	2	2	2,5	1	1	0	2	1	2	3	**5,30**
Green roofs	3	3	3	2,5	3	1	0	2	2	2	2	**7,12**
Permeable conveyance systems												
Filter drain	1	1	1	2,5	3	1	1	2	1	1	1	**4,70**
Swales	2	2	3	2,5	3	2	1	2	1	2	3	**7,12**
Passive treatment												
Filter strips	1	2	2	1,5	2	2	1	2	1	1	2	**5,30**
Detention basin	2	3	3	2	2	2	1	3	2	2	3	**7,58**
Retention ponds	2	3	3	2,5	2	2	1	3	2	2	3	**7,73**
Wetlands	3	3	3	2,5	1	2	1	3	3	3	3	**8,33**
Bioretention areas	3	3	3	2,5	1	2	1	3	3	3	3	**8,33**

(1) health; (2) public opinion; (3) aesthetics and degradation; (4) safety of the environmental; (5) integration with existing infrastructure; (6) R+D+I; (7) efficiency in changes of land use; (8) distribution of production benefits; (9) economic development; (10) employment; (11) user-oriented design

Table 17. Multi criteria analysis for social concerns criterion

Results for sustainable drainage systems

Source control systems

Permeable surfaces

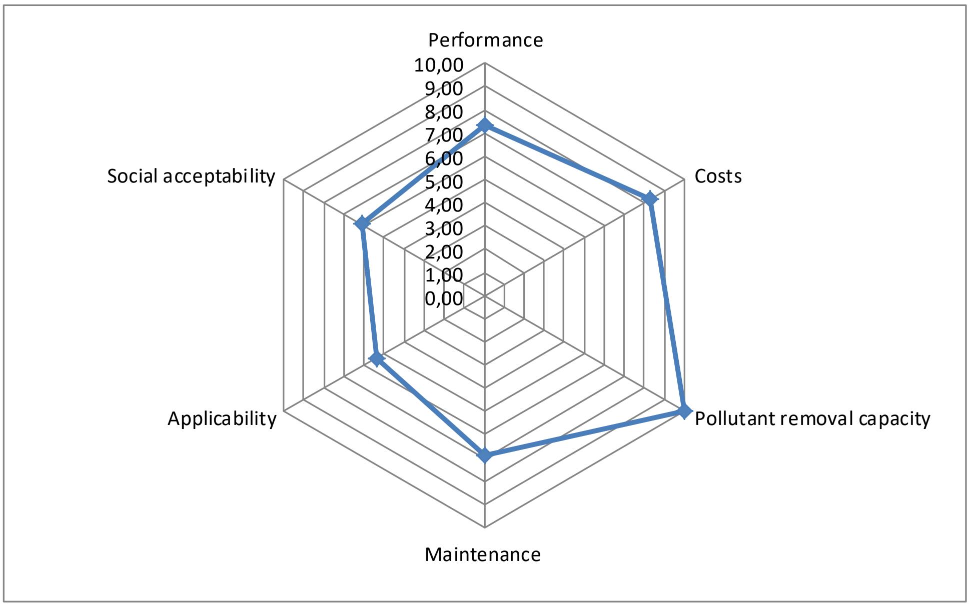


Figure 44. Multi criteria analysis for permeable surfaces

Soakaways

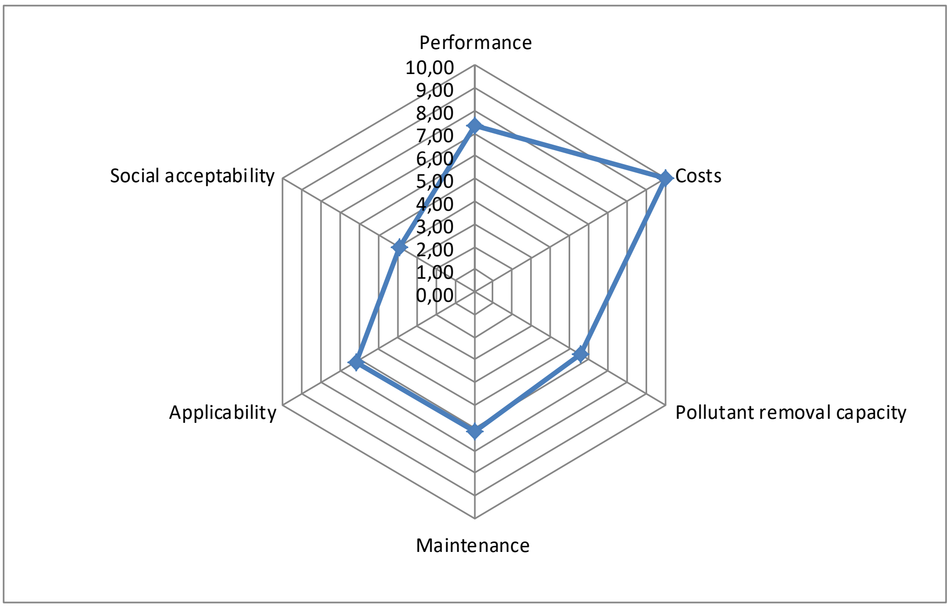


Figure 45. Multi criteria analysis for soakaways

Filtration trenches

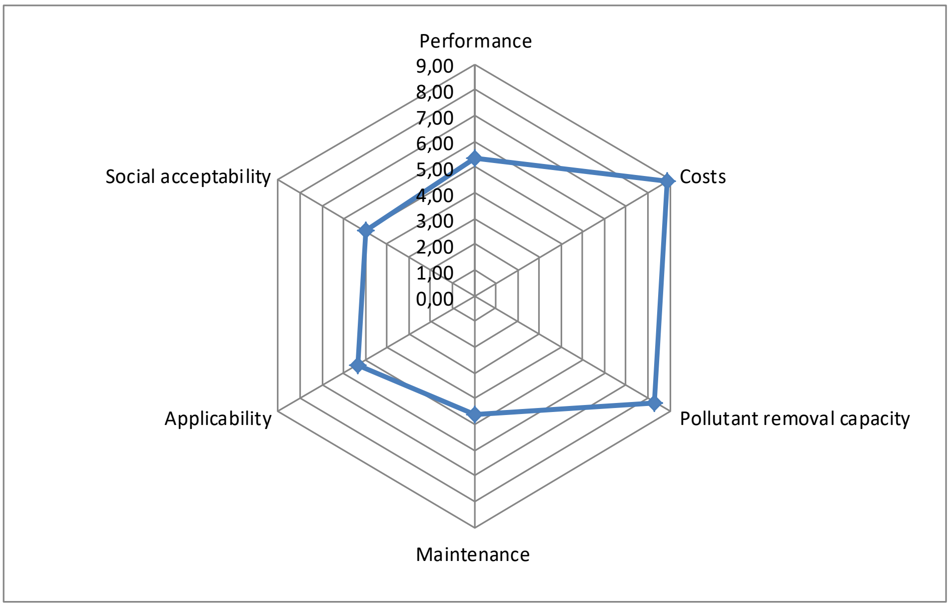


Figure 46. Multi criteria analysis for filtration trenches

Infiltration trenches

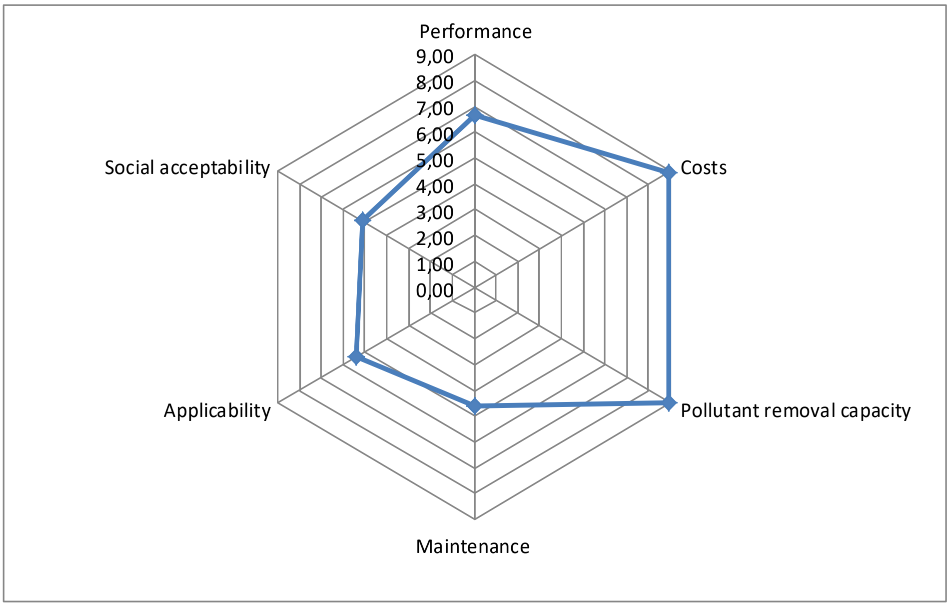


Figure 47. Multi criteria analysis for infiltration trenches

Infiltration basins

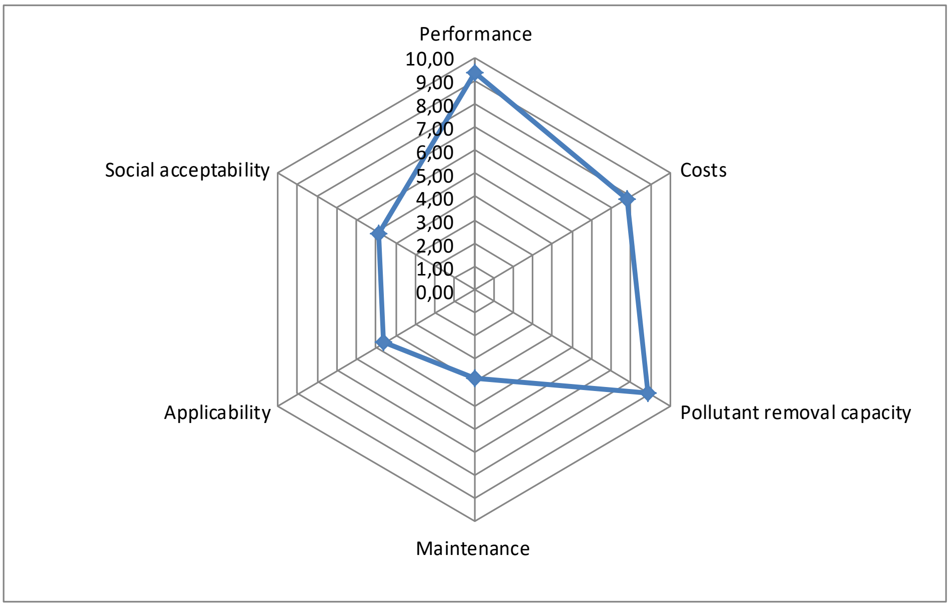


Figure 48. Multi criteria analysis for infiltration basins

Green roofs

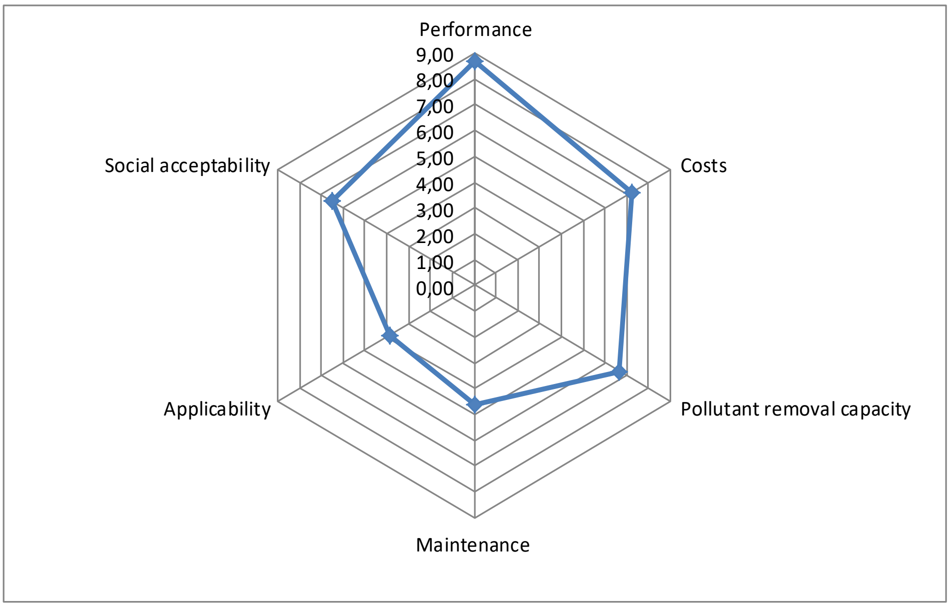


Figure 49. Multi criteria analysis for green roofs

Permeable conveyance systems

Filter drain

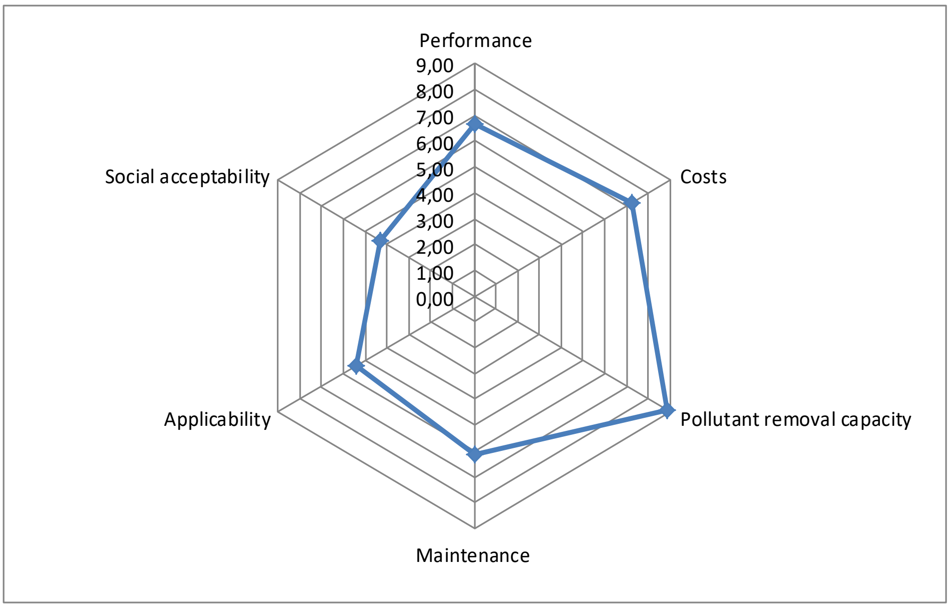


Figure 50. Multi criteria analysis for filter drains

Swales

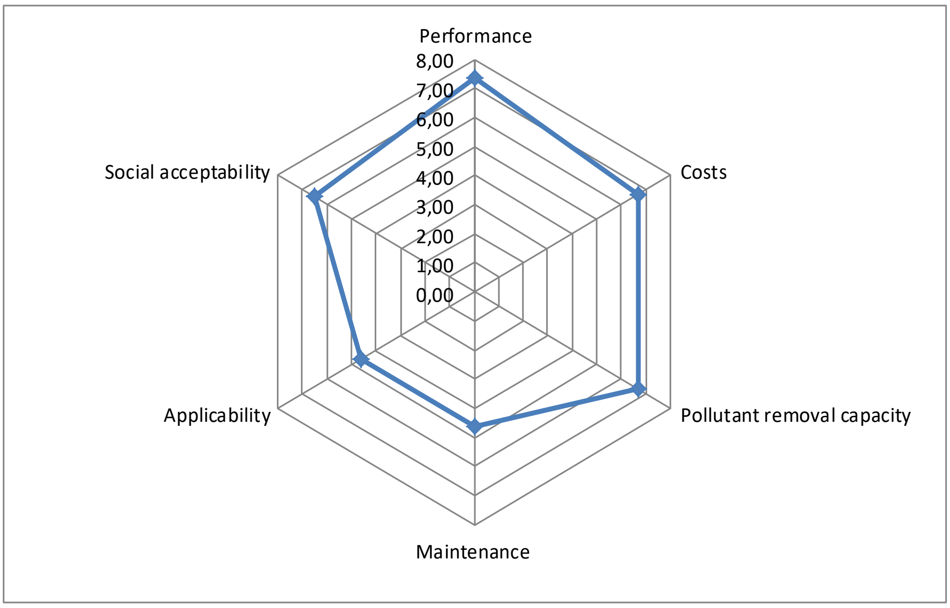


Figure 51. Multi criteria analysis for swales

Passive treatments

Filter strips

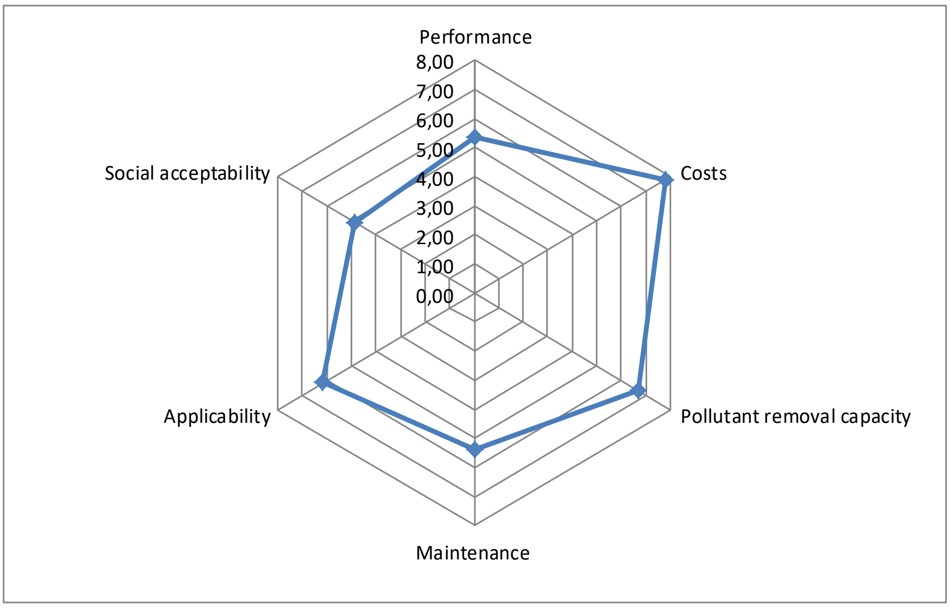


Figure 52. Multi criteria analysis for filter strips

Detention basin

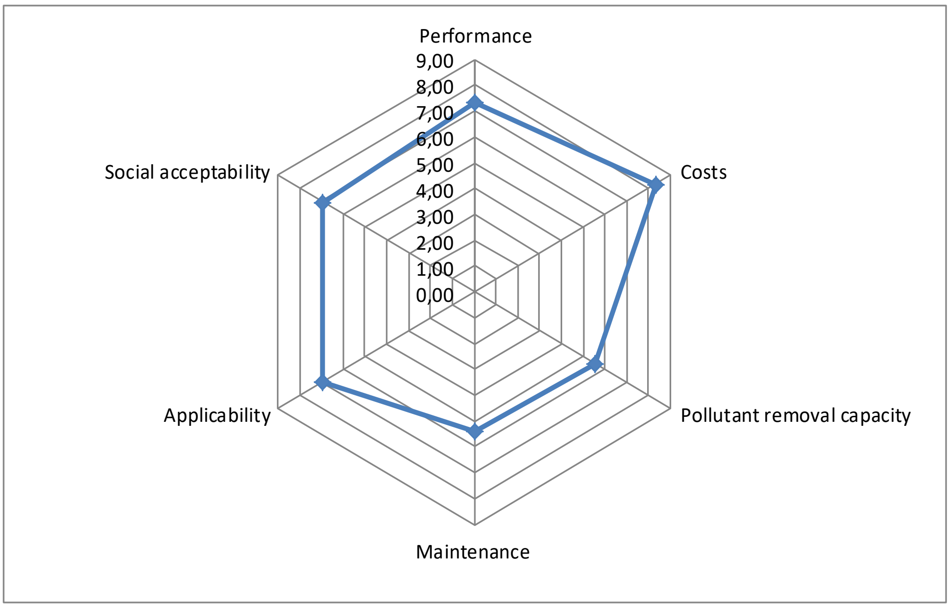


Figure 53. Multi criteria analysis for detention basins

Retention ponds

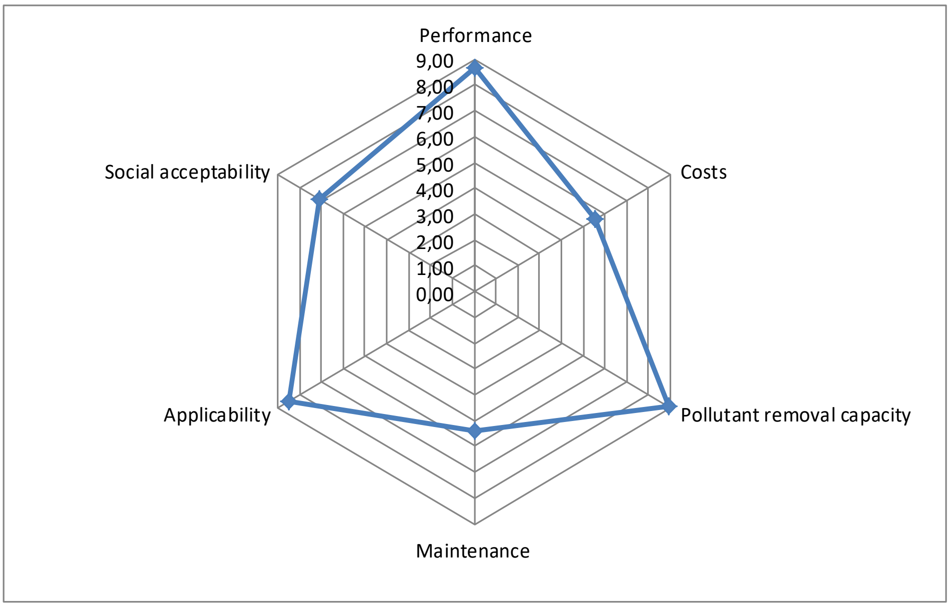


Figure 54. Multi criteria analysis for retention ponds

Wetlands

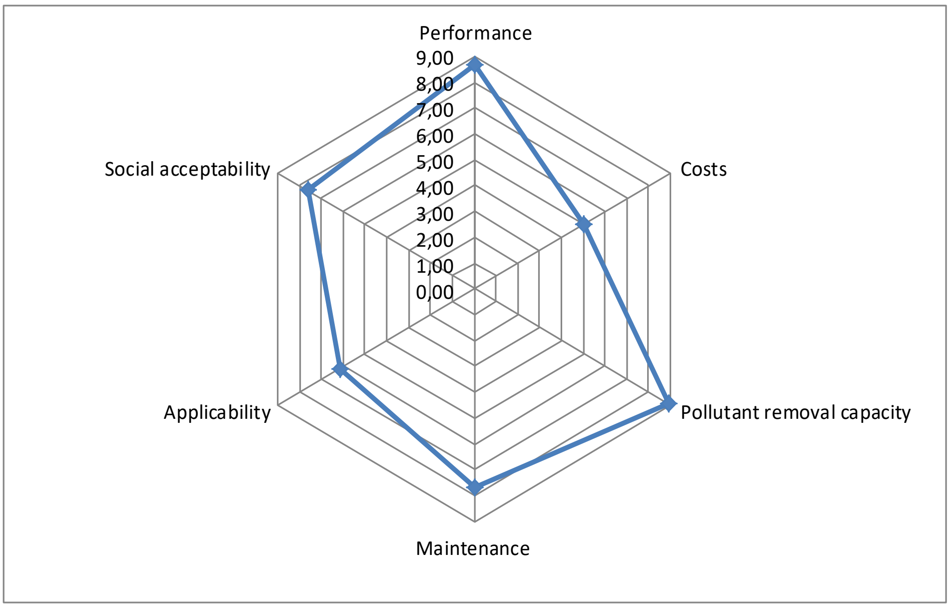


Figure 55. Multi criteria analysis for wetlands

Bioretention areas

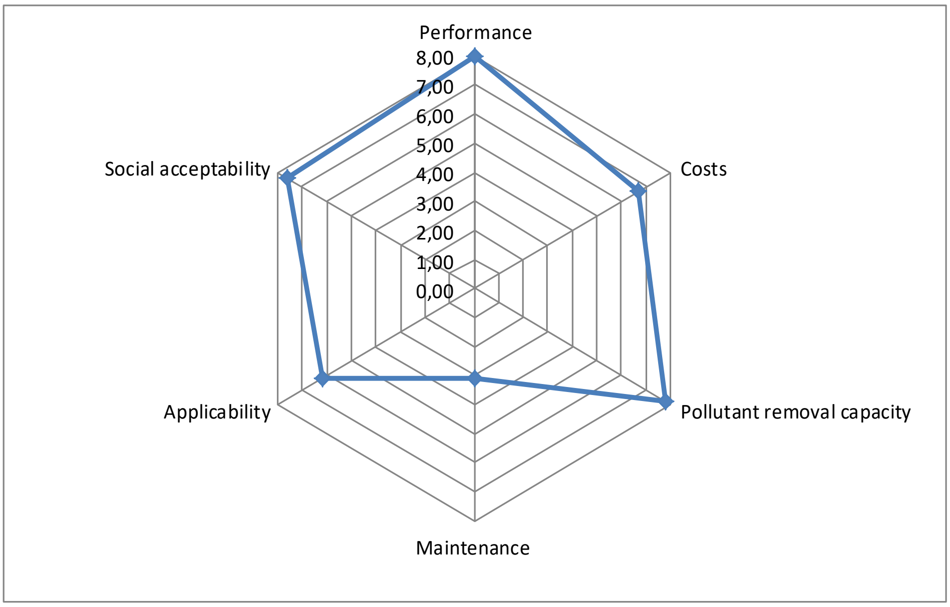


Figure 56. Multi criteria analysis for bioretentions