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D4RUNOFF

Data driven implementation of hybrid nature-based solutions for preventing and managing diffuse pollution from urban water runoff

D3.1. Parametric library of Nature Based Solutions (NBS)

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[a] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[b] **PU**=Public, **SEN**=Sensitive, limited under the conditions of the GA

1.0	31.08.2023	Final version to deliver
2.0	03-05-2024	New version incorporates the changes requested by the project officer during the first monitoring period, mainly an explanation on the categories and percentages of increase and decrease (page 121-122). The colour of NBS' factsheets (pages 16-97) as well as tables from 3 to 14 (pages 122 to 150) have been changed to make them more readable.

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Executive Summary

This deliverable 3.1 (D3.1) is the first one of the Work Package 3 (WP3) in the D4RUNOFF project. WP3 is divided in four tasks of six months each, with a total of three deliverables. In this one, the work done during the first year of the project is summarised in a public document open to comments and suggestions: the urban drainage library and the parametric design of the Nature-Based Solutions (NBS) included in this library. The next two deliverables (D3.2 and D3.3) will complete the WP3 adding the Multi-Criteria Decision Analysis (MCDA) and the Geographical Information Systems (GIS) with the final aim of selecting the best place for the NBS needed to improve the existing urban drainage conditions.

The principal objective of the D3.1 is to propose a library of urban drainage solutions and a simplified parametric design methodology of the NBS. Firstly, the D4RUNOFF researchers have reviewed the main references, highlighting the NBS classification made by the European project Green-Up, to propose a simplified list of techniques that includes a total of 13 NBS in the context of the urban drainage. Each one of the techniques included in the library counts with a complete file that includes information related with different aspects and criteria to be considered during the decision-making process. Afterwards, the design methodology of each one of the NBS was studied, identifying the main parameters like occupation area or water depth. With this knowledge, an Excel spreadsheet has been prepared to help with the initial design. This tool is openly available as annex and a specific chapter describes how to use it. Moreover, from the parametric calculations, a methodology to develop NBS drainage elements for Building Information Modelling (BIM) is proposed, giving the needed instructions to work with the NBS design Excel spreadsheet. This methodology has been complemented by a detailed state of the art regarding the existing scientific publications dealing with the depuration capacity of some Contaminants of Emerging Concern (CECs) by the NBS.

As main final remarks, it is important to highlight the maturity of the main typologies of NBS, mainly related with infiltration (e.g., bioretention areas), and the probed depuration capacity of the NBS and their positive impact the drainage systems and the whole cities, with multiple advantages related with sustainability and resilience. With all, there is a deficit of knowledge in how some techniques deal with CECs, which confirms the need of new screening methods and sensors to make it possible to improve the monitorization of NBS soon.

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1 Introduction

1.1 Aim of the library

This library has been developed in the framework of the D4RUNOFF project as a tool for the selection of drainage systems for stormwater management in urban areas. The catalogue has been structured in factsheets, synthetizing the main parameters that conditions the use and application of the selected techniques for stormwater management in urban areas.

There are two categories of drainage systems included in this document:

- **Nature-based Solutions (NBS)**: NBS are techniques that help to mitigate the most common hazards and problems related to urban development, including heat island effect, stormwater management, and air and water pollution. NBS techniques mimic the processes of the natural environment to mitigate these problems, providing additionally other ecosystem services in urban areas. It is important to note that the NBS techniques collected and summarized in this catalogue are only those NBS that helps to mitigate stormwater problems in Urban areas, related to both water quality or water quantity.
- **Engineered Drainage Solutions**: These techniques are solutions which attempt to use small-scale highly engineered devices to manage stormwater in order to reduce their pollution and/or to mitigate water quantity related problems.

The aim of this library is to be a reference guide for the design and application of drainage techniques in urban areas. With this aim, the application of each drainage technique has been parametrized, and the main parameters that condition the applicability and the design of each system were collected, summarized and categorized in factsheets.

1.2 How to use this Library

This library has been conceived to be a reference guide for the selection and design of drainage solutions in urban environments. However, the library is expected to be completed with a Multi-Criteria Decision Analysis (MCDA) to be implemented in a Geographical Information System (GIS) in order to allow the automatization of the selection of the most appropriate techniques according to the information available. For this reason, the design and applicability of each system described in the library has been parametrized and categorized when possible. This parametrization and categorization aim to help decision makers to select the most appropriate technique or group of techniques according to the expected usage, needed efficiency and limiting factors and constrains at the location site. Even if there are multiple ways to use this library, the proposed possible uses are described in the flowchart showed in Figure 1.

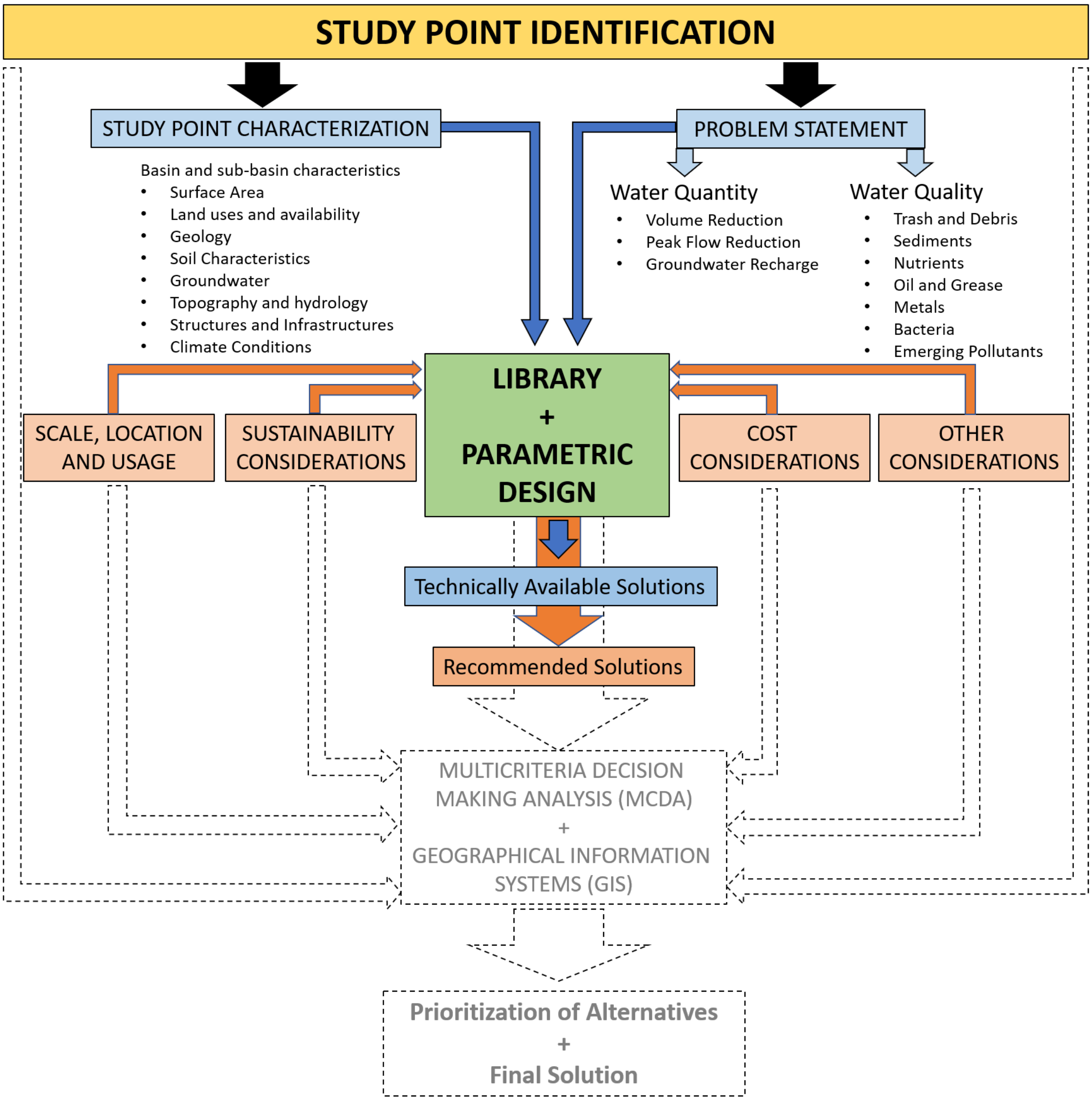

Figure 1. Flowchart defining the use of this library.

As it can be observed in the figure, the process begins with a conflictive point (Study point) where some stormwater related problem was detected. This point can be a river or water stream, a pump station of the sewerage system, a wastewater treatment plant, or any point of the storm sewer network. Once the study point was defined, the next step is to characterize the basins and sub-basins that drain into it, considering not only the direct runoff drained by gravity, but also the area drained through the sewer network that finally flow through the study point. Besides, it is necessary to define the problem statement, in other words, what stormwater related problem in relation to water quality or/and water quantity issues is necessary to treat. With this information it is possible to enter the library and obtain a list of technically available solutions for the problem stated in the selected study point. The more complete the characterization of the basins and sub-basins at the study point and the problem statement, the better the accuracy of the obtained solutions. Additionally, it is also possible to consider other variables like the scale of intervention, the expected usage for the system, sustainability issues, cost, or maintenance considerations to obtain a more accurate selection of recommended solutions for the study point in order to mitigate the defined problem fulfilling the rest of the parameters considered.

The catalogue of possible solutions, called Library, has been organized in two chapters containing the main types of NBS related with urban drainage, and the main types of conventional techniques in this matter, called engineered drainage solutions. After this, two specific chapters deal with the parametric design of NBS proposing the use of an Excel spreadsheet with Building Information Modelling (BIM). Finally, the Library is completed with a chapter dedicated to the discussion of CECs depuration in the NBS according to the literature.

It is important to note that, after this Library, it is needed to implement the Multi-Criteria Decision Analysis (MCDA) and Geographical Information Systems (GIS) to complete the rest of the tasks of the Work Package 3 (WP3).

1.3 Structure of the Factsheets

Factsheets has been structured in various sections that are briefly summarized below:

- **System**: In this section is referred the most commonly name of the technique described in the factsheet and a representative original icon of the technique.
- **Primary uses**: In this section are categorized the main uses that can be associated with the drainage techniques:
    - Source control: Systems which are used to the collection of stormwaters in the same place where it is produced.
    - Transportation: Refer to the techniques that are used for the transportation of stormwater from one point to another.
    - Retention: Techniques whose scope is to store totally or partially stormwater in order to reduce the amount of water that needs to be transported, treated, infiltrated or spilled to water bodies.
    - Infiltration: Refer to those techniques that are used to infiltrate stormwater into the ground.
    - Pretreatment: Techniques that are used to reduce runoff pollution levels (mainly in relation to trash, debris, oil, and sediments) in order to be latterly diverted to other systems that require lower pollution levels than those of the original stormwater.
    - Treatment: Systems and techniques which scope is to reduce stormwater pollution.
- **Description**: In this section, there is a brief summary of the system.
- **Subcategories**: In this section, the subcategories that exist of the specific technique (where appropriate), together with a brief description of each subsystem are summarized.
- **Applications**: In this section, the land uses associated to the urban areas where the technique can be used are categorized:
    - Residential: Can be used to treat stormwater in residential areas.
    - Commercial: Can be used to treat stormwater in commercial areas.
    - Industrial: Can be used to treat stormwater in industrial areas.
    - High density: Can be used to treat stormwater in densified urban areas.
    - Roads/Highways: Can be used to treat stormwater in highways and roads.

- **Location**: In this section, the main places in urban areas where each technique can be located are categorized:
    - Roadway/Roadside: Can be located in roads or roadsides.
    - Pathway/Cycleways: Can be located in pathways (sidewalks) or cycleways.
    - Car park: Can be located in car parks and parking lots.
    - Roundabout: Can be located in roundabouts along the roadways.
    - Gas Stations: Can be located in gas and fuel stations.
    - Vehicles Service Area: Can be located in service areas for cars, trucks or airplane. This item includes locations like vehicles dealerships, car workshops, washing centers, etc.
    - Green/Open areas: Can be located in big green open areas where there is enough available space.
    - Urban Parks: Can be located in Urban parks.
    - House/Building: Can be located in a building or house, or near to them.
    - Urban Planter: Refers to systems that can be applied as a replacement of conventional urban planters.
    - Square/Plaza: Refer to systems that can be installed in plazas and squares.
    - Water course: Refers to systems that can be used near to a steam or water course like riversides.
- **Scale of Application**: In this section, the special framework at which each system has to be designed and where its application is supported by the bibliography has been categorized. It is important to note that here only the scale at which it is necessary to design a single intervention was selected, but a group of interventions at lower scales can be used to manage stormwater of a higher scale (for instance: a group of interventions at building scale can be used to manage stormwater in a neighborhood). This section should be complemented with the section “Required Area” described below, and where the required area for the system, and the maximum drainage area that can be managed for the system are summarized. Four different scales where defined:
    - Building: Systems that are conceived to manage runoff for a single building or house.
    - Neighborhood: Systems that were conceived to manage stormwater for a group of houses or buildings.
    - District: Systems that are designed to manage runoff for a group of neighborhoods and hence requires high land availability.
    - City: Systems that requires a lot of land space and are normally conceived to manage runoff for a whole city.
- **Lifespan**: In this section, the expected durability of the system has been categorized. Three categories have been established:
    - Short Term: Less than 10 years.
    - Medium term: Between 10 and 30 years.
    - Long term: More than 30 years.
- **Space Usage**: This section attempts to show if the system requires an exclusive use of the space for its installation, or the space can be used for other purposes. Here two categories are considered:
    - Monofunctional: The system space usage is monofunctional, so the system required land area should be exclusively used as a drainage system.

  - Multifunctional: Refers to the systems that apart from being a drainage system have, or can have, other uses (for instance: a green roof, apart from being a drainage system is also a roof, so its space usage is multifunctional).
- **Required Area**: This section collects information about the range of drainage areas that can drain into the system (Drainage Area) and the land space required for a single intervention (System Area). Normally, system area is expressed as a function of the drainage area because the space usage is related to the amount of water that needs to be treated, and hence is related to the drainage area that drains into the system.
- **Ecosystem Functions**: In this section the main ecosystem functions that the system can provide are collected. This section was used as base for the development of the section “Relationship with SDG” described below.
- **Benefits**: In this section the main benefits that the system provides are summarized and categorized. Additionally, the benefits of each system have been scored in a scale between 1 and 5. The selected categories for this section are:
  - Climate Change mitigation and adaptation
  - Water management
  - Green Space Management
  - Air Quality
  - Urban Regeneration
  - Participatory planning and governance
  - Social justice and social cohesion
  - Public health and wellbeing
  - Potential of economic opportunities and green jobs
- **Relationship with SDG**: This section summarizes the influence of each system in Sustainable Development Goals (SDG) and have been developed based on the above described section “Ecosystem Functions”. The ecosystem functions that each system provide have been linked to SDGs and finally, depending on the number of functions linked to each SDG, they have been categorized in “Direct” or “Indirect”.
- **Design Considerations:** This section collects the most important issues related to the system design. The section has been divided in two sub-sections:
  - Siting considerations: In this sub-section the most important limiting factor for sitting the systems are categorized and summarized:
    - Climate condition
    - Geology conditions
    - Soil conditions
    - Depth of groundwater table
    - Site slopes
    - Closeness to infrastructures
    - Light/Shade considerations
    - Accessibility considerations
    - Other considerations
  - Technical Considerations: The second sub-section is related to the technical considerations that needs to be considered when designing the system. Including embankments characteristics (where appropriate), materials requirements, inflow and outflow considerations, residence time, etc.
- **Limitations:** In this section the most important limitations and drawbacks of the system are summarized. Limitations can include all the factors that can limit the applicability of the system or that can provide a negative impact.

- **Pretreatment needs**: In this section is showed if the system needs or not pretreatment, or if it is optional depending on some condition. Additionally, when possible, it is showed the target pollutants when pretreatment is needed or optional.
- **Water Treatment**: In this section the main mechanisms that the system uses for treating stormwater are categorized. This categorization can help in the selection of a specific system where there is no evidence on pollutants removal efficiency. Additionally, it is showed the importance of each mechanism by a categorization in:
    - H: High importance
    - M: Medium Importance
    - L: Low Importance
    - -: No importance
- **Water Quality**: In this section the efficiency showed by each system in removing the most common pollutants groups that can be found in stormwater runoff is summarized. Six different groups of pollutants were established:
    - <u>Nutrients</u>: Refers to phosphorus and nitrogen mainly, both as a single element or in oxides, salts, etc.
    - <u>Sediments</u>: Refers to suspended particles and is related to Total Suspended Solids (TSS) and Turbidity of water.
    - <u>Metals</u>: Refers to the most common problematic metals in stormwater runoff: Lead, Zinc, Copper, and Nickel.
    - <u>Bacteria</u>: Refer to the ability of the system to treat the common bacteria pathogens in urban runoff waters.
    - <u>Trash and Debris</u>: Refer to the coarser fraction of sediments, including floatables, trash, organic matter like leaves, limbs, etc.
    - <u>Oil and grease</u>: Refer to Total Petroleum Hydrocarbons present in stormwater and originated by the automotive industry together with oils and greases that can be spilled from restaurants, etc.

  Additionally, for each group of pollutants the pollutant removal efficiency was categorized in four levels:
    - H: High removal efficiency (>80% pollutant removal)
    - M: Medium removal efficiency (30% – 80% pollutant removal)
    - L: Low removal efficiency (<30% pollutant removal)
    - -: Not proven pollutant removal
- **Emerging Pollutants:** Emerging contaminants are chemical compounds or materials that are newly detected in bodies of water and soil, with the potential to impact the environment negatively. In this section, the effectiveness of each system in treating emerging pollutants have been categorized and summarized. As the number of pollutants of emerging concern is high, they have been categorized in the following families:
    - Biocides and their transformation products
    - Pharmaceuticals
    - Microplastics
    - Personal Care products
    - Industrial Chemicals
    - Tyre Compounds
    - Fossil fuel and combustion compounds

  As the information available of drainage systems and related to emerging pollutant removal is relatively scarce and there is a huge number of pollutants related to each of the categories defined in this section, the performance of each system related to these pollutants have been categorized in only three categories:

- Y (Yes): The system provides some degree of removal related to any of the pollutants in the category.
- N (No): The system provides no removal efficiency related to any of the pollutants in the category.
- N/A: There is no information in the bibliography related to the efficiency of the system in treating the pollutants related to the category.

A more detailed description of the system capacity for CECs removal is shown in section 6. Just to mention here the difficulties of determining removal efficiencies in NBS (which are described in section 6.2), including the potential increase of CECs in NBS. Consequently, more specific evaluations of removal efficiencies are needed to assess the suitability of NBS systems.

- **Water Quantity**: In this section, the efficiency of the system in dealing with stormwater quantity issues is categorized and summarized. Three different categories were established:
  - Volume Reduction: Referring to the ability of the system to reduce stormwater volumes.
  - Peak Flow reduction: Refers to the capacity of the system to reduce the peak flow, or the maximum flow that is produced during storm events.
  - Groundwater recharge: Refers to the ability of the system to provide groundwater recharge through infiltration.

  Similar to the section of water quality, each function has been scored with 4 levels:
  - H: High
  - M: Medium
  - L: Low
  - -: Not recognized capacity
- **Maintenance**: In this section the main maintenance requirements of the system, providing also (when available in the literature) the frequency of maintenance activities is summarized.
- **Construction and Maintenance Costs**: In this section the averaged costs of construction and maintenance of the system are showed. It is important to note that the costs associated to each system were obtained from different sources, and hence, the estimated costs can have a high range of variation, so they should be used only as a reference value for a gross comparison.

2 Factsheets of Nature Based Solutions (NBS)

After collecting the main references and discuss the state of the art, UC propose in this chapter the 13 main categories of Nature Based Solutions (NBS) in the form of factsheets. There are many different classifications of NBS and Sustainable Drainage Systems (SuDS), and the work done to synthesize and select the main ones has been difficult, needing some simplifications. As this document is open to the public, any comment or correction from any reader will be welcome to improve the proposed classification.

System

Bioretention Areas

Primary uses

Source Control		Transportation		Retention		Infiltration	X
Pretreatment		Treatment	X				

Description[1,2,3]

Bioretention systems are bioretention shallow basins designed to collect, store, filter and treat water runoff. To optimize its functions, it must include a porous soil mixture, native vegetation and some hyperaccumulator plants, capable of phytoremediation. Bioretention areas are established in artificial surroundings and catches water runoff from roofs, roads and other (sealed) surfaces. Storm water runoff is drained into the area, where it is stored for a certain period, and infiltrates either into the ground soil or flows into the sewage system. A certain amount of water is taken up and transpired by plants. Bioretention systems should be incorporated into the site landscaping such that they do not require extra land take over and above the landscaping that would normally be required for the development.

Subcategories[2,4]

There are various types of bioretention areas to be used for stormwater management. Apart from full bioretention systems, which are relatively more complex to design and serve for bigger amounts of water, other types of bioretention areas may be defined:

- Rain gardens are typically small systems that serve part of a single property (roof or driveway). They are likely to be less engineered than full bioretention systems.
- Bioretention planters (or raised planters) are boxed systems constructed above the surrounding ground surface, with a planted soil mix and an underdrain to collect the filtered water. They are normally used to collect runoff from roofs and used more as treatment facility than an infiltration system.
- Bioretention tree pits are basically tree pits with enhanced performance achieved through extra surface planting providing increased interception and facilitating infiltration.
- Bioretention swales are bioretention areas placed in the base of a swales structure. They may involve a continuous component of bioretention along the length of the swale or a portion of bioretention, normally before the outlet of the swale. They are similar to undrained swales.
- Anaerobic bioretention systems are designed with a permanent water level within the drainage layer that is available for vegetation, leading to pollutants reduction mainly by the plant uptake. They are especially useful where big trees with deep root systems are planted so that they can reach the drainage layer and uptake the stored water in the permanent pool.

Applications[5]

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

Location[2,4,5]

Roadway/Roadside	X	Pathway/Cycleway	X	Car park	X	Roundabout	X
Gas Station		Vehicles serv. area		Green/Open Area	X	Urban Park	X
House/Building		Urban Planter	X	Square/Plaza	X	Water Course	

Scale of application

Building	X	Neighborhood	X	District		City	

Lifespan

Short Term		Medium Term		Long Term	X

Space usage

Monofunctional	X	Multifunctional	

Required Area[2,5,6]

- Drainage Area: 0 to 0.1 km².

System Area*: Typically, bioretention systems should have a surface area in the range of 2% – 7% of the drained watershed area. Not higher than 20%.

**The width of the system should be great than 600 mm and less than 20 m. The maximum length should be 40 m to avoid uneven distribution of water over the surface. The total filter area should not exceed 800 m²*

Ecosystem Functions[1]

Disturbance regulation, water regulation, water supply, erosion control and sediment retention, waste treatment, cultural.

Benefits[1]

Climate Change mitigation and adaptation (3/5)
Water management (5/5)
Green Space Management (4/5)
Air Quality (4/5)
Urban Regeneration (1/5)
Participatory planning and governance (3/5)
Social justice and social cohesion (3/5)
Public health and wellbeing (4/5), including in this case Traffic Calming options.
Potential of economic opportunities and green jobs (2/5)

Relationship with SDG

Direct	Indirect
3 Good Health and Well-Being	1 No poverty
6 Clear Water and Sanitation	2 Zero hunger
11 Sustainable Cities and Communities	12 Responsible Consumption and Production
13 Climate Action	
14 Life Below Water	
15 Life on Land	

Design Considerations[2,4,5,6,7]

Siting considerations

- Climate conditions: Rain gardens are not restricted to a certain climate condition and can be found in different climatic areas. But the selected components (plants and trees) should be native and well adapted to local climate conditions[3]. In arid and semiarid climates, drought-tolerant plants are the best landscaping option for bioretention practices.
- Geology conditions: Rain gardens can be used in most ground conditions; however, the base will require lining where infiltration to the ground is not appropriate.
- Soil conditions: In soils with poor infiltration rates, adding underdrains allows stormwater to percolate through the media and move downstream. In soils with naturally high infiltration rates, design engineers may exclude underdrains from the plans.
- Depth of groundwater table: Not suitable where groundwater is within 6 ft (1.83 m) of ground surface.
- Site slopes: Parking lots or residential landscaped areas with gentle slopes around 5% are ideal for bioretention practices. Not suitable for areas with slope higher than 20%.
- Closeness to infrastructures: Unlined bioretention systems should be located more than 5 m far from building foundations.
- Light/Shade considerations: -
- Accessibility:
- Other considerations: -

Technical Considerations

- Bioretention areas are generally applied to small catchments. For large catchments, a series of cascading systems could be considered. Another option is dividing larger sites into smaller parcels with multiple linked bioretention zones.
- The surface of a bioretention zone should be level, so in steeper catchments it could be more difficult to apply this technique, requiring some kind of retaining structure.
- Side slopes should be limited to 2:1.
- Minimum recommended width 3 m. Minimum Length to width ratio 2:1.
- Soil media depth must be between 30 and 120 cm.
- Depending on the pollutants loads it can be necessary to use a pretreatment system.
- Inflow water velocities should be below 0.5 m/s for avoiding surface scouring from bioretention zone.
- If bioretention area is placed in the bed of a swale for the full length of the system, it should be leveled by a series of terraces.
- Permeability of generic soil filter media should be between 100 and 300 mm/h.
- Drainage layer materials normally have porosities greater than 30%.
- Normally water depth should not exceed 15 cm and should be designed to drain within 72 hours (to prevent breeding of mosquitoes, design to drain within 24 hours).
- To achieve 90% TSS removal credit, pretreatment is required and may include:
  - For sheet flow: a vegetated filter strip, grass channel or swale or gravel strip (can be integrated in the bioretention area itself).
  - Direct pipe flow: sediment forebay (can be integrated in the bioretention area itself).

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Limitations[4,5,7]

- Bioretention practices are not suitable for treating large drainage areas. Surface soil layers can clog over time in areas with excessive sediment loadings.
- Although bioretention practices typically have small footprints, incorporating them into a parking lot design may reduce the number of parking spaces available if the design did not previously include islands. In addition, bioretention practices should leave space between the system and permanent structures, including buildings (with the exception of the bioretention planter box design variation).
- Bioretention practices can reduce local flooding but may not provide flood control during extreme storms. They can, however, alleviate the stress on other flood control measures by reducing peak flows and stormwater volumes within their drainage areas.
- Requires careful landscaping/maintenance.
- Not suitable for areas with slope higher than 20%.
- Not suitable for large drainage areas.
- Requires pretreatment.
- Not Suitable where groundwater is within 6 ft (1.83 m) of ground surface.

Pretreatment needs[4,5,7]

Optional (depending on the pollutants inflow: TSS and oil reduction, trash and debris).

Water treatment[4]

Sedimentation	**H**	Biological Processes	**H**	Filtration/ Sorption	**H**	Plant uptake	**L**

Water quality[4]

Nutrients	**M**	Sediments	**H**	Metals	**H**	Bacteria	**H**
Oil and Grease	**H**	Trash and Debris	**H**				

Emerging Pollutants

Biocides & T.P.	**Y**	Tyre Compounds	**N/A**	Pharmaceuticals	**Y**	Microplastics	**Y**
Personal Care Products	**Y**	Industrial Chemicals	**Y**	Fossil Fuel and Combustion products	**Y**		

Water quantity[4]*

Volume Reduction	**M**	Peak Flow Reduction	**L**	Groundwater Recharge	**M**

**Bioretention areas reduce pluvial flooding and mitigate peak water loads on the sewerage and stormwater systems by collecting, infiltrating, and storing stormwater. Literature acknowledges that the effectiveness of bioretention NBS greatly depends on their design and the frequency and the magnitude of rainfall, and on their ability to increase storage capacity using existing open spaces. Rain gardens are more effective in dealing with small discharge of rainwater. Several studies of bioretention basins in the city of Calgary, Canada, demonstrated up to 90% reduction of runoff volume and peak flow reduction of up to 41.65% in Hai He Basin, China.*

Maintenance[4,5]

Bioretention systems require intensive and regular maintenance to avoid clogging with sediments. The basins should be inspected monthly to identify further maintenance requirements; litter and plant debris should be removed, and eroded areas should be restored. Maintenance operations should include: pruning, mowing, watering, fertilization, dead plant removal, inlet and outlet inspection and filter media replacement.

Construction and maintenance costs*[4,5,7,8]

Construction costs: 150 to 250 Eur/m³ (storage volume) // 10 to 50 Eur/m² (drainage area) // 50 to 500 Eur/m² (system area).

Maintenance costs: 0.5 to 10% of construction costs per year (similar costs than normal landscape maintenance).

**Bioretention practices can vary depending on size, maintenance required and cost of materials. Estimated cost range of a bioretention is between $120 to $500 per square meter of bioretention area. Construction costs can range from $50,000 to $200,000 per acre of impervious surface treated, with smaller systems being more expensive per acre. In addition, retrofits with complex existing infrastructure may be more expensive than new construction. Maintenance costs can be estimated to be in the range of 0.5 – 10% of construction costs in an annual basis.*

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System

Detention Basins

Primary uses

Source Control		Transportation		Retention	X	Infiltration	
Pretreatment		Treatment	X				

Description[1,2]

Detention basins, also called extended detention basins, detention ponds or dry detention ponds are surface storage basins that retain storm water. During storm events, the area gets flooded and could lead to filling up of the detention pond in cases of longer duration of rainfall. After the rain ends, the stored water flows in the sewer system. In absence of storm events detention ponds are dry and could be used as a green area or playgrounds.

Subcategories[3,4,5]

- Detention basins can be on-line components, where surface runoff from regular events is routed through the basin and when the flows rise, because the outlet is restricted, the basin fills and provides storage of runoff and flow attenuation. They can also be off-line components into which runoff is diverted once flows reach a specified threshold, and which normally have an alternative principal use like amenity or recreational use.
- Additionally, detention basins can be classified according to the presence of a free water table. According to this criterion, detention basins can be classified in Surface Detention Basins, which have a free water surface area during rainfall events; and Subsurface Detention Basins which are located entirely below the ground surface. Runoff may be stored in a vault, perforated pipe, and/or stone bed. Because it is difficult to remove accumulated sediment from the stone bed, if a stone bed is utilized, all runoff must be pretreated to remove at least 50% of the TSS from the runoff volume of the system's maximum design storm.
- Finally, detention basins can also be classified according to the water residence time in the system. According to this criterion detention basins can be classified in Detention Basins, which have a retention time lower than 12 hours and are mainly used for peak flow reduction with very limited effect on water quality. On the other hand, Extended Detention Basins show a higher residence time (usually near to, and not higher than, 72 hours) which slightly increase the pollutants removal efficiency of the system.

Applications[6,7]

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

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Location[3,8,9]

Roadway/Roadside	X	Pathway/Cycleway		Car park		Roundabout	X
Gas Station		Vehicles serv. area		Green/Open Area	X	Urban Park	X
House/Building		Urban Planter		Square/Plaza		Water Course	

Scale of application

Building		Neighborhood	X	District	X	City	

Lifespan

Short Term		Medium Term	X	Long Term	

Space usage

Monofunctional		Multifunctional	X

Required Area[1,5]

- Drainage Area: 0 – 1 km².
- System Area: Recommended over 0.076 m³ (storage volume)/m² (drainage area).

Ecosystem Functions[10]

Disturbance Regulation, Water regulation, Erosion Control, waste treatment, Cultural.

Benefits[10]

Climate change mitigation and adaption (3/5)
Water Management (5/5)
Green Space Management (4/5)
Air quality (4/5)
Urban regeneration (1/5)
Public Health and wellbeing (4/5)
Potential of economic opportunities (2/5)

Relationship with SDG

Direct
3 Good Health and Well-Being
6 Clear Water and Sanitation
13 Climate Action
14 Life Below Water
15 Life on Land

Indirect
1 No poverty
12 Responsible Consumption and Production

Design Considerations[2,3,4,5,11]

Siting considerations[2,4,11]

- Climate conditions: Detention Basins can be used in almost all climate conditions. Minor changes in cold or arid climates.
- Geology conditions: Extended detention basins can be used with almost all geology. Minor changes in regions with karst (i.e., limestone) topography.

- Soil conditions: Extended detention basins can be used with almost all soils, with minor design adjustments for regions of rapidly percolating soils such as sand.
- Depth of groundwater table: The base of the detention basin should not intersect the groundwater table, being recommended a minimum distance of 1 m.
- Site slopes: Dry detention ponds can operate at sites with slopes up to about 15 percent.
- Closeness to infrastructures: It is important to avoid siting detention basins in areas where water storage may cause slope stability or foundation problems, e.g. in areas of landslides or at the top of slopes, unless a full engineering risk assessment has been carried out. Dry extended detention ponds may become a nuisance due to mosquito breeding if improperly maintained or if shallow pools of water form for more than 3 days. Additionally, they can detract value from properties, so it is recommended to maintain detention basins far from buildings.
- Light/Shade considerations: No specific requirements.
- Accessibility: Detention Basins require sufficient space and generally should be sited in an unobstructed location that can be easily accessed by maintenance vehicles.
- Other considerations: Sediment basins that are used during construction can be converted into dry detention basins after the construction is completed. If used during construction as a sediment basin, completely clean out the basin, re-grade, and vegetate with permanent vegetation within 14 days of completion of construction.

Technical considerations[3,5]

- Vegetated detention basins, especially those that will be in view of travelling public, should not normally follow a geometric profile but they should have edges with curves and undulations to produce aesthetically interesting and natural-looking feature.
- The maximum depth of water in the basin should not normally exceed 2 m.
- The bottom of a detention basin should be as flat as possible with a gentle slope (near to 0.5 – 2%) .
- Length to width ratios should be in the range of 2:1 and 5:1.
- Side slopes usually not exceed 1:3 (V:H).
- Spillways should be placed 10 to 20 cm over the maximum theoretical water level.
- An additional storage capacity of 25% of the detention volume should be incorporated for sediment storage.
- Detention basins may need to include erosion control measures at the outfall and energy dissipation at the inlet.
- Vegetation used in detention basins should be flood tolerant for the expected water residence time.

Limitations[2,5]

- Low to moderate pollutant removal rates, primarily provided by sedimentation processes.
- Can detract value from properties due to the adverse aesthetics of dry, bare areas and inlet/outlet structures.

Pretreatment needs[5]

No (Recommended pretreatment for Extended detention to reduce TSS, trash and debris when pollutants loads are high).

Water treatment[5]

Sedimentation	H	Biological Processes	M	Filtration/Sorption	H	Plant uptake	-

Water quality[5]

Nutrients	L	Sediments	M	Metals	M	Bacteria	M
Oil and Grease	M	Trash and Debris	H				

Emerging Pollutants

Biocides & T.P.	Y	Tyre Compounds	Y	Pharmaceuticals	N/A	Microplastics	Y
Personal Care Products	N/A	Industrial Chemicals	Y	Fossil Fuel and Combustion products	Y		

Water quantity[5]

Volume Reduction	L	Peak Flow Reduction	H	Groundwater Recharge	-

Maintenance[2,3,5]

- Maintenance of detention basins is relatively straightforward for landscape contractors and typically there should only be a small amount of extra work (if any) required for a detention basin over and above what is necessary for standard public open spaces.
- The major maintenance requirement for detention basins is usually mowing.
- Occasionally sediments accumulated at the bottom of the detention basin will need to be removed. This operation should be performed in dry conditions at least one time per year.
- All structural components should be inspected at least annually.
- Components expected to receive and/or trap debris must be inspected for clogging at least twice annually.
- Other remedial actions can be required as reseeding, repair erosion or repair of some structural component, inlets or outlets.
- During the first 6 months after construction is recommended to do monthly inspections of the whole system to ensure the good performance of all components.

Construction and maintenance costs[1]

Construction costs: (Low, Medium, High): 9 – 110 Eur/m³ (Detention volume).
Maintenance costs: (Low, Medium, High): 0.5 – 5 Eur/m² (Basin area) per year.

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System

Filter Strips

Primary uses

Source Control		Transportation		Retention		Infiltration	
Pretreatment	X	Treatment					

Description[1]

Filter strips are uniformly graded and gently sloping strips of grass or other dense vegetation that are designed to treat runoff from adjacent impermeable areas by promoting sedimentation, filtration and infiltration. The runoff flows as a sheet across the filter strip at sufficiently low velocities that allows treatment processes to take place effectively. They are normally used as pretreatment component before swales, bioretention systems and trenches. Filter strips are most suitable for treating stormwater discharge from roads and highways, roof downspouts, very small parking lots, and pervious surfaces.

Subcategories[2]

Vegetative Filter Strips: Planted with perennial grass or legumes with high rates of nitrogen fixation and removal.

Prairie filter strip: Populated with local prairie grasses provides more biodiversity and make filter strips better suited for adverse weather.

Forested riparian buffer: Populated by indigenous trees and flora. Better suited for local fauna.

Wind buffer: Structured in rows of planted trees in order to prevent soil erosion. Mainly used to prevent drifting of snow and as noise barriers along highways.

Applications[3]

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

Location[4,5]

Roadway/Roadside	X	Pathway/Cycleway		Car park	X	Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area	X	Urban Park	X
House/Building	X	Urban Planter		Square/Plaza		Water Course	X

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Scale of application							
Building	X	Neighborhood	X	District	X	City	

Lifespan					
Short Term		Medium Term		Long Term	X

Space usage			
Monofunctional		Multifunctional	X

Required Area[4,5,6]

Drainage Area: <0.1 km² (Maximum upstream drainage length of 50 m).

System Area: The filter strip should extend the entire length of the area that is drained. Recommended drainage to filter strip area ratio is 6:1. Minimum filter strip length is recommended to be in the range of 3 – 5 m depending on the slope and vegetation cover (higher lengths for higher slopes and lower vegetation coverages). Lengths between 5 and 15 m are generally effective.

Ecosystem Functions[7]

Disturbance regulation, water regulation, erosion control and sediment retention, waste treatment, cultural.

Benefits[7]

Climate change mitigation and adaptation (3/5)
Water management (5/5)
Green space management (4/5)
Air quality (4/5)
Urban regeneration (1/5)
Public health and wellbeing (4/5)
Potential of economic opportunities and green jobs (2/5)

Relationship with SDG

Direct
3 Good Health and Well-Being
6 Clear Water and Sanitation
11 Sustainable Cities and Communities
13 Climate Action

Indirect
14 Life Below Water
15 Life on Land

Design Considerations[3,4,5,8,9]

Siting considerations [3,4,5,8]

- Climate conditions: In cold climates the depth of soil media that serves as the planting bed must extend below the frost line to minimize the effects of freezing. They may be impractical in arid areas where the cost of irrigating the grass on the filter strip will most likely outweigh its water quality benefits.
- Geology conditions: Can be used in almost all geology.
- Soil conditions: The soil should be native or amended with organic compost to allow for water retention and infiltration. Soils with high clay content are not suitable for filter strips, as they prevent infiltration. An ideal soil infiltration rate is between 0.5 and 12 inches per hour (12.7 – 304.8 mm/h). Subsoils may need to be tilled to 300 mm and amended to meet specifications for engineered soils. In cold climates the depth of soil media must be extended below the frost line.

- Depth of groundwater table: To ensure that infiltration potential is maintained, the seasonally high groundwater table should as far as possible be more than 1 m below ground level. Filter strips should not slope toward or convey stormwater over septic drain fields or contaminated groundwater plumes. Filter strips should be separate from the groundwater or any confining layer.
- Site slopes: -
- Closeness to infrastructures: -
- Light/Shade considerations: Filter strips should not be located in shaded areas. Vegetal species selection should be made according to local climate conditions.
- Accessibility: -
- Other considerations: Filter strips are impractical in urban areas because they require a large amount of space.

Technical considerations[3,4,5,8]

- The contributing drainage area should have a shallow slope that falls toward filter strip. Maximum contributing area slope should be generally less than 5%.
- Where the sensitivity or vulnerability of the underlaying groundwater means that infiltration should be prevented, filter strips can be designed including an impermeable geomembrane liner at a depth of 0.5 m. In that cases risk of waterlogging should be considered.
- Filter strips should be designed with a slope between 1 to 5%. A consistent slope across the filter strip should be maintained. Maximum lateral slope is recommended to be in the range of 1%.
- Maximum flow velocities across the filter strip are recommended to be 1.5 m/s for preventing erosion.
- Peak flow velocities should be lower than 0.3 m/s to promote settlement.
- The flow depth should be lower than the vegetation height.
- Residence time of runoff should be at least of 5 mins (recommended 9 minutes).
- There should always be a drop of at least 50 mm from the pavement edge (or the edge of the drained impervious area) to prevent the formation of sediment lips.
- Filter strips surface should be planted with an appropriate grass mixture or turfed. A mixture of dry area and wet area grasses is required to meet the performance conditions of the system. If winter salting is needed in adjacent areas (e.g. roads) then it is necessary to select salt tolerant species.
- Vegetation length should be maintained in the range of 75 – 150 mm.

Limitations[3,4,5,8]

- Filter strips are applicable in most regions but are restricted in some situations because they consume a large amount of space relative to other practices.
- Filter strips may be impractical in arid areas where the cost of irrigating the grass on the filter strip will most likely outweigh its water quality benefits.
- Do not locate vegetated filter strips in soils with high clay content that have limited infiltration or in soils that cannot sustain grass cover.
- The maximum likely groundwater level should always be at least 1 m below the lowest level of the filter strip.
- Filter strips should not be located in areas where trees or structures will cause shade conditions that limit grass grow.

Pretreatment needs

No

Water treatment[4]

Sedimentation	**M**	Biological Processes	**L**	Filtration/Sorption	**M**	Plant uptake	**-**

Water quality[4]

Nutrients	L	Sediments	M	Metals	L	Bacteria	L
Oil and Grease	M	Trash and Debris	M				

Emerging Pollutants

Biocides & T.P.	Y	Tyre Compounds	N/A	Pharmaceuticals	N/A	Microplastics	N/A
Personal Care Products	N/A	Industrial Chemicals	Y	Fossil Fuel and Combustion products	Y		

Water quantity[4]

Volume Reduction	M	Peak Flow Reduction	M	Groundwater Recharge	L

**Filter strips provide some degree of peak flow attenuation and volume reduction, especially in unlined systems with subsoils that allows infiltration. However, it should be noted that their main scope is to reduce sediments and sediment-related pollutants as a pretreatment device for other NBS.*

Maintenance[4]

Maintenance of filter strips is relatively straightforward for landscape contractors and typically there should be a small amount of extra work (if any) required for a filter strip over and above what is necessary for standard public spaces. The major maintenance requirement for filter strips is mowing. Occasionally, sediments will need to be removed.

Construction and maintenance costs[6,7]

Construction costs: 2 – 5 Eur/m² with maximum costs in the range of 10 Eur/m².

Maintenance costs: 0.02 – 0.35 Eur/m².

References

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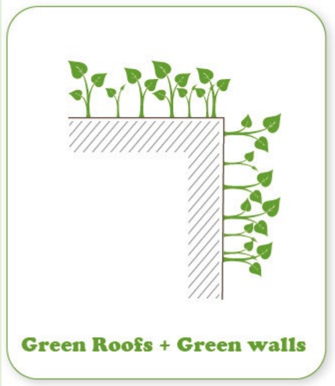
System

Green Roofs and Facades



Primary uses

Source Control	X	Transportation		Retention		Infiltration	
Pretreatment		Treatment					

Description[1]

Green roofs refer to the external upper covering of a building which the main objective is to favor the growth of vegetation keeping the habitability conditions in the rooms below. Similarly, green facades (also called green walls) are vegetated coverages for external building walls.

Subcategories[1,2]

- There are two main types of green roofs: Extensive green roofs and intensive green roofs, which main differences are the type of vegetation used, the substrate height, the maintenance needed and costs. A third type between extensive and intensive green roofs is often included in some catalogues as semi-intensive green roof. Other types of more exotic green roofs exist: Smart roofs, wet roofs, solar green roofs or urban roof-top farms which may give some additional benefits.
- On the other hand, Vertical greening systems (green walls or green facades) can be classified into façade greenings and living walls systems according to their growing method. Green façades are based on the use of climbers attached directly to the building surface or supported by cables or trellis. In the case of an indirect greening system, where cables or meshes support vegetation, various materials can be used as a support for climbing plants such as steel, wood, plastic or aluminum. Indirect greening systems can be combined with planter boxes at different heights of the façade. It should be noted that the effect of green walls or facades in stormwater management are very limited, being their main function related to thermal regulation of buildings.

Applications[3]

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	

Location[4]

Roadway/Roadside		Pathway/Cycleway		Car park		Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area		Urban Park	
House/Building	X	Urban Planter		Square/Plaza		Water Course	

Scale of application

Building	X	Neighborhood		District		City	

Lifespan

Short Term		Medium Term		Long Term	X

Space usage

Monofunctional		Multifunctional	X

Required Area[5,6]

System area: 0 to 0.1 km².

Drainage area: It is recommended that impervious roof area that drain into the green roof not surpass 50% of the green roof area.

Ecosystem Functions[4]

Air quality maintenance, climate regulation, pollination, inspiration, aesthetic values, social relations, recreations and ecotourism.

Benefits[4]

Climate change mitigation and adaptation (5/5)
Water management (3/5)
Green Space management (3/5)
Air quality (2/5)
Urban regeneration (1/5)
Public health and wellbeing (2/5)
Potential of economic opportunities and green jobs (3/5)

Relationship with SDG

Direct
3: Good Health and well-being
7: Affordable and Clean Energy
11: Sustainable Cities and Communities
13: Climate Action

Indirect
2: Zero Hunger
6: Clean Water and Sanitation
15: Life on land

Design Considerations[1,10]

Siting considerations

- Climate conditions: Green roofs and walls can be built adapted to practically all climatic conditions with an adequate design and vegetal species selection. In arid or semi-arid climates, drought-resistant plants need care and freshwater irrigation[8].
- Geology conditions: -
- Soil conditions: -
- Depth of groundwater table: -
- Site slopes:
- Closeness to infrastructures: -
- Light/Shade considerations: Green roofs and walls can be built adapted to practically all climatic and light conditions with an adequate design and vegetal species selection.
- Accessibility: Provide access for maintenance activities.
- Other considerations: Green Roofs and walls should be located in houses and buildings that can effectively support the loads generated by the green roof or wall avoiding geometrical configurations that cannot be used for installing these systems (see Limitations section below).

Technical considerations

- Certain roof materials, such as exposed chemically treated wood and uncoated galvanized metal, may not be appropriate for green roof tops due to potential pollutants leaching from these materials in wet conditions.
- A green roof water storage volume is at its maximum on a relatively flat roof (slopes of **1% or 2%**). A slope of up to 7% is most efficient for rainwater retention.
- Green roofs can be designed for receiving also runoff for surrounding impervious roof areas (**maximum 50% of the green roof area**).
- Vegetation and moisture should be selected for resisting the environmental conditions in the application area, considering **drought and inundation tolerance of vegetation, light requirements, freezing resistance and irrigation needs**.

Limitations[4,9,10]

- *The structural capacity of existing* roofs and walls must be considered to support the weight of a green roof and the additional volume of water. As reference values can be considered the following: Extensive green roofs **20 kg/m² to 190 kg/m²**. Intensive roofs and rooftop gardens: **190 kg/m² to 680 kg/m²**. For Green Walls, it can be expected a maximum weight to be supported by the wall of 80 – 100 Kg/m² including plants, built elements and eventual contribution of ice, snow and/or water.
- *The inclination of the roof* must be between **0 and 45 degrees**, but for slopes higher than 25 degrees it can be necessary to use stabilizing methods as anti-slip mats.

Pretreatment needs[11]

No

Water treatment[11]

Sedimentation	**L**	Biological Processes	**L**	Filtration/Sorption	**L**	Plant uptake	**-**

Water quality[11]

Nutrients	**L**	Sediments	**L**	Metals	**L**	Bacteria	**L**
Oil and Grease	**L**	Trash and Debris	**L**				

Emerging Pollutants

Biocides & T.P.	Y	Tyre Compounds	N/A	Pharmaceuticals	Y	Microplastics	N/A
Personal Care Products	Y	Industrial Chemicals	N/A	Fossil Fuel and Combustion products	N/A		

Water quantity[3,11,12,13,14,15]

Volume Reduction	M	Peak Flow Reduction	L	Groundwater Recharge	-

Green Roofs are able to manage around 23 to 100% of the stormwater they receive depending on the rainfall patterns in the site location, the green roof structure, season and interval between storms. Standard water retention capacity range in green roofs, depending on the type of green roof, varies from 20 – 50 l/m² for extensive green roofs to 30 – 160 l/m² for intensive green roofs. When totally saturated the hydraulic performance of green roofs tends to be similar to standard roofs. Evapotranspiration can be assumed to be in the range of 1 – 6 mm/day, higher in summer periods and in hottest areas.

It is important to note that green wall effectiveness credit for water management is conditioned to the use of water collected on the building or house rooftop to irrigate vegetation in the green wall since the capacity of vertical greening system to catch rainwater is very limited due to their reduced plan dimensions. In these conditions, the use of collected rainwater in the rooftop to irrigate vegetation in a green wall that cover a full sidewall of a building can reduce between 45% and 75% of total rainfall generated by a building during a single storm event.

Maintenance[1,14]

Green roofs require **semi-annual inspections** to ensure water outlets are clear of (dead and living) plants and debris. Extensive green roofs require minimal maintenance while an intensive green roof requires regular garden maintenance including pruning, cleaning and removal of debris, soil amendment, and nourishment. Maintenance of Green Walls is quite similar than for green roofs, consisting mainly in pruning and cleaning.

Construction and maintenance costs[5,9,10]

The cost of green roof installation varies widely depending on the types of building solutions, the complexity of the installation roof, and material and labor costs at the site location. As reference costs can be considered: for extensive green roofs: **50 Eur/m² – 225 Eur/m²**; and for Intensive green roofs: **> 150 Eur/m²**.

The cost of Green Facades (Green walls) installation varies widely depending on the system used. The cost of direct greening system is around **30 to 45 Eur/m²** for grown climbing plants. In the case of indirect greening system, the cost range is **40 to 75 Eur/m²**. When planter boxes are combined with supporting systems the costs significantly vary from **100 to 800 Eur/m²**, depending on the used material. In the case of living wall system, the costs can significantly vary: from 400 to **1200 Eur/m²** depending on system conception and material used.

Maintenance costs on green roofs will be a function of the type of roof as well as of the local climate and weather. Intensive green roofs are generally more expensive than extensive green roofs (Extensive green roofs: **0.5 Eur/m²/year** to **3 Eur/m²/year**; Intensive green roofs: **3.50 Eur/m²/year – 15 Eur/ m²/year**). Maintenance costs of green walls ranged from 2.8 Eur/m²/ year to 14.5 Eur/m²/year depending on the used system, being higher for living walls and systems that use planter boxes.

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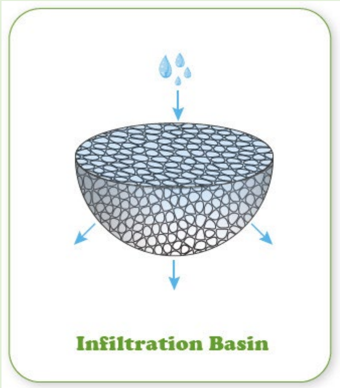
System

Infiltration Basins



Primary uses

Source Control		Transportation		Retention		Infiltration	X
Pretreatment		Treatment					

Description[1,2,3]

Infiltration basins are stormwater impoundments, over permeable soils with vegetated bottoms and side slopes. Infiltration basins are designed to reduce stormwater volumes through exfiltration and groundwater recharge. They are ideal for use as playing field, recreational areas or public open space.

Subcategories[4,5]

There are 2 types of infiltration basins: full exfiltration and partial or off-line exfiltration. Full exfiltration basins are designed to store, treat, and exfiltrate all the inflow water. Partial or off-line exfiltration basins are designed to exfiltrate a portion of the runoff (usually the “first flush”), while diverting the remaining runoff to another system through flow splitters or weirs.

Additionally, infiltration basins may be designed as surface or sub-surface system. Surface systems are those which have a free water surface area, while sub-surface systems provide similar functions without a free water surface area (below ground system).

Applications[1,2,6]

Residential	X	Commercial	X	Industrial		High Density		Road/Highway	

Location[4]

Roadway/Roadside		Pathway/Cycleway		Car park		Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area	X	Urban Park	X
House/Building		Urban Planter		Square/Plaza		Water Course	

Scale of application[1]							
Building		Neighborhood	X	District	X	City	
Lifespan							
Short Term		Medium Term	X	Long Term			
Space usage							
Monofunctional		Multifunctional	X				

Required Area[1,7]

Drainage Area: 2 to 20 ha (recommended <10 ha).

System Area: Maximum relation of contributing to drainage area is recommended to be 5:1.

Ecosystem Functions[8]

Water regulation, Erosion Control, water purification and waste treatment, Educational Values, Aesthetic Values, Inspiration, Social relations, Recreation.

Benefits[8]

Climate change mitigation and adaption (3/5)
Water Management (5/5)
Green Space Management (4/5)
Urban regeneration (2/5)
Public Health and wellbeing (4/5)
Potential of economic opportunities (2/5)

Relationship with SDG

Direct	Indirect
3 Good Health and Well-Being	4 Quality Education
6 Clear Water and Sanitation	8 Decent Work and Economic Growth
11 Sustainable Cities and Communities	12 Responsible Consumption and Production
13 Climate Action	14 Life Below Water

Design Considerations[1,2,3,4,5,9,10]

Siting considerations[2]

- Climate conditions: Infiltration basins apply in most places, with some design modifications in cold and arid climates. In extremely cold climates (i.e., regions that experience permafrost), infiltration basins may be infeasible. They are feasible in most cold climates, but there are some challenges to their use. First, a basin may become inoperable during portions of the year when its surface becomes frozen. Designers may also need to increase the treatment capacity to accommodate the additional volume of stormwater associated with spring snowmelt.
- Geology conditions: For infiltration basins, underlying soils and geology must be highly pervious. They are often inappropriate in karst (i.e., limestone) regions due to concerns of sinkhole formation and groundwater contamination.
- Soil conditions: For infiltration basins, underlying soils and geology must be highly pervious. Subsoil design permeability should be greater than 1.25 cm/h and not higher than 25 cm/h.
- Depth of groundwater table: Distance to water table should be greater than 60 cm (recommended higher than 1 m).

- Site slopes: Infiltration basins may not be constructed in areas where the surrounding slopes are 15% or greater.
- Closeness to infrastructures: It is particularly important to avoid siting in areas where water storage and infiltration may cause slope stability or foundation problems. They should not be located too close to groundwater drinking water catchments. Basins should be sited a minimum 30 m from drinking water wells. Basins should be sited a minimum 30 m up-gradient and 6 m down-gradient from building foundations and pavements.
- Light/Shade considerations: No specific considerations.
- Accessibility: Provide accessibility for maintenance activities.
- Other considerations: -

Technical considerations[3,4,5,9,10]

- Residence time should be shorter than 72 hours in order to allow basin functionality for the next storm and avoid anaerobic conditions, odor, and both water quality and mosquito breeding issues.
- The area of the basin intended for infiltration must be as level as possible in order to uniformly distribute runoff infiltration over the subsoil.
- Side slopes should be of 3:1 (H:V) or flatter. Longitudinal slope, if used, shall not exceed 1%. It is recommended to include an access route of 3.5 to 4 m width and 6:1 slope for maintenance operations.
- It is recommended to design infiltration basins with increased infiltration surface areas and reduced water depths in the basin if it is possible at the site location.
- An emergency outlet should be incorporated to prevent overflows.
- Vegetation in side slopes should be flooding tolerant in order to survive at least 72 hours under water
- It is recommended that water depth in the basin should be no greater than 60 cm.
- The bottom of the basin should be covered with 15 – 30 cm of sand in order to preserve permeability rates over time (permeability of sand higher than 50 cm/h).

Limitations[2,3,4,10]

- Infiltration basins are not appropriate for areas with compacted or poorly infiltrating soils, typically limiting their use in urban environments.
- They are also not suitable for areas with a high groundwater table or where groundwater contamination is a concern.
- May not be appropriated for industrial sites or locations where spills may occur.
- They have to be placed away from buildings and pavement foundations to prevent instabilities.
- Existing infiltration basins have the highest failure rate of any BMP. The primary reasons are lack of pretreatment for removal of substances which can clog the basin, and lack of maintenance.

Pretreatment needs[1,3,4,5,9]

Yes (Oil and TSS reduction)

Water treatment[11]

Sedimentation	**H**	Biological Processes	**M**	Filtration/Sorption	**H**	Plant uptake	**-**

Water quality[11]

Nutrients	**M**	Sediments	**H**	Metals	**H**	Bacteria	**H**
Oil and Grease	**M**	Trash and Debris	**H**				

Emerging Pollutants

Biocides & T.P.	**Y**	Tyre Compounds	**N/A**	Pharmaceuticals	**Y**	Microplastics	**N/A**
Personal Care Products	**N/A**	Industrial Chemicals	**N/A**	Fossil Fuel and Combustion Products	**N/A**		

Water quantity[11]

Volume Reduction	**H**	Peak Flow Reduction	**M**	Groundwater Recharge	**H**

Maintenance[3]

- The most critical maintenance item is the periodic removal of accumulated sediment from the basin bottom. If sediment is allowed to accumulate, surface soils will become clogged and the basin will cease to operate as designed. Sediment should be removed only when the surface is dry and "mud-cracked." Light equipment must be used in order to avoid compacting soils. After removal of sediment, the infiltration area should be deep tilled to restore infiltration rates. Normally, sediment should be removed at least once a year. More frequent tilling may be necessary in areas with soils that are only marginally permeable.
- Other maintenance items include mowing buffer/filter strips, side slopes, and the basin floor. Debris and litter accumulated in the basin must be removed. Eroding or barren areas must be revegetated as soon as possible.

Construction and maintenance costs

Construction costs: (Low, Medium, High): 15 to 90 Eur/m³ (detention volume). 135000 to 200000 Eur/ha of impervious area treated.

Maintenance costs: (Low, Medium, High): 0.15 to 5.5 Eur/m² (basin area). 1400 to 4100 Eur/ha of infiltration basin per year.

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D4RUNOFF

System	
Dry Wells	

Primary uses

Source Control		Transportation		Retention		Infiltration	X
Pretreatment		Treatment					

Description[1, 2]

Dry wells are excavated pits (usually small), backfilled with aggregate, and used to infiltrate uncontaminated runoff from roofs. Dry wells are constructed to reduce stormwater runoff volumes through increased groundwater recharge and can be used as retrofits of highly urbanized areas. Dry wells are stormwater infiltration devices typically constructed of a vertical pipe that extends deep into the subsurface without contacting the groundwater table. They are characterized as infiltration facilities that are deeper than they are wide. Perforations are located along the length of the pipe and/or at the bottom to permit stormwater to flow from various parts of the well into the surrounding soils.

Subcategories[1, 2]

There are many varieties in construction and design practices that affect the placement of perforations, use of geotextiles, and use of internal gravel or rocks. Dry wells can be used in a variety of situations, but have unique advantages in areas with shallow clay or hardpan soils because they facilitate the movement of stormwater runoff below these types of constricting layers to facilitate infiltration. Multiple dry wells can be installed to create treatment trains for large drainage areas.

Applications[2]

Residential	X	Commercial	X	Industrial		High Density	X	Road/Highway	

Location[1,2]

Roadway/Roadside		Pathway/Cycleway		Car park		Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area		Urban Park	
House/Building	X	Urban Planter		Square/Plaza		Water Course	

Scale of application

Building	X	Neighborhood		District		City	

Lifespan

Short Term		Medium Term		Long Term	X

Space usage

Monofunctional	X	Multifunctional	

Required Area[1]

Drainage Area: < 5 ha.

System Area: The area of the infiltration trench should allow for infiltration through the trench bottom within 24 hours for medium sized rain (T=30 years).

Ecosystem Functions[3]

Water regulation, water purification and waste treatment, erosion control

Benefits[3]

Water Management (5/5)
Green Space Management (3/5)
Urban regeneration (2/5)
Public Health and wellbeing (2/5)
Potential of economic opportunities and green jobs (1/5)

Relationship with SDG

Direct
6 Clear Water and Sanitation
13 Climate Action
14 Life Below Water

Indirect
3 Good Health and Well-Being

Design Considerations[1,2,4]

Siting considerations

- Climate conditions: Precaution should be taken in cold climates in order to consider the frost depth in the system design.
- Geology conditions: Can be used in almost all geology conditions that provide enough infiltration.
- Soil conditions: The soil composition should be inspected prior to installation to ensure that the dry well is well past any impermeable layers or layers in which the water will not infiltrate adequately.

- Depth of groundwater table: Systems designed for infiltration should allow at least 1 m clearance between the base of the soakaway and the seasonally high groundwater table.
- Site slopes: Soakaways should not be used on unstable ground: ground stability should be verified by assessing site soil and groundwater conditions prior to construction. On sloping sites, an assessment should be made to ensure that infiltrating water will not cause raised groundwater levels further downslope or waterlogging of downhill areas, and that slope stability would not be affected.
- Closeness to infrastructures: Dry well must be placed at least 3 m (10 feet) away from building foundation. Dry wells should not be installed too close to drinking water wells to minimize the risk of contamination or in areas where soil or groundwater has been contaminated to avoid flushing contamination into groundwater. They should also not be installed in or near sites where contamination by dissolved pollutants is likely (e.g., auto repair shops).
- Light/Shade considerations: -
- Accessibility: Provide access for maintenance activities.
- Other considerations: -

Technical considerations

- Dry Wells are sized to temporarily retain and infiltrate stormwater runoff from roofs of structures. Must draw down within 72 hours.
- Dry Wells should be able to convey system overflows to downstream drainage systems.
- Construct dry well 1 ft (30.5 cm) below ground surface. Maximum depth should not exceed 10 ft (3.05 m).
- Perforations of inlet pipe into dry well must begin 30.5 cm (1 foot) from side of well.
- Line top, bottom, and sides with a geotextile or filter fabric.
- Fill with washed 4 – 8 mm (1.5 – 3 inch) diameter gravel with a void ratio of 0.40.

Limitations[1,2]

- High potential for clogging.
- Treats small tributary area.
- Can cause structural damage to nearby buildings due to water seepage.
- Not yet efficient at treating some water-soluble contaminants and non-aqueous phase liquids that may be present in stormwater.
- Not suitable for areas with steep slopes, a water table that is near the ground surface, or soil or groundwater that has been contaminated.
- Unclear local regulations in some areas.

Pretreatment needs[1]

No

Water treatment[1]

Sedimentation	**H**	Biological Processes	**L**	Filtration/Sorption	**M**	Plant uptake	**-**

Water quality[1]

Nutrients	**L**	Sediments	**H**	Metals	**L**	Bacteria	**L**
Oil and Grease	**L**	Trash and Debris	**L**				

Emerging Pollutants

Biocides & T.P.	**Y**	Tyre Compounds	**N/A**	Pharmaceuticals	**N/A**	Microplastics	**N/A**
Personal Care Products	**N/A**	Industrial Chemicals	**Y**	Fossil Fuel and Combustions Products	**N/A**		

Water quantity[1]

Volume Reduction	**H**	Peak Flow Reduction	**M**	Groundwater Recharge	**H**

Maintenance[1,2]

- Inspect well at least 4 times a year and after major storm events to ensure that maximum draw down time (72 hours) is not being exceeded.
- Clean roof gutters to prevent clogging of dry well.
- Replace filter screen as necessary.

Construction and maintenance costs[1,2,4]

Construction costs: 90 to 315 Eur/m³ (storage volume). Typical costs range from 500 to 1000 Eur.

Maintenance costs: yearly maintenance costs of 0.25 – 1.25 Eur/m² (treated area). Around 5 to 10% of construction costs per year.

References

[1]*Boston Water and Sewer Commission (2013). Stormwater Best Management Practices: Guidance Document. Boston, MA, USA. Available at: https://www.bwsc.org/sites/default/files/2019-01/stormwater_bmp_guidance_2013.pdf*
[2]*Pennsylvania Stormwater Best Management Practices Manual (2006). Chapter 6: Structural BMPs. Available at: http://www.starkenvironmental.com/downloads/PADEP.pdf*
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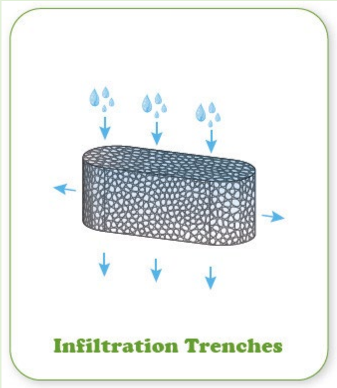
System

Infiltration Trenches



Primary uses

Source Control		Transportation		Retention		Infiltration	X
Pretreatment		Treatment					

Description[1, 2]

Infiltration trenches can be defined as simply linear soakaways and are shallow excavations covered with rubble or stone that enhance the natural ability of soil to drain water. An Infiltration Trench is a linear stormwater BMP consisting of a continuously perforated pipe at a minimum slope in a stone-filled trench. An Infiltration Trench may be used as part of a larger storm sewer system, such as a relatively flat section of storm sewer, or it may serve as a portion of a stormwater system for a small area, such as a portion of a roof or a single catch basin. In all cases, an Infiltration Trench should be designed with a positive overflow. Usually, an Infiltration Trench is part of a conveyance system. Their main function is to infiltrate runoff water and hence are normally used as end of train systems or to infiltrate runoff water from nearby impervious areas.

Subcategories[1, 2]

Infiltration Trenches generally have a vegetated (grassed) or gravel surface. Infiltration Trenches also may be located alongside or adjacent to roadways or impervious paved areas with proper design. Infiltration trenches can be built with crushed stone or rubble in order to allow high void ratios in the system that improves water storage and infiltration. Systems can include an underlying perforated pipe to prevent overflow. Reactive media (e.g., zeolite, activated carbon, oxide-coated sand, etc.) may be incorporated into the design to increase sorption capacity and target specific pollutants.

Applications[2]

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

Location[3]

Roadway/Roadside	X	Pathway/Cycleway		Car park	X	Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area		Urban Park	X

House/Building	X	Urban Planter		Square/Plaza		Water Course	

Scale of application

Building	X	Neighborhood	X	District		City	

Lifespan

Short Term		Medium Term	X	Long Term	

Space usage

Monofunctional	X	Multifunctional	

Required Area[1]

Drainage Area: < 5 ha.

System Area: The area of the infiltration trench should allow for infiltration through the trench bottom within 24 hours for medium sized rain (T=30 years).

Ecosystem Functions

Water regulation, water purification and waste treatment, erosion control.

Benefits[3]

Water Management (5/5)
Green Space Management (3/5)
Urban regeneration (2/5)
Public Health and wellbeing (2/5)
Potential of economic opportunities and green jobs (1/5)

Relationship with SDG

Direct
6 Clear Water and Sanitation
13 Climate Action
14 Life Below Water

Indirect
3 Good Health and Well-Being

Design Considerations[1]

Siting considerations [1,2]

- Climate conditions: Precaution should be taken in cold climates in order to consider the frost depth in the system design. If vegetation cover Is used grass selection should be made according to local climate conditions, considering potential salting in roads environment during winter season.
- Geology conditions: -
- Soil conditions: The soils underlying the site should be permeable and have a clay content of less than 20%, as well as a silt content of less than 40%.
- Depth of groundwater table: The infiltration structure should be at least 1 m above the seasonally high groundwater levels.
- Site slopes: To limit the velocity of surface runoff water and accommodate infiltration and pollutant removal, the longitudinal slope should not exceed 2%.
- Closeness to infrastructures: Infiltration trenches must be placed at least 10 ft (3.05 m) away from building foundation. They should not be installed too close to drinking water wells to minimize the risk of contamination or in areas where soil or groundwater has been contaminated to avoid flushing

contamination into groundwater. They should also not be installed in or near sites where contamination by dissolved pollutants is likely (e.g., auto repair shops).

- Light/Shade considerations: If vegetation cover is used, Infiltration trenches should not be located in shaded areas.
- Accessibility: Provide enough access for maintenance activities. Large Infiltration trenches may need heavy machinery to remove gravel.
- Other considerations: Infiltration trenches are most effective for catching surface runoff water in locations with low sediment loading (e.g. car parks). If this is not the case, pre-treatment is needed to remove sediment and fine silt to prevent clogging (Swales, filter strips, etc.).

Technical considerations[1,2]

In general, an infiltration trench should consist of the following features:

- A topsoil layer of minimum 15 cm with vegetation or gravel.
- A layer of coarse aggregate wrapped in unwoven geotextile (on the top, sides and bottom).
- Normally, crushed stone of 40 to 80 mm should be used to allow high void ratios.
- A continuously perforated pipe can be included underneath, set at a minimum slope.
- A sand filter or fabric equivalent should be placed at the very bottom.
- Infiltration trenches can have vegetated, stone or gravel surfaces and require minimal land take.
- Generally, they should be 1 – 2 m deep and are restricted to relatively flat sites.
- Infiltration trenches should be limited in width (around 1 – 2.5 m) and depth of stone (maximum of 1.8 m recommended).

Limitations[1]

Infiltration trenches cannot be used near buildings and when contaminated groundwater is present, are ineffective on steep slopes, lose or unstable areas.

Pretreatment needs[3]

Yes (TSS, oil, trash and debris).

Water treatment[3]

Sedimentation	M	Biological Processes	L	Filtration/Sorption	H	Plant uptake	-

Water quality[3]

Nutrients	H	Sediments	H	Metals	H	Bacteria	H
Oil and Grease	M	Trash and Debris	H				

Emerging Pollutants

Biocides & T.P.	N/A	Tyre Compounds	N/A	Pharmaceuticals	Y	Microplastics	N/A
Personal Care Products	Y	Industrial Chemicals	N/A	Fossil Fuel and Combustion Products	N/A		

Water quantity[3]

Volume Reduction	H	Peak Flow Reduction	H	Groundwater Recharge	H

Maintenance[1]

It is essential to conduct regular maintenance, including removing litter and debris, inspecting for clogging and trimming any roots that could cause blockages. The catch basin and inlets require inspection and cleaning at least two times per year. In addition, the vegetation (if used) should be kept in good condition and bare spots should be repaired as quickly as possible. For the first few months after construction, the site should be inspected after every big storm to make sure the infiltration trench is stabilized and functioning.

Construction and maintenance costs[1,4]

Construction costs: 70–90 Eur/m^3 stored volume.

Maintenance costs: 0.25–4 Eur/m^2 (surface area)/year.

References

[1]*Iwaszuk, E., Rudik, G., Duin, L., Mederake, L., Davis, M., Naumann, S., and Wagner, I., (2019). Addressing Climate Change in Cities. Catalogue of Urban Nature-Based Solutions. Ecologic Institute, the Sendzimir Foundation: Berlin, Krakow. Available at: https://www.ecologic.eu/sites/default/files/publication/2020/addressing-climate-change-in-cities-nbs_catalogue.pdf*

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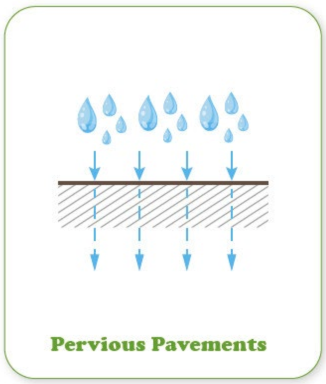
System

Permeable Pavements



Primary uses

Source Control	X	Transportation		Retention		Infiltration	X
Pretreatment		Treatment					

Description[1,2]

Permeable pavements are nature-based infrastructures which increases percolation of rain and surface water through a paved surface. They infiltrate, treat, and store rainwater and reduce runoff by allowing rain and snowmelt to seep to underlying layers. They generally consist of a surface pavement layer, an underlying reservoir layer, and may include a filter layer or fabric installed at the bottom, all of them above a well compacted soil. These types of pavements are normally used for pedestrian ways and sidewalks, parking lots or in streets or roads with light traffic.

Subcategories[1,3,4,5,6,7,8]

- According to the surface layer the following types can be defined: interlocking pavers permeable pavements, porous permeable pavements (porous asphalt and porous concrete) and grass reinforced permeable pavements (concrete or plastic grids filled with soil and grassed surface).
- Permeable pavements can be lined or not, and can include perforated pipes in the sub-base for water drainage or not, all depending on the specific conditions of the location site and the usage expected for permeable pavement.
- Additionally, reservoir or sub-base layer can be built with coarse aggregates, or plastic cells can be used to increase water storage.
- Other types of more exotic permeable pavements exist: permeable cool pavements, solar permeable pavements, macro-pervious pavements or photocatalytic permeable pavements that can provide additional benefits.

Applications[9,10]

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

Location[3]

Roadway/Roadside	X	Pathway/Cycleway	X	Car park	X	Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area	X	Urban Park	X
House/Building		Urban Planter		Square/Plaza	X	Water Course	

**Permeable Pavements can be used as pavement structures for trafficked roads, but only with low traffic intensity.*

Scale of application

Building	X	Neighborhood	X	District	X	City	

Lifespan

Short Term		Medium Term	X	Long Term	

Space usage

Monofunctional		Multifunctional	X

Required Area[7,9]

- Drainage Area: 0 to 0.1 km². Where adjacent areas drain into the permeable pavement surface, the ratio of impermeable to pervious should be limited to 2:1 to prevent clogging.
- System Area*: No max/min.

**There are no maximum or minimum dimensions for permeable pavements from a technical point of view. They can be installed for a private parking bay in a particular house or in bigger areas like shopping centers car parks or along main streets sidewalks. However, considering design, transportation and installation costs very small permeable pavement areas can be not cost-effective.*

Ecosystem Functions[1]

Water regulation, water purification and waste treatment, erosion control, climate regulation.

Benefits[1]

Climate change mitigation and adaption (2/5)
Water management (5/5)
Green Space management (3/5)
Urban regeneration (3/5)
Public health and wellbeing (2/5)
Potential of economic opportunities and green jobs (3/5)

Relationship with SDG

Direct
3 Good Health and Well-Being
6 Clear Water and Sanitation
11 Sustainable Cities and Communities
13 Climate Action

Indirect
8 Decent Work and Economic Growth
14 Life Below Water
15 Life on Land

Design Considerations[1,3,7,9]

Siting considerations[1,3,7,9]

- Climate conditions: Permeable pavements can be applied in all environmental conditions. However, maintenance needs can be influenced by the location site in order to maintain enough infiltration capacity to manage stormwater runoff.
- Geology conditions: -
- Soil conditions: It is necessary to perform a prior analysis of the soil characteristics in terms of bearing capacity (California Bearing Ratio - CBR higher than 2.5%) and infiltration.
- Depth of groundwater table: It should not be installed within 1.2 m above a bedrock or a groundwater high point.
- Site slopes: On steeper slopes, internal dams may be used in the sub-base to control drainage flow and maximize the sub-base storage. However, to be very efficient, the slope should not exceed 1 – 2.5% to avoid surface runoff.
- Closeness to infrastructures: It should not be installed within 30 m of a well. It should not be installed within 3 m of building foundation located above or 30 m for building foundation located below Foundations and pavements.
- Light/Shade considerations: -
- Accessibility: -
- Other considerations: Not recommended in areas with high risk of silt loads on the surface. It should never be within the vicinity of possible contamination sources such as gas stations.

Technical considerations[1,3,7,9]

- The slope of the installation should not exceed 5%, the flatter, the better. When slopes are greater than 3% terracing or internal check dams should be considered. Some experiences pointed out that Permeable pavement surfaces can be perform well with slopes up to 20%, but the storage capacity of sub-base should be limited by the slope.

Limitations[11]

Several factors may limit permeable pavement use:

- Permeable pavements are not as strong as conventional asphalt or concrete and are not appropriate for applications with high traffic volumes and extreme pollutant loads.
- Permeable pavements are also not appropriate for stormwater hot spots where hazardous material loading, unloading or storage occurs, or in areas where spills and fuel leakage are possible.
- Designers may want to limit units with large openings containing aggregate for paths or parking areas that disabled persons, bicycles, pedestrians with high heels and the elderly use.

Pretreatment needs

No

Water treatment[12]

Sedimentation	**M**	Biological Processes	**L**	Filtration/Sorption	**M**	Plant uptake	**-**

Water quality[12]

Nutrients	**M**	Sediments	**H**	Metals	**M**	Bacteria	**M**
Oil and Grease	**H**	Trash and Debris	**H**				

Emerging Pollutants

Biocides & T.P.	N/A	Tyre Compounds	Y	Pharmaceuticals	N/A	Microplastics	Y
Personal Care Products	N/A	Industrial Chemicals	N/A	Fossil Fuel and Combustion Products	Y		

Water quantity[12]

Volume Reduction	H	Peak Flow Reduction	M	Groundwater Recharge	H

**Water quantity performance of permeable pavements depends mainly on the type and category of permeable pavement. The used materials and design, the topographic slope and the clogging level of surface layer are key factors that influence infiltration and interception capacity of Permeable Pavements. The higher the infiltration capacity of the surface layer, the higher the velocity of water infiltration. Similarly, higher storage volumes in the sub-base layer lead to higher water interception. Finally, in unlined permeable pavements, higher soil infiltration rates provide increased interception capacities. According to these criteria, the minimum expected interception capacity of permeable pavements can be considered to be near to 5 mm with maximum levels that can be as much as the total fallen rainfall. As an average, can be expected that permeable pavements can infiltrate up to 95% of the total rainfall in an annual basis. Peak Flow rates can be expected to be 30% lower than in conventional pavements and the time of concentration can be estimated to be 5 to 10 minutes higher than in conventional pavements. Typical values of outflow rates from permeable pavements are 2 to 7 L/s·ha.*

Maintenance[7,12,13]

- Regular inspection and maintenance are important for the effective operation of permeable pavements. They could need to be regularly cleaned of silt and other sediments to preserve their infiltration capacity. Extensive experience suggests that **sweeping once or twice per year** should be sufficient to maintain an acceptable infiltration rate on most sites. However, in some instances, frequency should be adjusted to suit site-specific circumstances. For instance, there are sites where the frequency should be increased to 4 or more sweeping operations per year, while in others may not be necessary to perform maintenance operation even after years of continuous use. A bush and suction cleaner should be used for sweeping operations. If the surface has clogged, then a more specific sweeper with water jetting and oscillating and rotating brushes may be required, especially for porous surfaces (porous concrete and porous asphalt).
- No winter sanding should be conducted when porous surfaces are used.

Construction and maintenance costs[9,13,14]

Construction costs: **40 Eur/m² – 300 Eur/m².**

Maintenance costs: **1 Eur/m² – 5 Eur/m²** per year.

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D4RUNOFF

System

Retention Ponds

Primary uses

Source Control		Transportation		Retention	X	Infiltration	
Pretreatment		Treatment	X				

Description[1,2,3]

Retention Ponds or Wet Ponds are ponds or pools designed with additional storage capacity to attenuate surface runoff during rainfall events. They consist of a permanent pond area with landscaped banks and surroundings to provide additional storage capacity during rainfall events. They are created by using an existing natural depression, by excavating a new depression, or by constructing embankments. Retention ponds can provide both storm water attenuation and water quality treatment by providing additional storage capacity to retain runoff and release this at a controlled rate. The retention time and still water promotes pollutant removal through sedimentation, while aquatic vegetation and biological uptake mechanisms offer additional treatment. Retention ponds have good capacity to remove urban pollutants and improve the quality of surface runoff.

Subcategories[4]

Wet Ponds can be designed as either an online or offline facility. They can also be used effectively in series with other sediment reducing techniques that reduce the sediment load such as vegetated filter strips, swales, and filters. Other more exotic solutions can include floating vegetated platforms (eco-islands) to enhance sedimentation and biological uptake. Wet Ponds may be a good option for retrofitting existing dry detention basins.

Retention Ponds are often organized into three groups:

- Wet Ponds primarily accomplish water quality improvement through displacement of the permanent pool and are generally only effective for small inflow volumes (often they are placed offline to regulate inflow).
- Wet Detention Ponds are similar to Wet Ponds but use extended detention as another mechanism for water quality and peak rate control.
- Pocket Wet Ponds are smaller Wet Ponds that serve drainage areas between approximately 5 and 10 acres (2 – 4 ha) and are constructed near the water table to help maintain the permanent pool. They often include extended detention as well.

Applications[4]

Residential	X	Commercial	X	Industrial	X	High Density		Road/Highway	X

Location[2,5]

Roadway/Roadside		Pathway/Cycleway		Car park		Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area	X	Urban Park	X
House/Building		Urban Planter		Square/Plaza		Water Course	

Scale of application

Building		Neighborhood	X	District	X	City	X

Lifespan

Short Term		Medium Term		Long Term	X

Space usage

Monofunctional		Multifunctional	X

Required Area[2,4,6]

Drainage Area: 0 – 10 km² (unless sufficient groundwater flow).

System Area: 1% – 7% of the drainage area (Minimum 0.1 ha).

Ecosystem Functions[1]

Disturbance Regulation, Water regulation, Erosion Control, waste treatment, Cultural.

Benefits[1]

Climate change mitigation and adaption (3/5)
Water Management (5/5)
Green Space Management (4/5)
Air quality (4/5)
Urban regeneration (1/5)
Public Health and wellbeing (4/5)
Potential of economic opportunities (2/5)

Relationship with SDG

Direct
3 Good Health and Well-Being
6 Clear Water and Sanitation
13 Climate Action

Indirect
11 Sustainable Cities and Communities
14 Life Below Water
15 Life on Land

Design Considerations[2,4,7]

Siting considerations

- Climate conditions: Some precaution should be taken in cold climates due to the expansion of freezing water.
- Geology conditions: Wet ponds can work in almost all geology, with minor design adjustments for regions of karst (i.e., limestone) topography.
- Soil conditions: Wet ponds can work in almost all soils. Designers can include liners for soils with high infiltration rates if water loss is a concern. Soils may require modification to reduce permeability. The stability of the soil needs to be checked, as additional precautions may need to be taken if it cannot support an adequate weight load for both construction and maintenance purposes.
- Depth of groundwater table: Retention ponds require groundwater or a dry-weather base flow if the permanent pool elevation is to be maintained year-round. The designer should consider the overall water budget to ensure that the baseflow will exceed evaporation, evapotranspiration, and seepage losses (unless the pond is lined).
- Site slopes: It may be difficult to construct a pond on steeply sloping land. Wet ponds can work at sites with an upstream slope up to about 15 percent. However, the local slope should be relatively shallow. Ponds would typically be sited at a low point in the catchment where it can receive drainage by gravity. Several ponds may be required at a large site, split into topographic sub catchments. The position chosen should allow safe routing of flows above the design event for the pond, and the consequence of any pond embankment failure considered.
- Closeness to infrastructures: -
- Light/Shade considerations: -
- Accessibility: Permanent access must be provided to the forebay, outlet, and embankment areas. It should be at least 9 feet wide, have a maximum slope of 15%, and be stabilized for vehicles.
- Other considerations: Ponds should be located outside the flood plain of any watercourse which might cause the pond to be inundated during storm events. Where possible ponds should be located in non-intensively managed landscapes where native vegetation is already established and/or will flourish. Ponds are frequently positioned in a low location in the watershed where gravity can assist drain the water. A large site may necessitate several ponds divided into topographic sub-catchments.

Technical considerations

- Wet Ponds must be able to receive and retain enough flow from rain, runoff, and groundwater to ensure long-term viability. A permanent water surface in the deeper areas of the WP should be maintained during all but the driest periods.
- Wet Ponds should have a drainage area of at least 10 acres (4 ha) or 5 acres (2 ha) for Pocket Wet Ponds, or some means of sustaining constant inflow.
- Wet Ponds should be designed with a length to width ratio of at least 2:1 wherever possible.
- Slopes in and around Wet Ponds should be 4:1 to 5:1 (horizontal: vertical) or flatter whenever possible (10:1 max).
- Although there is no minimum slope requirement, there needs to be enough elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system.
- Wet Ponds should have an average depth of 3 to 6 feet (0.9 – 1.8 m) and a maximum depth of 8 feet (2.4 m). This should be shallow enough to minimize thermal stratification and short-circuiting and deep enough to prevent sediment resuspension, reduce algal blooms, and maintain aerobic conditions.
- Wet Ponds normally incorporate a Forebay for TSS reduction. The forebays should contain 10 to 15 percent of the total permanent pool volume and should be 4 to 6 feet deep (1.2 – 1.8 m).

Limitations[5,6,7]

- Safety concerns associated with open water.
- Requires both physical supply of water and a legal availability to impound water.
- Sediment, floating litter, and algae blooms can be difficult to remove or control.

- Ponds can attract waterfowl which can add to the nutrients and bacteria leaving the pond.
- Ponds increase water temperature.
- Difficult to implement in high-density urban areas.
- Costlier than extended dry detention basins.
- Larger storage volumes for the permanent pool and flood control require more land area.
- Infiltration and groundwater recharge is minimal, so runoff volume control is negligible.
- Moderate to high maintenance requirements.
- Can be used to treat runoff from land uses with higher potential pollutant loads if bottom is lined.
- Invasive species control required.

Pretreatment needs[7]

Yes (TSS, trash and debris reduction, normally provided by sediment forebay).

Water treatment[6]

Sedimentation	H	Biological Processes	M	Filtration/Sorption	H	Plant uptake	-

Water quality[6]

Nutrients	M	Sediments	H	Metals	M	Bacteria	M
Oil and Grease	M	Trash and Debris	H				

Emerging Pollutants

Biocides & T.P.	Y	Tyre Compounds	N/A	Pharmaceuticals	Y	Microplastics	Y
Personal Care Products	Y	Industrial Chemicals	Y	Fossil Fuel and Combustion Products	Y		

Water quantity[6]

Volume Reduction	H	Peak Flow Reduction	H	Groundwater Recharge	-

Maintenance[2]

- Regular inspection and maintenance are important for the effective operation of ponds as designed. Regular maintenance activities include litter and debris removal; vegetation maintenance (including cutting of bank and aquatic vegetation and removal of nuisance plants); inlet/outlet inspection and maintenance; and sediment removal from forebay (where applicable). Less frequent maintenance may include sediment removal from permanent pond; repairs; ongoing inspections and monitoring.
- Frequency of maintenance activities is once or twice a year.

Construction and maintenance costs[2]

Construction costs: (Low, Medium, High): 10 – 60 Eur/m³ (storage volume)

Maintenance costs: (Low, Medium, High): 1 – 5 Eur/m² (pond surface area) per year

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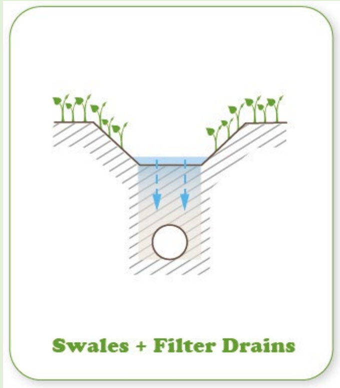
System

Linear Sustainable Drainage Systems (Swales + Filter Drains)



Primary uses

Source Control		Transportation	X	Retention		Infiltration	
Pretreatment		Treatment					

Description[1,2]

Linear sustainable drainage systems are multilayered ditches that collect, convey, slow down, infiltrate and filter surface runoff water, reducing the pressure on traditional sewage systems. They are linear in nature and have parabolic, trapezoidal, or v-shaped cross sections. They replace typical drainage elements such as concrete sewage channels and can incorporate a range of different planting strategies depending upon the site characteristics and system objectives.

Subcategories[2,3,4,5]

The primary classification relies on the use of vegetation.

- Non-vegetated systems, normally referred as Filter Drains, are shallow trenches filled with stone/gravel that create temporary subsurface storage for the attenuation, conveyance, and filtration of surface water runoff. The stone may be contained in a simple trench lined with a geotextile, geomembrane, or other impermeable liner or within more structural facility such as concrete trough.
- Vegetated systems are normally called Swales. Depending on the type of vegetation and the expected usage of the system can be sub-classified in the following types:
    - The most common type of swale is called Conveyance Swale, which is basically a grassed channel where infiltration is allowed. Additionally, depending on the usage of vegetation, swales can be classified in grassed swales, and bio-swales (or vegetated swales).
    - On the other hand, swales can be designed to maintain a minimum water level along the time (wet swales) or to be only ponded during storm events and otherwise be dry (dry-swales). Besides, swales can be lined or unlined depending on the location site and the usage of the swale.
    - Finally, according to the water inflow mechanism, swales can be classified as Point inflow swales, or linear inflow swales.
- Normally, bio-swales (or vegetated swales) are wet swales, while grassed swales can be dry or wet.
- Vegetated swales or bio-swales are normally more effective in treating pollutants because they act like linear pond/wetland systems. They have also better integration into landscape due to the vegetation used and give more aesthetical values than grassed swales.

Applications[6,7,8,9]

Residential	X	Commercial	X	Industrial	X	High Density		Road/Highway	X

Location

Roadway/Roadside	X	Pathway/Cycleway	X	Car park	X	Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area		Urban Park	X
House/Building		Urban Planter		Square/Plaza		Water Course	

**Linear drainage systems can be used in roadways, both, at the roadside or at the median of the roadway.*

Scale of application

Building		Neighborhood	X	District	X	City	

Lifespan

Short Term		Medium Term	X	Long Term	

Space usage

Monofunctional	X	Multifunctional	

Required Area[2,4,5,7]

System Area: Swales should have an area of at least 1% of the drainage area*.

Drainage Area: less than 0.1 km^2.

**Swales should generally be designed with a bottom width of[2] 0.5 – 2.0 m. When used to convey runoff from a driveway, the length should be equal to, or greater than, the driveway length. Maximum swale depth is normally in the range of 600 mm with maximum side slopes 1:3 (V:H) Minimum length for grassed swales is[5] 15 m, however for pollutants removal (especially TSS) a minimum of 60m is recommended.*

Ecosystem Functions[3]

Disturbance regulation, water regulation, erosion control and sediment retention, waste treatment, cultural.

Benefits[3]

Climate change mitigation and adaptation (3/5)
Water management (5/5)
Green space management (4/5)
Air quality (4/5)
Urban regeneration (1/5)
public health and wellbeing (4/5)
Potential of economic opportunities and green jobs (2/5)

Relationship with SDG

Direct	Indirect
3 Good Health and Well-Being	9 Industry, Innovation and Infrastructure
6 Clear Water and Sanitation	14 Life Below Water
11 Sustainable Cities and Communities	15 Life on Land
13 Climate Action	

Design Considerations[2,8,9]

Siting considerations [2]

- Climate conditions: Linear drainage systems can be applied in all climate conditions with an appropriate design.
- Geology conditions: Linear drainage systems can be applied in all geology conditions with an appropriate design.
- Soil conditions: Linear drainage systems can be applied in all soil conditions with an appropriate design.
- Depth of groundwater table: The maximum likely groundwater level should be always, at least, 1 m below the lowest level of the linear drainage system.
- Site slopes: Longitudinal slopes should be constrained to 0.5 – 6% (10% for swales if check dams are used).
- Closeness to infrastructures: -
- Light/Shade considerations: Swales should not be located where extensive areas of trees or overhead structures will cause shade conditions that could limit growth of grass or other vegetation.
- Accessibility: -
- Other considerations: Should be set back from shellfish growing areas and bathing beaches.

Technical considerations[2, 8, 9]

- Cross sections are typically trapezoidal, parabolic (swales) or rectangular (filter drain).
- FILTER DRAINS
  - Depths should be 1 – 2 m. Widths should generally be dimensions on the basis of the perforated pipe (3 times the diameter) and the flow that needs to be conveyed by the Filter Drain.
  - Depth of filter medium should be 0.5 m.
  - Maximum groundwater level should be 1 m below the base of the Filter Drain.
  - It is recommended a filter strip prior the entrance of runoff into the Filter Drain.
  - Longitudinal slope should be maintained below 2%.
  - Typical cross sections are rectangular or trapezoidal.
- SWALES
  - Check dams should be incorporated on slopes greater than 3% and permanent reinforcing matting should be considered for high water velocities. Using check dams, it is possible to increase slopes up to 10%. Check dams, where used, are normally provided at 10 – 20 m interval and may be constructed with 100 – 600 mm coarse aggregates.
  - The length of any section between culverts should be 5 m or greater for maintenance access purposes.
  - Where Swales are located next to roads, a lateral gravel filled drain may be provided at the edge of the pavement.
  - CONVEYANCE SWALE
    - Vegetation in the swale should typically be maintained at a height of 75 –150 mm.
    - The depth of the flow should be maintained below the height of vegetation.
    - Typical designs allow the stormwater from the 2-year storm to flow without causing erosion and are able to convey water of 10-year storm without overflows (t=24 h). The maximum flow velocity should be 0.3 m/s for 15 minutes event with T=1 year. For extreme events, velocity should be kept below 1 m/s.
    - The water residence time should be at least of 9 minutes.
    - Underdrains are required for conveyance swales with a slope <1.5% or wet swales can be considered for these scenarios.
  - DRY SWALE

- Dry swales include a filter bed or prepared soil that overlays an underdrain system which provides additional treatment and conveyance capacity. Underdrain should use 100 mm PVC pipes with 150 mm clean gravel above the pipe.
- Can include a filter strip pretreatment for high sediment and contaminant loadings in runoff.

- WET SWALE
  - Require wetland vegetation planting.
  - Can include a filter strip pretreatment and a sand/gravel/mulch bed layer.

Limitations[10]

- Higher degree of maintenance required than for curb and gutter systems.
- Roadside elements are subject to damage from off-street parking, snow removal, and winter deicing.
- Subject to erosion during large storms.
- Individual dry swales treat a relatively small area.
- Impractical in areas with very flat grades, steep topography, or poorly drained soils.
- Wet swales can produce mosquito breeding habitat.
- Should be set back from shellfish growing areas and bathing beaches.

Pretreatment needs

Optional (in areas with high loads of TSS, trash and debris: suggested filter strips for linear inflow systems or sediment forebay for point inflow systems).

Water treatment[10]

Sedimentation	H	Biological Processes	M	Filtration/Sorption	L	Plant uptake	-

Water quality[10]

Nutrients	L	Sediments	H	Metals	M	Bacteria	L
Oil and Grease	M	Trash and Debris	M				

Emerging Pollutants

Biocides & T.P.	Y	Tyre Compounds	N/A	Pharmaceuticals	N/A	Microplastics	N/A
Personal Care Products	N/A	Industrial Chemicals	Y	Fossil Fuel and Combustion Products	Y		

Water quantity[10]

Volume Reduction	L	Peak Flow Reduction	L	Groundwater Recharge	L

Maintenance[2,8,9]

- Swales require regular maintenance to ensure continuing operation to design performance standards. Maintenance of Swales typically consist in mowing vegetation, removing sediments, remove nuisance plants and inspect inlets, infiltration surfaces and vegetation coverage. Frequency of maintenance activities depends on the location site, with normal values around 6-months or 1-year frequency and with a maximum of a monthly frequency.
- Filter drains require regular maintenance consisting mainly in removing litter and debris, inspect surface, inlet/outlet and perforated pipe for clogging and structural damage, inspect pretreatment, remove sediments from pretreatment.

Construction and maintenance costs[10,11]

Construction cost: 50 Eur/m² – 230 Eur/m².

Maintenance costs: 0.5 Eur/m² – 2 Eur/m² per year.

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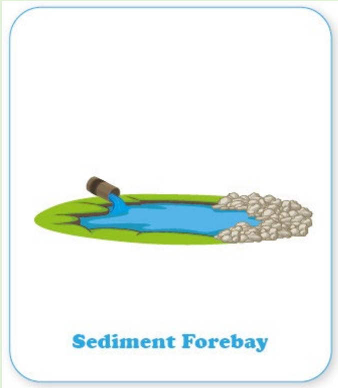
System

Sediments Forebays



Primary uses

Source Control		Transportation		Retention		Infiltration	
Pretreatment	X	Treatment					

Description[1,2]

A sediment forebay is a post-construction practice consisting of an excavated pit, bermed area, or cast structure combined with a weir, designed to slow incoming stormwater runoff and facilitating the gravity separation of suspended solids. A sediment forebay is an essential component of most impoundment and infiltration NBS including retention, detention, extended-detention, constructed wetlands, and infiltration basins.

Subcategories[2]

There are not subcategories for this system.

Applications

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

Location

Roadway/Roadside	X	Pathway/Cycleway	X	Car park	X	Roundabout	X
Gas Station	X	Vehicles serv. area	X	Green/Open Area	X	Urban Park	X
House/Building		Urban Planter		Square/Plaza		Water Course	

Scale of application

Building	X	Neighborhood	X	District	X	City	X

Lifespan					
Short Term		Medium Term	X	Long Term	

Space usage			
Monofunctional	X	Multifunctional	

Required Area[1,2]

- Drainage Area: Not limited over and above the drainage area of the system where the sediments forebay is used as pretreatment.
- System Area: The sediment forebay should be sized to hold 0.25 inches of runoff per impervious acre of contributing drainage area (1.57 cm/ha), with an absolute minimum of 0.1 inches per impervious acre (0.63 cm/ha). For smaller stormwater facilities, a more appropriate sizing criterion of 10% of the total required pool or detention volume may be more practical.

Ecosystem Functions

Water purification and waste treatment.

Benefits

Climate Change mitigation and adaptation (1/5)

Water management (2/5)

Potential of economic opportunities and green jobs (1/5)

Relationship with SDG

Direct

6: Clean Water and Sanitation

13: Climate Action

Design Considerations[1,2]

Siting considerations

- Climate conditions: Can be applied in all climate conditions. However, maintenance needs can be influenced by the climate in the location site. Precaution should be taken in cold climates.
- Geology conditions: can be used in almost any soil or terrain.
- Soil conditions: can be used in almost any soil or terrain.
- Depth of groundwater table: Systems are normally lined; however, precaution should be taken if the sediment forebay intersect groundwater table in order to prevent groundwater contamination.
- Site slopes: -
- Closeness to infrastructures: -
- Light/Shade considerations: -
- Accessibility: Provide sufficient access for operation and maintenance (O & M) by heavy machinery.
- Other considerations: -

Technical considerations

- The sediment forebay should be sized to hold 0.25 inches of runoff per impervious acre of contributing drainage area (0.0015 mm/m²), with an absolute minimum of 0.1 inches per impervious acre (0.00062 mm/m²). For smaller stormwater facilities, a more appropriate sizing criterion of 10% of the total required pool or detention volume may be more practical.
- When routing the 2-year and 10-year storms through the sediment forebay, design the forebay to withstand anticipated velocities without scouring.
- A typical forebay is excavated below grade with earthen sides and a stone check dam.
- Design elevated embankments to meet applicable safety standards.
- Stabilize earth slopes and bottoms using grass seed mixes recommended by the NRCS and capable of resisting the anticipated shearing forces associated with velocities to be routed through the forebay.
- Use only grasses. Using other vegetation will reduce the storage volume in the forebay. Make sure that the selected grasses are able to withstand periodic inundation under water, and drought- tolerant during the summer.
- Alternatively, the bottom floor may be stabilized with concrete or stone to aid maintenance. Concrete floors or pads, or any hard bottom floor, greatly facilitate the removal of accumulated sediment. When the bottom floor is vegetated, it may be necessary to remove accumulated sediment by hand, along with re-seeding or re-sodding grasses removed during maintenance. Sediment forebays may require excavation so concrete flooring may not always be appropriate.
- Make the side slopes of sediment forebays no steeper than 3:1.
- Design the sediment forebay so that the discharge or outflow velocity can control the 2-year peak discharge without scour. Design the channel geometry to prevent erosion from the 2-year peak discharge.

Limitations[1]

- Removes only coarse sediment fractions.
- No removal of soluble pollutants.
- Provides no recharge to groundwater.
- No control of the volume of runoff.
- Frequent maintenance is essential.

Pretreatment needs

No

Water treatment[1]

Sedimentation	L	Biological Processes	-	Filtration/Sorption	L	Plant uptake	-

Water quality[1]

Nutrients	-	Sediments	L	Metals	-	Bacteria	-
Oil and Grease	-	Trash and Debris	M				

Emerging Pollutants

Biocides & T.P.	N/A	Tyre Compounds	N/A	Pharmaceuticals	N/A	Microplastics	N/A
Personal Care Products	N/A	Industrial Chemicals	N/A	Fossil Fuel and Combustion Products	N/A		

Water quantity[1]					
Volume Reduction	**-**	Peak Flow Reduction	**L**	Groundwater Recharge	**-**

Maintenance[1,2]

- Sediments and associated pollutants are removed only when sediment forebays are actually cleaned out, so regular maintenance is essential. In general, sediment should be removed from the forebay every 3 to 5 years, or when 6 to 12 inches (15 – 30 cm) have accumulated, whichever comes first.
- Frequently removing accumulated sediments will make it less likely that sediments will be resuspended. At a minimum, inspect sediment forebays monthly and clean them out at least four times per year.
- Stabilize the floor and sidewalls of the sediment forebay before making it operational, otherwise the practice will discharge excess amounts of suspended sediments.
- When mowing grasses, keep the grass height no greater than 6 inches (15.2 cm). Set mower blades no lower than 3 to 4 inches (7.6 – 10.2 cm).
- Check for signs of rilling and gullying and repair as needed.
- After removing the sediment, replace any vegetation damaged during the clean-out by either reseeding or resodding.
- When reseeding, incorporate practices such as hydroseeding with a tackifier, blanket, or similar practice to ensure that no scour occurs in the forebay, while the seeds germinate and develop roots.

Construction and maintenance costs

Construction costs: Typical cost range between **$2000 and $3000 per unit** but can rise up to **$1000000** for special devices with specific requirements, normally for industry applications.

Maintenance costs: Typical maintenance costs ranged between **1000 – 2000 Eur/year.**

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D4RUNOFF

System

Free Water Surface (FWS) Wetlands

Primary uses

Source Control		Transportation		Retention		Infiltration	
Pretreatment		Treatment	X				

Description[1]

Wetlands are systems that utilize the natural processes involving wetland vegetation, soils and their associated microbial assemblages to assist in treating wastewater and to provide other supplementary functions. In urban regions, wetlands can help offset the negative anthropogenic effects on the environment, sequester carbon, and help cities adapt to climate change. They can also help reduce organic, inorganic, and excess nutrient contaminants in surface and groundwater, municipal wastewater, industrial wastewater, domestic sewage, and other polluting sources. In arid climates and other areas with water shortages, wetlands can also provide great value by cleaning and allowing the reuse of water, recharging the aquifers, and directly contributing to the conservation of natural resources. Wetlands also offer scenic, recreational, educational, psychological, and economic value to the communities and a habitat for a great variety of species. Free water surface (FWS) constructed wetlands closely resemble natural wetlands in appearance and function, with a combination of open-water areas, emergent vegetation, varying water depths and other typical wetland features Such free surface water treatment wetlands mimic the hydrologic regime of natural wetlands.

Subcategories[2,3,4,5,6]

- There are not subcategories in FWS constructed wetlands. However they can be classified in Conventional FWS constructed wetlands and the so-called Pocket wetlands or mini-wetlands, which are a particular form of compact stormwater constructed wetland which is suitable for small sites.

Applications

Residential	X	Commercial	X	Industrial	X	High Density		Road/Highway	X

Location

Roadway/Roadside		Pathway/Cycleway		Car park		Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area	X	Urban Park	X
House/Building		Urban Planter		Square/Plaza		Water Course	X

Scale of application

Building		Neighborhood		District	X	City	X

Lifespan

Short Term		Medium Term		Long Term	X

Space usage

Monofunctional		Multifunctional	X

Required Area[5,6,7,8,9]

- Drainage Area:
  - The minimum recommended watershed area to be treated by a common constructed wetland should be at least of 8 – 10 ha (FWS and SSF) and 0.5 – 5 ha (Pocket Wetlands).
- System Area:
  - Various empirical approaches have been proposed for establishing a minimum land cover for constructed wetlands leading to values of the Wetland to Watershed Area Ratio (WWAR) in the range of 1 to 5%, with a median value of 3%.
  - Other approaches are used for wetlands that are expected to treat not only runoff but also wastewater from residential sources. These approaches are based on the population equivalent (PE) to be served by the wetland. FWS wetlands, needed area is higher and normally double the requirements for SSF wetlands (3 – 5 m²/PE).

**Even if values based in watershed area or PE can be considered for predesign purposes, for the final design they need to be validated by more theoretical approaches based on hydrological, hydraulic and water quality parameters at the location site.*

Ecosystem Functions[10]

Water regulation, water supply, water purification and waste treatment, erosion control and sediment retention, climate regulation, recreation, cultural, educational values, aesthetic values.

Benefits[10]

Climate change mitigation and adaption (3/5)

Water management (5/5)

Green space management (3/5)

Air quality (3/5)

Urban regeneration (1/5)

Potential of economic opportunities and green jobs (3/5)

Relationship with SDG

Direct	Indirect
3 Good Health and Well-Being	4 Quality Education
6 Clear Water and Sanitation	9 Industry, Innovation and Infrastructure
11 Sustainable Cities and Communities	12 Responsible Consumption and Production
13 Climate Action	
14 Life Below Water	
15 Life on Land	

Design considerations[5,6,7,8,9]

Siting considerations

- Climate conditions: Constructed wetlands are found in a wide range of climatological settings, including cold climates where ice forms on the surface for four to six months of the year. Special considerations must be included in the design of these systems for the formation of an ice layer and the effect of cold temperatures on mechanical systems, such as the influent and effluent works. Minimum temperatures limit the ability of wetlands to treat some, but not all, pollutants. Wetlands continue to treat water during cold weather.
- Geology conditions: At sites where bedrock is close to the surface, high excavation costs may make constructed stormwater wetlands infeasible.
- Soil conditions: Soils consisting entirely of sands are inappropriate unless the groundwater table intersects the bottom of the constructed wetland (precaution with groundwater contamination), or the constructed stormwater wetland is installed over the sand to hold water. Medium-fine texture soils (such as loams and silt loams) are best at establishing vegetation, retaining surface water, facilitating groundwater discharge, and capturing pollutants. Where on-site soils or clay provide an adequate seal, compaction of these materials may be sufficient to line the wetland. Existing natural soils with permeability less then approximately 10^{-6} cm/s are generally adequate as an infiltration barrier. For site soils with higher permeabilities, some type of liner material will likely be required.
- Depth of groundwater table: the majority of the applications require some type of barrier to prevent groundwater contamination.
- Site slopes: FWS constructed wetlands can be built on sites with a wide range of topographic relief. Construction costs are lower for flat sites since sloped sites require more grading and berm construction. Site topography will generally dictate the basic shape and configuration of the FWS constructed wetland.
- Closeness to infrastructures: A large buffer zone should be placed between the wetland and neighboring property. The wetland should not be placed next to the edge of the property.
- Light/Shade considerations: -
- Accessibility: The site should be accessible to personnel, delivery vehicles, and equipment for construction and maintenance. Provide access for operation and maintenance activities through heavy machinery. Provide an access for maintenance, with a minimum width of 15 feet (4.6 m) and a maximum slope of 15%.
- Other considerations: Do not locate constructed stormwater wetlands within natural wetland areas or in flood plains.

Technical considerations

•For FWS Wetlands, it is recommended:

- A minimum preliminary/primary treatment is recommended to remove the settleable solids and hydrocarbons. Typical systems include stabilization ponds and primary sedimentation systems.
- FWS wetlands can be configured as single stage wetlands or be partitioned in different zones. It is recommended to configure FWS wetlands for wastewater treatment in 3 zones: Fully vegetated (1), open water (2) and fully vegetated (3) zones. If it is necessary to retain settleable particles a supplementary inlet settling zone can be included.
- It is recommended to maintain Wetland Aspect in the range of (length/width): 3:1 to 5:1 avoiding ratios higher than 10:1.
- Water depth should be in the range of 0.6-0.9 m in fully vegetated zones and between 1.2 and 1.5 m in open-water zones. Water depth in the inlet settling zone (if necessary) should be in the range of 1.0 m.
- Where the availability of land and finance is not problematic, the constructed wetland should be designed to treat storms with a return period of 10 years, although the design of attenuation could be up to the 100-year return period.
- the most cost-effective stormwater storage volumes for water quality treatment could lie between 50 - 75 m^3/ha for most residential and commercial/industrial catchments.
- It is recommended a Hydraulic Residence Time (HRT) of 2 days in each zone of the wetland (1 – 3). Always higher than 10 – 15 hours.
- Porosity of the wetland can be considered of 75% in fully vegetated zones and near to 100% in open water zones.
- Flow velocity should not exceed 0.3 to 0.5 m/s at the inlet zone if effective sedimentation is to be achieved. At velocities greater than 0.7 m/s, high flow may damage the plants physically and cause a decline in system efficiency.
- Maximum slope of the wetland bed should be between 0.5 and 1%.
- Wetlands can be constructed by excavating basins, by building up earth embankments (dikes), or by a combination of the two. Interior berms containing FWS wetland cells should be built with up to 3H:1V side slopes. To ensure long-term stability dikes should be sloped no steeper than 2H:1V and riprapped or protected by erosion control fabric on the slopes. An emergency spillway should be provided.
- While there are some wetland applications where infiltration is desirable, the majority of the applications require some type of barrier to prevent groundwater contamination. Where on-site soils or clay provide an adequate seal, compaction of these materials may be sufficient to line the wetland. Existing natural soils with permeability less then approximately 10^{-6} cm/s are generally adequate as an infiltration barrier. For site soils with higher permeabilities, some type of liner material will likely be required.
- The soil substrate for wetland vegetation should be agronomic in nature (e.g., loam), well loosened, and at least 150 mm (6 inches) deep.

Limitations[5,6,7,8,9]

- Depending upon design, more land requirements than other BMPs.
- Until vegetation is well established, pollutant removal efficiencies may be lower than anticipated.
- Relatively high construction costs compared to other BMPs.
- May be difficult to maintain during extended dry periods.
- Does not provide recharge.
- Creates potential breeding habitat for mosquitoes.
- May present a safety issue for nearby pedestrians.
- Can serve as decoy wetlands, intercepting breeding amphibians moving toward vernal pools.
- The high flows caused by heavy rains and rapid snowmelt shorten residence times. The efficiency of a wetland may therefore decrease during rainfall and snowmelt because of increased flow velocities and shortened contact times. High flows may dilute some dissolved pollutants while increasing the amount of suspended material as sediments in the wetland are resuspended and additional sediments are carried into the wetland by runoff.

Pretreatment needs							
Yes (TSS, trash and debris reduction): Suggested sediment forebay.							
Water treatment[5,11]							
Sedimentation	H	Biological Processes	M	Filtration/Sorption	H	Plant uptake	M
Water quality[5,11]							
Nutrients	M	Sediments	H	Metals	H	Bacteria	L
Oil and Grease	M	Trash and Debris	H				
Emerging Pollutants							
Biocides & T.P.	Y	Tyre Compounds	Y	Pharmaceuticals	Y	Microplastics	Y
Personal Care Products	Y	Industrial Chemicals	Y	Fossil Fuel and Combustion Products	Y		
Water quantity*[5,11]							
Volume Reduction	L	Peak Flow Reduction	H	Groundwater Recharge	L		

**Wetlands deliver significant positive flow regulation services corresponding to reduced frequency and magnitude of flooding, increased flooding return period, augmented low flows, and reduced streamflow and runoff. However, the quantification of these effects is quite difficult due to the lack of reliable data in the available bibliography and the variability in the location sites, systems characteristics and rainfall patterns which ultimately influence flow regulation of wetlands (e.g., unlined wetlands will show greater flow reduction capacities than unlined structures due to water infiltration through the wetland bed).*

Maintenance[5]

Suggest maintenance intervals vary between monthly (inlet, outlet, drop structures), annually (grass cutting) and bi-annually (valve checks, wetland sediment/plants etc.). In practice, the maintenance frequency will be determined normally by site-specific needs.

Maintenance operations should include:

- Checking inlet and outlet structures.
- Checking weir settings.
- Cleaning-off surfaces where solids and floatable substances have accumulated to an extent that they may block flows.
- Removal of gross litter/solids.
- Checking sediment accumulation levels (wetlands, sediment traps, infiltration trenches etc.).
- Bank erosion.
- General maintenance of the appearance and status of the vegetation and any surrounding landscaped zones.

Construction and maintenance costs[5]

Construction costs: **50 Eur/m².**

Maintenance costs: **300 Eur/Ha/year** of maintenance.

**Typical construction costs range from 50000 to 250000 Eur.*

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System

Sub-Surface Flow (SSF) Wetlands

Primary uses

Source Control		Transportation		Retention		Infiltration	
Pretreatment		Treatment	X				

Description[1]

Sub-surface flow (SSF) wetlands do not resemble natural wetlands because they have no standing water. They contain a bed of media (such as crushed rock, small stones, gravel, sand or soil) which has been planted with aquatic plants. When properly designed and operated, wastewater stays beneath the surface of the media, flows in contact with the roots and rhizomes of the plants, and is not visible or available to wildlife.

Subcategories[2,3,4,5,6]

- SSF wetlands can be classified in: Horizontal Subsurface flow (HSSF) or Vertical Subsurface Flow (VSSF) wetlands. In HSSF wetlands, water flows horizontally from a point inlet structure to an outlet one. In VSSF wetlands, the inlet structure is designed to distribute the water evenly over the entire wetland surface. Water then percolates through the soil media and is collected in a subsurface underdrain.

Applications

Residential	X	Commercial	X	Industrial	X	High Density		Road/Highway	X

Location

Roadway/Roadside		Pathway/Cycleway		Car park		Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area	X	Urban Park	X
House/Building		Urban Planter		Square/Plaza		Water Course	X

Scale of application

Building		Neighborhood		District	X	City	X

Lifespan					
Short Term		Medium Term		Long Term	X

Space usage			
Monofunctional	X	Multifunctional	

Required Area[5,6,7,8,9]

- Drainage Area:
  - The minimum recommended watershed area to be treated by a common constructed wetland should be at least of 8 – 10 ha.
- System Area:
  - Various empirical approaches have been proposed for establishing a minimum land cover for constructed wetlands leading to values of the Wetland to Watershed Area Ratio (WWAR) in the range of 1 to 5%, with a median value of 3%.
  - Other approaches are used for wetlands that are expected to treat not only runoff but also wastewater from residential sources. These approaches are based on the population equivalent (PE) to be served by the wetland, establishing values in the range of 0.8 – 1.5 m^2/pe for HSSF Wetlands and between 1 and 2 m^2/PE for VSSF wetlands.

**Even if values based in watershed area or PE can be considered for predesign purposes, for the final design they need to be validated by more theoretical approaches based on hydrological, hydraulic and water quality parameters at the location site.*

Ecosystem Functions[10]

Water regulation, Water supply, water purification and waste treatment, Erosion control and sediment retention, Climate regulation, recreation, cultural, educational values, aesthetic values.

Benefits[10]

Climate change mitigation and adaption (3/5)
Water management (5/5)
Green space management (3/5)
Air quality (3/5)
Urban regeneration (1/5)
Potential of economic opportunities and green jobs (3/5)

Relationship with SDG

Direct	Indirect
3 Good Health and Well-Being	4 Quality Education
6 Clear Water and Sanitation	9 Industry, Innovation and Infrastructure
11 Sustainable Cities and Communities	12 Responsible Consumption and Production
13 Climate Action	

Design considerations[5,6,7,8,9]

Siting considerations

- Climate conditions: Constructed wetlands are found in a wide range of climatological settings, including cold climates where ice forms on the surface for four to six months of the year. Special considerations must be included in the design of these systems for the formation of an ice layer and the effect of cold temperatures on mechanical systems, such as the influent and effluent works. Minimum temperatures limit the ability of wetlands to treat some, but not all, pollutants. Wetlands continue to treat water during cold weather.

- Geology conditions: At sites where bedrock is close to the surface, high excavation costs may make constructed stormwater wetlands infeasible.
- Soil conditions: Soils consisting entirely of sands are inappropriate unless the groundwater table intersects the bottom of the constructed wetland (precaution with groundwater contamination), or the constructed stormwater wetland is installed over the sand to hold water. Medium-fine texture soils (such as loams and silt loams) are best at establishing vegetation, retaining surface water, facilitating groundwater discharge, and capturing pollutants. Where on-site soils or clay provide an adequate seal, compaction of these materials may be sufficient to line the wetland. Existing natural soils with permeability less then approximately 10^{-6} cm/s are generally adequate as an infiltration barrier. For site soils with higher permeabilities, some type of liner material will likely be required.
- Depth of groundwater table: the majority of the applications require some type of barrier to prevent groundwater contamination.
- Site slopes: -
- Closeness to infrastructures: -
- Light/Shade considerations: -
- Accessibility: -
- Other considerations: Do not locate constructed stormwater wetlands within natural wetland areas.

Technical considerations

•For HSSF Wetlands it is recommended:

- It is recommended that the planting media not exceed 20 mm (3/4 in) in particle diameter, and the minimum depth should be 100 mm (4 in). Typical media depths range between 0.5 to 0.6 m.
- The media in the inlet and outlet zones should be between 40 and 80 mm (1.5 – 3 in) in diameter to minimize clogging and should extend from the top to the bottom of the system. The inlet zone should be about 2 m long, and the outlet zone should be about 1 m long. Crushed limestone can be used but is not recommended for VSB systems because of the potential for media breakup and dissolution under the strongly reducing environment of a VSB, which can lead to clogging.
- It is recommended to use a design maximum water depth (at the inlet of the VSB) of 0.40 m (16 in). The depth of the media will be defined by the level of the wastewater at the inlet and should be about 0.1 m (4 in) deeper than the water. Typical values for water depth range between 0.4m and 0.5 m.
- The recommended maximum width is 61 m. The recommended minimum length is 15 m. Recommended length to width ratios ranged from 1:1 to 1:2.
- It is recommended that the average diameter of media in the treatment zone media be between 20 and 30 mm in diameter.
- The top surface of the media should be level or nearly level for easier planting and routine maintenance. A practical approach is to uniformly slope the bottom along the direction of flow from inlet to outlet to allow for easy draining when maintenance in required. No research has been done to determine an optimum slope, but a slope of 1/2 to 1% is recommended for ease of construction and proper draining.
- The slope of the berms should be as steep as possible, consistent with the soils, construction methods and materials.

•For VSSF Wetlands it is recommended:

- It is recommended to use substrate depth of 70 cm, which can provide adequate nitrification.
- It is recommended to use sand (0 – 4 mm) as main substrate with d_{10} > 0.3 mm, d_{60}/d_{10} < 4 and having permeability of 10^{-3} to 10^{-4} m/s.

Limitations

- Depending upon design, more land requirements than other BMPs.
- Until vegetation is well established, pollutant removal efficiencies may be lower than anticipated.
- Relatively high construction costs compared to other BMPs.
- May be difficult to maintain during extended dry periods.
- Does not provide recharge.

- Creates potential breeding habitat for mosquitoes.
- May present a safety issue for nearby pedestrians.
- Can serve as decoy wetlands, intercepting breeding amphibians moving toward vernal pools.
- The high flows caused by heavy rains and rapid snowmelt shorten residence times. The efficiency of a wetland may therefore decrease during rainfall and snowmelt because of increased flow velocities and shortened contact times. High flows may dilute some dissolved pollutants while increasing the amount of suspended material as sediments in the wetland are resuspended and additional sediments are carried into the wetland by runoff.

Pretreatment needs

Yes (sediment forebay)

Water treatment[5,11]

Sedimentation	H	Biological Processes	M	Filtration/Sorption	H	Plant uptake	M

Water quality[5,11]

Nutrients	M	Sediments	H	Metals	H	Bacteria	L
Oil and Grease	M	Trash and Debris	H				

Emerging Pollutants

Biocides & T.P.	Y	Tyre Compounds	N/A	Pharmaceuticals	Y	Microplastics	Y
Personal Care Products	Y	Industrial Chemicals	Y	Fossil Fuel and Combustion Products	Y		

Water quantity*[5,11]

Volume Reduction	L	Peak Flow Reduction	H	Groundwater Recharge	L

**Wetlands deliver significant positive flow regulation services corresponding to reduced frequency and magnitude of flooding, increased flooding return period, augmented low flows, and reduced streamflow and runoff. However, the quantification of these effects is quite difficult due to the lack of reliable data in the available bibliography and the variability in the location sites, systems characteristics and rainfall patterns which ultimately influence flow regulation of wetlands (e.g., unlined wetlands will show greater flow reduction capacities than unlined structures due to water infiltration through the wetland bed).*

Maintenance[5]

Suggest maintenance intervals vary between monthly (inlet, outlet, drop structures), annually (grass cutting) and bi-annually (valve checks, wetland sediment/plants etc.). In practice, the maintenance frequency will be determined normally by site-specific needs.

Maintenance operations should include:

- Checking inlet and outlet structures.
- Checking weir settings.
- Cleaning-off surfaces where solids and floatable substances have accumulated to an extent that they may block flows.
- Removal of gross litter/solids.

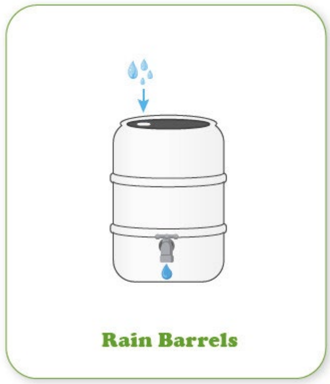
- Checking sediment accumulation levels (wetlands, sediment traps, infiltration trenches etc.). - Bank erosion. - General maintenance of the appearance and status of the vegetation and any surrounding landscaped zones.
Construction and maintenance costs[5] Construction costs: **50 Eur/m².** Maintenance costs: **300 Eur/ha/year** of maintenance. **Typical construction costs range from 50000 to 250000 Eur.*
References *[1]World Bank, (2021). A Catalogue of Nature-Based Solutions for Urban Resilience. World Bank. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/36507/A-Catalogue-of-Nature-based-Solutions-for-Urban-Resilience.pdf?sequence=1&isAllowed=y* *[2]Ollis, D.J., Day, J.A., Mbona, N., Dini, J.A. South African wetlands: Classification of ecosystem types (2018) The Wetland Book: I: Structure and Function, Management, and Methods, pp. 1533-1544. Available at: https://doi.org/10.1007/978-94-007-6172-8_334-1* *[3]U. S Environmental Protection Agency (2021). Types of Wetlands (EPA 843-F-01-002b). Office of Water and Office of Wetlands, Oceans and Watersheds. Available at: https://www.epa.gov/sites/default/files/2021-01/documents/types_of_wetlands.pdf* *[4]Passeport, E., Vidon, P., Forshay, K.J., Harris, L., Kaushal, S.S., Kellogg, D.Q., Lazar, J., Mayer, P., Stander, E.K. Ecological engineering practices for the reduction of excess nitrogen in human-influenced landscapes: A guide for watershed managers (2013) Environmental Management, 51 (2), pp. 392-413. Available at: https://doi.org/10.1007/s00267-012-9970-y* *[5]Ellis, J.B., Shutes, R.B.E., and Revitt, D.M. (2003). Guidance Manual for Constructed Wetlands, R&D Technical Report P2-159/TR2. Urban Pollution Research Centre, Middlesex University, London. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/964634/WITHDRAWN-Guidance-Manual-for-Constructed-Wetlands.pdf* *[6] United States Environmental Protection Agency (2000). Constructed wetlands treatment of municipal wastewaters. National Risk Management Research Laboratory, Office of research and development, U.S. Environmental Protection Agency, Cincinnati, Ohio, U.S. Available at: https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=64144* *[7]Woods Ballard, B., Wilson, S., Udale-Clarke, H., Illman, S., Scott, T., Ashley, R., & Kellagher, R. (2015). The SuDS Manual; CIRIA: London, UK. Available at: https://www.ciria.org/CIRIA/Memberships/The_SuDS_Manual_C753_Chapters.aspx* *[8]U. N Human Settlements Programme (2008). Constructed wetlands manual. UN-HABITAT Water for Asian Cities Programme Nepal, Kathmandu. Available at: https://unhabitat.org/constructed-wetlands-manual* *[9] U.S Environmental Protection Agency (1994). A handbook of constructed wetlands, a guide to creating wetlands for--agricultural wastewater, domestic wastewater, coal mine drainage, stormwater in the Mid-Atlantic Region. U.S Government Printing Office. Washington D.C., U.S. Available at: https://www.epa.gov/sites/default/files/2015-10/documents/constructed-wetlands-handbook.pdf* *[10]Urban GreenUP, (2018). Urban GreenUP D1.1: NBS Catalogue. Available at: https://www.urbangreenup.eu/kdocs/1907476/urban_greenup_d1.1_nbs_catalogue_31-05-2018.pdf* *[11]Boston Water and Sewer Commission (2013). Stormwater Best Management Practices: Guidance Document. Boston, MA, USA. Available at: https://www.bwsc.org/sites/default/files/2019-01/stormwater_bmp_guidance_2013.pdf*

3 Factsheets of Engineered Drainage Solutions

In this chapter, the engineered drainage solutions, used widely as conventional drainage techniques, are classified in six main groups. The last one is the most extensive with a huge variety of components and sizes (e.g., multitude of pipes with different diameters). These engineered drainage solutions combined with the NBS result in the hybrid drainage systems. With all, the parametric design of the engineered drainage solutions is out of the scope of this project, and the factsheets included in this chapter make it possible to compare NBS with Engineering Drainage Solutions in a simplified way, enough to work lately in the MCDA.

System

Rain Barrels and Cisterns



Primary uses

Source Control	X	Transportation		Retention		Infiltration	
Pretreatment		Treatment					

Description[1]

Cisterns and rain barrels are structures that store rooftop runoff and reuse it for landscaping and other non-potable uses. Instead of a nuisance to get rid of, consider rooftop runoff as a resource that can be reused or infiltrated. In contrast, conventional stormwater management strategies take rooftop runoff, which is often relatively free of pollutants, and direct it into the stormwater treatment system along with runoff from paved areas.

Subcategories[1,2,3]

- The primary classification of these systems relies on the water stored volume. While barrels are used where little amount of water is expected, cisterns are much bigger and can be used for a single building or neighborhood.
- Other classification refers to the water flow type. In this sense, Rain Barrels or Cisterns can rely on gravity flow (surface systems) or may work by a pressurized flow through pumps in sub-surface systems. Composite systems use the advantages of both gravity and pumped processes.
- Finally, systems can be conceived for their use only for watering plants and green areas, or can be used as inflow for domestic water reuse. Depending on the use, water quality treatment may have to be considered.

Applications[2]

Residential	X	Commercial	X	Industrial		High Density	X	Road/Highway	

Location[1,3]

Roadway/Roadside		Pathway/Cycleway		Car park		Roundabout	
Gas Station		Vehicles serv. area		Green/Open Area		Urban Park	
House/Building	X	Urban Planter		Square/Plaza		Water Course	

**Permeable Pavements can be used as pavement structures for trafficked roads, but only with low to medium traffic intensities.*

Scale of application							
Building	X	Neighborhood		District		City	
Lifespan							
Short Term		Medium Term		Long Term	X		
Space usage							
Monofunctional	X	Multifunctional					

Required Area[1,3,4]

Drainage Area: 0 to 0.1 km².

System Area: Very low. There are no maximum limits over and above the available land space for water storage. Recommended 2 m³ of average attenuation volume.

Ecosystem Functions[5]

Disturbance Regulation, Water regulation, Erosion Control, waste treatment, Cultural.

Benefits[5]

Climate change mitigation and adaption (3/5)
Water Management (5/5)
Green Space Management (4/5)
Air quality (4/5)
Urban regeneration (1/5)
Public Health and wellbeing (4/5)
Potential of economic opportunities (2/5)

Relationship with SDG

Direct	Indirect
3 Good Health and Well-Being	11 Sustainable Cities and Communities
6 Clear Water and Sanitation	
13 Climate Action	

Design Considerations[1,2,3]

Siting considerations[1,2,3]

- Climate conditions: Some precaution should be taken in cold climates in order to prevent cracking by the expansion of freezing water in the storage tank.
- Geology conditions: -
- Soil conditions: Tanks should not generally be placed on filled ground. Geotechnical investigation should be undertaken to ensure suitability for cisterns and tank foundations.
- Depth of groundwater table: -
- Site slopes: -
- Closeness to infrastructures: -
- Light/Shade considerations: Barrels and cisterns placed above ground should not be placed in very sunny areas in order to limit pathogen proliferation during the storage period of the collected water.
- Accessibility: -
- Other considerations: Rain barrels and systems can be placed almost in every building since there are free available space to place them.

Technical considerations[1,2,3]

- Cisterns must be designed to dewater in 72 hours or less.
- Rain barrels with gravity flow should be placed at least 0.5 – 1 m over the soil surface.
- Gravity flow systems performs better with a dripping irrigation system.
- Systems can be designed to divert the first flush.
- It is recommended to direct the system overflow to an infiltration system (dry well, infiltration basin, etc.).
- Precaution should be taken to prevent mosquitoes by sealing all the surface with mosquito netting or other system.
- It is important to keep leaves and debris out of the storage tank (barrel or cistern).
- It is recommended to hide rain barrels and cisterns with shrubs or other landscape features.
- Barrels or cisterns water storage range from 200 l to more than 15000 l. They can be placed in series to augment the capacity of store water.

Limitations[1,2]

- Rain barrels and cisterns are proprietary systems, and can only be used for small-scale source control in single buildings or group of buildings.
- They don't provide any water treatment, so they only provide volume reduction and peak flow attenuation.
- Water storage capacity of barrels and cisterns is relatively low in relation to the amount of runoff water produced in a roof. If the amount of runoff from the treated rooftop surpasses the capacity of one single barrel, a set of various barrels in series can be used instead of cisterns.
- Provides mosquito-breeding habitat unless properly sealed.
- May need to be disconnected and drained in winter to avoid cracking of storage structure.

Pretreatment needs[2,3]

Yes (Trash and debris in order to prevent contamination in the stored water)

Water treatment

Sedimentation	**N/A**	Biological Processes	**N/A**	Filtration/Sorption	**N/A**	Plant uptake	**N/A**

Water quality

Nutrients	**N/A**	Sediments	**N/A**	Metals	**N/A**	Bacteria	**N/A**
Oil and Grease	**N/A**	Trash and Debris	**N/A**				

Emerging Pollutants

Biocides & T.P.	**N/A**	Tyre Compounds	**N/A**	Pharmaceuticals	**N/A**	Microplastics	**N/A**
Personal Care Products	**N/A**	Industrial Chemicals	**N/A**	Fossil Fuel and Combustion Products	**N/A**		

Water quantity[2]

Volume Reduction	**H**	Peak Flow Reduction	**H**	Groundwater Recharge	**N/A**

Maintenance[1]

- Maintenance requirements for rain barrels are minimal and consist only of inspecting the unit as a whole and any of its constituent parts and accessories twice a year.

Construction and maintenance costs[2,5]

Construction costs: (Low, Medium, High): 0.5 to 2 Euro per Liter of stored water.

Maintenance costs: (Low, Medium, High): 0.25 to 1 Eur/m² of roof area.

References

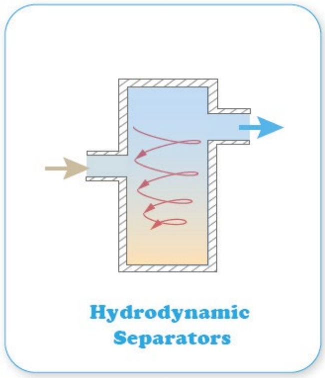
[1]*Boston Water and Sewer Commission (2013). Stormwater Best Management Practices: Guidance Document. Boston, MA, USA. Available at:* https://www.bwsc.org/sites/default/files/2019-01/stormwater_bmp_guidance_2013.pdf

[2]*Pennsylvania Department of Environment (2006). Pennsylvania Stormwater Best Management Practices Manual. Available at:* http://www.stormwaterpa.org/bmp-manual-chapter-6.html

[3]*Woods Ballard, B., Wilson, S., Udale-Clarke, H., Illman, S., Scott, T., Ashley, R., & Kellagher, R. (2015). The SuDS Manual; CIRIA: London, UK. Available at:* https://www.ciria.org/CIRIA/Memberships/The_SuDS_Manual_C753_Chapters.aspx

[4]*Environmental Protection Agency (2021). Stormwater Best Management Practice: Rainwater Harvesting. Available at:* http://nwrm.eu/sites/default/files/nwrm_ressources/u2_-_rainwater_harvesting.pdf

[5]*Urban GreenUP, (2018). Urban GreenUP D1.1: NBS Catalogue. Available at:* https://www.urbangreenup.eu/kdocs/1907476/urban_greenup_d1.1_nbs_catalogue_31-05-2018.pdf

System	
Hydrodynamic Separators	

Primary uses

Source Control		Transportation		Retention		Infiltration	
Pretreatment	X	Treatment	X				

Description[1,2]

Hydrodynamic separator devices are proprietary stormwater BMPs that remove trash, debris, and coarse sediment from incoming flows using screening, gravity settling, and centrifugal forces generated by forcing the influent into a circular motion. By having the water move in a circular fashion, rather than a straight line, it is possible to obtain significant removal of coarse sediments and attached pollutants with less space as compared to other traditional gravity settling devices. Several types of hydrodynamic separation devices are also designed to remove floating oils and grease using sorbent media and baffles, while trash racks can be added to reduce trash and debris. Hydrodynamic separators are typically installed underground. Devices are designed and manufactured by private businesses and come in different sizes to accommodate different design storms and flow conditions. Hydrodynamic devices are commonly used as pretreatment device for TSS reduction previous to other SUDS such as ponds, bioretention, filters, detention and infiltration structures.

Subcategories[3,4]

- A variety of products are available from different manufacturers. The primary purpose is to use various methods to remove sediments and pollutants. These methods include baffle plate design, vortex design, tube settler design, inclined plate settler design or a combination of these.
- Some of the most commonly used HDS manufactured products are:
  - Stormceptor®: HDS developed by CSR America. It is designed to trap and retain a variety of non-point source pollutants, using a by-pass chamber and treatment chamber. Manufacturer reports that it is capable of removing 50 to 80 percent of the total sediment load when used properly.
  - Vortechs®: storm water treatment system, manufactured by Vortechnics™ of Portland, Maine, has been available since 1988. The device removes floating pollutants and settleable solids from surface runoff. This system is constructed of precast concrete and uses four structures to optimize water treatment through its system: Baffle walls, Circular Grit Chamber, Flow Control Chamber and Oil Chamber.
  - Downstream Defender®: The Downstream Defender system is adaptable to all types of land uses. Additionally, the Downstream Defender can be installed in existing pipe systems as a retrofit. The Downstream Defender is characterized by a concrete cylindrical structure with stainless steel components, and an internal 30º sloping base. Runoff entering the structure passes through a tangential inlet pipe, resulting in a swirling motion. The Downstream Defender has no moving parts and requires no external power source.

Applications[5]									
Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

Location[1,3,5]							
Roadway/Roadside	X	Pathway/Cycleway	X	Car park	X	Roundabout	X
Gas Station	X	Vehicles serv. area	X	Green/Open Area		Urban Park	
House/Building		Urban Planter		Square/Plaza		Water Course	

Scale of application							
Building	X	Neighborhood	X	District		City	

Lifespan					
Short Term		Medium Term		Long Term	X

Space usage			
Monofunctional		Multifunctional	X

Required Area

- Drainage Area: The recommended maximum contributing drainage area to individual devices varies by manufacturer, model, etc. As a general reference value, Hydrodynamic separators are typically limited in use to drainage areas less than 5 – 10 acres (2 – 4 ha). It is recommended that the contributing drainage area to any single separator be limited to 1 acre (0.4 ha) or less of impervious cover.
- System Area: Depends on manufacturer and treated area. Commercial devices ranged from 1 to 6 m in diameter and depths between 1 to 5 m.

Ecosystem Functions

Water regulation, water purification and waste treatment.

Benefits

Climate change mitigation and adaption (1/5)
Water management (3/5)
Urban regeneration (2/5)
Public health and wellbeing (2/5)
Potential of economic opportunities and green jobs (2/5)

Relationship with SDG

Direct

6: Clean Water and Sanitation

13: Climate Action

Design Considerations[1,3,5]

Siting considerations

- Climate conditions: Can be applied in all climate conditions. However, maintenance needs can be influenced by the climate in the location site. Precaution should be taken in cold climates, where water can freeze and influence the performance of HDS.
- Geology conditions: Manufactured separation systems can be used in almost any soil or terrain.
- Soil conditions: Manufactured separation systems can be used in almost any soil or terrain.
- Depth of groundwater table: Manufactured separation systems can be used in almost any soil or terrain.
- Site slopes: -
- Closeness to infrastructures: -
- Light/Shade considerations: -
- Accessibility: -
- Other considerations: -

Technical considerations

- Design, construct, and maintain in accordance with manufacturer's specifications.
- Typically sized based on flow rate.
- Primarily used for pretreatment and placed at beginning of stormwater treatment train.
- May have baffles or other devices to direct incoming water into and through a series of chambers and/or skirts or weirs to keep trapped sediments from re-suspending during larger flows.
- Design to include safe inspection and access ports for maintenance.

Limitations[1,3]

- They have variable and limited effectiveness at removing fine, soluble pollutants such as nutrients, metals and bacteria.
- Must be purchased from private sector firm.
- May require more maintenance than conventional or green techniques.
- Can become a source of pollutants due to re-suspension of sediment unless maintained regularly.
- No groundwater recharges and no control of runoff volume.

Pretreatment needs

No

Water treatment[1]

Sedimentation	**M**	Biological Processes	**L**	Filtration/Sorption	**L**	Plant uptake	**-**

Water quality[1]

Nutrients	**L**	Sediments	**M**	Metals	**M**	Bacteria	**L**
Oil and Grease	**L**	Trash and Debris	**H**				

Emerging Pollutants

Biocides & T.P.	**N/A**	Tyre Compounds	**N/A**	Pharmaceuticals	**N/A**	Microplastics	**N/A**
Personal Care Products	**N/A**	Industrial Chemicals	**N/A**	Fossil Fuel and Combustion Products	**N/A**		

D4RUNOFF

Water quantity[1]

Volume Reduction	-	Peak Flow Reduction	L	Groundwater Recharge	-

Maintenance[1,6]

- Inspect and clean in accordance with manufacturer requirements, but no less than twice a year following installation, and no less than once a year thereafter.
- Vector trucks or manual removal of sediment are typical means used for cleaning these devices.
- Maintenance of HDS is typically performed with a vacuum truck to evacuate captured sediment and floatables from the unit. Maintenance is normally performed from the surface, without need for confined space entry.

Construction and maintenance costs[1,4,6]

Construction costs: **6000 – 450000 Eur** (depending on the manufacturer, size, operation and water inflow).

Maintenance costs: **1000 – 4000 Eur/year.**

References

[1]*Boston Water and Sewer Commission, (2013). Stormwater Best Management Practices: Guidance Document. Boston, MA, USA. Available at: https://www.bwsc.org/sites/default/files/2019-01/stormwater_bmp_guidance_2013.pdf*

[2]*Stormwater Equipment Manufacturers Association (SWEMA), (2018). SWEMA Fact Sheet: Hydrodynamic Separators. Available at: https://www.stormwaterassociation.com/assets/docs/FACTSheets/swm_may2018_FACT%20SHEET%20Hydrodynamic%20Separators.pdf*

[3]*Virginia Department of Transportation (VDOT), (2013). BMP Design Manual of Practice: Chapter 16- Hydrodynamic Separators. Available at: https://vdot.virginia.gov/business/resources/LocDes/BMP_Design-Manual/BMP_Design_Manual_Cover.pdf*

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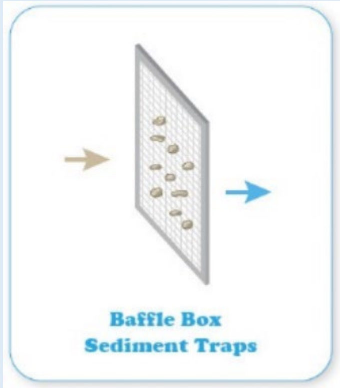
[5]*Pennsylvania Department of Environment (2006). Pennsylvania Stormwater Best Management Practices Manual. Available at: http://www.stormwaterpa.org/bmp-manual-chapter-6.html*

[6]*United States Environmental Protection Agency (USEPA), (2021). NPDES: Stormwater Best Management Practice – Stormwater Inlet Controls. Available at: https://www.epa.gov/system/files/documents/2021-11/bmp-stormwater-inlet-bmps.pdf*

D4RUNOFF

System	
Baffle Boxes	

Primary uses

Source Control		Transportation		Retention		Infiltration	
Pretreatment	X	Treatment	X				

Description[1,2]

Baffle boxes are proprietary concrete or fiberglass structures containing a series of sediment settling chambers separated by baffles. The stormwater runoff enters the box and begins to fill the first chamber, as the runoff encounters the first baffle, the velocity decreases allowing sediment and pollutants to drop out into internal storage zones. When the first chamber is full, flow is directed to the second chamber where additional settling of sediment occurs. To provide additional removal of trash, oil, and grease trash racks, screens, or skimmers may be used. Baffle boxes may be used as pretreatment devices and typically discharge to other treatment or infiltration BMPs. Baffle boxes have proven effective in removing sediment from storm water runoff. They are mainly utilized in areas where sediment control is a primary concern, while other stormwater Best Management Practices (BMPs) may be more effective in areas where additional stormwater pollutants, such as dissolved nutrients, oil and grease, or metals, are prevalent.

Subcategories[1,2]

- Possible modifications to a standard baffle box design to accommodate site-specific conditions include: a two-chamber box for small pipes and small drainage areas; a three-chamber box for larger pipes; and two multi-chambered boxes in a series.
- Some baffle box manufacturing companies are:
    - Suntree Technologies Inc.: http://www.suntreetech.com.
    - ACF Environmental: http://www.acfenvironmental.com/nsbb.html.
    - BIOCLEAN Environmental Services, Inc.: http://www.biocleanenvironmental.com.

Applications[1,2]

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

Location

Roadway/Roadside	X	Pathway/Cycleway	X	Car park	X	Roundabout	X
Gas Station	X	Vehicles serv. area	X	Green/Open Area		Urban Park	
House/Building		Urban Planter		Square/Plaza		Water Course	

Scale of application

Building	X	Neighborhood	X	District		City	

Lifespan

Short Term		Medium Term		Long Term	X

Space usage

Monofunctional		Multifunctional	X

Required Area[1,2]

- Drainage Area: The recommended maximum contributing drainage area to individual devices varies by manufacturer, model, etc. Recommended maximum drainage area according to the literature reviewed is 10 ha.
- System Area*: Depends on manufacturer, water inflow and treated area. Typical baffle boxes are 3 to 5 meters (10 to 15 feet) long, 0.6 meters (2 feet) wider than the pipe, and 2 to 2.7 meters (6 to 8 feet) high.

Ecosystem Functions

Water regulation, water purification and waste treatment

Benefits

Climate change mitigation and adaption (1/5)
Water management (2/5)
Urban regeneration (2/5)
Public health and wellbeing (2/5)
Potential of economic opportunities and green jobs (2/5)

Relationship with SDG

Direct

6: Clean Water and Sanitation
13: Climate Action

Design Considerations[1,2]

Siting considerations

- Climate conditions: Can be applied in all climate conditions. However, maintenance needs can be influenced by the climate in the location site. Precaution should be taken in cold climates, where water can freeze and influence the performance of HDS.
- Geology conditions: Manufactured separation systems can be used in almost any soil or terrain.

- Soil conditions: Manufactured separation systems can be used in almost any soil or terrain.
- Depth of groundwater table: Manufactured separation systems can be used in almost any soil or terrain.
- Site slopes: -
- Closeness to infrastructures: -
- Light/Shade considerations: -
- Accessibility: -
- Other considerations: -

Technical considerations

- Consult manufacturer for specific design considerations for their product.
- Typical baffle boxes consist of an inlet pipe, concrete or fiberglass structure, baffles, trash screens or other treatment devices, and an outlet pipe.
- Typical baffle boxes are: 10 – 15 feet long (3.05 – 4.57 m), 2 ft (0.61 m) wider than the inflow pipe, and 6 – 8 ft (1.83 – 2.44 m) high. Baffle (weir) heights are usually 3 ft (0.91 m) high.
- Set baffle height level with the pipe invert to minimize hydraulic losses.
- For pipe diameters up to 48 inches (1.22 m) the baffle box can be precast, for pipe diameters up to 60 inches (1.52 m), the baffle box shall be cast in-place.
- Manholes are set over each chamber for ease of inspection and maintenance.

Limitations[1,2]

- They have variable and limited effectiveness at removing fine, soluble pollutants such as nutrients, metals and bacteria.
- Must be purchased from private sector firm.
- May require more maintenance than conventional or green techniques.
- Can become a source of pollutants due to re-suspension of sediment unless maintained regularly.
- No groundwater recharges and no control of runoff volume.

Pretreatment needs

No

Water treatment[1]

Sedimentation	**H**	Biological Processes	**L**	Filtration/Sorption	**L**	Plant uptake	**-**

Water quality[1]

Nutrients	**L**	Sediments	**H**	Metals	**L**	Bacteria	**L**
Oil and Grease	**M**	Trash and Debris	**M**				

Emerging Pollutants

Biocides & T.P.	**N/A**	Tyre Compounds	**N/A**	Pharmaceuticals	**N/A**	Microplastics	**N/A**
Personal Care Products	**N/A**	Industrial Chemicals	**N/A**	Fossil Fuel and Combustion Products	**N/A**		

Water quantity[1]

Volume Reduction	N/A	Peak Flow Reduction	L	Groundwater Recharge	N/A

Maintenance[1,2]

- Inspect and clean every 2 to 3 months (during dry season) or monthly (in wet season) to dispose of accumulated sediment. If not properly maintained, sediment can re-suspend with subsequent storms. Use Vactor trucks to remove sediment (vacuum trucks).
- Remove stagnant water every 2 to 3 months to prevent odors and mosquito breeding.
- Consult manufacturer for specific maintenance requirements for their product.

Construction and maintenance costs[1,2]

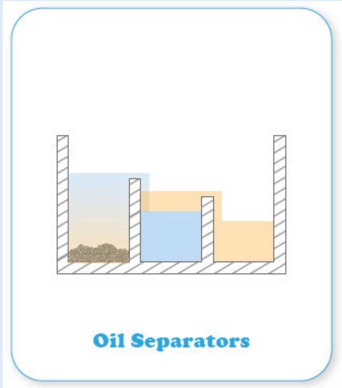
Construction costs: The cost of a baffle box will depend on the site characteristics and desired goal, with a typical cost range **between $20000** and **$30000.**

Maintenance costs: Average cleanout of a Baffle Box costs between **0.2 and 0.3 Eur/Kg of sediments**. Frequency of maintenance activities depends on the sediment load at the catchment site.

References

[1]*Boston Water and Sewer Commission, (2013). Stormwater Best Management Practices: Guidance Document. Boston, MA, USA. Available at:* *https://www.bwsc.org/sites/default/files/2019-01/stormwater_bmp_guidance_2013.pdf*
[2]*United States Environmental Protection Agency (USEPA), (2001). Stormwater Technology Fact Sheet: Baffle Boxes. Available at:* *https://nepis.epa.gov/Exe/ZyPDF.cgi/P100IL55.PDF?Dockey=P100IL55.PDF*

System



Oil and Particle Separators (Water Quality Inlets)

Primary uses

Source Control		Transportation		Retention		Infiltration	
Pretreatment	X	Treatment	X				

Description[1,2,3]

Oil/particle separators, also called oil/grit separators, water quality inlets, and oil/water separators, are underground storage tanks which consist typically of two or three chambers designed to remove trash and debris and to promote sedimentation of heavy particles and separation of free oil from stormwater runoff. They are very similar to Baffle boxes, but design consider also oil removal. Due to their limited storage capacity and volume, these systems have only limited water quality treatment capabilities. While oil/particle separators can effectively trap sediments, floatables and oil and grease, they are ineffective at removing nutrients and metals and only capture coarse sediment.

Subcategories[3,4]

Several conventional oil/particle separator design variations exist, including:

- Conventional gravity separators (water quality inlets): Conventional gravity separators (also called American Petroleum Institute or API separators) typically consist of three baffled chambers and rely on gravity and the physical characteristics of oil and sediments to achieve pollutant removal. The first chamber is a sedimentation chamber where floatable debris is trapped and gravity settling of sediments occurs. The second chamber is designed primarily for oil separation, and the third chamber provides additional settling prior to discharging to the storm drain system or downstream treatment practice.
- Coalescing plate (oil/water) separators: The basic gravity separator design can be modified by adding coalescing plates to increase the effectiveness of oil/water separation and reduce the size of the required unit. A series of coalescing plates, constructed of oil-attracting materials such as polypropylene and typically spaced an inch apart, attract small oil droplets which begin to concentrate until they are large enough to float to the water surface and separate from the stormwater.
-

Applications[1,3]

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

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Location[1,3]

Roadway/Roadside	X	Pathway/Cycleway	X	Car park	X	Roundabout	X
Gas Station	X	Vehicles serv. area	X	Green/Open Area		Urban Park	
House/Building		Urban Planter		Square/Plaza		Water Course	

Oil/particle separators are typically designed as off-line systems for pretreatment of runoff from small impervious areas, and therefore provide minimal attenuation of flow.

Oil/particle separators are especially suitable for commercial and industrial areas including petroleum storage yards, vehicle maintenance facilities, manufacturing areas, airports, utility areas (water, electric, gas), and fueling stations. They are also suitable for parking lots at convenience stores, fast food restaurants, grocery stores, shopping malls, discount warehouse stores, banks, truck fleets, auto and truck dealerships, and delivery services.

Scale of application

Building	X	Neighborhood	X	District		City	

Lifespan

Short Term		Medium Term		Long Term	X

Space usage

Monofunctional		Multifunctional	X

Required Area[2]

- Drainage Area: Recommended up to 0.4 ha (1 acre).
- System Area: 1.1 m³ of storage per each 0.04 ha (0.1 acres, approx.).

Ecosystem Functions

Water purification and waste treatment.

Benefits

Climate change mitigation and adaption (2/5)
Water management (3/5)
Urban regeneration (3/5)
Potential of economic opportunities and green jobs (2/5)

Relationship with SDG

Direct

6: Clean Water and Sanitation

13: Climate Action

Design Considerations[1,2,3,4,5,6]

Siting considerations

- Climate conditions: Can be applied in all climate conditions. However, maintenance needs can be influenced by the climate in the location site. Precaution should be taken in cold climates.

- Geology conditions: Manufactured separation systems can be used in almost any soil or terrain.
- Soil conditions: Manufactured separation systems can be used in almost any soil or terrain.
- Depth of groundwater table: Manufactured separation systems can be used in almost any soil or terrain.
- Site slopes: -
- Closeness to infrastructures: -
- Light/Shade considerations: -
- Accessibility: Provide sufficient access for operation and maintenance (O & M).
- Other considerations: -
    - Sufficient land area.
    - Adequate TSS control or pretreatment capability.
    - Compliance with environmental objectives.
    - Adequate influent flow attenuation and/or bypass capability.

Technical considerations

- If practicable, determine oil/grease (or TPH) and TSS concentrations, lowest temperature, pH; and empirical oil rise rates in the runoff, and the viscosity, and specific gravity of the oil. Also determine whether the oil is emulsified or dissolved. Do not use oil and water separator BMPs for the removal of dissolved or emulsified oils such as coolants, soluble lubricants, glycols, and alcohols.
- Locate the oil and water separator BMP off-line, and bypass the incremental portion of flows that exceed the off-line 15-minute. If it is necessary to locate the separator on-line, try to minimize the size of the area needing oil control.
- Use only impervious conveyances for oil contaminated stormwater.
- Specify appropriate performance tests after installation and shakedown. Expeditious corrective actions must be taken if it is determined the oil and water separator BMP is not achieving acceptable performance levels.
- Add a pretreatment BMP for TSS that could cause clogging of the CP separator, or otherwise impair the long-term effectiveness of the separator.
- For API separators:
    - A minimum length to width ratio of 5:1 is recommended for all API separator designs to keep operating conditions as close to plug flow as possible, minimizing the potential for short circuiting.
    - A minimum depth to width ratio of 0.3 to 0.5 is recommended so that separation units are not excessively deep; minimizing the amount of time it takes for oil particles to rise to the surface.
    - The maximum API separator channel width is 20 ft (6 m); maximum depth is 8 ft (2.5 m).
    - Maintaining a horizontal velocity of no more than 3.0 ft/min (0.9 m/min) has been shown to minimize turbulence and its effect on interfering with the separation of oil from wastewater.
    - To minimize the effect of high wastewater inlet velocities into the API separator, and possible short-circuiting associated with these high velocities, reaction jet baffles are recommended to diffuse influent flows across the width and depth of the API separator.
    - Majority of oil particles in most refinery wastewaters are 150 micron in size or larger. Therefore, the design standards for API separators were developed for the removal of oil particles of this size. Particles smaller than 150 micron will normally exit an API separator and will need to be removed by downstream treatment processes, unless allowances are made in the sizing of the API separator to remove these smaller particles.

Limitations[1]

- Limited pollutant removal. Cannot effectively remove soluble pollutants, fine particles or bacteria.
- Can become a source of pollutants due to re-suspension of sediment unless maintained frequently. Maintenance often neglected ("out of sight and out of mind").
- Susceptible to flushing during large storms.
- Limited to relatively small contributing drainage areas.
- Requires proper disposal of trapped sediments and oils.
- May be expensive to construct and maintain.
- Entrapment hazard for amphibians and other small animals.

Pretreatment needs No

Water treatment[1]

Sedimentation	**H**	Biological Processes	**L**	Filtration/Sorption	**L**	Plant uptake	**-**

Water quality[1]

Nutrients	**L**	Sediments	**M**	Metals	**L**	Bacteria	**L**
Oil and Grease	**M**	Trash and Debris	**M**				

Emerging Pollutants

Biocides & T.P.	**N/A**	Tyre Compounds	**N/A**	Pharmaceuticals	**N/A**	Microplastics	**N/A**
Personal Care Products	**N/A**	Industrial Chemicals	**N/A**	Fossil Fuel and Combustion Products	**N/A**		

Water quantity[1]

Volume Reduction	**N/A**	Peak Flow Reduction	**L**	Groundwater Recharge	**N/A**

Maintenance[1,2,3,4]

- Maintenance is critical for proper operation of oil/particle separators. Separators that are not maintained can be significant sources of pollution. Separators should be inspected at least monthly and typically need to be cleaned every one to six months. Typical maintenance includes removal of accumulated oil and grease, floatables, and sediment using a vacuum truck or other ordinary catch basin cleaning equipment.
- Plans for oil/particle separators should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.
- Polluted water or sediment removed from separators should be properly handled and disposed in accordance with local, state, and federal regulations. Before disposal, appropriate chemical analysis of the material should be performed to determine proper methods for storage and disposal.

Construction and maintenance costs

Construction costs: Typical cost range between **$2000 and $3000 per unit** but can rise up to **$1000000** for special devices with specific requirements, normally for industry applications.

Maintenance costs: Typical maintenance costs ranged between **1000 – 2000 Eur/year.**

References

[1]*Boston Water and Sewer Commission, (2013). Stormwater Best Management Practices: Guidance Document. Boston, MA, USA. Available at:* https://www.bwsc.org/sites/default/files/2019-01/stormwater_bmp_guidance_2013.pdf

[2]*United States Environmental Protection Agency (USEPA), (1999). Stormwater Technology Fact Sheet: Water Quality Inlets. Available at:* https://nepis.epa.gov/Exe/ZyPDF.cgi/91018M1X.PDF?Dockey=91018M1X.PDF

[3]*Connecticut Department of Environmental Protection (2004). Connecticut Stormwater Quality Manual: Oil/Particle Separators. Available at:* https://portal.ct.gov/-/media/DEEP/water_regulating_and_discharges/stormwater/manual/CH11OPSS4pdf.pdf

[4]*Stormwater Equipment Manufacturers Association (SWEMA), (2018). SWEMA Fact Sheet: Oil / Water Separators. Available at:* https://www.stormwaterassociation.com/assets/docs/FACTSheets/swm_may2018_FACT%20SHEET%20Oil%20and%20Water%20Separators.pdf

[5]*Department of Ecology – State of Washington (2019). Stormwater Management Manual for Western Washington. Available at:* https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/Content/Topics/VolumeV/OilAndWaterSeparatorBMPs/OilAndWaterSeparatorBMPs_Intro.htm

[6]*The Wastewater blog-Wastewater treatment topics: API Separator (Retrieved at:* https://www.thewastewaterblog.com/single-post/2016/10/20/API-Separator*) (21/12/2022)*

System

Storm Tanks

Primary uses

Source Control		Transportation		Retention	X	Infiltration	
Pretreatment		Treatment					

Description

Storm tanks collect and store wastewater during a storm event, normally during the first flush, and then release it at controlled rates to the downstream drainage system, thereby attenuating peak discharge rates from the site. They differ from detention facilities (detention basins) because they are used in combined sewerage systems and store runoff combined with wastewaters, and hence have to face some specific problems related to contamination of waters.

With such systems in place, the drainage system as a whole can cater for higher intensity storms brought about by increasing uncertainties due to climate change. Storm tanks are normally placed underground in subsurface facilities, so they can be used beneath areas with a primary purpose other than drainage, including amenity, roads, and parking areas. Due to the storage of wastewaters they have to be placed in areas with an adequate accessibility and separated from residential or commercial areas where the odors produced can cause problems to citizens.

Subcategories

Storm tanks can be configured as online or offline systems.

- For online detention systems, wastewater from the entire catchment of the drain is routed through the storm tank via an inlet. After the storm ends, stored water is diverted to a wastewater treatment plant or spilled to a water body.
- Off-line storm tank facilities consist of tanks that store and/or treat combined sewer flows diverted from combined trunk sewers and interceptors. These facilities provide storage up to the volume of the tanks, as well as sedimentation treatment for flows that pass through the facilities in excess of the tank volume. Coarse screening, floatable control, and disinfection are commonly provided.

According to their function, Storm tanks can be classified in:

- Anti CSO storm tanks: their main function is to prevent Combined Sewer Overflows (CSO).
- Anti-flooding storm tanks: their main function is to prevent flooding.
- Mixed storm tanks: combined the two previous functions in one device.

According to the emptiness method:

- By gravity: The water flows by gravity once the storm is finished.
- Pumped: The water is pumped to the sewer system once the storm is finished.
- Mixed: The water flows by gravity until some point, after which it has to be pumped.

According to the water management they can be classified in:

- Trap systems: Once the system is full, the water is diverted to the sewer network through a bypass.
- Flow systems: The water continuously flows through to the system.

Applications

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

Location

Roadway/ Roadside	X	Pathway/Cycleway		Car park	X	Roundabout	X
Gas Station		Vehicles serv. area		Green/Open Area	X	Urban Park	
House/Building		Urban Planter		Square/Plaza	X	Water Course	

Scale of application

Building		Neighborhood	X	District	X	City	X

Lifespan

Short Term		Medium Term		Long Term	X

Space usage

Monofunctional		Multifunctional	X

Required Area

- Drainage Area: Depends on population and rainfall patterns.
- System Volume: Maximum of 35000 m³.

Ecosystem Functions

Water management and waste treatment.

Benefits

Climate change mitigation and adaption (4/5)
Water management (4/5)
Green Space Management (3/5)
Potential of economic opportunities and green jobs (4/5)

Relationship with SDG

Direct

6: Clean Water and Sanitation
13: Climate Action

Design Considerations

Siting considerations

- Climate conditions: Can be applied in all climate conditions.
- Geology conditions:
- Soil conditions:
- Depth of groundwater table:
- Site slopes: -
- Closeness to infrastructures: -
- Light/Shade considerations: -
- Accessibility: Provide sufficient access for operation and maintenance (O & M) by heavy machinery.
- Other considerations: -

Technical considerations

- Storm tanks are often divided in the following areas: main channel, retention camera, overflow channel and water flow regulation chamber. All of the different chambers should have access for inspection.
- It is possible to develop storm tanks by connecting in series pipes with big diameters (2.5 – 3 m) when retention volume is expected to be low (< 500 m³).

Limitations

- No recognized water quality benefits (however can provide some degree of pollutant removal mainly through sedimentation).

Pretreatment needs

Optional (TSS, trash, debris, and oil reduction).

Water treatment

Sedimentation	L	Biological Processes		Filtration/Sorption		Plant uptake	

Water quality

Nutrients	N/A	Sediments	L	Metals	N/A	Bacteria	N/A
Oil and Grease	N/A	Trash and Debris	M				

Emerging Pollutants

Biocides & T.P.	N/A	Tyre Compounds	N/A	Pharmaceuticals	N/A	Microplastics	N/A

Personal Care Products	**N/A**	Industrial Chemicals	**N/A**	Fossil Fuel and Combustion Products	**N/A**

Water quantity

Volume Reduction	**N/A**	Peak Flow Reduction	**M**	Groundwater Recharge	**N/A**

Maintenance

- In the storm tanks, especially in CSO systems, sludge and mud are settled to the bottom of the tank. Despite many efforts made to optimize the storm tanks design and minimize maintenance, practice shows that is not possible to get a self-cleaning design for the tank by itself. To avoid healthy and odor related problems due to the accumulation of sediments, the Water Company must do a regular cleaning of the tank. Personal costs and healthy risks associated are the reasons why storm tanks are equipped with automatic cleaning systems.

Construction and maintenance costs

Construction costs: in the range of **300 – 1200 Eur/m³.**

Maintenance costs: **1 – 4%** of construction costs (yearly).

References

[1]*Gobierno de España, Ministerio de Agricultura, Alimentación y Medio Ambiente (2014). Manual Nacional de Recomendaciones para el diseño de tanques de tormenta. Available at: https://www.aeas.es/images/publicaciones/manuales/Manual_Tanques_Tormenta_MAGRAMA.pdf*

[2]*United States Environmental Protection Agency (1993). Combined Sewer Overflow Control. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/30004MAO.PDF?Dockey=30004MAO.PDF*

System

Storm Drains, Pipes, and Ditches

Primary uses

Source Control	X	Transportation	X	Retention		Infiltration	
Pretreatment		Treatment					

Description

The combination of storm drains and pipe or ditch systems are the most common way to collect and transport runoff from urban areas in most countries and cities.

Storm drains are basically openings in roads, roadsides, sidewalks and other impermeable surfaces that are normally covered by a steel grate which main scope is to retain coarse trash and debris. Their function is to collect runoff and convey it to the sewer system. This system can be a wastewater network (when combined sewer is used) or a stormwater network (in separative sewers).

Ditches are simple water channels, catalogued as linear drainage systems and conceived to transport water. They are commonly used to collect runoff from linear impermeable areas like roads, and normally placed in the roadside or in the median in order to collect the runoff and transport it to a storm drain.

Subcategories

Pipes can come in many different cross-sectional shapes (rectangular, square, bread-loaf-shaped, oval, inverted pear-shaped, egg shaped, and most commonly, circular). Drainage systems may have many different features including waterfalls, stairways, balconies, and pits for catching rubbish, sometimes called Gross Pollutant Traps (GPTs). Pipes made of different materials can also be used, such as brick, concrete, high-density polyethylene, or galvanized steel. Fiber reinforced plastic is being used more commonly for drainpipes and fittings. Dimensions range from 150 mm to more than 2 m.

Ditches are normally made of concrete but can also be built with stabilized or compacted soils, aggregates or even have a vegetated surface in the so-called grassed channels. They can also be classified according to their cross section, being the most common geometry parabolical or trapezoidal.

There are a lot of types and designs for storm drains. There are two main types of stormwater drain inlets: side inlets and grated inlets. Side inlets are located adjacent to the curb and rely on the ability of the opening under the back stone or lintel to capture flow. Grate inlets have gratings or grids to prevent people, vehicles, large objects, or debris from falling into the storm drain. Grate bars are spaced so that the flow of water is not impeded, but sediment and many small objects can also fall through.

Applications

Residential	X	Commercial	X	Industrial	X	High Density	X	Road/Highway	X

Location

Roadway/ Roadside	X	Pathway/Cycleway	X	Car park	X	Roundabout	X
Gas Station	X	Vehicles serv. area	X	Green/Open Area	X	Urban Park	X
House/Building	X	Urban Planter	X	Square/Plaza	X	Water Course	

Scale of application

Building	X	Neighborhood	X	District	X	City	X

Lifespan

Short Term		Medium Term		Long Term	X

Space usage

Monofunctional		Multifunctional	X

Required Area

- Drainage Area: The maximum drainage to be drained to a single storm drain, pipe or gutter depends on the dimensions of the system. This value is normally established by local authorities depending on the site characteristics.
- System Area: Sewer pipes can range from 15 cm to more than 2 m in diameter. Storm drains are normally small and have dimensions established by local laws with maximum values normally in the range of 10 – 50cm width and 40 – 100 cm long.

Ecosystem Functions

Water management and waste treatment.

Benefits

Climate change mitigation and adaption (3/5)
Water management (5/5)
Potential of economic opportunities and green jobs (4/5)

Relationship with SDG

Direct

6: Clean Water and Sanitation
13: Climate Action

Design Considerations

Siting considerations

- Climate conditions: can be applied in all climate conditions with an appropriate design.
- Geology conditions: can be applied in all geology conditions with an appropriate design.
- Soil conditions: can be applied in all soil conditions with an appropriate design.
- Depth of groundwater table: The maximum likely groundwater level should be always, at least, 1 m below the lowest level of the system.
- Site slopes: Longitudinal slopes should be constrained to a minimum of 0.5% or the slope that produce a velocity of, at least, 0.3 – 0.6 m/s. The maximum velocity shall be 3 m/s – 6 m/s
- Closeness to infrastructures: -
- Light/Shade considerations: -
- Accessibility: It is necessary to provide access for maintenance and inspection of the network.
- Other considerations: -

Technical considerations

- Depth of pipes should be at least of 1m in trafficked areas and 0.6 m otherwise.
- Pipes are normally circular in shape and should have a minimum pipe diameter of 300 mm. Other shapes can be considered like ovoid or elliptic shapes.
- Pipes can be made of concrete, PVC, PE or the materials allowed by local authorities and should be dimensioned according to local regulations.
- Service life of the components of the storm sewerage system is expected to be 50 years.
- Water can flow through the pipes by gravity or can be necessary to include a pump station where gravity cannot guarantee the water flow through the system.

Limitations

- No pollutant removal credit. Potential increase of water pollution due to resuspension of sedimented pollutants.
- Storm drains are often unable to manage the quantity of rain that falls during heavy rains and/or storms. When storm drains are inundated, basement and street flooding can occur.
- Catch basins are commonly designed with a sump area below the outlet pipe level—a reservoir for water and debris that helps prevent the pipe from clogging. Unless constructed with permeable bottoms to let water infiltrate into underlying soil, this subterranean basin can become a mosquito breeding area.

Pretreatment needs

No

Water treatment

Sedimentation	-	Biological Processes	-	Filtration/Sorption	-	Plant uptake	-

Water quality

Nutrients	N/A	Sediments	N/A	Metals	N/A	Bacteria	N/A
Oil and Grease	N/A	Trash and Debris	N/A				

Emerging Pollutants

Biocides & T.P.	**N/A**	Tyre Compounds	**N/A**	Pharmaceuticals	**N/A**	Microplastics	**N/A**
Personal Care products	**N/A**	Industrial Chemicals	**N/A**	Fossil Fuel and Combustion Products	**N/A**		

Water quantity

Volume Reduction	**N/A**	Peak Flow Reduction	**N/A**	Groundwater Recharge	**N/A**

Maintenance

- Maintenance of sewers consists mainly of the removal or prevention of stoppages, cleaning of sewers and other sewer appurtenances, and repair works. Maintenance of sewers becomes costly only when they are laid on flat gradients and tree roots find easy entrance in sewers through defective joints. The maximum expenditure in maintenance comes on the cleaning of sewers, which have been clogged due to deposition of silt, grease, and oily materials.
- The period of inspection is generally as follows:
    - Sewers on flat grades – 3 months
    - Sewers troubled by roots – 3 months
    - Sewers having no trouble – 6 to 12 months
    - Intercepting sewers – 7 to 30 days
    - Flushing tanks – 1 month
    - Inverted siphons – 7 to 30 days
    - Storm water overflows – during rains.

Construction and maintenance costs

Construction costs: **300 to 2400 Eur/m (of pipe).**

Maintenance costs: N/A (Not available).

References

[1]*Guía Técnica sobre redes de saneamiento y drenaje urbano. CEDEX (Centro de Estudios y Experimentación de Obras Publicas), Ministerio de Fomento y Ministerio de Medio Ambiente. 2007. Available at:* https://www.miteco.gob.es/es/agua/temas/concesiones-y-autorizaciones/vertido-desbordamiento-sistema-saneamiento-dss/vertidos-dss-documentacion.html

[2]*Storm Drainage Design and Technical Criteria Manual, City of Brookings, SD. Ecological Resource Consultants, Inc. Available at: https://cityofbrookings-sd.gov/DocumentCenter/View/305/Storm-Drainage-Design-and-Technical-Criteria-Manu?bidId*=

4 NBS parametric design spreadsheet

The NBS parametric design spreadsheet (available in: D4RUNOFF - NBS Parametric Design Spreadsheets_v2g.xlsm) has been developed in order to be an all-in-one module that helps designers to produce a predesign of NBS for stormwater management according to the specific conditions of the location site at which the NBS is intended to be installed. The spreadsheet is composed of different sheets, some of which should be completed by the user in order to provide the input data needed for the calculations. In order to follow a simple rule for the completion of the required data, the cells where the value is red-colored should be completed by the user, while the values in black or green are values that are fixed or automatically calculated during the design process.

4.1 Hydrology

The first sheet of the spreadsheet is called "HYDROLOGY" and is the hydrology calculation module. This module has been developed in order to support the users in providing reasonable approximations to the required hydrologic parameters for NBS sizing with very limited information of the basin characteristics, so the results provided should be considered as simple estimations for predesign purposes. In this sheet the user should complete the 24 hours maximum rainfall data for the last 30 years at the location site, which is considered enough for hydrological calculations. If the user has limited data (<30 years) from the intervention point, the missing data can be completed following conventional hydrological procedures by correlating data from near Meteorological Stations. If the available number of data points is higher than 30, the data should be truncated for the last 30 years.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Year	P24max (mm)	Position	Ordered Position	P24max(ordered) (mm)	Log10 (P24max(orordered))	Probability	Cumulated probability	Normal	Log-Normal	Log-Pearson III	Gumbel
2	Year 1	35	23	30	18,7	1,271841607	0,033333333	0,033333333	0,05599678	0,015260588	0,006564026	0,01342119
3	Year 2	34,5	24	29	22,1	1,344392274	0,033333333	0,066666667	0,07709023	0,037963085	0,026057732	0,03045528
4	Year 3	25	27	28	24	1,380211242	0,033333333	0,1	0,09125573	0,056704308	0,045306048	0,04489349
5	Year 4	82,6	4	27	25	1,397940009	0,033333333	0,133333333	0,09944578	0,068357286	0,057993854	0,05410259
6	Year 5	39	21	26	29,5	1,469822016	0,033333333	0,166666667	0,14295009	0,134951432	0,134654036	0,11006666
7	Year 6	22,1	29	25	31,7	1,501059262	0,033333333	0,2	0,16832704	0,174625228	0,18113793	0,14583518
8	Year 7	29,5	26	24	34,5	1,537819095	0,033333333	0,233333333	0,20456421	0,229882319	0,245182077	0,19821077
9	Year 8	56,1	11	23	35	1,544068044	0,033333333	0,266666667	0,21149192	0,240163102	0,256950653	0,20824959
10	Year 9	18,7	30	22	36,3	1,559906625	0,033333333	0,3	0,23013404	0,267306621	0,287759776	0,23515612
11	Year 10	59	10	21	39	1,591064607	0,033333333	0,333333333	0,27163648	0,324856279	0,351723593	0,29394334
12	Year 11	87,5	2	20	44,5	1,648360011	0,033333333	0,366666667	0,36618757	0,441405871	0,475341338	0,4187136
13	Year 12	49,5	16	19	44,8	1,651278014	0,033333333	0,4	0,37165849	0,447577971	0,481668677	0,42548584
14	Year 13	81,5	5	18	44,9	1,652246341	0,033333333	0,433333333	0,37348797	0,44962904	0,483766573	0,42773928
15	Year 14	44,5	20	17	49,2	1,691965103	0,033333333	0,466666667	0,45432508	0,534287844	0,568341068	0,52179316
16	Year 15	53,5	14	16	49,5	1,694605199	0,033333333	0,5	0,46007789	0,53990241	0,573814962	0,52808625
17	Year 16	53,6	13	15	51	1,707570176	0,033333333	0,533333333	0,48894337	0,567338223	0,600332254	0,55889836
18	Year 17	59,6	8	14	53,5	1,728353782	0,033333333	0,566666667	0,53710651	0,610597062	0,64138932	0,60759666
19	Year 18	24	28	13	53,6	1,72916479	0,033333333	0,6	0,53902645	0,612261283	0,642951052	0,60947086
20	Year 19	90,5	1	12	56	1,748188027	0,033333333	0,633333333	0,58473111	0,650646602	0,678623298	0,65266122
21	Year 20	62,5	7	11	56,1	1,748962861	0,033333333	0,666666667	0,58661519	0,652180897	0,680035591	0,65438495
22	Year 21	31,7	25	10	59	1,770852012	0,033333333	0,7	0,64022118	0,69441645	0,718526543	0,7016864
23	Year 22	49,2	17	9	59,1	1,771587481	0,033333333	0,733333333	0,64202793	0,695795512	0,719771226	0,7032247
24	Year 23	44,8	19	8	59,6	1,77524626	0,033333333	0,766666667	0,65101333	0,702614394	0,725914906	0,71082377
25	Year 24	51	15	7	62,5	1,795880017	0,033333333	0,8	0,701341	0,739695352	0,759025921	0,75189749
26	Year 25	80	6	6	80	1,903089987	0,033333333	0,833333333	0,9153284	0,888083992	0,888174816	0,90815158
27	Year 26	59,1	9	5	81,5	1,911157609	0,033333333	0,866666667	0,92602863	0,896092249	0,895130966	0,91595579
28	Year 27	36,3	22	4	82,6	1,916980047	0,033333333	0,9	0,93319501	0,901607922	0,899934914	0,92127276
29	Year 28	44,9	18	3	86	1,934498451	0,033333333	0,933333333	0,95198311	0,916906522	0,913336655	0,93574466
30	Year 29	56	12	2	87,5	1,942008053	0,033333333	0,966666667	0,95879871	0,922887604	0,918617329	0,9412804
31	Year 30	86	3	1	90,5	1,956648579	0,033333333	1	0,97007866	0,933599895	0,928155767	0,95099887
32	N	30						Coef.Determ. (R^2)	0,97742192	0,981418806	0,97061101	0,98399825

	A	B	C	D	H	I
34	Data		Log(Data)		Log Pearson tipo III	
35	MAX	90,5	MAX	1,956648579	Lambda	0,03620591
36	MIN	18,7	MIN	1,271841607	Beta	26,6130813
37	RANGE	71,8	RANGE	0,684806973	Epsilon	0,71234142
38	AVERAGE	51,57333333	AVERAGE	1,675892253		
39	MEDIAN	50,25	MEDIAN	1,701087688	Gumbel	
40	GEOMETRIC AV.	47,41243417	GEOMETRIC AV.	1,665434103	Alfa	16,1274117
41	STANDARD DEVIATION	20,68420909	STANDARD DEVIATION	0,186778573	U	42,2645913
42	ASSIMETRY COEFFICIENT	0,388807025	ASSIMETRY COEFFICIENT	-0,387688051		
43	VARIATION COEFFICIENT	0,401064034	VARIATION COEFFICIENT	0,111450228		

Figure 2. Input data and calculations at HYDROLOGY sheet.

Once the data is included, the module calculates the maximum daily rainfall for 2, 5, 10, 50, 100 and 200 years according to 4 different data distributions: Normal, Log-Normal, Gumbel and Log-Pearson III.

Gumbel

T=	2 years	5 years	10 years	50 years	100 years	200 years
d=	24 hours	24 hours	24 hours	24 hours	24 hours	24 hours
Kt=	-0,2	0,723512	1,308618	2,596343	3,140735	3,683141
Xt=	**48 mm**	**66,5386 mm**	**78,6411 mm**	**105,277 mm**	**116,537 mm**	**127,756 mm**
It=	**2 mm/h**	**2,77244 mm/h**	**3,27671 mm/h**	**4,38653 mm/h**	**4,85571 mm/h**	**5,32317 mm/h**
α	0,05	0,05	0,05	0,05	0,05	0,05
β	0,9	0,9	0,9	0,9	0,9	0,9
P	0,95	0,95	0,95	0,95	0,95	0,95
Z	1,64	1,644854	1,644854	1,644854	1,644854	1,644854
a	0,95	0,953353	0,953353	0,953353	0,953353	0,953353
b	-0,1	0,433285	1,622295	6,65081	9,774032	13,47534
Kt(U)	0,14	1,10743	1,799835	3,387136	4,069567	4,752644
Kt(L)	-0,5	0,410396	0,945461	2,059625	2,519254	2,974069
Ut	**55 mm**	**74,4796 mm**	**88,8015 mm**	**121,634 mm**	**135,749 mm**	**149,878 mm**
Lt	**42 mm**	**60,0621 mm**	**71,1294 mm**	**94,1751 mm**	**103,682 mm**	**113,09 mm**

Figure 3. Maximum daily rainfall for different return periods together with confidence bands (95%) for Gumbel probability distribution.

In the next sheet of the spreadsheet, called "IDF", the module calculates the Intensity-Duration-Frequency curves according to each data distribution. The curves are calculated for the most common return periods in hydrology calculations: 2, 5, 10, 50, 100 and 200 years. Each curve is developed using the following durations: 0.1, 0.2, 0.3, 0.4, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 and 24 hours.

NORMAL

T	P24(mm)	Id(mm/h)	d(h)= 0,1	d(h)= 0,2	d(h)= 0,3	d(h)= 0,4	d(h)= 0,5	d(h)= 1	d(h)= 2	d(h)= 3	d(h)= 4	d(h)= 5	d(h)= 6	d(h)= 7	d(h)= 8	d(h)= 9	d(h)= 10	d(h)= 11	d(h)= 12	d(h)= 13	d(h)= 14	d(h)= 15	d(h)= 16	d(h)= 17	d(h)= 18	d(h)= 19	d(h)= 20	d(h)= 21	d(h)= 22	d(h)= 23	d(h)= 24
2	51,57	2,15	71,17	51,07	41,60	35,78	31,74	21,49	14,15	10,93	9,04	7,77	6,85	6,15	5,59	5,14	4,76	4,44	4,16	3,92	3,70	3,51	3,34	3,19	3,05	2,93	2,81	2,71	2,61	2,52	2,43
5	68,98	2,87	95,19	68,30	55,63	47,85	42,45	28,74	18,92	14,62	12,09	10,40	9,17	8,23	7,48	6,87	6,36	5,93	5,56	5,24	4,95	4,70	4,47	4,27	4,08	3,91	3,76	3,62	3,49	3,37	3,25
10	78,08	3,25	107,76	77,32	62,98	54,17	48,05	32,54	21,42	16,55	13,69	11,77	10,38	9,31	8,47	7,78	7,20	6,72	6,30	5,93	5,61	5,32	5,06	4,83	4,62	4,43	4,26	4,10	3,95	3,81	3,68
50	94,06	3,92	129,80	93,14	75,86	65,25	57,88	39,19	25,81	19,93	16,49	14,18	12,50	11,22	10,20	9,37	8,68	8,09	7,58	7,14	6,75	6,41	6,10	5,82	5,57	5,34	5,13	4,93	4,76	4,59	4,44
100	99,70	4,15	137,58	98,72	80,41	69,17	61,35	41,54	27,35	21,13	17,48	15,03	13,25	11,89	10,81	9,93	9,20	8,58	8,04	7,57	7,16	6,79	6,46	6,17	5,90	5,66	5,44	5,23	5,04	4,87	4,70
200	104,86	4,37	144,71	103,83	84,57	72,75	64,53	43,69	28,77	22,22	18,38	15,81	13,94	12,51	11,37	10,45	9,68	9,02	8,45	7,96	7,53	7,14	6,80	6,49	6,21	5,95	5,72	5,50	5,30	5,12	4,95

log NORMAL

T	P24(mm)	Id(mm/h)	0,1	0,2	0,3	0,4	d(h)= 0,5	d(h)= 1	d(h)= 2	d(h)= 3	d(h)= 4	d(h)= 5	d(h)= 6	d(h)= 7	d(h)= 8	d(h)= 9	d(h)= 10	d(h)= 11	d(h)= 12	d(h)= 13	d(h)= 14	d(h)= 15	d(h)= 16	d(h)= 17	d(h)= 18	d(h)= 19	d(h)= 20	d(h)= 21	d(h)= 22	d(h)= 23	d(h)= 24
2	47,41	1,98	65,43	46,95	38,24	32,89	29,18	21,49	14,15	10,93	9,04	7,77	6,85	6,15	5,59	5,14	4,76	4,44	4,16	3,92	3,70	3,51	3,34	3,19	3,05	2,93	2,81	2,71	2,61	2,52	2,43
5	68,09	2,84	93,96	67,42	54,91	47,23	41,90	28,37	18,68	14,43	11,94	10,26	9,05	8,12	7,39	6,78	6,28	5,86	5,49	5,17	4,89	4,64	4,41	4,21	4,03	3,86	3,71	3,57	3,44	3,32	3,21
10	82,28	3,43	113,54	81,47	66,36	57,08	50,63	34,28	22,57	17,44	14,42	12,40	10,94	9,81	8,92	8,20	7,59	7,08	6,63	6,25	5,91	5,61	5,34	5,09	4,87	4,67	4,49	4,32	4,16	4,02	3,88
50	114,70	4,78	158,29	113,57	92,51	79,57	70,58	47,79	31,47	24,31	20,11	17,29	15,25	13,68	12,44	11,43	10,58	9,87	9,25	8,71	8,24	7,81	7,44	7,10	6,79	6,51	6,25	6,02	5,80	5,60	5,41
100	128,97	5,37	177,97	127,70	104,02	89,47	79,36	53,74	35,38	27,33	22,61	19,44	17,14	15,38	13,99	12,85	11,90	11,09	10,40	9,79	9,26	8,79	8,36	7,98	7,63	7,32	7,03	6,77	6,52	6,30	6,09
200	143,57	5,98	198,13	142,16	115,80	99,60	88,35	59,82	39,39	30,42	25,17	21,64	19,08	17,13	15,57	14,30	13,25	12,35	11,58	10,90	10,31	9,78	9,31	8,88	8,50	8,15	7,83	7,53	7,26	7,01	6,77

GUMBEL

T	P24(mm)	Id(mm/h)	0,1	0,2	0,3	0,4	d(h)= 0,5	d(h)= 1	d(h)= 2	d(h)= 3	d(h)= 4	d(h)= 5	d(h)= 6	d(h)= 7	d(h)= 8	d(h)= 9	d(h)= 10	d(h)= 11	d(h)= 12	d(h)= 13	d(h)= 14	d(h)= 15	d(h)= 16	d(h)= 17	d(h)= 18	d(h)= 19	d(h)= 20	d(h)= 21	d(h)= 22	d(h)= 23	d(h)= 24
2	48,26	2,01	66,60	47,78	38,92	33,48	29,70	21,49	14,15	10,93	9,04	7,77	6,85	6,15	5,59	5,14	4,76	4,44	4,16	3,92	3,70	3,51	3,34	3,19	3,05	2,93	2,81	2,71	2,61	2,52	2,43
5	66,54	2,77	91,82	65,88	53,67	46,16	40,95	27,72	18,25	14,10	11,66	10,03	8,84	7,94	7,22	6,63	6,14	5,72	5,36	5,05	4,78	4,53	4,31	4,12	3,94	3,78	3,63	3,49	3,36	3,25	3,14
10	78,64	3,28	108,52	77,87	63,43	54,56	48,39	32,77	21,57	16,66	13,79	11,85	10,45	9,38	8,53	7,84	7,26	6,76	6,34	5,97	5,65	5,36	5,10	4,87	4,66	4,46	4,29	4,13	3,98	3,84	3,71
50	105,28	4,39	145,28	104,24	84,91	73,03	64,78	43,87	28,88	22,31	18,45	15,87	13,99	12,56	11,42	10,49	9,71	9,06	8,49	7,99	7,56	7,17	6,83	6,51	6,23	5,98	5,74	5,52	5,32	5,14	4,97
100	116,54	4,86	160,82	115,39	93,99	80,85	71,71	48,56	31,97	24,70	20,43	17,57	15,49	13,90	12,64	11,61	10,75	10,02	9,40	8,85	8,37	7,94	7,56	7,21	6,90	6,61	6,35	6,11	5,89	5,69	5,50
200	127,76	5,32	176,30	126,50	103,04	88,63	78,62	53,23	35,05	27,07	22,40	19,26	16,98	15,24	13,86	12,73	11,79	10,99	10,30	9,70	9,17	8,70	8,28	7,91	7,56	7,25	6,97	6,70	6,46	6,24	6,03

log PEARSON III

T	P24(mm)	Id(mm/h)	0,1	0,2	0,3	0,4	d(h)= 0,5	d(h)= 1	d(h)= 2	d(h)= 3	d(h)= 4	d(h)= 5	d(h)= 6	d(h)= 7	d(h)= 8	d(h)= 9	d(h)= 10	d(h)= 11	d(h)= 12	d(h)= 13	d(h)= 14	d(h)= 15	d(h)= 16	d(h)= 17	d(h)= 18	d(h)= 19	d(h)= 20	d(h)= 21	d(h)= 22	d(h)= 23	d(h)= 24
2	49,05	2,04	67,69	48,57	39,56	34,03	30,18	21,49	14,15	10,93	9,04	7,77	6,85	6,15	5,59	5,14	4,76	4,44	4,16	3,92	3,70	3,51	3,34	3,19	3,05	2,93	2,81	2,71	2,61	2,52	2,43
5	68,56	2,86	94,61	67,88	55,29	47,56	42,19	28,57	18,81	14,53	12,02	10,33	9,11	8,18	7,44	6,83	6,33	5,90	5,53	5,21	4,92	4,67	4,45	4,24	4,06	3,89	3,74	3,60	3,47	3,35	3,23
10	80,66	3,36	111,31	79,87	65,05	55,96	49,63	33,61	22,13	17,09	14,14	12,16	10,72	9,62	8,75	8,04	7,44	6,94	6,50	6,12	5,79	5,49	5,23	4,99	4,77	4,58	4,40	4,23	4,08	3,94	3,81
50	122,62	5,11	169,21	121,41	98,90	85,06	75,45	51,09	33,64	25,98	21,49	18,48	16,30	14,63	13,30	12,22	11,31	10,55	9,89	9,31	8,80	8,35	7,95	7,59	7,26	6,96	6,69	6,43	6,20	5,99	5,79
100	113,96	4,75	157,26	112,84	91,91	79,06	70,13	47,48	31,26	24,15	19,98	17,18	15,15	13,59	12,36	11,35	10,51	9,80	9,19	8,65	8,18	7,76	7,39	7,05	6,75	6,47	6,21	5,98	5,76	5,56	5,38
200	161,27	6,72	222,54	159,68	130,07	111,88	99,24	67,19	44,24	34,17	28,27	24,31	21,43	19,24	17,49	16,07	14,88	13,87	13,00	12,25	11,58	10,99	10,46	9,98	9,55	9,15	8,79	8,46	8,16	7,87	7,61

Figure 4. IDF curves developed according to the 4 probability distribution models used.

4.2 Input data

The next sheet in the spreadsheet is called “INPUT DATA”, and here is where the user should incorporate the main characteristics at the location site where the NBS is expected to be placed. In the sheet there is generic data related to basin characteristics, that is used for the calculation of all NBS techniques, and specific input data for each NBS that is used only for the calculation of the specific technique where the data is included. For each relevant data a “HELP” sheet is also provided, accessible by clicking in the hyperlink, where a description of the requested data and standardized values are provided in order to help the user to complete the required data.

(a)

BASIN CHARACTERISTICS			
Drainage Area	Ad	2500	m²
% Impervious	Imp	95	%
Average Slope	S	5	%
Length	Lb	100	m
Width	Wb	25	m
Runoff Coeffcient	R	0,905	
Time of Concentration	Tc	0,1	h
INTERVENTION POINT CHARACTERISTICS			
Available Area for the practice	Aa	600	m²
Available Length	La	30	m
Available Width	Wa	20	m
Soil infiltration rate	Ks	0,000100	m/s
Groundwater Table depth	Dgw	5	m

(b)

SPECIFIC CHARACTERISTICS FOR NbS DESIGN			
Grassed Swale			
Site Slope (in flow direction)	S	0,02	m/m
Side Slope (H:V)	z	3	m/m
The system include underdrains		NO	
Filter Drain			
Site Slope (in flow direction)	S	0,02	m/m
Porosity of filling material	Nf	0,5	
Permeability of Filling Material	Kf	2,5	m/s
The system include underdrains		YES	
Detention Basin			
Objective Peak Discharge	qp(out)	0,01	m³/s
Detention Time	Td	72	h
Side Slope (H:V)	z	3	m/m

Figure 5. Main input data requested for calculations: (a) Basin and Intervention Point and (b) Specific NBS.

In this sheet, the stormwater volumes and flows calculated according to the basin characteristics and the hydrological data incorporated in the “HYDROLOGY” sheet are also showed. It should be noted that these calculations are simple estimations that can help the users to approximate the results, but needs to be validated with more detailed models that consider detailed geological and topographical information. The estimations provided in the worksheet have been made following the rational method in combination with the recommendations and methods provided in the document called *TR-55: Urban hydrology for small watersheds* from the US-EPA[a] and in the Appendix A of the *Stormwater Best Management Practice Design Guide Volume 1* from the US-EPA[b] for estimating the peak discharge and the water quality volume for small storm BMP design by the Short-Cut method.

[a] Urban Hydrology for Small Watersheds. TR-55. United States Department of Agriculture https://www.nrc.gov/docs/ML1421/ML14219A437.pdf

[b] Stormwater Best Management Practice Design Guide Volume 1: General Considerations. United States Environmental Protection Agency (2004). https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=99739

The users are encouraged to use their own hydrological data and calculations in order to obtain more accurate and detailed results.

HYDROLOGY			
Maximum 24h rainfall height (T=2)	P24(T=2)	48,26	mm
Maximum 24h rainfall height (T=10)	P24(T=10)	78,64	mm
Maximum 24h rainfall height (T=100)	P24(T=100)	116,54	mm
Maximum 24h rainfall intensity (T=2)	I24(T=2)	2,01	mm/h
Maximum 24h rainfall intensity (T=10)	I24(T=10)	3,28	mm/h
Maximum 24h rainfall intensity (T=100)	I24(T=100)	4,86	mm/h
Maximum 1h rainfall intensity (T=2)	I1(T=2)	21,49	mm/h
Maximum 1h rainfall intensity (T=10)	I1(T=10)	32,77	mm/h
Maximum 1h rainfall intensity (T=100)	I1(T=100)	48,56	mm/h
Water Quality Volume (T=2)	Vwq(T=2)	3930,72	m³
Water Quality Volume (T=10)	Vwq(T=10)	6405,31	m³
Water Quality Volume (T=100)	Vwq(T=100)	9491,93	m³
Peak Discharge (T=2)	q(T=2)	0,881	m³/s
Peak Discharge (T=10)	q(T=10)	1,435	m³/s
Peak Discharge (T=100)	q(T=100)	2,127	m³/s

Figure 6. Main hydrologic parameters used for calculation and developed on the basis of the drainage area characteristics and the Hydrologic data provided.

For each technique, there are some verifications that should be done prior to the hydraulic calculations that are mainly related to the drainage area that drains to the location site, the ratio between drainage and available area for NBS construction, the soil infiltration rate, and the amount of impervious area in the watershed that drains to the NBS. Beside each verification dialogue, a cell shows if the conditions at the location site for the considered watershed meets the conditions required for each NBS technique.

18	SUITABILITY OF NbS TECHNIQUES		
19	TRANSPORTATION NbS		
20	Grassed Swale	OK	Solve for Dimensions
21	Filter Drain	OK	Solve for Dimensions
22	INFILTRATION NbS		
23	Infiltration Basin	NO	Solve for Dimensions
24	Infiltration Trench	NO	Solve for Dimensions
25	Dry Well	NO	Solve for Dimensions
26	Infiltrating Biorretention Area	NO	Solve for Dimensions
27	SOURCE CONTROL NbS		
28	Permeable Pavement	NO	Solve for Dimensions
29	Green Roof	NO	Solve for Dimensions
30	TREATMENT NbS		
31	Filter Strip	OK	Solve for Dimensions
32	Filtering Biorretention Area	OK	Solve for Dimensions
33	Rain Garden	OK	Solve for Dimensions
34	DETENTION NbS		
35	Detention Basin	NO	Solve for Dimensions
36	Retention Pond	OK	Solve for Dimensions
37	Constructed Wetland	NO	Solve for Dimensions

Figure 7. Input data for NBS solutions and verification check of required conditions.

4.3 Results

Once the data is completed, the user can click on the button “Solve for dimensions” in order to calculate the dimensions required for each technique according to the input data provided. Once the user presses the button, the excel spreadsheet begins an iterative process by using the “Evolutionary” method of the “solver” application in EXCEL, that should finally provide a solution adapted to the location site. The results of this iterative process are showed in the sheet called “RESULTS” where the dimensions and main characteristics of the designed NBS are showed. Additionally, some other useful parameters of the calculated NBS are showed, and some comments are also provided in relation to the designed solutions, especially related to the capacity or not to treat and receive all the inflow, and hence, the necessity for diverting some water volume.

INFILTRATION BASIN DIMENSIONS			
Total Depth	**D**	**0,70**	m
Water Depth	**Dw**	**0,24**	m
Freeboard	**Df**	**0,46**	m
Top Radius	**Rb2**	**10,00**	m
Base Radius	**Ab2**	**7,91**	m
IB Volume	V	176,41	m^3
IB Storage Volume	Vs	51,58	m^3
IB surface area	Ad	314,16	m^2
DrawDawn Time	T	24,0	h
Comments	Infiltration Basin dimensions are not enough to treat all the inflow. Volume to be diverted is:		
	212,09		m^3

Figure 8. Dimensions of Infiltration Basin provided at the “RESULTS” sheet together with comments regarding the designed solution.

The user is also able to check the full calculations performed for each NBS and the main limiting values used for each parameter simply by acceding to the specific sheet developed for each technique as can be seen in Figure 9.

2	HYDROLOGY				CALCULATIONS					
3	Water Quality Volume (T=2)	Vwq(T=2)	109,19	m^3	Required Storage Volume (T=10)	Smax	152	m^3		Iteration Value
4	Water Quality Volume (T=10)	Vwq(T=10)	177,93	m^3	Required Detention Volume (T=10)	Dv	190	m^3		Limiting Factor
5	Water Quality Volume (T=100)	Vwq(T=100)	263,66	m^3	Water Depth at WQV (T=10)	D(WQV)	1,20	m	Value	User imput Value
6	Peak Discharge (T=2)	q(T=2)	0,042	m^3/s	Freeboard	Dfb	0,30	m		
7	Peak Discharge (T=10)	q(T=10)	0,068	m^3/s	Total Depth	D	1,50	m		
8	Peak Discharge (T=100)	q(T=100)	0,101	m^3/s	Detention Time	Td	10,62	h		
9	NBS DESIGN PARAMETERS				Base length	Lb	18,69	m		
10	Objetive Peak discharge	qp(out)	0,01	m^3/s	Base Width	Wb	3,53	m		
11	Minimum Side Slope	z(min)	3	m/m	Length to Width Ratio at WQV	L/W(WQV)	2,28			
12	Maximum Side Slope	z(max)	5	m/m	Side Slopes	z	3,47			
13	Minimum Length to Width ratio at WQV level	L/W(min)	2	m/m	Length at WQV	Ld	26,99	m		
14	Maximum Length to Width Ratio at WQV level	L/W(max)	5	m/m	Width at WQV	Wd	11,83	m		
15	Minimum base Width	Wb(min)	2	m	Top Length	Lt	29,07	m		
16	Minimum base Length	Lb(min)	2	m	Top Width	Wt	13,91	m		
17	Maximum top width	Wt(max)	20	m	DB Detention Volume	Vd	211,70	m^3		
18	Maximum top Length	Lt(max)	30	m	DB Total Volume	Vt	316,28	m^3		
19	Minimum Drawdown Time	T(min)	1	h	Minimum sediment size retained	dmin	0,0000365	mm		
20	Maximum Drawdown Time	T(max)	24	h	Water Volume Balance	DifV	0,00	m^3		
21	Minimum Water Depth	D(min)	0,5	m						
22	Maximum Water Depth	D(max)	2	m						
23	Maximum Depth according to GWT	D(GW)	4	m						

Figure 9. Detailed calculations and limiting factors for NBS calculation.

It is important to note that this spreadsheet is a Beta version, and hence, can result in some failing calculations due to the programming of the "Solver" module. The users are asked to provide feedback and report the problems that can find in the spreadsheet to info@d4runoff.eu.

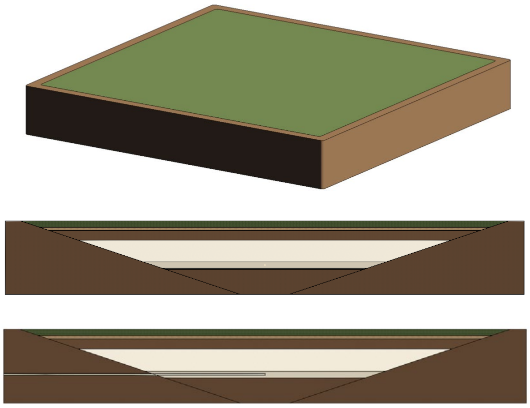
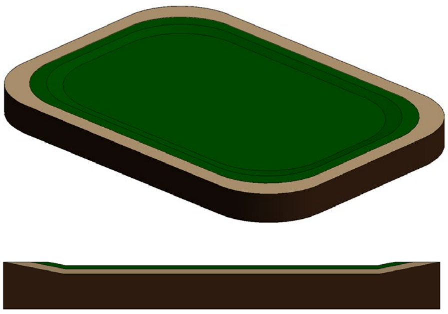
5 Implementation of the parametric design in BIM

For the D4RUNOFF project, UC has developed the NBS Library add-in. The Revit NBS Library add-in is a software program integrated with Autodesk Revit to create Nature Based Solution (NBS) parametric BIM objects according to spreadsheet (files .IFC available in: D4RUNOFF - NBS_IFC.zip).

5.1 NBS BIM objects

NBS BIM objects have been designed using different types and configurations, depending on the technique geometry (different number and type of parameters), type of location (covering an area or along a lineal feature), and element-based (standalone or host-based). The BIM object collection is illustrated in Table 1.

Table 1. NBS BIM objects collection

Bioretention Area	
Standalone family Category: pavement **Layers:** - Vegetation - Mulch - Bioretention soil - Sand - Aggregate - [opt] Geomembrane - Native Soil [opt] Perforated pipe in aggregate layer	
Detention Basin	
Standalone family Category: pavement **Layers:** - Vegetation - Soil Media - [opt] Fabric liner - Native soil	

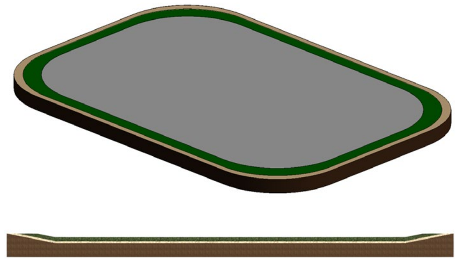
Retention Pond

Standalone family

Category: pavement

Layers:

- Water
- Vegetation
- Soil Media
- [opt] Fabric liner
- Native soil



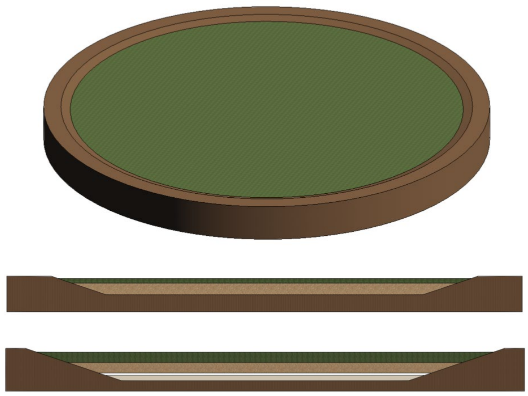
Infiltration Basin

Standalone family

Category: pavement

Layers:

- Vegetation
- Engineered soil
- [opt] Sand filter
- [opt] Subsurface storage
- Native soil



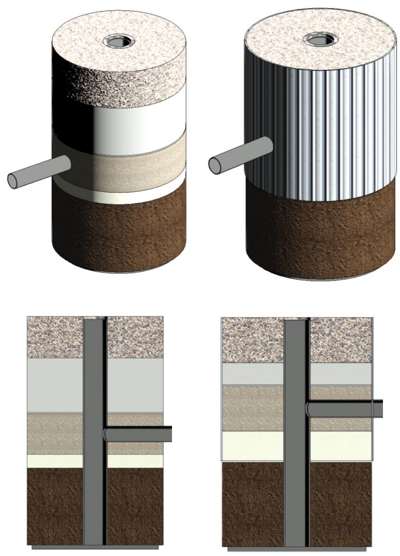
Dry Well

Standalone family

Category: pavement

Layers:

- [opt]Permeable surface coverage
- Gravel layer 1
- Non-woven geotextile
- Gravel layer 2
- Sand filter
- Native soil
- [opt] perforated pipe in gravel layer 2
- [opt] filter fabric



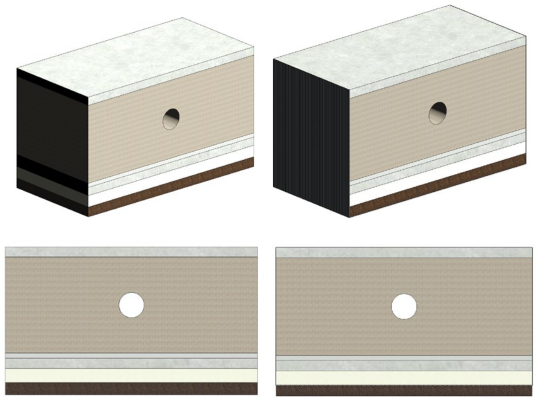
Infiltration Trench

Standalone family line-based

Category: structural frame

Layers:

- [opt]Permeable surface coverage
- Gravel layer 1
- Non-woven geotextile
- Gravel layer 2
- Sand filter
- Native soil
- [opt] perforated pipe in gravel layer 2
- [opt] filter fabric



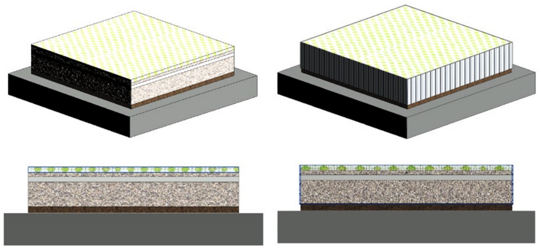
Permeable Pavement

Standalone family plane-based

Category: pavement

Layers:

- Surface
- Aggregate
- Geotextile
- Aggregate sub-base
- Native soil
- [opt] liner
- [opt] pipe



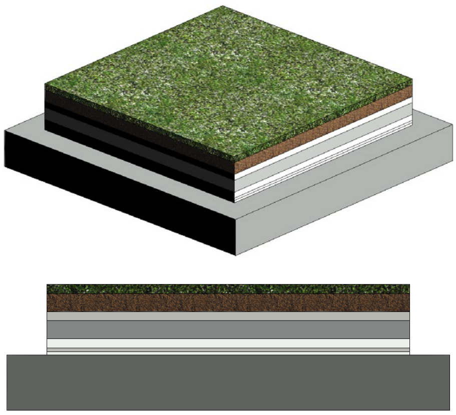
Green Roof

Standalone family plane-based

Category: pavement

Layers:

- Growing medium soil
- Filter
- Drainage
- Root barrier
- Waterproofing
- Roof support



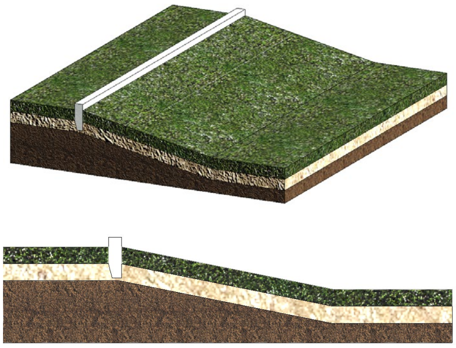
Filter Strip

Standalone family line-based

Category: Structural frame

Layers:

- Vegetation
- Growing medium
- Native soil



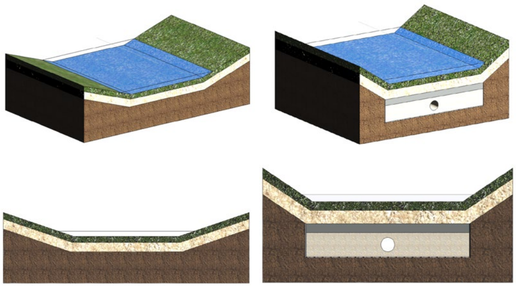
Grassed Swale

Standalone family line-based

Category: structural frame

Layers:

- Vegetation
- Growing medium
- [opt] Sand
- [opt] Gravel
- [opt] Perforated pipe
- [opt] Geotextile



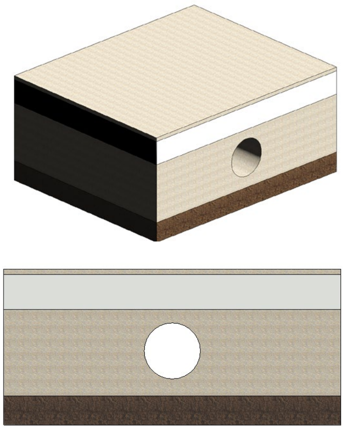
Filter Drain

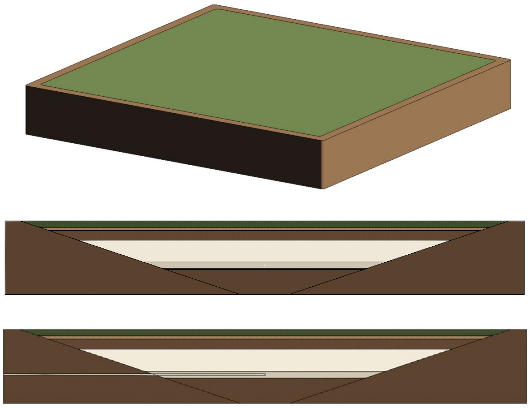
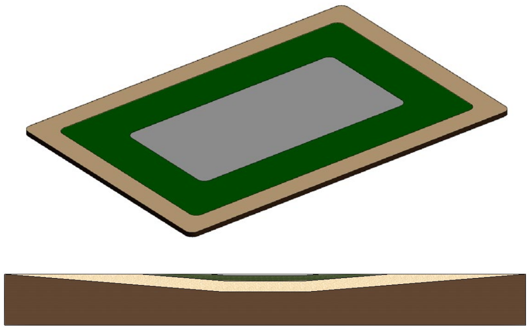
Standalone family line-based

Category: structural frame

Layers:

- Gravel 1
- Non woven geotextile
- Gravel 2
- Native soil
- [opt] perforated pipe
- [opt] impermeable liner



Rain garden	
Standalone family Category: pavement **Layers:** - Vegetation - Mulch - Bioretention soil - Sand - Aggregate - [opt] Geomembrane - Native Soil [opt] Perforated pipe in aggregate layer	
Wetland	
Standalone family Category: pavement **Layers:** - Water - Vegetation - Soil Media - [opt] Fabric liner - Native soil	

5.2 Requirements and Manual installation

The add-in is developed using C# and .NET Framework, supporting Revit 2023.1 version.

<u>Base requirements:</u>

- Revit 2023.1 version.
- Microsoft Office: Excel.

<u>Manual installation</u>

Copy addin files to Revit 2023 Addins folder: “C:\ProgramData\Autodesk\Revit\Addins\2023”

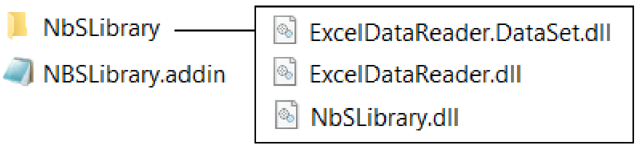


Figure 10. Add-in files.

5.3 First Execution

1. Open Revit. First time Revit is launched with the new add-in, an information message box appears about trusting the new installation. Click on *Cargar siempre/Load always*.

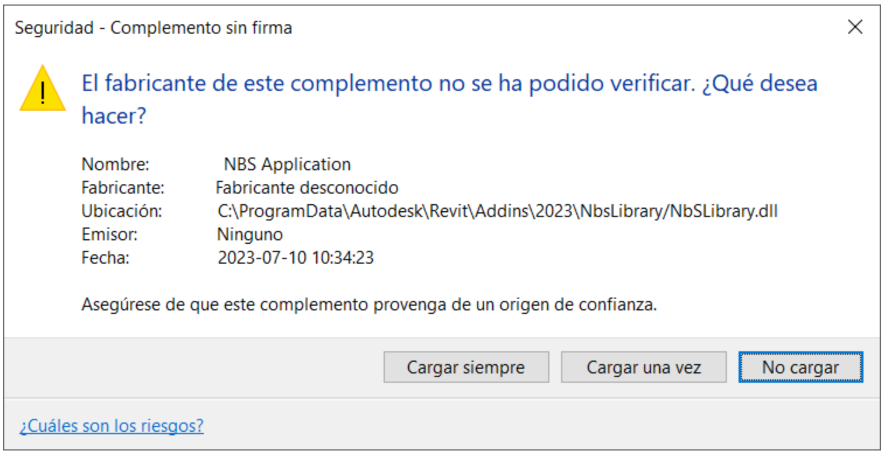


Figure 11. Splash message in the first execution.

2. It is necessary to have a project or a family opened to access to Revit commands. Open an existing project or create a new one. Commands ribbon is now visible. Activate NBS tab.

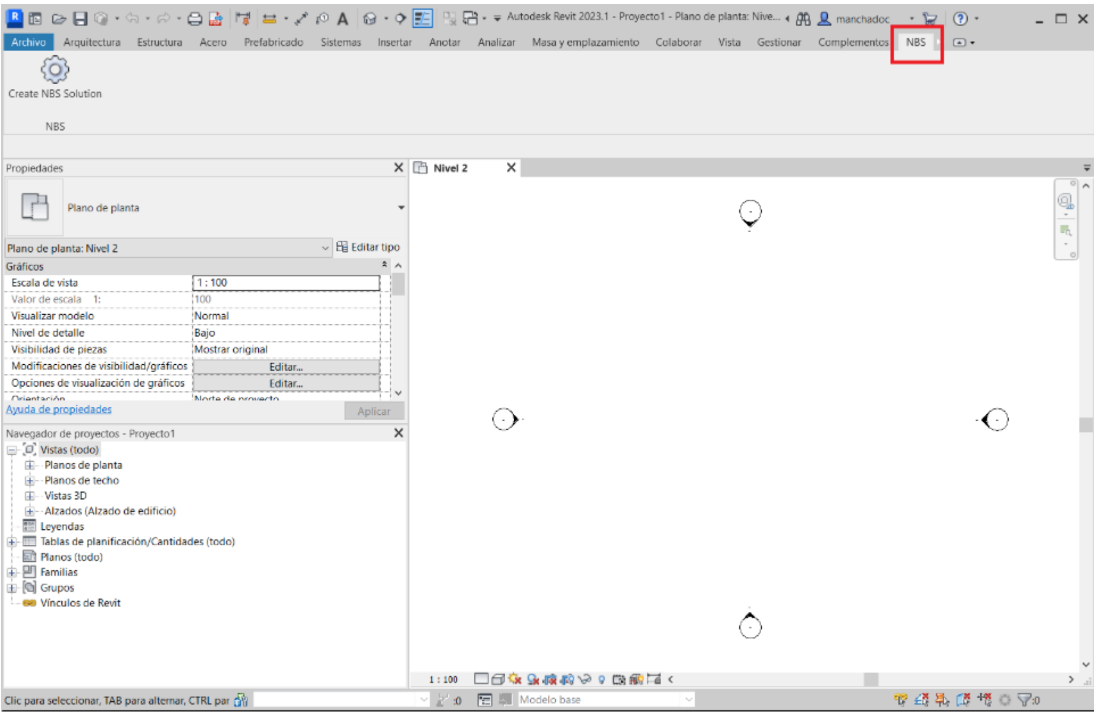


Figure 12. Initial Revit Screen. NBS tab activated.

3. Click on *Create NBS Solution* button. A new form dialog appears with the available NBS solutions. User steps:
    a. Select the Excel file with calculations by clicking on the ... button (number 1 on Figure 13).
    b. After selecting the Excel file, the dropdown list labelled with *Excel sheet name* offer the different existing sheets on the Excel file. Select the one with calculation results (number 2 on Figure 13).
    c. Select the folder that store the base BIM object files, by clicking on the ... button (number 3 on Figure 13).
    d. Select the NBS solution to generate by clicking on one of the NBS buttons (number 4 on Figure 13).

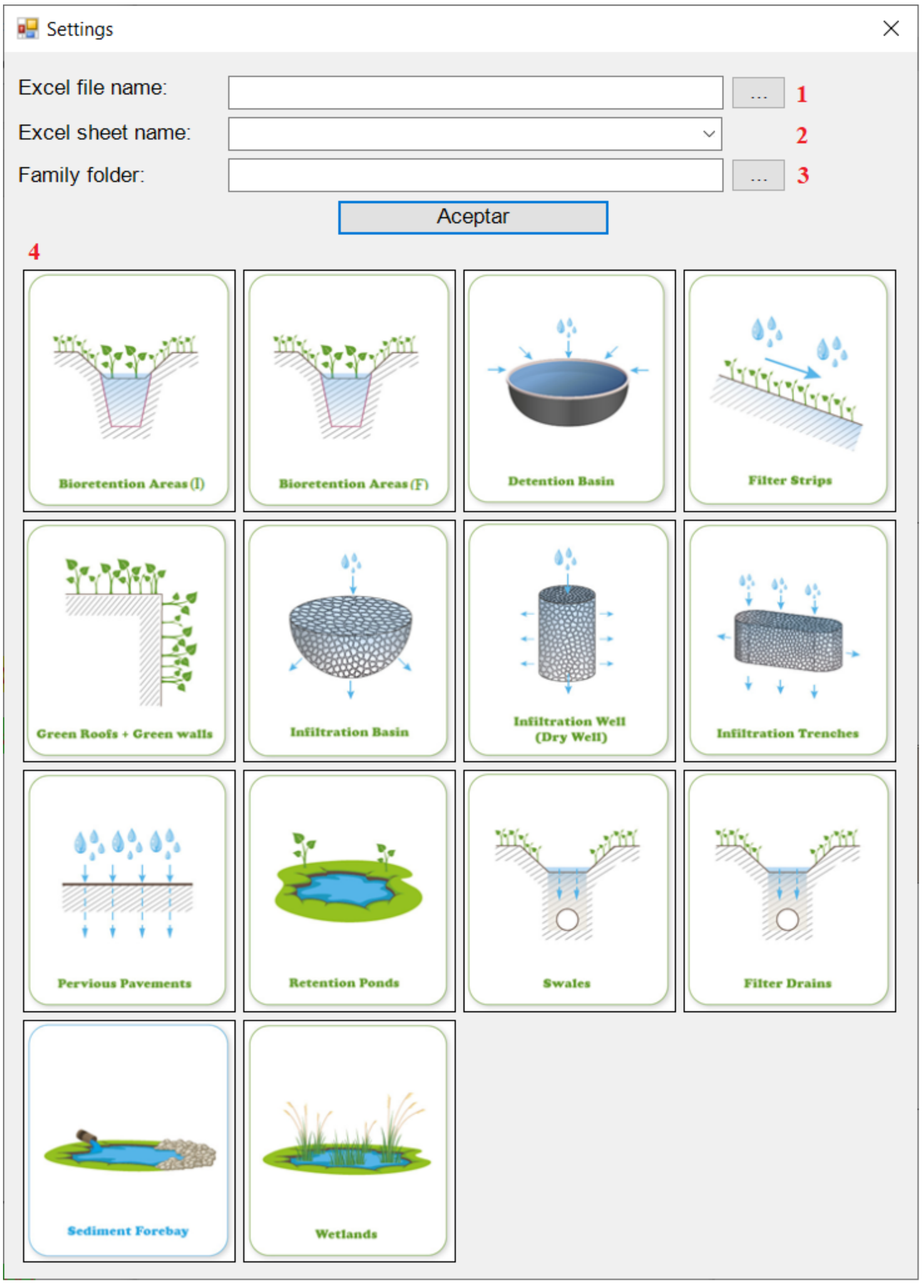


Figure 13. NBS Solutions catalogue.

4. Once the NBS is selected, a user transparent process starts:
    a. The plug-in opens the base BIM object for the selected NBS.
    b. The plug-in reads the calculated data for the selected NBS from the Excel calculations file.
    c. The NBS geometry is reconfigured and adapted according to calculated data.
    d. The associated parameters in the base BIM object are automatically updated with the read data (see in the next figures for example result).

    Both geometry and associated data is stored in a BIM 3D object ready to be loaded in any Revit project.

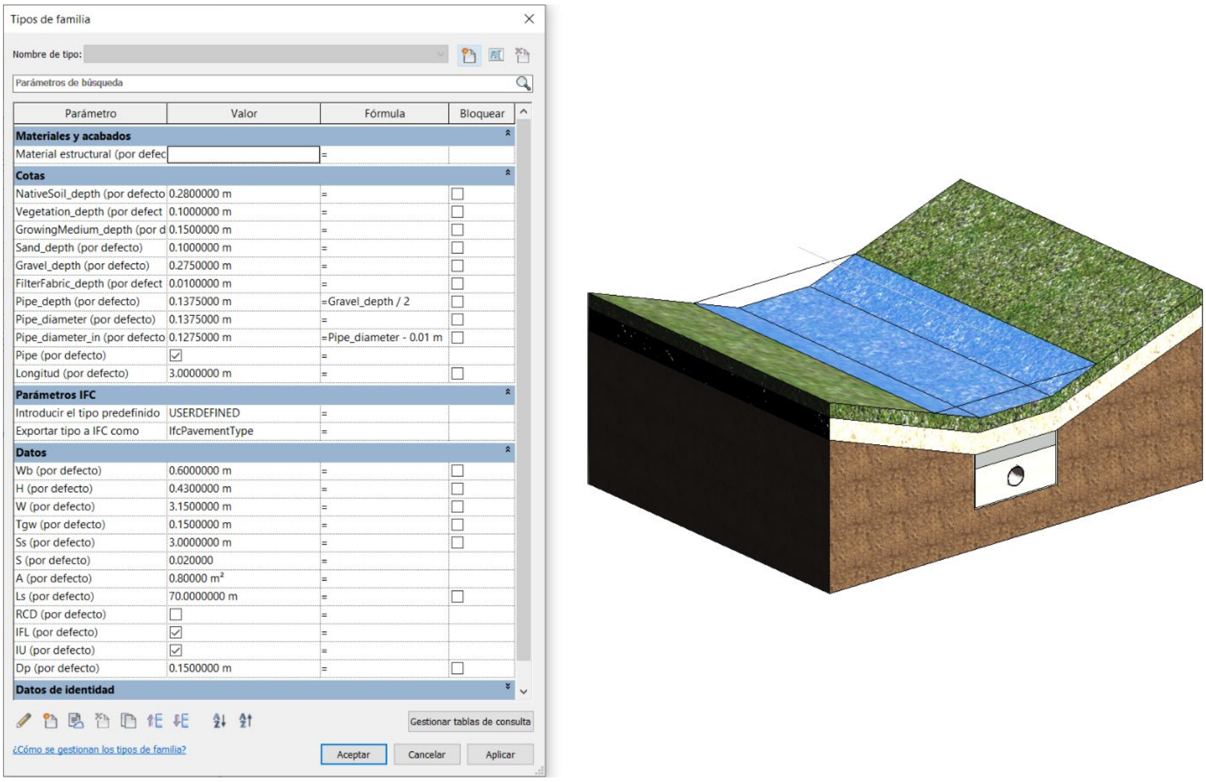


Figure 14. Grassed swale. Left: associated parameters. Right: geometry.

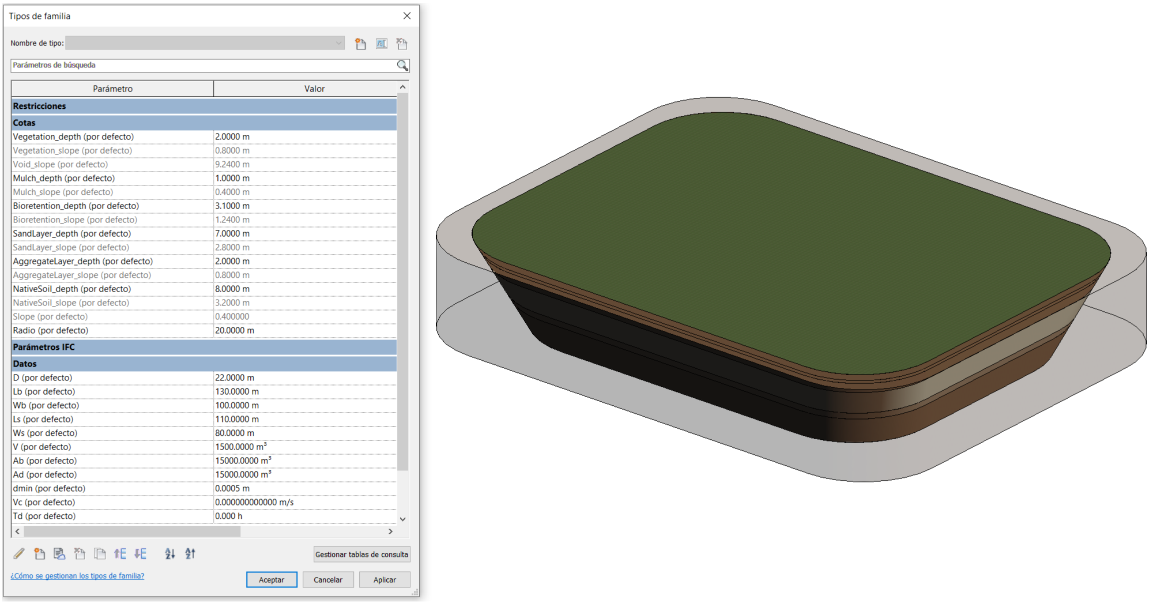


Figure 15. Bioretention area (transparent native soil). Left: associated parameters. Right, geometry.

5.4 Working with Excel and Revit simultaneously

It is possible to work with Excel calculations file and Revit families in a parallel way. User steps:

1. Open Excel calculations file and Revit.
2. Modify calculation settings for the desired NBS solution (see example with grassed swale in Figure 16).
3. Save Excel file.
4. Execute Revit plug-in, as explained in section 3.

This process (steps 2 to 4) can be executed as many times as the user wants to. Information is one-directional: NBS calculation only can be performed on the Excel file. Revit plug-in will read the results and will adapt NBS geometry and parameters according to them.

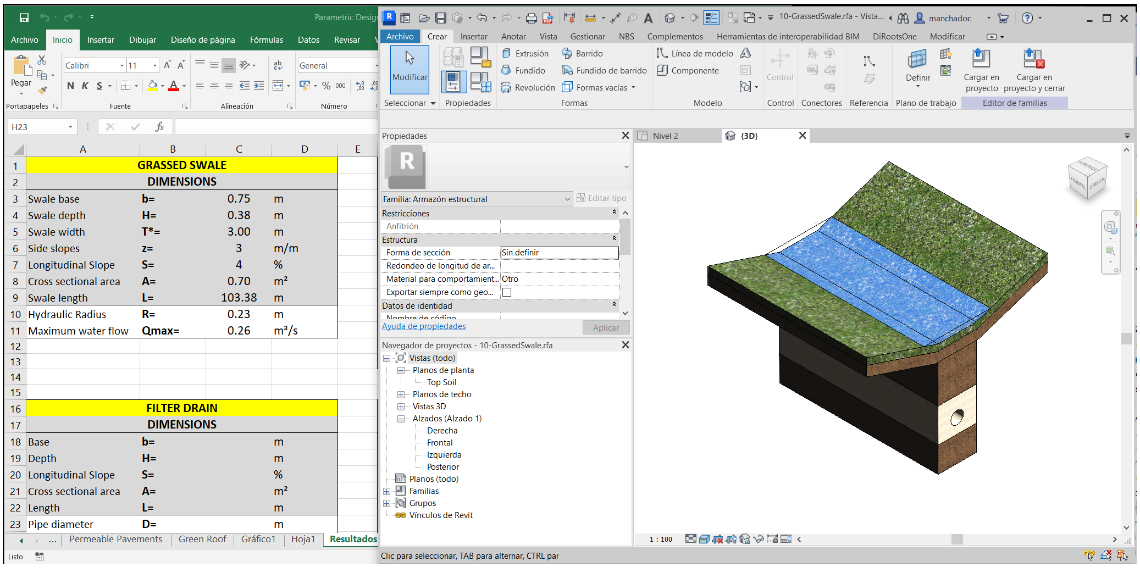


Figure 16. Excel calculations file and Revit working simultaneously.

5.5 NBS parametric objects on project examples

The images below show two different NBS line-based BIM objects after placing them on a existent surface. Those line-based BIM objects can adapt.

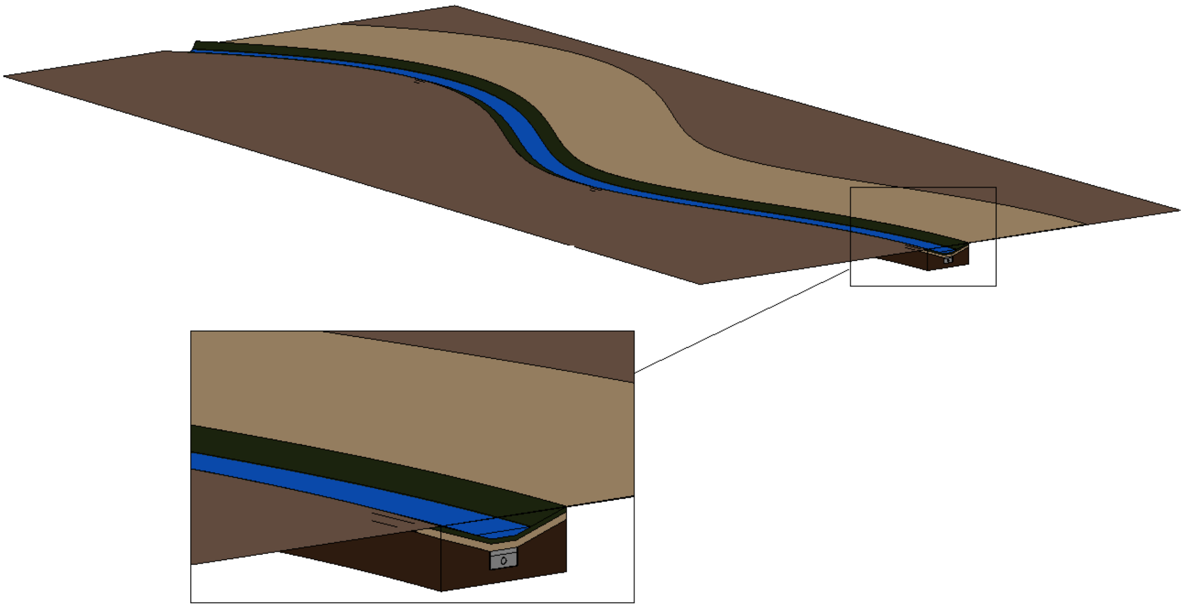


Figure 17. Grassed swale along a spline.

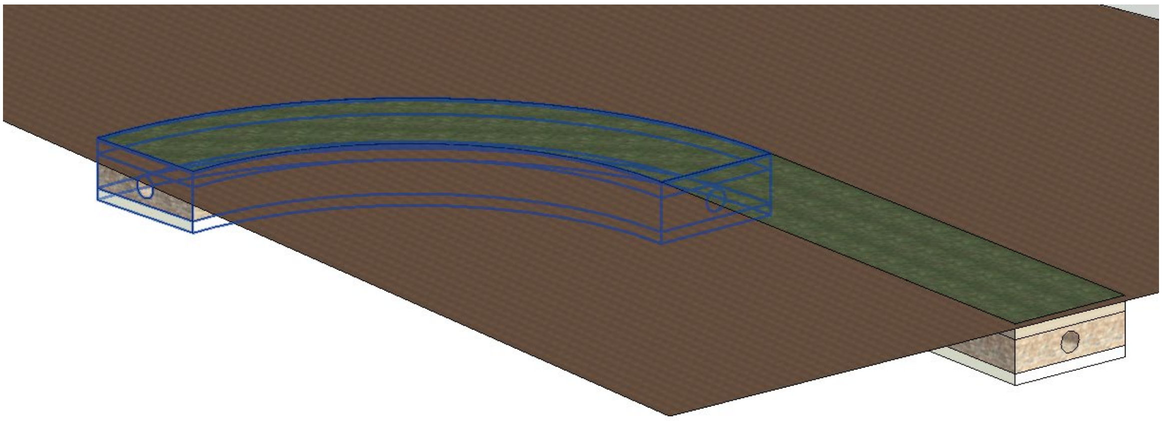


Figure 18. Filter drain along an arc and a line.

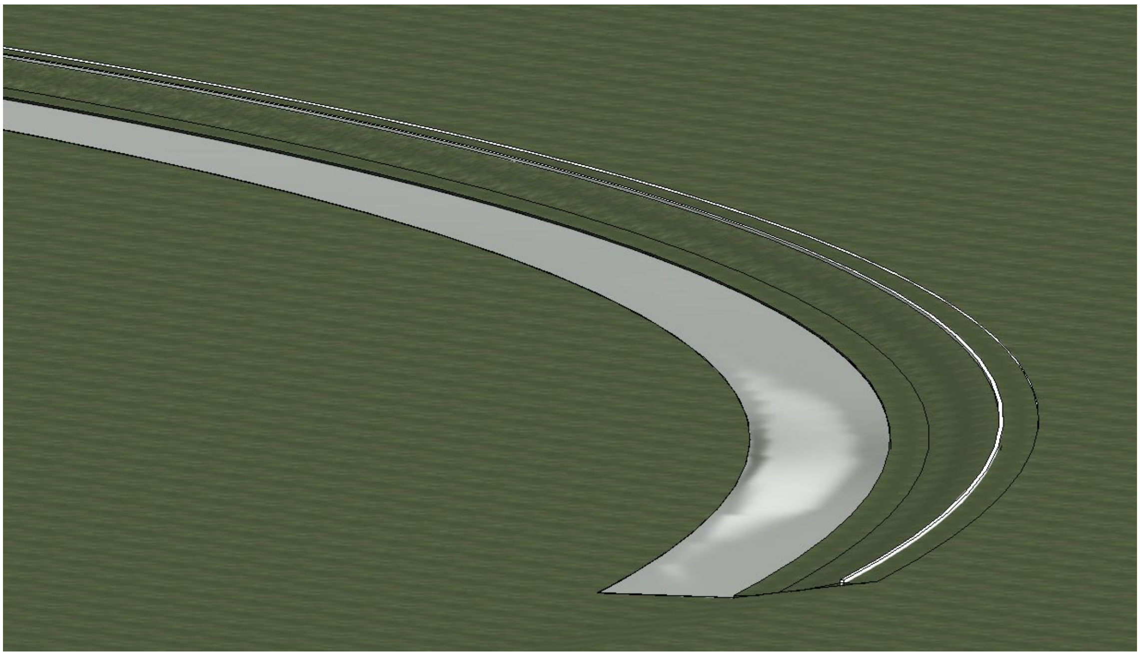


Figure 19. Filter strip along a platform.

6 Review of CECs removal in NBS

Main objective in WP3 is the development of a methodology for the design of enhanced hybrid sustainable urban drainage solutions, based on MCDA, considering, specially, climate change and urban development challenges (SO3). Regarding the capability of NBS or Sustainable Drainage Systems (SuDS) to mitigate trace element contaminant loads associated with urban and road runoff, UC has reviewed the existing scientific literacy related to the aforementioned techniques in order to take an initial picture to a deeply understanding of the potential cleaning capacity of each system and also the gaps to overcome along with the project duration and in future works.

This compilation (available also in Excel spreadsheet format in: D4RUNOFF - NBS Pollutant Removal Review-D4RUNOFF WP3.xlsx) is only for an understanding of the "state of the art" regarding pollutant removal in NBS (to complete the library) and also for an internal use (MCDA & Mitigation measurement).

6.1 Identification of Contaminants of Emerging Concern

In 2005, the European Commission funded the NORMAN project to promote a permanent network of reference laboratories and research centers, including academia, industry, standardization bodies, and NGOs[a]. Actually, NORMAN[b] is the acronym of "*Network of reference laboratories, research centers and related organizations for monitoring of emerging environmental substances*". According to NORMAN, emerging environmental substances or CEC´s are not necessarily new chemicals. They are substances that have often long been present in the environment but whose presence and significance are only now being elucidated. Furthermore, the definition of "**Emerging pollutants**" can be defined as pollutants that are currently not included in routine monitoring programmes at the European level and which may be candidates for future regulation, depending on research on their (eco)toxicity, potential health effects and public perception and on monitoring data regarding their occurrence in the various environmental compartments.

[a] Brack et al. (2017). Towards the review of the European Union Water Framework Directive: Recommendations for more efficient assessment and management of chemical contamination in European surface water resources. Sci Total Environ. 2017 January 15; 576: 720–737. doi: 10.1016/j.scitotenv.2016.10.104.

[b] https://www.norman-network.net/

Table 2. Correspondence between the D4RUNOFF categories and the NORMAN list.

D4RUNOFF INTERNAL CATEGORIES	CATEGORIES FROM NORMAN LIST INCLUDED
BIOCIDES & THEIR TRANSFORMATION PRODUCTS	Biocides (BIOCID) Persistent, mobile and toxic substances (PMT) Personal Care Products (PCP) Plant protection products (PPP) REACH chemical (REACH)
PERSONAL CARE PRODUCTS:	Personal Care Products (PCP) REACH chemical (REACH)
TYRE COMPOUNDS	REACH chemical (REACH)
INDUSTRIAL CHEMICAL	Flame retardants (FRET) Food Additives (FOODA) Food contact chemicals (FOODC) Indoor environment substances (INDOOR) Industrial Chemical (IND) Plastic additives (PLAST) REACH chemical (REACH) Surfactants (SURF)
PHARMACEUTICALS	Drugs of abuse (DOA) Human metabolites (HUME) Indoor environment substances (INDOOR) Persistent, mobile and toxic substances (PMT) Personal Care Products (PCP) Pharmaceuticals (PHARMA) REACH chemical (REACH) Smoke compounds (SMOKE)
FOSSIL FUEL AND COMBUSTION PRODUCTS	Industrial Chemical (IND) Per- and polyfluoroalkyl substances (PFAS) REACH chemical (REACH)
MICROPLASTICS	REACH chemical (REACH)

6.2 Review considerations

In tables from 3 to 14, a list of contaminants of emerging concern and the removal capacity tested in each drainage technique is categorized and listed.

Main factors to consider prior to utilize them are described below:

- The references indicated in the last column are listed at the end of this chapter.
- All data included is related to pilot or full scale, avoiding lab experiences.
- Search is mainly focus on runoff, stormwater, or rainwater, nevertheless in order to collect and merge all the available information related to CEC´s removal in NBS, information related to greywater or wastewater are being covering to request.
- Even the provided data are supported for 2 or 3 references, these are obtained in particular experiences considering different variables. Their purpose is only orientated and not have to be taken into consideration as fixed data.
- In case of simulation or decision-making process, UC team suggest for scientific personnel or technicians to go deep into the references in order to understand the set of variables or particularities to considerer into the research to understand or modify conditions to fit their needs.
- In case of field utilization for a real implementation, their removal capacity has to be matched though real sampling campaign.
- Regarding different variables detected in the reviewed scientific literacy, among other these are principal items:
  - Climatology.
  - Rainfall pattern or regimen.
  - Seasonality (winter /summer including temperature and sunlight changes along the year).
  - The hydraulic retention time into the NBS.
  - Soil type and composition (Canisteo silty clay loam, Mesocosm sand, mixed gravel substrates, vesuvianite, Zeolite and so on).
  - NBS constructive materials (including material for an enhanced retention capacity like wood filters, biochar, zeolites, sunlight-induced processes (with TiO_2) and so on).
  - Performance (specific design, alone or in a treatment train).
  - Kind of vegetation (*Juncus patens, Festuca California, Verbena lilacina "De la Mina", Echinops bannaticus, Brunnera macrophylla, Echinacea purpurea, Eutrochium purpureum, Rudbeckia hirta, Bromus inermis, Poa pratensis, Festuca arundinacea, Thymus)* and biological community *(Rhizobacteria, Endophytic rhizobium, Diaphorobacter nitroreductase, Chloroflexus sp., Pseudomonas sp, Stenotrophomonas sp*., and so on) involved.
  - The sampling campaign, duration, and procedure.
  - The selected analytic methodologies including GC-MS analysis, GD-FID, GC–ECD, ICP-MS, FPA-μFTIR, ATR-FTIR, Thermal decomposition coupled to GC-MS analysis, Nontarget analysis, Microscopy, Raman spectroscopy.

Categorization of the removal: Legend

Main verified references for calculating the removal capacity of the tested system are based on the differences between the inlet and the outlet pollutant concentration in water. Nevertheless, there are studies that use other data like the analysis of composite soil core samples or textural analysis of sediment samples (soil profile studios).

In some cases, author express the removal capacity in quantitative numerical percentages, while in other cases removal is categorized in qualitative terms. Some authors focus only on the pollutant elimination but other authors talk about the increasing concentration of the pollutant (based on a previous retention and accumulation in the system followed by a subsequence liberation).

In order to be able to classify the existing data, six categories are established: low, medium or high increase & low, medium or high decrease. It is also necessary to establish two classes depending on whether the bibliographic source is based on quantitative or qualitative data (Figure 20). Sometimes, the compound is trapped or retained in the NBS, but quantification it´s not possible. In such cases the legend allocated is “Not quantified”. In order to understand the relationship between the different NBS and the type of associated compounds whose degradation and/or accumulation has been tested in relevant environments in the literature, it is decided to mark with the label "Non-information found in the bibliography" to underline that there is a GAP in the knowledge regarding the whole chemical family.

QUALITATIVE DATA	
HIGH INCREASED	More than 60% increased
MEDIUM INCREASED	Among 40-60% increased concentration
LOW INCREASED	Less than 40% increased concentration
HIGH DECREASED	More than 60% decreased
MEDIUM DECREASED	Among 40-60% decreased concentration
LOW DECREASED	Less than 40% decreased concentration

QUANTITATIVE DATA	
HIGH INCREASED	More than 80% increased
MEDIUM INCREASED	Among 30-80% increased concentration
LOW INCREASED	Less than 30% increased concentration
HIGH DECREASED	More than 80% decreased
MEDIUM DECREASED	Among 30-80% decreased concentration
LOW DECREASED	Less than 30% decreased concentration

Figure 20. Legend of categorised CECs removal in NBS

6.3 Capacity of drainage system for pollutant removal according to bibliography

This compilation is available also in an Excel spreadsheet format named “D4RUNOFF - NBS Pollutant Removal Review-D4RUNOFF WP3.V2.xlsx”. In excel format, each compound is characterized by its name, the belonging family group and three identifiers for chemical substances including the “CAS Number”, the International Chemical Identifier (InChI) and

Simplified molecular-input line-entry system (SMILE). This format allows us to execute a quick search to answer questions like for instance, what kind of NBS are capable to remove pesticides at high rate? Where authors found diclofenac in water? or What it´s the diclofenac concentration tendency in each NBS?

Nevertheless, in this document there is a short version of the “D4RUNOFF - NBS Pollutant Removal Review-D4RUNOFF WP3.V2.xlsx” that includes the compound name, the family name, the CAS number, the reported removal capacity and the bibliographic reference. A Screenshot of the excel spreadsheet is showed in Figure 21.

	NBS	FAMILY	COMPOUND	CAS NUMBER	InChI Key	SMILES	REPORTED REMOVAL CAPACITY	REFERENCE
2	BIORETENTION AREAS							
3	Bioretention Areas	Pesticides & T.P.	N-methyl-alpha-phenyl-benzene-acetamide*	954-21-2	DIZKGJLRHOCMTP-UHFFFAOYSA-N	CNC(=O)C(C1=CC=CC=C1)C1=CC=CC=C1	LOW INCREASE	*Gu et al (2021)*
4	Bioretention Areas	Pesticides & T.P.	Cycluron*	2163-69-1	DQZCVNGCTZLGAQ-UHFFFAOYSA-N	CN(C)C(=O)NC1CCCCCCC1	LOW INCREASE	*Gu et al (2021)*
5	Bioretention Areas	Pesticides & T.P.	2-Methyl-4,6-dinitrophenol*	95713-52-3	NEPLBHLFDJOJGP-BYPYZUCNSA-N	C[C@H](NC1=CC(F)=C(C=C1[N+]([O-])=O	MEDIUM INCREASE	*Gu et al (2021)*
6	Bioretention Areas	Pesticides & T.P.	Carbendazim*	10605-21-7	TWFZGCMQGLPBSX-UHFFFAOYSA-N	COC(=O)NC1=NC2=CC=CC=C2N1	LOW INCREASE	*Gu et al (2021)*
7	Bioretention Areas	Pesticides & T.P.	3-Hydroxycarbofuran*	16655-82-6	RHSUJRQZTQNSLL-UHFFFAOYSA-N	CNC(=O)OC1=CC=CC2=C1OC(C)(C)C2O	HIGH DECREASE	*Gu et al (2021)*
8	Bioretention Areas	Pesticides & T.P.	Carbofuran*	1563-66-2	DUEPRVBVGDRKAG-UHFFFAOYSA-N	CNC(=O)OC1=CC=CC2=C1OC(C)(C)C2	HIGH DECREASE	*Gu et al (2021)*
9	Bioretention Areas	Pesticides & T.P.	Propoxur*	114-26-1	ISRUGXGCCGIOQO-UHFFFAOYSA-N	CNC(=O)OC1=CC=CC=C1OC(C)C	HIGH DECREASE	*Gu et al (2021)*
10	Bioretention Areas	Pesticides & T.P.	Methyl 5-hydroxy-2-benzimidazolecarbamate*	22769-68-2	UINGPWWYGSJYAY-UHFFFAOYSA-N	COC(=O)NC1=NC2=CC=C(O)C=C2N1	MEDIUM DECREASE	*Gu et al (2021)*
11	Bioretention Areas	Pesticides & T.P.	DEET*	134-62-3	MMOXZBCLCQITDF-UHFFFAOYSA-N	CCN(CC)C(=O)C1=CC=CC(C)=C1	MEDIUM DECREASE	*Gu et al (2021)*
12	Bioretention Areas	Pesticides & T.P.	Phthalic acid*	88-99-3	XNGIFLGASWRNHJ-UHFFFAOYSA-N	OC(=O)C1=CC=CC=C1C(O)=O	MEDIUM DECREASE	*Gu et al (2021)*
13	Bioretention Areas	Pesticides & T.P.	4-Dimethylamino-3,5-xylenol*	3096-70-6	GCWYXRHXGLFVFE-UHFFFAOYSA-N	CC1=CC(O)=CC(C)=C1N	HIGH DECREASE	*Gu et al (2021)*
14	Bioretention Areas	Personal Care Products	Pentyl salicylate*	2050-08-0	RANVDUNFZBMTBK-UHFFFAOYSA-N	CCCCCOC(=O)C1=C(O)C=CC=C1	LOW DECREASE	*Gu et al (2021)*
15	Bioretention Areas	Personal Care Products	(E)-beta-damascone*	35044-68-9	BGTBFNDXYDYBEY-UHFFFAOYSA-N	CC=CC(=O)C1=C(C)CCCC1(C)C	MEDIUM DECREASE	*Gu et al (2021)*
16	Bioretention Areas	Tyre Compounds						Non-information found in bibliography
17	Bioretention Areas	Industrial Chemical	Polychlorinated biphenyls (PCBs)				HIGH DECREASE	*Gilbreath et al (2019)*
18	Bioretention Areas	Industrial Chemical	3,3´- Dimethylbisphenol A*	1568-83-8	OJYIBEYSBXIQOP-UHFFFAOYSA-N	COC1=CC=C(C=C1)C(C)(C)C1=CC=C(OC)C	LOW INCREASE	*Gu et al (2021)*
19	Bioretention Areas	Industrial Chemical	Dibutyl (2E)-but-2-enedioate*	82807-35-0	JBSLOWBPDRZSMB-UHFFFAOYSA-N	CCCCOC(=O)C=CC(=O)OCCCC	LOW INCREASE	*Gu et al (2021)*
20	Bioretention Areas	Industrial Chemical	Geranyl acetate*	105-87-3	HIGQPQRQIQDZMP-DHZHZOJOSA-N	CC(C)=CCC\C(C)=C\COC(C)=O	MEDIUM INCREASE	*Gu et al (2021)*
21	Bioretention Areas	Industrial Chemical	N-(2-methylphenyl)-3-oxobutamide*	93-68-5	TVZIWRMELPWPPR-UHFFFAOYSA-N	CC1=CC=CC=C1NC(=O)CC(=O)C	LOW INCREASE	*Gu et al (2021)*
22	Bioretention Areas	Industrial Chemical	Prop-2-en-1-yl(3-methylbutoxy)acetate*	67634-00-8	XCWPXUNHSPOFGV-UHFFFAOYSA-N	CC(C)CCOCC(=O)OCC=C	MEDIUM INCREASE	*Gu et al (2021)*
23	Bioretention Areas	Industrial Chemical	2,4-dinitroaniline*	97-02-9	LXQOQPGNCGEELI-UHFFFAOYSA-N	NC1=C(C=C(C=C1)[N+]([O-])=O)[N+]([O-	LOW INCREASE	*Gu et al (2021)*
24	Bioretention Areas	Industrial Chemical	Benzyl methacrylate*	2495-37-6	AOJOEFVRHOZDFN-UHFFFAOYSA-N	CC(=C)C(=O)OCC1=CC=CC=C1	LOW INCREASE	*Gu et al (2021)*
25	Bioretention Areas	Industrial Chemical	Allyl methacrylate*	96-05-9	FBCQUCJYYPMKRO-UHFFFAOYSA-N	CC(=C)C(=O)OCC=C	LOW INCREASE	*Gu et al (2021)*

Removal Categorisation

Figure 21. “D4RUNOFF - NBS Pollutant Removal Review-D4RUNOFF WP3.V2.xlsx” screenshot.

6.3.1 Bioretention Areas

Table 3. Reported removal capacity in Bioretention areas

FAMILY	COMPOUND	CAS NUMBER	REPORTED REMOVAL CAPACITY	REF.
Biocides & T.P.	2-METHYL-4,6-DINITROPHENOL	95713-52-3	MEDIUM INCREASE	1
Biocides & T.P.	3-HYDROXYCARBOFURAN	16655-82-6	HIGH DECREASE	1
Biocides & T.P.	4-DIMETHYLAMINO-3,5-XYLENOL	3096-70-6	HIGH DECREASE	1
Biocides & T.P.	CARBENDAZIM	10605-21-7	LOW INCREASE	1
Biocides & T.P.	CARBOFURAN	1563-66-2	HIGH DECREASE	1
Biocides & T.P.	CYCLURON	2163-69-1	LOW INCREASE	1
Biocides & T.P.	DEET	134-62-3	MEDIUM DECREASE	1

Biocides & T.P.	METHYL 5-HYDROXY-2-BENZIMIDAZOLECARBAMATE	22769-68-2	MEDIUM DECREASE	[1]
Biocides & T.P.	N-METHYL-ALPHA-PHENYL-BENZENE-ACETAMIDE	954-21-2	LOW INCREASE	[1]
Biocides & T.P.	PHTHALIC ACID	88-99-3	MEDIUM DECREASE	[1]
Biocides & T.P.	PROPOXUR	114-26-1	HIGH DECREASE	[1]
Personal Care Products	(E)-BETA-DAMASCONE	35044-68-9	MEDIUM DECREASE	[1]
Personal Care Products	PENTYL SALICYLATE	2050-08-0	LOW DECREASE	[1]
Tyre Compounds	Non-information found in bibliography			
Industrial Chemical	1,2,4-TRIMETHYLBENZENE	95-63-6	MEDIUM DECREASE	[1]
Industrial Chemical	2,3,4 - TRIMETHYLCYCLOPENT-2-EN-1-ONE	28790-86-5	MEDIUM DECREASE	[1]
Industrial Chemical	2,4-DINITROANILINE	97-02-9	LOW INCREASE	[1]
Industrial Chemical	2-HYDROXY-1-(4-(2-HYDROXYETHOXY) PHENYL)-2-METHYLPROPAN-1-ONE	106797-53-9	LOW DECREASE	[1]
Industrial Chemical	3,3´- DIMETHYL BISPHENOL A	1568-83-8	LOW INCREASE	[1]
Industrial Chemical	ALLYL METHACRYLATE	96-05-9	LOW INCREASE	[1]
Industrial Chemical	BENZYL METHACRYLATE	2495-37-6	LOW INCREASE	[1]
Industrial Chemical	DIBUTYL (2E)-BUT-2-ENEDIOATE	82807-35-0	LOW INCREASE	[1]

Industrial Chemical	GERANYL ACETATE	105-87-3	MEDIUM INCREASE	1
Industrial Chemical	N-(2-METHYLPHENYL)-3-OXOBUTAMIDE	1266615-59-1	LOW INCREASE	1
Industrial Chemical	POLYCHLORINATED BIPHENYLS (PCBS)	1336-36-3	HIGH DECREASE	1
Industrial Chemical	PROP-2-EN-1-YL(3-METHYLBUTOXY) ACETATE	67634-00-8	MEDIUM INCREASE	1
Industrial Chemical	PROPANEDIOIC ACID, PHENYL-, DIETHYL ESTER	83-13-6	LOW DECREASE	1
Pharmaceutical	(IS)- (-)-CAMPHOR	76-22-2	HIGH DECREASE	1
Pharmaceutical	2´(OCTYLOXY)-ACETANILIDE	55792-61-5	HIGH DECREASE	1
Pharmaceutical	2H-ISOINDOLE-2-CARBOXYLIC ACID, 1,3-DIHYDRO-1,3-DIOXO-, ETHYL ESTER	22509-74-6	HIGH DECREASE	1
Pharmaceutical	4´-AMINOPROPIOPHENONE	70-69-9	HIGH DECREASE	1
Pharmaceutical	6-AMINOCAPROIC ACID	60-32-2	LOW INCREASE	1
Pharmaceutical	ALPRENOLOL	13655-52-2	HIGH DECREASE	1
Pharmaceutical	ARECOLINE	63-75-2	LOW INCREASE	1
Pharmaceutical	ASPYRONE	17398-00-4	LOW DECREASE	1
Pharmaceutical	BAMETHAN	3703-79-5	HIGH DECREASE	1
Pharmaceutical	DIETHYLSTILBESTROL	56-53-1	LOW INCREASE	1
Pharmaceutical	EPITIOSTANOL	2363-58-8	LOW INCREASE	1
Pharmaceutical	GEMFIBROZIL	25812-30-0	LOW DECREASE	1
Pharmaceutical	LIMONENE DIOXIDE	96-08-2	LOW INCREASE	1
Pharmaceutical	METHANONE, CYCLOHEXYL(3,4-DIHYDROXY-5-NITROPHENYL)	254912-15-7	HIGH DECREASE	1
Pharmaceutical	NONANEDIOIC ACID	123-99-9	MEDIUM DECREASE	1

Pharmaceutical	PRILOCAINE	721-50-6	LOW INCREASE	1
Pharmaceutical	TROPINE	120-29-6	MEDIUM INCREASE	1
Pharmaceutical	VALPROMIDE	2430-27-5	MEDIUM INCREASE	1
Pharmaceutical	VENLAFAXINE	93413-69-5	HIGH DECREASE	1
Fossil fuel and combustion products	Σ POLYAROMATIC HYDROCARBONS	-	HIGH DECREASE	2, 3, 4
Microplastics	-	-	HIGH DECREASE	2,5,6, 7

6.3.2 Detention Basins

Table 4. Reported removal capacity in Detention Basin

FAMILY	COMPOUND	CAS NUMBER	REPORTED REMOVAL CAPACITY	REF.
Biocides & T.P.	2,4-MCPA	94-74-6	MEDIUM DECREASE	8
Biocides & T.P.	AMONIUM GLYPHOSATE	114370-14-8	MEDIUM DECREASE	8
Biocides & T.P.	AMPA	74341-63-2	MEDIUM INCREASE	8
Biocides & T.P.	ATRAZINE	1912-24-9	No proven evidences	8
Biocides & T.P.	CARBENZADIM	10605-21-7	LOW INCREASE	8
Biocides & T.P.	CHLORFENVINPHOS	470-90-6	No proven evidences	8
Biocides & T.P.	CHLORPYRIFOS	2921-88-2	No proven evidences	8
Biocides & T.P.	DIURION	330-54-1	MEDIUM INCREASE	8
Biocides & T.P.	GLYPHOSATE	1071-83-6	MEDIUM DECREASE	8
Biocides & T.P.	ISODRIN	465-73-6	MEDIUM DECREASE	8

Biocides & T.P.	MECOPROP	93-65-2	HIGH DECREASE	8
Personal Care Products	Non-information found in bibliography			
Tyre Compounds	Tyre compound (SBS, Bitumen, Tyre)	-	Retained in sediments (not quantified)	9
Industrial Chemical	4-NONYLPHENOL	104-40-5	MEDIUM DECREASE	8
Industrial Chemical	4-TERT-OCTYLPHENOL	140-66-9	MEDIUM DECREASE	8
Industrial Chemical	NONYLPHENOL-DI-ETHOXYLATE	1356927-15-5	MEDIUM DECREASE	8
Industrial Chemical	NONYLPHENOL-MONO-ETHOXYLATE	104-35-8	MEDIUM DECREASE	8
Industrial Chemical	OCTYLPHENOL-DI-ETHOXYLATE	9002-93-1	MEDIUM DECREASE	8
Industrial Chemical	POLYBROMINATE DIPHENYL ETHER (BDE100)	189084-64-8	MEDIUM DECREASE	8
Industrial Chemical	POLYBROMINATE DIPHENYL ETHER (BDE153)	68631-49-2	HIGH DECREASE	8
Industrial Chemical	POLYBROMINATE DIPHENYL ETHER (BDE183)	207122-16-5	HIGH DECREASE	8
Industrial Chemical	POLYBROMINATE DIPHENYL ETHER (BDE209)	1163-19-5	MEDIUM DECREASE	8
Industrial Chemical	POLYBROMINATE DIPHENYL ETHER (BDE28)	41318-75-6	HIGH DECREASE	8
Pharmaceutical	Non-information found in bibliography			

Fossil fuel and combustion products	POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)	-	MEDIUM DECREASE	10,11
Microplastics			Retained in sediments (not quantified)	9

6.3.3 Filter Strips

Table 5. Reported removal capacity in Filter Strips

FAMILY	COMPOUND	CAS NUMBER	REPORTED REMOVAL CAPACITY	REF.
Biocides & T.P.	2,4-D	94-75-7	MEDIUM DECREASE	12
Biocides & T.P.	ACETOCHLOR	34256-82-1	HIGH DECREASE	13, 14
Biocides & T.P.	ALACHLOR	15972-60-8	MEDIUM DECREASE	12
Biocides & T.P.	ATRAZINE	1912-24-9	HIGH DECREASE	13,14,5
Biocides & T.P.	BIFENOX	42576-02-3	HIGH DECREASE	12
Biocides & T.P.	CHLORPYRIFOS	2921-88-2	HIGH DECREASE	13,15
Biocides & T.P.	CYANAZINE	21725-46-2	MEDIUM DECREASE	13
Biocides & T.P.	DEISOPROPYLATRAZINE	1007-28-9	MEDIUM DECREASE	12
Biocides & T.P.	DESETHYLATRAZINE	6190-65-4	MEDIUM DECREASE	12
Biocides & T.P.	DICAMBA	1918-00-9	HIGH DECREASE	15
Biocides & T.P.	DICHLORPROP	120-36-5	HIGH DECREASE	15
Biocides & T.P.	DIFLUFENICAN	83164-33-4	HIGH DECREASE	12
Biocides & T.P.	FENITROTHION	122-14-5	HIGH DECREASE	15
Biocides & T.P.	FLUOMETURON	2164-17-2	MEDIUM DECREASE	12
Biocides & T.P.	ISOPROTURON	34123-59-6	MEDIUM DECREASE	12
Biocides & T.P.	ISOXABEN	82558-50-7	MEDIUM DECREASE	12

Biocides & T.P.	MCPA	94-74-6	HIGH DECREASE	15
Biocides & T.P.	MECOPROP	93-65-2	HIGH DECREASE	15
Biocides & T.P.	METOLACHLOR	87392-12-9	HIGH DECREASE	13,14
Biocides & T.P.	METRIBUZIN	21087-64-9	MEDIUM DECREASE	12
Biocides & T.P.	METSULFURON	79510-48-8	MEDIUM DECREASE	12
Biocides & T.P.	NORFLURAZON	27314-13-2	MEDIUM DECREASE	12
Biocides & T.P.	SIMAZINE	122-34-9	MEDIUM DECREASE	15
Biocides & T.P.	TRIFLURALIN	1582-09-8	HIGH DECREASE	12
Personal Care Products	Non-information found in bibliography			
Tyre Compounds	Non-information found in bibliography			
Industrial Chemical	ALKYLPHENOL (4-TERT-OCTYLPHENOL)	140-66-9	HIGH DECREASE	16
Industrial Chemical	ALKYLPHENOL (NONYLPHENOL DIETHOXYLATE)	20427-84-3	LOW DECREASE	16
Industrial Chemical	ALKYLPHENOL (NONYLPHENOL MONOETHOXYLATE)	104-35-8	MEDIUM DECREASE	16
Industrial Chemical	ALKYLPHENOL (OCTYLPHENOL DIETHOXYLATE)	9002-93-1	MEDIUM DECREASE	16
Industrial Chemical	ALKYLPHENOL (OCTYLPHENOL MONOETHOXYLATE)	51437-89-9	MEDIUM DECREASE	16
Industrial Chemical	BISPHENOL A	80-05-7	HIGH DECREASE	16
Industrial Chemical	PHTHALATES (BIS(2-ETHYLHEXYL) PHTHALATE)	117-81-7	MEDIUM DECREASE	16
Industrial Chemical	PHTHALATES (DIBUTYL PHTHALATE)	84-74-2	MEDIUM DECREASE	16

Industrial Chemical	PHTHALATES (DIISOBUTYL PHTHALATE)	84-69-5	MEDIUM DECREASE	16
Industrial Chemical	PHTHALATES (DIMETHYL PHTHALATE)	131-11-3	LOW DECREASE	16
Industrial Chemical	PHTHALATES (DINONYL PHTHALATE)	84-76-4	HIGH DECREASE	16
Pharmaceutical	Non-information found in bibliography			
Fossil fuel and combustion products	PAH (PHENANTHRENE)	85-01-8	HIGH DECREASE	16
Fossil fuel and combustion products	PAH ((BENZO(B)FLUORANTHENE)	205-99-2	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (1-METHYL NAPHTHALENE)	90-12-0	MEDIUM DECREASE	16
Fossil fuel and combustion products	PAH (2-METHYL NAPHTHALENE)	91-57-6	MEDIUM DECREASE	16
Fossil fuel and combustion products	PAH (ACENAPHTHENE)	83-32-9	MEDIUM DECREASE	16
Fossil fuel and combustion products	PAH (ACENAPHTHYLENE)	208-96-8	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (ANTHRACENE)	120-12-7	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (BENZO (G, H, I) PERYLENE)	191-24-2	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (BENZO(A)ANTHRACENE)	200-280-6	HIGH DECREASE	16

Fossil fuel and combustion products	PAH (BENZO(A)PYRENE)	50-32-8	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (BENZO(K)FLUORANTHENE)	207-08-9	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (CHRYSENE)	218-01-9	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (CORONONE)	191-07-1	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (DIBENZO (A, H) ANTHRACENE)	53-70-3	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (FLUORANTHENE)	206-44-0	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (FLUORENE)	86-73-7	MEDIUM DECREASE	16
Fossil fuel and combustion products	PAH (INDENO(1,2,3-CD) PYRENE)	193-39-5	HIGH DECREASE	16
Fossil fuel and combustion products	PAH (NAPHTHALENE)	91-20-3	MEDIUM DECREASE	16
Fossil fuel and combustion products	PAH (PYRENE)	129-00-0	HIGH DECREASE	16
Fossil fuel and combustion products	TOTAL PETROLEUM HYDROCARBONS	-	MEDIUM DECREASE	16
Fossil fuel and combustion products	Σ 16 PAHS	-	HIGH DECREASE	16
Microplastics	Non-information found in bibliography			

6.3.4 Green Roofs and Facades

Table 6. Reported removal capacity in Green Roof and Façade

FAMILY	COMPOUND	CAS NUMBER	REPORTED REMOVAL CAPACITY	REF.
Biocides & T.P.	DIETHYLTOLUAMIDE (DEET)	134-62-3	LOW DECREASE	17
Personal Care Products	OXYBENZONE	131-57-7	HIGH DECREASE	17
Personal Care Products	PROPYLENE GLYCOL (PG)	57-55-6	HIGH DECREASE	18
Personal Care Products	SODIUM DO-DECYL SULPHATE (SDS)	151-21-3	HIGH DECREASE	18
Personal Care Products	TRI METHYL AMINE (TMA)	75-50-3	HIGH DECREASE	18
Personal Care Products	TRICLOSAN	3380-34-5	HIGH DECREASE	17
Tyre Compounds	Non-information found in bibliography			
Industrial Chemical	BISPHENOL A (BPA)	80-05-7	MEDIUM DECREASE	17
Industrial Chemical	NONYLPHENOL	104-40-5	HIGH DECREASE	17
Pharmaceutical	ACETAMINOPHEN	103-90-2	HIGH DECREASE	17
Fossil fuel and combustion products	Non-information found in bibliography			
Microplastics	Non-information found in bibliography			

6.3.5 Infiltration Systems

The parametric library includes three techniques that involves the infiltration of runoff water into the groundwater for aquifer recharged. These techniques are:

- **INFILTRATION BASIN**
- **DRY WELL**
- **INFILTRATION TRENCH**

Regarding the pollutant removal capacity of these systems for cleaning water as an output to recharge the aquifer, a risk assessment should be undertaken before using Infiltration components in order to understand the water quality in terms of chemical composition and quantity[a]. In fact, some results suggest that for example using dry wells to infiltrate stormwater would pose minimal risk to groundwater quality when proper pretreatment is employed, and source water does not contain potentially mobile groundwater contaminants[b]. This could be possible due to the fact that dry wells are specified for infiltrate uncontaminated runoff from roofs and even in this case, a pre-treatment is highly recommended. Consequently, to be extremely environmentally safe two considerations are, from our standpoint, mandatory:

I. Understand "infiltration techniques" as the end of a treatment system. Other SuDS techniques where particles and dissolved pollutants could be trapped or degraded (eliminated) before water infiltration occurs is the key of success.
II. Water quality control in the "infiltration system" inlet for a long-term historical database of pollutant quantity.

Attending to these previous considerations, UC will not exhibit the removal tendency. Nevertheless, in order to shed light into the subject, next tables show the compounds founded into the bibliography and the references.

[a] https://www.susdrain.org/delivering-suds/using-suds/suds-components/infiltration/infiltration.html

[b] Edwars, E.C., Nelson, C., Harter, T., Bowles, C., Li. Xue, Lock, B., Fogg, G.E., Washburn, B.S. Potential effects on groundwater quality associated with infiltrating stormwater through dry wells for aquifer recharge". J. Contam. Hydrol. 246 (2022) 103964.

6.3.5.1 Infiltration basin

Table 7. Reported pollutants in Infiltration basin

FAMILY	COMPOUND	CAS NUMBER	REF.
Biocides & T.P.	2,6-DICHLOROBENZAMIDE (BAM)	2008-58-4	19,20
Biocides & T.P.	ATRAZINE	1912-24-9	19,20
Biocides & T.P.	ATRAZINE-DESETHYL	6190-65-4	20
Biocides & T.P.	BROMACIL	314-40-9	19,20
Biocides & T.P.	CARBENDAZIM	10605-21-7	19,20
Biocides & T.P.	DEET	134-62-3	19,20
Biocides & T.P.	DEETHYLATRAZINE (DEA)	6190-65-4	19
Biocides & T.P.	DIURON	330-54-1	19,20
Biocides & T.P.	ETHIDIMURON	30043-49-3	20
Biocides & T.P.	FLUOPYRAM	658066-35-4	19,20
Biocides & T.P.	HEXACINONE	51235-04-2	19,20
Biocides & T.P.	IMIDACLOPRID	138261-41-3	19,20
Biocides & T.P.	ISOPROTURON	34123-59-6	20
Biocides & T.P.	METOLACHLOR	51218-45-2	19,20
Biocides & T.P.	PROPICONAZOLE	60207-90-1	20
Biocides & T.P.	PROPYZAMIDE	23950-58-5	20
Biocides & T.P.	SIMAZINE	122-34-9	19
Personal Care Products	Non-information found in bibliography		
Tyre Compounds	Non-information found in bibliography		
Industrial Chemical	Non-information found in bibliography		
Pharmaceutical	CARBAMAZEPINE	298-46-4	19

Pharmaceutical	COTININE	486-56-6	21
Pharmaceutical	DICLOFENACO	15307-86-5	19
Pharmaceutical	LAMOTRIGINE	84057-84-1	19
Pharmaceutical	NICOTINE	54-11-5	21
Pharmaceutical	SULFAMETHOXAZOLE	723-46-6	19
Fossil fuel and combustion products	Non-information found in bibliography		
Microplastics	Non-information found in bibliography		

6.3.5.2 Dry well

Table 8. Reported pollutants in Dry Well

FAMILY	COMPOUND	CAS NUMBER	REF.
Biocides & T.P.	BIFENTHRIN	82657-04-3	22
Biocides & T.P.	FIPRONIL	120068-37-3	22
Biocides & T.P.	IMIDACLOPRID	138261-41-3	22
Personal Care Products	Non-information found in bibliography		
Tyre Compounds	Non-information found in bibliography		
Industrial Chemical	BENZO(A)PYRENE	50-32-8	22
Industrial Chemical	NAPHTHALENE	91-20-3	22
Pharmaceutical	Non-information found in bibliography		
Fossil fuel and combustion products	Non-information found in bibliography		
Microplastics	Non-information found in bibliography		

6.3.5.3 Infiltration trenches

Table 9. Reported pollutants in Infiltration Trenches

FAMILY	COMPOUND	CAS NUMBER	REF.
Biocides & T.P.	Non-information found in bibliography		
Personal Care Products	2-PHENYL-5-BENZIMIDAZOLESULFONIC ACID	27503-81-7	23
Tyre Compounds	Non-information found in bibliography		
Industrial Chemical	Non-information found in bibliography		
Pharmaceutical	AMISULPRIDE	53583-79-2	23
Pharmaceutical	ATENOLOL	29122-68-7	23
Pharmaceutical	AZITHROMYCIN DIHYDRATE	117772-70-0	23
Pharmaceutical	BISOPROLOL	66722-44-9	23
Pharmaceutical	CARBAMAZEPINE	298-46-4	23
Pharmaceutical	CARBAMAZEPINE 10.11 EPOXIDE	36507-30-9	23
Pharmaceutical	CETIRIZINE	83881-51-0	23
Pharmaceutical	CITALOPRAM	59729-33-8	23
Pharmaceutical	CLARITHROMYCIN	81103-11-9	23
Pharmaceutical	CLIMBAZOLE	38083-17-9	23
Pharmaceutical	CLOPIDOGREL	113665-84-2	23
Pharmaceutical	DICLOFENAC	15307-86-5	23
Pharmaceutical	EDDP	31161-17-8	23
Pharmaceutical	FENOFIBRIC ACID	42017-89-0	23
Pharmaceutical	FLECAINIDE	54143-55-4	23
Pharmaceutical	FLUCONAZOLE	86386-73-4	23
Pharmaceutical	GABAPENTIN	60142-96-3	23

Pharmaceutical	IOPROMIDE	73334-07-3	23
Pharmaceutical	IRBESARTAN	138402-11-6	23
Pharmaceutical	KETOPROFEN	22071-15-4	23
Pharmaceutical	LAMOTRIGINE	84057-84-1	23
Pharmaceutical	LEVOFLOXACIN	100986-85-4	23
Pharmaceutical	LOSARTAN	114798-26-4	23
Pharmaceutical	METHAMPHETAMINE	537-46-2	23
Pharmaceutical	METOPROLOL	37350-58-6	23
Pharmaceutical	METOPROLOL ACID	56392-14-4	23
Pharmaceutical	NIFLUMIC ACID	4394-00-7	23
Pharmaceutical	OLMESARTAN	144689-63-4	23
Pharmaceutical	SITAGLIPTIN	486460-32-6	23
Pharmaceutical	SOTALOL	3930-20-9	23
Pharmaceutical	SULPIRIDE	15676-16-1	23
Pharmaceutical	TELMISARTAN	144701-48-4	23
Pharmaceutical	TRAMADOL	27203-92-5	23
Pharmaceutical	VALSARTAN	137862-53-4	23
Pharmaceutical	VENLAFAXINE	93413-69-5	23
Fossil fuel and combustion products	Non-information found in bibliography		
Microplastics	Non-information found in bibliography		

6.3.6 Permeable Pavements

Table 10. Reported removal capacity in Permeable Pavements

FAMILY	COMPOUND	CAS NUMBER	REPORTED REMOVAL CAPACITY	REFERENCE
Biocides & T.P.	Non-information found in bibliography			
Personal Care Products	Non-information found in bibliography			
Tire Compounds	-	-	Retained in pores (not quantified)	24
Industrial Chemical	Non-information found in bibliography			
Pharmaceutical	Non-information found in bibliography			
Fossil fuel and combustion products	NAPHTALENE (PAH)	91-20-3	LOW DECREASE	25
Microplastics	-	-	Retained in pores (not quantified)	24

6.3.7 Retention Ponds

Table 11. Reported removal capacity in Retention pond

FAMILY	COMPOUND	CAS NUMBER	REPORTED REMOVAL CAPACITY	REF.
Biocides & T.P.	2,4-D	94-75-7	LOW DECREASE	26
Biocides & T.P.	ATRAZINE	1912-24-9	MEDIUM DECREASE	26
Biocides & T.P.	BIFENTHRIN	82657-04-3	MEDIUM DECREASE	27
Biocides & T.P.	CYFLUTHRIN	68359-37-5	HIGH DECREASE	27
Biocides & T.P.	DIAZINON	333-41-5	MEDIUM DECREASE	26
Biocides & T.P.	FIPRONIL	120068-37-3	MEDIUM DECREASE	27
Biocides & T.P.	FIPRONIL DESULFINYL	205650-65-3	HIGH DECREASE	27
Biocides & T.P.	FIPRONIL SULFIDE	120067-83-6	HIGH DECREASE	27
Biocides & T.P.	FIPRONIL SULFONE	120068-36-2	MEDIUM DECREASE	27
Personal Care Products	CASHMERAN	33704-61-9	MEDIUM DECREASE	26
Personal Care Products	CELESTOLIDE	13171-00-1	MEDIUM DECREASE	26
Personal Care Products	GALAXOLIDE	1222-05-5	HIGH DECREASE	26
Personal Care Products	HYDROCCINNAMIC ACID	501-52-0	HIGH DECREASE	26
Personal Care Products	KETOPROFEN	22071-15-4	HIGH DECREASE	26
Personal Care Products	METHYL DIHYDROJASMONATE	24851-98-7	HIGH DECREASE	26, 28

Personal Care Products	METHYLPARABEN	99-76-3	MEDIUM DECREASE	26
Personal Care Products	OXYBENZONE	131-57-7	HIGH DECREASE	26
Personal Care Products	TRICLOSAN	3380-34-5	HIGH DECREASE	26
Tyre Compounds	Non-information found in bibliography			
Industrial Chemical	5-METHYL BENZOTRIAZOLE	136-85-6	HIGH DECREASE	26
Industrial Chemical	BENZOTRIAZOLE	95-14-7	MEDIUM DECREASE	26
Industrial Chemical	BISPHENOL A	80-05-7	HIGH DECREASE	26
Industrial Chemical	OCTYLPHENOL	1806-26-4	HIGH DECREASE	26
Industrial Chemical	TONALIDE	21145-77-7	MEDIUM DECREASE	26
Industrial Chemical	TRIBUTYL PHOSPHATE	126-73-8	HIGH DECREASE	26
Industrial Chemical	TRIPHENYL PHOSPHATE	115-86-6	MEDIUM DECREASE	26
Industrial Chemical	TRIS(2-CHLOROETHYL) PHOSPHATE	115-96-8	MEDIUM DECREASE	26
Pharmaceutical	2-HIDROXY-CBZ (METABOLITE)	-	MEDIUM DECREASE	29
Pharmaceutical	3-HYDROXY-CBZ (METABOLITE)	-	MEDIUM DECREASE	29
Pharmaceutical	ACETAMINOPHEN	103-90-2	HIGH DECREASE	29

Pharmaceutical	ACYCLOVIR	59277-89-3	HIGH DECREASE	29
Pharmaceutical	ATENOLOL	29122-68-7	HIGH DECREASE	29
Pharmaceutical	BENZAFIBRATE	41859-67-0	MEDIUM DECREASE	29
Pharmaceutical	BENZOTHIAZOLE	95-16-9	MEDIUM DECREASE	29
Pharmaceutical	CAFFEINE	58-08-2	HIGH DECREASE	26,28
Pharmaceutical	CARBAMAZEPINE (CBZ)	298-46-4	LOW DECREASE	26, 29
Pharmaceutical	CIPROFLOXACIN	85721-33-1	HIGH DECREASE	30
Pharmaceutical	CLARITHROMYCIN	81103-11-9	MEDIUM DECREASE	29
Pharmaceutical	CODEINE	76-57-3	HIGH DECREASE	29
Pharmaceutical	DHDH-CBZ (METABOLITE)	-	LOW DECREASE	29
Pharmaceutical	DHH-CBZ (METABOLITE)	-	MEDIUM DECREASE	29
Pharmaceutical	DIATRIZOATE	737-31-5	MEDIUM DECREASE	29
Pharmaceutical	DICLOFENAC	15307-86-5	MEDIUM DECREASE	26,28, 29
Pharmaceutical	ERYTHROMYCIN	114-07-8	MEDIUM DECREASE	29
Pharmaceutical	FLUCONAZOLE	86386-73-4	LOW DECREASE	29
Pharmaceutical	IBUPROFEN	15687-27-1	HIGH DECREASE	26,28
Pharmaceutical	IBUPROFEN	15687-27-1	MEDIUM DECREASE	28
Pharmaceutical	IOMEPROL	78649-41-9	MEDIUM DECREASE	29
Pharmaceutical	IOPROMIDE	73334-07-3	MEDIUM DECREASE	29
Pharmaceutical	METOPROLOL	37350-58-6	HIGH DECREASE	29
Pharmaceutical	N, O-DDM-VLX (METABOLITE)	-	MEDIUM DECREASE	29
Pharmaceutical	N, O-DDM-TMD (METABOLITE)	-	LOW DECREASE	29
Pharmaceutical	NAPROXEN	22204-53-1	MEDIUM DECREASE	26,28
Pharmaceutical	N-DM-TMD (METABOLITE)	-	MEDIUM DECREASE	29

Pharmaceutical	N-DM-VLX (METABOLITE)	-	MEDIUM DECREASE	29
Pharmaceutical	O-DM-TMD (METABOLITE)	-	MEDIUM DECREASE	29
Pharmaceutical	O-DM-VLX (METABOLITE)	-	MEDIUM DECREASE	29
Pharmaceutical	OH-BENZOTHIAZOLE	-	MEDIUM DECREASE	26
Pharmaceutical	OXAZEPAM	604-75-1	LOW DECREASE	29
Pharmaceutical	SALICYLIC ACID	69-72-7	HIGH DECREASE	28
Pharmaceutical	SULFAMETHOXAZOLE (SMX)	723-46-6	MEDIUM DECREASE	29,30
Pharmaceutical	TRAMADOL (TMD)	27203-92-5	MEDIUM DECREASE	29
Pharmaceutical	TRIMETHOPRIM	738-70-5	HIGH DECREASE	29
Pharmaceutical	VENLAFAXINE (VLX)	93413-69-5	MEDIUM DECREASE	29
Pharmaceutical	ΣSMX+ACETYL-SMX	-	MEDIUM DECREASE	29
Fossil fuel and combustion products	ΣPAH	-	LOW DECREASE	31
Microplastics	PP / POLYESTER / PA / ACRYLIC / PS / OTHERS	-	HIGH DECREASE	32, 33, 34

6.3.8 Linear Sustainable Drainage Systems

Table 12. Reported removal capacity in Linear Drainage Systems

FAMILY	COMPOUND	CAS NUMBER	REPORTED REMOVAL CAPACITY	REF.
Biocides & T.P.	BIFENTHRIN	82657-04-3	HIGH DECREASE	35
Biocides & T.P.	CYFLUTHRIN	68359-37-5	HIGH DECREASE	35
Biocides & T.P.	CYPERMETHRIN	52315-07-8	HIGH DECREASE	35
Biocides & T.P.	FIPRONIL	120068-37-3	HIGH DECREASE	35

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Biocides & T.P.	FIPRONIL SULFIDE	120067-83-6	HIGH DECREASE	35
Biocides & T.P.	FIPRONIL SULFONE	120068-36-2	HIGH DECREASE	35
Biocides & T.P.	L-CYHALOTHRIN	91465-08-6	HIGH DECREASE	35
Biocides & T.P.	PERMETHRIN	52645-53-1	HIGH DECREASE	35
Personal Care Products	Non-information found in bibliography			
Tyre Compounds	Non-information found in bibliography			
Industrial Chemical	BISFENOL -A (BPA)	80-05-7	MEDIUM DECREASE	16
Industrial Chemical	DI(2-ETILHEXIL) FTALATO (DEHP)	204-211-0	LOW DECREASE	16
Industrial Chemical	NONYLPHENOL	104-40-5	LOW DECREASE	16
Industrial Chemical	OCTYPHENOL	217-302-5	MEDIUM DECREASE	16
Pharmaceutical	Non-information found in bibliography			
Fossil fuel and combustion products	PHENANTHRENE	85-01-8	MEDIUM DECREASE	16
Fossil fuel and combustion products	PYRENE	129-00-0	MEDIUM DECREASE	16
Fossil fuel and combustion products	ΣPAH	-	HIGH DECREASE	35
Microplastics	Non-information found in bibliography			

6.3.9 Sediments Forebays

Non-information found in bibliography related to any of the pollutant families.

6.3.10 Free Water Surface (FWS) Wetland

Table 13. Reported removal capacity in Free Water Surface Wetland

FAMILY	COMPOUND	CAS NUMBER	REPORTED REMOVAL CAPACITY	REF.
Biocides & T.P.	ATRAZINE	1912-24-9	HIGH DECREASE	36
Biocides & T.P.	BIFENTHRIN	82657-04-3	HIGH DECREASE	37
Biocides & T.P.	CHLORPYRIFOS	2921-88-2	HIGH DECREASE	37, 38
Biocides & T.P.	CYHALOTHRIN	91465-08-6	HIGH DECREASE	37
Biocides & T.P.	CYPERMETHRIN	52315-07-8	HIGH DECREASE	37
Biocides & T.P.	DEET	134-62-3	LOW DECREASE	39
Biocides & T.P.	DIAZINON	333-41-5	HIGH DECREASE	37
Biocides & T.P.	ESFENVALERATE	66230-04-4	HIGH DECREASE	37
Biocides & T.P.	METOLACHLOR	87392-12-9	MEDIUM DECREASE	40
Biocides & T.P.	PERMETHRIN	52645-53-1	HIGH DECREASE	36, 37
Biocides & T.P.	S-METOLACHLOR	87392-12-9	HIGH DECREASE	36
Personal Care Products	GALAXOLIDE	1222-05-5	MEDIUM DECREASE	41
Personal Care Products	METHYL DIHYDROJASMONATE	24851-98-7	MEDIUM DECREASE	41
Personal Care Products	METHYLPARABEN	99-76-3	HIGH DECREASE	41
Personal Care Products	N, N-DIETHYL-META-TOLUAMIDE	134-62-3	LOW DECREASE	41
Personal Care Products	PROPYLPARABEN	94-13-3	MEDIUM DECREASE	41

Personal Care Products	TONALIDE	21145-77-7	MEDIUM DECREASE	41
Personal Care Products	TRICLOSAN	3380-34-5	HIGH DECREASE	41
Tyre Wear	-	-	LOW DECREASE	42
Industrial Chemical	ALKYL BENZENE SULFONATES (LINEAL)	42615-29-2	MEDIUM DECREASE	43
Industrial Chemical	SUCRALOSE	56038-13-2	Not degraded	44
Pharmaceutical	17ß-ESTRADIOL	50-28-2	MEDIUM DECREASE	41
Pharmaceutical	17A-ETHINYLESTRADIOL	57-63-6	MEDIUM DECREASE	41
Pharmaceutical	ACETAMINOPHEN	103-90-2	HIGH DECREASE	45
Pharmaceutical	ANTIBIOTICS (AVERAGE)	-	MEDIUM DECREASE	46
Pharmaceutical	ATENOLOL	29122-68-7	MEDIUM DECREASE	45
Pharmaceutical	BEZAFIBRATE	41859-67-0	MEDIUM DECREASE	45
Pharmaceutical	CAFFEINE	58-08-2	MEDIUM DECREASE	45
Pharmaceutical	CARBAMAZEPINE	298-46-4	LOW DECREASE	45
Pharmaceutical	CIPROFLOXACIN	85721-33-1	MEDIUM DECREASE	47
Pharmaceutical	CLARITHROMYCIN	81103-11-9	MEDIUM DECREASE	45
Pharmaceutical	CLOFIBRIC ACID	882-09-7	LOW DECREASE	45
Pharmaceutical	CLOPIDOGREL	113665-84-2	MEDIUM DECREASE	47
Pharmaceutical	CODEINE	76-57-3	MEDIUM DECREASE	45
Pharmaceutical	DICLOFENAC	15307-86-5	MEDIUM DECREASE	45
Pharmaceutical	DILTIAZEM	42399-41-7	MEDIUM DECREASE	45
Pharmaceutical	DOXYCYCLINE	564-25-0	MEDIUM DECREASE	45
Pharmaceutical	ERYTHROMYCIN	114-07-8	MEDIUM DECREASE	47
Pharmaceutical	ESTRIOL	50-27-1	MEDIUM DECREASE	45

Pharmaceutical	FEXOFENADINE	83799-24-0	LOW DECREASE	[45]
Pharmaceutical	GEMFIBROZIL	25812-30-0	LOW DECREASE	[45]
Pharmaceutical	IBUPROFEN	15687-27-1	MEDIUM DECREASE	[45]
Pharmaceutical	KETOPROFEN	22071-15-4	MEDIUM DECREASE	[45]
Pharmaceutical	LOMEFLOXACIN	98079-51-7	HIGH DECREASE	[47]
Pharmaceutical	MECLIZINE	569-65-3	MEDIUM DECREASE	[48]
Pharmaceutical	METOPROLOL	37350-58-6	LOW DECREASE	[45]
Pharmaceutical	MIRTAZAPIN	61337-67-5	MEDIUM DECREASE	[45]
Pharmaceutical	NAPROXEN	22204-53-1	MEDIUM DECREASE	[45]
Pharmaceutical	NORFLOXACIN	70458-96-7	MEDIUM DECREASE	[47]
Pharmaceutical	OFLOXACIN	82419-36-1	HIGH DECREASE	[47]
Pharmaceutical	OXYLETRACYCLINE	79-57-2	MEDIUM DECREASE	[47]
Pharmaceutical	RANITIDINE	66357-35-5	MEDIUM DECREASE	[45]
Pharmaceutical	ROXITHROMYCIN	80214-83-1	MEDIUM DECREASE	[45]
Pharmaceutical	SALICYLIC ACID	69-72-7	MEDIUM DECREASE	[45]
Pharmaceutical	SOTALOL	3930-20-9	LOW DECREASE	[45]
Pharmaceutical	SULFADIAZINE	68-35-9	MEDIUM DECREASE	[45]
Pharmaceutical	SULFAMETHAZINE	57-68-1	MEDIUM DECREASE	[45]
Pharmaceutical	SULFAMETHOXAZOLE	723-46-6	LOW DECREASE	[49]
Pharmaceutical	SULFAMETHOXAZOLE	723-46-6	MEDIUM DECREASE	[45]
Pharmaceutical	SULFAPYRIDINE	144-83-2	MEDIUM DECREASE	[45]
Pharmaceutical	TESTOSTERONE	58-22-0	MEDIUM DECREASE	[41]
Pharmaceutical	TETRACYCLINE	60-54-8	HIGH DECREASE	[47]
Pharmaceutical	TRAMADOL	27203-92-5	LOW DECREASE	[45]
Pharmaceutical	TRIMETHOPRIM	738-70-5	MEDIUM DECREASE	[45]
Pharmaceutical	VENLAFAXINE	93413-69-5	MEDIUM DECREASE	[45]

Pharmaceutical	WARFARIN	81-81-2	LOW DECREASE	48
Fossil fuel and combustion products	PAHs		MEDIUM DECREASE	50
Fossil fuel and combustion products	ΣBTEX		HIGH DECREASE	51
Fossil fuel and combustion products	ΣPAH		HIGH DECREASE	51
Microplastics	-	-	HIGH DECREASE	52
Microplastics	-	-	LOW DECREASE	42

6.3.11 Sub-Surface Flow (SSF) Wetland

Table 14. Reported removal capacity in Free Water Surface Wetland

FAMILY	COMPOUND	CAS NUMBER	REPORTED REMOVAL CAPACITY	REF.
BIOCIDES & T.P.	AMINOMETHYLPHOSPHONIC ACID (AMPA)	1066-51-9	MEDIUM DECREASE	53
BIOCIDES & T.P.	CHLORPYRIFOS	2921-88-2	HIGH DECREASE	54
BIOCIDES & T.P.	DEET	134-62-3	LOW DECREASE	44
BIOCIDES & T.P.	DEET	134-62-3	MEDIUM DECREASE	53
BIOCIDES & T.P.	GLYPHOSATE	1071-83-6	HIGH DECREASE	53
BIOCIDES & T.P.	TOLYTRIAZOLE	29385-43-1	HIGH DECREASE	53
Personal Care Products	ACESULFAME	55589-62-3	LOW DECREASE	41
Personal Care Products	GALAXOLIDE	1222-05-5	MEDIUM DECREASE	55 ,41

Personal Care Products	GALAXOLIDE	1222-05-5	HIGH DECREASE	41
Personal Care Products	METHYL DIHYDROJASMONATE	24851-98-7	HIGH DECREASE	55 ,41
Personal Care Products	METHYLPARABEN	99-76-3	LOW DECREASE	41
Personal Care Products	N, N-DIETHYL-META-TOLUAMIDE	134-62-3	HIGH DECREASE	41
Personal Care Products	OXYBENZONA	131-57-7	HIGH DECREASE	41
Personal Care Products	TONALIDE	21145-77-7	MEDIUM DECREASE	55 ,41
Personal Care Products	TRICLOSAN	3380-34-5	HIGH DECREASE	41
Tyre Wear	Non-information found in bibliography			
Industrial Chemical	SUCRALOSE	56038-13-2	Not degraded	44
Industrial Chemical	TRIBUTIL PHOSPHATE	126-73-8	MEDIUM DECREASE	41
Industrial Chemical	TRIS (2-CHLOROETHYL) PHOSPHATE	115-96-8	LOW DECREASE	41
Industrial Chemical	TRIPHENYL PHOSPHATE	115-86-6	MEDIUM DECREASE	41
Industrial Chemical	ALKYL BENZENE SULFONATES (LINEAL)	42615-29-2	MEDIUM DECREASE	43
Industrial Chemical	PERFLUOROOCTANESULFONIC ACID (PFOS)	1763-23-1	MEDIUM DECREASE	53
Industrial Chemical	PERFLUOROOCTANOIC ACID (PFOA)	335-67-1	LOW DECREASE	53

Industrial Chemical	BENZOTRIAZOLE	95-14-7	HIGH DECREASE	53
Industrial Chemical	TRIS(2-CHLOROISOPROPYL) PHOSPHATE (TCPP)	13674-84-5	LOW DECREASE	53
Pharmaceutical	17ß-ESTRADIOL	50-28-2	MEDIUM DECREASE	41
Pharmaceutical	17A-ETHINYLESTRADIOL	57-63-6	MEDIUM DECREASE	41
Pharmaceutical	ACETAMINOPHEN	103-90-2	HIGH DECREASE	45
Pharmaceutical	ATENOLOL	29122-68-7	MEDIUM DECREASE	45, 53
Pharmaceutical	AZITHROMYCIN	83905-01-5	MEDIUM DECREASE	56
Pharmaceutical	BEZAFIBRATE	41859-67-0	MEDIUM DECREASE	45
Pharmaceutical	BOLDENONE	13103-34-9	HIGH DECREASE	41
Pharmaceutical	CAFFEINE	58-08-2	HIGH DECREASE	44
Pharmaceutical	CAFFEINE	58-08-2	HIGH DECREASE	45
Pharmaceutical	CARBAMAZEPINE	298-46-4	LOW DECREASE	45
Pharmaceutical	CARBAMAZEPINE	298-46-4	HIGH DECREASE	53
Pharmaceutical	CIPROFLOXACIN	85721-33-1	MEDIUM DECREASE	56, 47
Pharmaceutical	CLARITHROMYCIN	81103-11-9	MEDIUM DECREASE	45, 56
Pharmaceutical	CLOFIBRIC ACID	882-09-7	MEDIUM DECREASE	45
Pharmaceutical	CODEINE	76-57-3	HIGH DECREASE	45
Pharmaceutical	DICLOFENAC	15307-86-5	MEDIUM DECREASE	45
Pharmaceutical	DILTIAZEM	42399-41-7	MEDIUM DECREASE	45
Pharmaceutical	DOXYCYCLINE	564-25-0	MEDIUM DECREASE	45
Pharmaceutical	ERYTHROMYCIN	114-07-8	MEDIUM DECREASE	47, 56
Pharmaceutical	ESTRIOL	50-27-1	HIGH DECREASE	41
Pharmaceutical	ESTRONE	53-16-7	MEDIUM DECREASE	41
Pharmaceutical	FEXOFENADINE	83799-24-0	MEDIUM DECREASE	45

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Pharmaceutical	GEMFIBROZIL	25812-30-0	MEDIUM DECREASE	45
Pharmaceutical	IBUPROFEN	15687-27-1	MEDIUM DECREASE	45
Pharmaceutical	KETOPROFEN	22071-15-4	MEDIUM DECREASE	45
Pharmaceutical	LEUCOMYCIN	22875-15-6	LOW DECREASE	56
Pharmaceutical	LEVONORGESTREL	797-63-7	HIGH DECREASE	41
Pharmaceutical	LIDOCAINE	137-58-6	HIGH DECREASE	53
Pharmaceutical	LOMEFLOXACIN	98079-51-7	HIGH DECREASE	47
Pharmaceutical	METOPROLOL	37350-58-6	MEDIUM DECREASE	45
Pharmaceutical	METOPROLOL	37350-58-6	HIGH DECREASE	53
Pharmaceutical	MIRTAZAPIN	61337-67-5	LOW DECREASE	45
Pharmaceutical	N-ACETYL SULFAMETHOXAZOLE	21312-10-7	LOW DECREASE	53
Pharmaceutical	NAPROXEN	22204-53-1	MEDIUM DECREASE	45
Pharmaceutical	NORETHISTERONE	68-22-4	HIGH DECREASE	41
Pharmaceutical	NORFLOXACIN	70458-96-7	MEDIUM DECREASE	47,56
Pharmaceutical	OFLOXACIN	82419-36-1	HIGH DECREASE	47
Pharmaceutical	OXOLINIC ACID	14698-29-4	LOW DECREASE	56
Pharmaceutical	OXYLETRACYCLINE	79-57-2	MEDIUM DECREASE	47
Pharmaceutical	PREDNISONE	53-03-2	HIGH DECREASE	41
Pharmaceutical	PROGESTERONE	57-83-0	HIGH DECREASE	41
Pharmaceutical	PROPRANOLOL	525-66-6	HIGH DECREASE	53
Pharmaceutical	RANITIDINE	66357-35-5	LOW DECREASE	45
Pharmaceutical	ROXITHROMYCIN	80214-83-1	LOW DECREASE	47,56
Pharmaceutical	SALICYLIC ACID	69-72-7	HIGH DECREASE	45
Pharmaceutical	SOTALOL	3930-20-9	LOW DECREASE	45

Pharmaceutical	SULFADIAZINE	68-35-9	MEDIUM DECREASE	45
Pharmaceutical	SULFAMETHAZINE	57-68-1	MEDIUM DECREASE	45
Pharmaceutical	SULFAMETHOXAZOLE	723-46-6	MEDIUM DECREASE	45, 44, 53
Pharmaceutical	SULFAPYRIDINE	144-83-2	HIGH DECREASE	45
Pharmaceutical	TESTOSTERONE	58-22-0	HIGH DECREASE	41
Pharmaceutical	TETRACYCLINE	60-54-8	HIGH DECREASE	47
Pharmaceutical	TRAMADOL	27203-92-5	MEDIUM DECREASE	45
Pharmaceutical	TRIMETHOPRIM	738-70-5	HIGH DECREASE	44
Pharmaceutical	TRIMETHOPRIM	738-70-5	MEDIUM DECREASE	45
Pharmaceutical	TYLOSIN	1401-69-0	LOW DECREASE	56
Pharmaceutical	VENLAFAXINE	93413-69-5	LOW DECREASE	45
Fossil fuel and combustion products	PAHs	-	MEDIUM DECREASE	43
Microplastics	-	-	HIGH DECREASE	57, 58

6.4 References of this chapter

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7 Final Remarks

In this library a synthesis of the available knowledge about stormwater management systems in urban areas has been done, including the use of the so-called Nature-Based Solutions (NBS) for urban drainage. This library is only the starting point of a more complex and complete work, where the information summarized in the factsheets have to be linked with parametric design, Multi-Criteria Decision Analysis (MCDA) and Geographical Information Systems (GIS) in order to provide a prioritization of solutions according to all the specific situations that can arise in urban areas or that needs to be solved by decision makers.

From the synthesis of the information summarized in this library it can be stated that NBS provides alternative ways for dealing with stormwater management issues in Urban areas. These techniques, apart from providing the necessary treatment in terms of water quality and quantity for runoff waters of most urban areas, also showed to provide alternative benefits in terms of ecosystem functions that are difficult to quantify, but that needs to be considered in stormwater management plans.

8 Acronyms

Table 15. Acronyms

Acronyms	Name
BIM	Building Information Modelling
CECs	Contaminants of Emerging Concern
D	Deliverable
GIS	Geographical Information System
MCDA	Multi-criteria decision analysis
NBS	Nature-based Solutions
SuDS	Sustainable Drainage Systems
WP	Work package