NTNU
Norwegian University of
Science and Technology

Infrastructure asset management for nature-based solutions (NBS): a guidance for collecting asset information and data for NBS maintenance management Application at Trondheim district (Norway)

Carlos Hidalgo Martínez

Master of Science in Civil and Environmental Engineering
Submission date: July 2016
Supervisor: Rita Maria Ugarelli, IVM
Co-supervisor: Sægrov Sveinung, IVM

Norwegian University of Science and Technology
Department of Hydraulic and Environmental Engineering

Infrastructure asset management for nature-based solutions (NBS): a guidance for collecting asset information and data for NBS maintenance management Application at Trondheim district (Norway)

Author: Carlos Hidalgo Martínez

Supervisor: Rita Maria Ugarelli

Index

Figures

Tables

Abstract

Nature-based solutions (NBS) are called to be the future solution in the stormwater management. The current systems are not enough to manage the changes that are happening; the adaptability of traditional solutions is not enough to handle the climate change and it is necessary to change the point of view in the storm water management. It is not only necessary to try to assess the economic aspect, but it is also necessary to give the same weight to the environmental and the social aspects in the design of stormwater management systems. This NBS are a new way to solve the actual problems, in which it should be applied all knowledge acquired during years in the field asset management of other water systems such as the pipe systems. It is necessary to continue working with this NBS to learn how to manage the systems that compose them in the most efficient way and develop the required tools to help to make this process easier.

Scope and goals of the master thesis

The objective of this master thesis is to give a short breath about what nature-based solutions are, explaining what they are and which criteria are used to design them. It is also provided a list of systems which they are composed of, together with how important these systems are nowadays and how NBS will become more important in the future.

One of the most important components of NBS are the Green solutions. For this reason in this report, they are analysed 5 of these green solutions that are the most commonly utilized. In these analyses, they are studied which characteristics each of these solutions have and which benefits could be provided by each one. They are also provided some basic guidelines to do a predesign, with some advices about how to reduce the maintenance, or improve the behaviour of the systems. In addition, it is proposed a schedule of maintenance, proposing the frequencies of the required inspections and maintenance.

The last goal of this master thesis is to provide 5 excel sheets to register each green solution, in order to have a compendium of all of the nature-based solution existent in a specific place. In these excel sheets they are registered the date of construction and the date of the different inspections of the systems, the main characteristics of each one, and in these excel sheets they are also implemented some design equations with which it is possible to calculate the expected values of water treatment rate, or the dimensions required to manage a specific rainfall. In this way, it is possible to check if the actual systems will have a correct behaviour. All of this allows having a better asset management making the maintenance planning and the maintenance actions much easier.

What are Nature Based Solutions (NBS)?

The Nature-based solutions (NBS) is a new concept that aims to address the actual problems related whit the environmental , social and economic challenges that concern the humanity, with a new point of view inspired in how nature solves these issues and developing actions trying to copy and imitate its behaviour.

With the NBS it is not enough to solve a problem applying low impact development (LID) infrastructures and to do it in the most efficient way, applying methods like best manage practices (BMP). With this new point of view, it will be applied a combination of this LID and BMP but in addition, it is intended to improve the well-being of the citizens, the maintaining of the systems and the protection of the environment. But these are not the only issues of NBS, these solutions try to address other topics like: the use of energy and how it could be possible to save it; the resource-efficient use; how to enhance suitable urbanisation; how to restore degraded ecosystems; how to develop stormwater systems which are able to adapt to the climate change and how to mitigate the possible changes. [1]

Many NBS have multiple co-benefits for society, health, cost, and the environment, and thus, they can be more beneficial and cost-effective profitable solutions than more traditional approaches.[2]

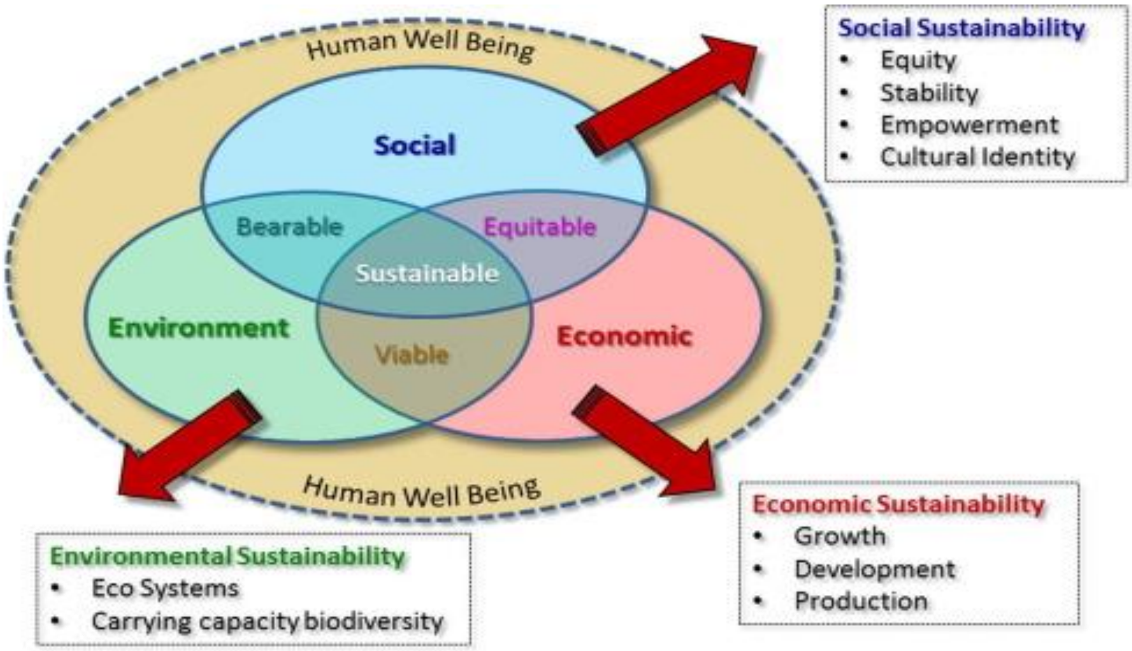

Figure 1. NBS aims [3]

This is the general definition of NBS but now the question is: *How to materialize this new way to solve problems focused on the management of stormwater?* The easiest answer is, mimicking how nature solves these problems applying a set of Green, Blue and Grey solutions that imitate how nature manages stormwater. It means that to solve an issue, they should be applied methods that do the same function as nature but trying always to improve the environment condition and produce a positive social impact. NBS also should solve the problems in a sustainable development in a short and long term, and reduce the cost of maintenance and repair tasks.[4]

To know about what NBS are composed, they will be defined the 3 possible systems that can be part in a NBS stormwater system:

Green solutions

Green Infrastructures are a kind of stormwater management that have as a goal to protect the society from floods and contamination by pollutants preserving and restoring the environment mimicking nature hydrology. These solutions provide peak flow reduction and stormwater volume retention and promote the groundwater recharge. To achieve these goals, constructions that use mechanisms as percolation, evapotranspiration, and infiltration is used. On these systems, the soils serve to storage water and produce the infiltration; on the other hand, the vegetation produces the evapotranspiration and interception process.

The green solutions are based on Low impact development (LID) and Best management practices (BMP) where the aim of these two philosophies is to achieve the water quantity and quality objectives in the stormwater management, having the highest cost-effectiveness and reducing the environmental erosion.

Some of these infrastructures are: soakaways, green roofs, bioretention, strips, and swales. These systems will be analysed deeper in next sections. [5]

Blue Solutions

The blue infrastructures are not usually defined as an independent type of infrastructure; they are usually linked to the green solutions because they follow the same philosophy of BMP and LID, but the blue solutions add the concept of saving and reusing as much amount of water as possible and designing the systems according to this idea.[6]

Grey Solutions

The grey solutions are the traditional measures applied especially in the past to address the stormwater problems, using concrete or synthetic elements that do not produce any reduction or retention by evapotranspiration or infiltration. They are also used systems such as membranes and reverse osmosis to produce water treatment to reduce the amount of pollutants.

In this type of infrastructures, it is usually applied the ¨End of pipe¨ philosophy. It means that all wastewaters are collected into a sewer and conveyed until a release point without practically any pre-treatment. In these solutions, it usually exists a treatment plant at the end of the system just before releasing the water into a river or a sea.

Why use NBS?

The principal reason to change from stormwater management traditional methods to NBS is that the traditional methods manage the stormwater in an obsolete way. The traditional methods usually do a ¨End of pipe¨ treatment, incrementing a lot the cost of transport. Regarding the material used, they are materials that have a ¨short¨ life cycle if they are not well maintained. This means that the cost of maintenance will be very high. Besides, they have not a good adaptability if a change occurs in the water that is necessary to treat. Nowadays these types of systems are not suitable for the changes produced by climate change.

NBS solve all of these problems in a more suitable form because with them it is possible to do a micromanagement of the storm water, reducing the cost by transport and they usually have a good adaptability because their design could be modified without big costs, allowing the management of more water.

Regarding the maintenance, nowadays it is an important aspect to take into account in the design of a system. For example in the selection of the most suitable solution, the construction cost could be low but the maintenance cost could increment a lot the total cost, making that this solution will not be the most suitable one. NBS have a longer life cycle than the traditional solutions and the cost of maintenance in a long-term is lower: they do not have a big number of elements that have to be replaced and also the elements of NBS have a lower degradation with the time.

Continuing with the materials of NBS, they are basic materials that could be obtained in the construction place and could be constructed by the local population. Generally, NBS have the better adaptability to the local environment than the traditional systems and do a sustainable use of nature resources having higher resource efficiency than the traditional solutions.

To conclude, one of the most important points in NBS is that they produce a social progress and improvement of well-being besides the technical benefits.[7]

Design criteria for NBS:

The design of NBS focused in stormwater management is based on 5 main points: Water quantity, Water quality, Amenity, Biodiversity, and Maintenance. When NBS is being designed, these 5 criteria should be considered doing a multi-criteria design and giving weight to all of them without forgetting any of them, in order to get a sustainable stormwater management. Then each of these criteria will be explained and which the most important aspects are in all of them[8]:

Water quantity

Water quantity; in this part, in general guidelines they are analysed the requirements of which amount of water is necessary to treat and which percentage of reduction is necessary. The different points considered in this part are:

- The use of the water runoff as a resource
- Study of the necessary Runoff volume reduction and Peak flow attenuation
- Management of the stormwater imitating the nature
- Management of the flood risk in the most effective way
- Establishment of a drainage system in a sustainable way and with a long life cycle
- The design of a system with a good adaptability and flexibility for possible future changes (climate change)

Water quality

Water quality; in this part, they are analysed the pollutant presence in the water that arrives at the treatment systems and which minimum requirements of quality are necessary for the released water. The different points considered in this part are:

Enchantment of the released water in general

Application of different and effective treatments, in function of stormwater pollutants

Design of a system that is eco-friendly with the environment and that can be adapted to the future changes

Establishment of a standard level of quality in function of the importance of the release place

Amenity

Amenity; in this part, they are grouped all the social aspects such as:

Maximising the multi-functional use of spaces

Production of a social benefit and improvement of the life quality derived from the construction of a NBS

Reduction of the heat island effect

Design of safe systems and with a high level of adaptability

Enhancement of visual aspect of cities

Biodiversity

Biodiversity; in this part, they are analysed the environmental benefits produced by the use of NBS, such as:

Protection of nature and the local animal and plants

Protection of the environment erosion produced by stormwater

Contribution to the habitat connectivity

Renaturalization of cities

Maintenance

Maintenance; in this part, they are analysed the cost of maintenance in a short and long term, including how the maintenance cost will evolve in function of the time. The different points considered in this part are:

The cost of maintenance.

Evolution of maintenance whit the time

Life cycles analysis

Possible systems

In the Table 1 are listed some of the systems that could be used as a part of a NBS, classified according to which stormwater manage problems could each one solve. This table tries to present which options are available to solve a specific stormwater management problem and environmental problems. In this way is possible to compare the efficiency of all of them doing a predesign to find which system is the most suitable to solve the problem. In the first column are listed the possible problems, and in the third column are listed the different solutions that could be applied in each case[9].

In the case of floods exist a second column where are indicated the two principal ways to solve this problem, producing a peak flow attenuation or doing a runoff volume reduction. Finally in the part of reduction of pollutants are listed which are the pollutant that could be removed by this systems.[10]

Table 1. Stormwater problems - Solutions proposed

Possible problems and proposed solutions		
Floods	Peak flow attenuation	Green roofs Infiltration trenches Swales Wetland Soakaways Blue Roof Systems Bioretention Wet ponds Stormwater Chamber Systems
	Runoff volume reduction	Rain tanks Soakaways Permeable pavement Graver bed Perforated Pipe Systems Stormwater Chamber Wet ponds Dry ponds Blue Roof Systems Green roofs(limited)
High concentration of pollutants	Pb Zn Cu Sediments (TSS)	Green roofs Filter strip Bioretention Sand filter (superficial) Sand filter (non-Superficial)
Temperature (City) Urban heat island)		Green roofs Blue Roof Systems

Restoring degraded ecosystems		Green roofs Wetland Bioretention Wet ponds Swales
Reuse water (lack of water)		Blue Roof Systems Wet ponds Dry ponds Rainwater harvesting
Erosion problems		Swales Vegetated strips Wetland Graver bed Perforated Pipe Systems Stormwater Chamber
High cost of maintenance (reduction of maintenance)		Green roofs Swales Wetland Soakaways Bioretention Wet ponds
High concentration of sediments		Green roofs Infiltration trenches Swales Wetland Bioretention Wet ponds Sand filter (surface) Sand filter (non-surface)

High percentage of impervious zones (reduction of impervious areas without changes in the normal use of the zone of application)		Permeable pavement Green roofs Wet ponds Stormwater Chamber Systems Graver bed Perforated Pipe Systems
High runoff coefficient (Necessary augment the permeable areas)		Wet ponds Swales Vegetated strips Green roofs Bioretention Soak away Wetlands

Solution approach

In this part, it is done a deeper analysis of five of them, soakaways, green roofs, bioretention, strips and swales. This analysis will follow the next parts:

- Description and types
- Parts
- Benefits
- Basic design
- Modifications in the design, to reduce the long-term maintenance cost and extend the life cycle
- Maintenance proposed

Green roofs

Description

Green roofs are a type of Nature based solution that consists of vegetated areas installed on the top of buildings. The reasons to install a green roof instead of a classical roof include benefits such as peak flow attenuation, volume control design, reduction of pollutants, energy saving, visual benefit and ecological value. Green roofs can be divided into two different groups[11]:

- **Extensive roofs:** This type have a low substrate depth (20-150 mm), it means that increment of loading transmitted to the building structure is small. The planted plants have shallow roots and the maintenance is easy to do it. This type is not usually accessible (It is only accessible for maintenance works).

- **Intensive roofs:** This type have a large substrate depth, it means that increment of loading transmitted to the building structure could be significant and should be included in the structural calculations. The planted plants have deep roots and the cost of maintenance could be significant. It is usually necessary to do an irrigation system during the dry periods. This type of green roof could be used to recreational uses and is usually accessible to the people.

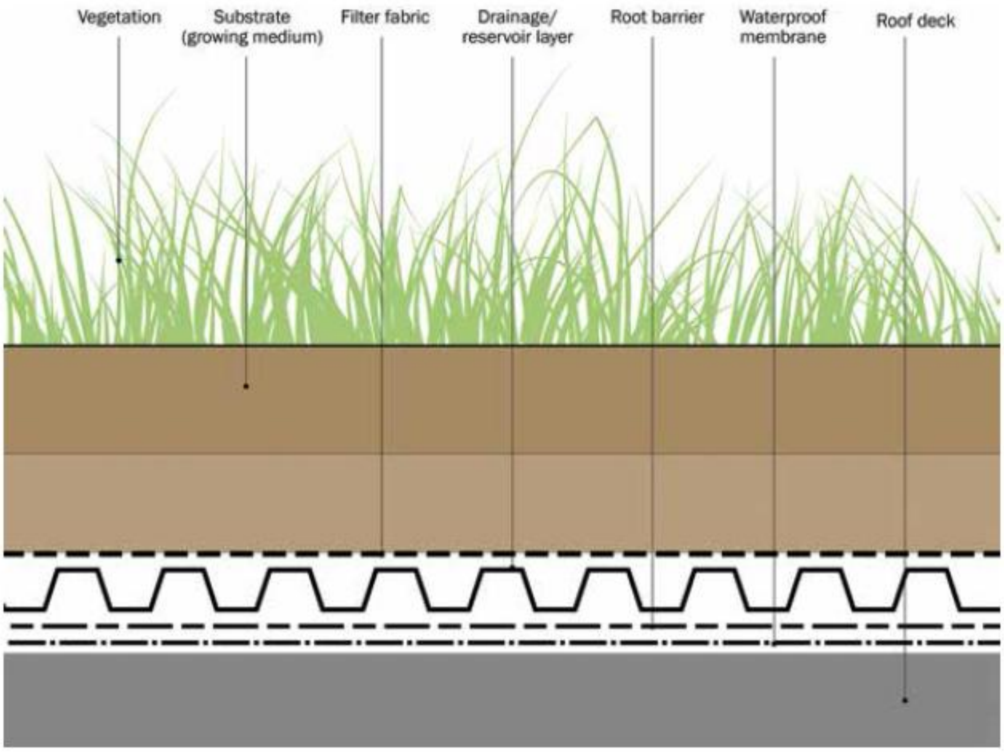

Figure 2 Green roof parts [12]

A typical green roof is composed of different layers as could be observed in the figure 2, from the top to the bottom they are:[13] [14]

- **Vegetation**: With long or short roots, depending on which type of roof is it.

- **Substrate**: It has a different composition in function of which plants are seeded, and it depens on which reduction of pollutants is desirable. A suggestion of composition to this layer could be:

Table 2.Green Roof grain size graduation

Reference values		
Physical property	Extensive	Intensive
Particle size ≤ 0.063 mm (fines)	≤ 15% (by mass)	≤ 20% (by mass)
Particle size > 4.0 mm	≤ 50% (by mass)	≤ 40% (by mass)
Maximum water holding capacity	≥ 25% ≤ 65% (by volume)	≥ 45% (by volume)
Water permeability	0.6–70 mm/min	0.3–30 mm/min
pH value	6.0–8.5	6.0–8.5
Organic content	≤ 65 g/1	≤ 90 g/1

- **Filter layer**: It could be a natural filter, made with a material of different particles size or could be a geotextile. The function of this layer is preventing the wash of fines.

- **Drainage**: In this part, the water is collected and stored before to be released to the general drainage system.

- **Roof barrier and waterproof membrane**: They are the layers that protect the roof of the building against the water and isolate it.

Benefits

Green roofs are one of the Nature-based solutions that use a space that usually does not have any use and give to this space several functions. Usually, the green roofs are more expensive than the conventional roofs, but this kind of roof produce a long-term and hydrological benefits, besides other benefits explained below.

Peak flow attenuation: Green roof can provide a reduction of peak flow rates in the small or medium rainfall events. The reduction is most significant in summer where the temperatures are higher, therefore, the evaporation is higher too.

The rainfall events to design green roofs usually are around 12 to 36 hours; this represents the conditions of autumn and winter, when the reduction of volume is smaller.

Volume control design: The volume control is produced by two mechanisms, the first one is the volume storage in the void space of the different layers, and the second one is the volume reduced by evapotranspiration.

The reduction rate assumed during summer is around 3 mm/day and in winter is 0 mm/day; on the contrary, reduction produced by a green roof during an extreme event does not produce a big impact in the peak flow attenuation or in the water volume reduction.

Reduction of pollutants: Green roofs could produce a reduction of some pollutants like TSS or Phosphorus dissolved in the rain water, but increases the amount of other pollutants. The problem here is that rainwater usually has a very low concentration of pollutant and the green roofs soil has a low concentration of pollutant too, but it is higher than the rain water concentration, therefore, it produces an increment of pollutants, as cold be observed in table 3[15] [16] [17] [18]

Table 3.Green roof, reduction of pollutants

	Median inflow	Median outflow	% Removal
Pb (µg/L)	6.58	17.26	-162.31
TSS (mg/L)	67.04	20.42	69.54
Cu (µg/L)	4.93	13.02	-164.10
Zn (µg/L)	28.64	52.28	-82.54
P (mg/L)	0.2	0.17	15.00
pH	5.62	6.84	-

Energy saving: Basically the energy saving produced by green roofs is because the coefficient of energy transference is reduced when the green roof is installed. A non-insulated roof has a coefficient of energy transference around 7.7-18.18 W/m2K whereas a moderately insulated roof have 0.74-0.80 W/m2K. If green roofs are installed in these roofs the coefficient of energy transference could be reduced until 1.73-1.99 W/m2K, in the non-insulated roof and to 0.55-0.59 W/m2K, in the moderately insulated roof. This reduction of transference of heat produces a total annual energy saving of 31-44% in non-insulated and 3-7% in the moderately insulated. All of this values are represented in the table number 4, obtained from the study of NIchaou in 2001. [20]

Table 4.Green roof, Energy saving

Roof construction	U-value without green roof(W/m^2K)	U-value with green roof(W/m^2K)	Annual energy saving % for heating
Moderately Insulated	0.74-0.80	0.55-0.59	3-7 %
Non insulated	7.76-18.18	1.73-1.99	31-44 %

Biodiversity: This is another benefit of green roofs, it helps to conserve and create the biodiversity creating a green space in the middle of the cities and creating a habitat for animals and insects. This green roofs can be designed to provide benefits to different objectives, as birds, invertebrates. Depending on these objectives could be planted different types of vegetation. If the objective is to support these animals the minimum depth of substrate should be 80 mm, besides have a variable depth around the surface could enhance this objective. [20]

Basic design

Green roofs have a similar behaviour as soil moisture behaviour in ground soil, which they have some inflows minus some outflow and this balance produce a storage or deficit in the storage water, the basic equation(equation number 1) to characterise this phenomenon is:[21]

$$I - ET + P - RO - DP + CR \pm \Delta SF \pm \Delta SW = 0$$

(Eq. 1)

Where *I* is irrigation, *ET* is evapotranspiration, *P* is precipitation, *RO* is surface runoff, *DP* is deep percolation, *CR* is capillary rise, *SF* is the change in subsurface flow and *SW* is the change in soil water content. All variables are measured in millimetres.

But in a green roof, some of these phenomena don't exist or have a different behaviour. For example in the extensive green roof type, the irrigation is not used. The surface runoff is not considered because it is considered that the soil used in the substrate has enough porosity to not produce runoff. Deep percolation doesn't exist but can be assimilated as the outflow produced by the green roof through lower part. The capillary rise is not possible because it is not accessible to the water table. And subsurface flow is considered zero [22].

Taking into account all of these considerations the previous equation (number 2) it is simplified to:

$$ET = P - RR \pm \Delta SW$$

(Eq. 2)

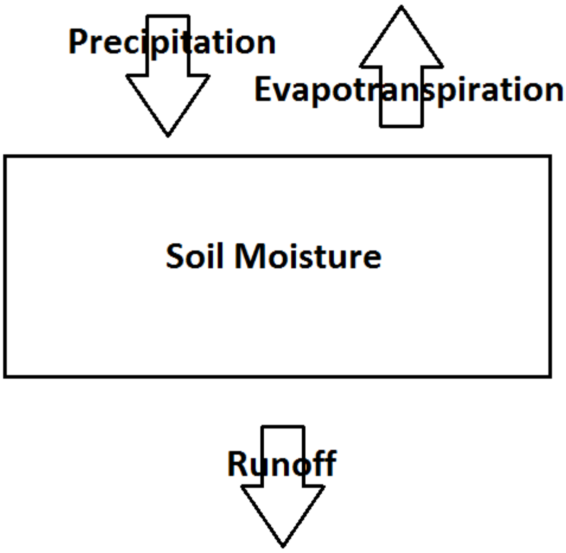

Figure 3. Soil moisture routine

Where P is the precipitation and RR is the Roof runoff, in the first equation was considered as deep percolation. And SW is the change in soil water content.

Using the *"Hargreaves equation"* it is possible tocalculate the evapotranspiration in function of temperatures and radiation (equation number 3) [23]:

$$ET = 0.023 * Ra * (T_{ave} + 17.8)(T_{max} - T_{min})^{0,5} \quad \text{(Eq. 3)}$$

The variables in this equation are average temperature (T_{ave}), maximum temperature (T_{max}), minimum temperature and extra-terrestrial radiation (Ra)

The precipitation is obtained directly from meteorological systems or rain gauges installed in the area. The change in the storage volume depends on the reservoir layer characteristics such as: field capacity, wilting point, density, and fractions of sand, silt, and clay. Finally, the runoff is obtained as a result of applying the equation number 2.

Variables

Irrigation *mm* (I)

Evapotranspiration *mm* (ET)

Precipitation *mm* (P)

Surface runoff *mm* (RO,RR)

Deeper percolation *mm* (DP)

Capillarity Rise *mm* (CR)

Surface flow *mm* (SF)

Storage volume *mm* (SW)

Extra-terrestrial radiation $MJ/m^2 day$ (Ra)

Average temperature *°C* (T_{ave})

Minimum temperature *°C* (T_{min})

Maximum temperature *°C* (T_{max})

On the other hand,it is possible to use a simplification of the hydrological model called HBV. Green roof behaviour could be assimilated to the subroutine of soil moisture illustrated in the figure 4[23].

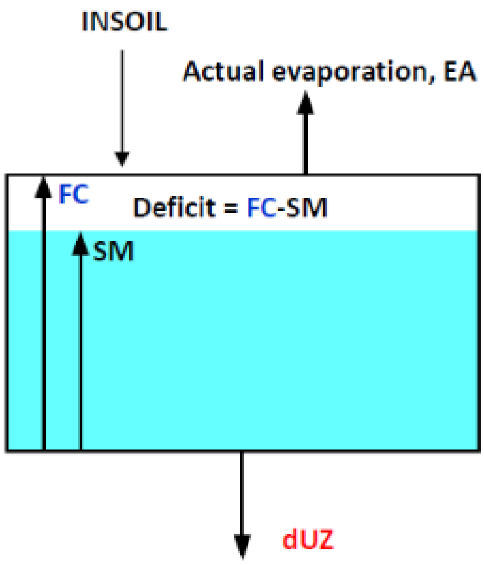

Figure 4. HBV model soil moisture routine [24]

SM = Actual soil water storage

FC = Field capacity

LP = Threshold for potential evapotranspiration

dUZ = RR = Roof runoff

EA = Actual evapotranspiration

EPOT = Potential evapotranspiration

INSOIL = P = Precipitation

β = Empty factor

$$dUZ = P * \left(\frac{SM}{FC}\right)^{\beta}$$

(Eq. 4)

In this model the runoff is calculated as a function of the precipitation, which the maximum field capacity is, and which the actual water storage is, as it is indicated in the equation 4. The factor β explains how the discharge on the ground is produced. If the soil has a fast response it corresponds with a factor of β = 0,5 ; if the response is normal, β = 1; and if the response is slow β = 2 as could be observed in the figure 5.

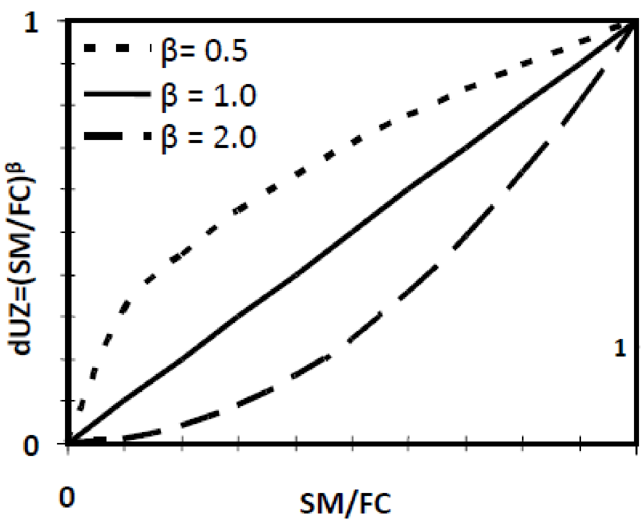

Figure 5. HBV model, runoff response [25]

The evapotranspiration is calculated as a reduction of the potential evapotranspiration, reduced in function of how saturated the soil is as it is showed in the equation 5

$$EA = EPOT * \frac{SM}{LP}$$

$SM < LP: EA = EPOT * \left(\frac{SM}{LP}\right)$

$SM > LP: EA = EPOT$

(Eq. 5)

Finally to calculate the change of water content in the soil is possible to use the next equation (number 6):

$$SM_{t+1} = SM_t + INSOIL - dUZ - EA$$

(Eq. 6)

Modifications in the design, to reduce the long term maintenance cost and extend the life cycle.

Superficial erosion and erosion channels, produced by strong storms, or several numbers of storms [25].

- To reduce the erosive impact is possible to place a layer of gravels with a high permeability above the substrate, after the initial growth of the vegetation planted on it.

- Using a substrate well graduated could be avoided the appearance of erosion channels. The soil size grain graduation proposed is:

Table 5.Green roof, substrate grain size graduation

Material (Sieve size)	% of material
Clay and silt (< 0.063 mm)	< 10%
Fine gravel (2.0–6.0 mm)	> 75%

Rooftop permeability problems

- Using soils with a slow response (β = 2) to maintain the water into the soil instead of in reservoir layers could be prevented the storage of water in the top of the roof and problems of leakages. If the reservoir has a slow response the small storms could be retained and evaporated (less than 5mm of precipitation). In addition, if the extreme events are not common this measure can enhance the green roof behaviour.

- Ensuring a minimum slope of 2% to the roof to can convey the stored water into the reservoir sheet, until the drainage system when the maximum capacity is raised in this layer, in this way it is prevented the storage of water in the top of the roof and problems of leakages.

Water pounding in the system produced by the clogging of drainage system

- Using drain screens and covers to help to retain the leaves, debris and litter carried by the water, to prevent the clogging of the inlet.

- It is possible to prevent this phenomenon placing barriers of plants near to inlet of the drainage system for retaining the debris and litter carried by the water.

Low evapotranspiration, because there is a low solar radiation

- Installing green roof systems in roofs where the solar radiation is maximum this maximized the average, minimum, and maximum temperature, therefore, the evapotranspiration is bigger. In this way, it is more probable that the substrate layer will be not saturated; therefore, the substrate has less possibilities to stay always saturated .

- Studying the pattern of shadows to maximize the number of hours of sun that green roofs receive therefore it will have a higher evapotranspiration and the substrate have less possibilities to stay always saturated .

Maintenance proposed

Table 6.Green roof, schedule of maintenance

Type of maintenance	Actions	Frequency
Regular inspections	Inspect all the components looking for big damage, or differences between the actual situation and the initial one.	Annually or After severe storms
	Inspect if exist any leakage because the waterproof membrane is damaged.	Annually or After severe storms
	Inspect the drainage inlets and drainage screens to ensure that are not clogged.	Annually or After severe storms
	Inspect soil substrate in detail to find possible erosion or erosion channels.	Annually or After severe storms
Regular maintenance	Remove the litter and debris from drainage screens and vegetation to prevent the clogging of the inlet drainage.	Six monthly or as required
	Remove the fallen leaves and debris from the substrate layer.	Six monthly or as required
	Remove invasive vegetation.	Six monthly or as required
	Remove the dead plant and replant if is necessary.	Annually (in autumn)
Regular actions	If erosion channels or superficial erosion are detected, add a thin layer of substrate(same composition) if the damage is big could be considered add a thin layer of gravels	As required
	Drainage is settled, cracked or moved from the original position, repair or replace the inlet.	As required
	Leakages detected. Repair the waterproof membrane or apply a waterproof treatment in the roof if leakages are detected	As required

Soakaways

Description

Soakaways are excavations in the ground that are filled with a backfill material, that allows a temporary storage of stormwater inside of this voids space, therefore, the filling material should be designed to have the maximum void spaces as possible. These excavations could be filled with nature materials like gravel or with synthetics material like a geocellular units, that provide a high percentage of void space in comparison with the typical filling material (gravels or sands).

The soakaways can be classified and constructed in two different ways. The first type is constructed by precast concrete manhole rings, surrounded with granular backfill (Figure 6). The second type consists of an excavation in the ground, filled with granular backfill or geocellular structures; these are covered by a geomembrane or a filter material that separate the original material from the backfill (Figure 7)[26].

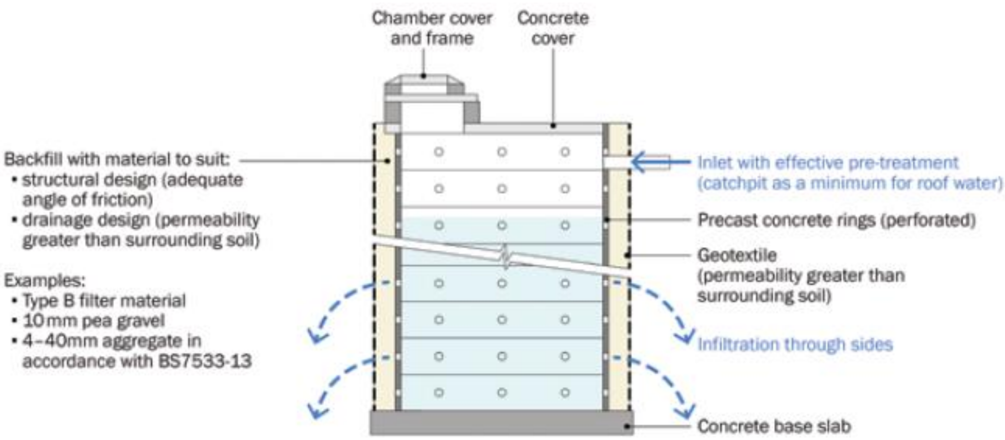

Figure 6 Soakaway -Concrete ring [27]

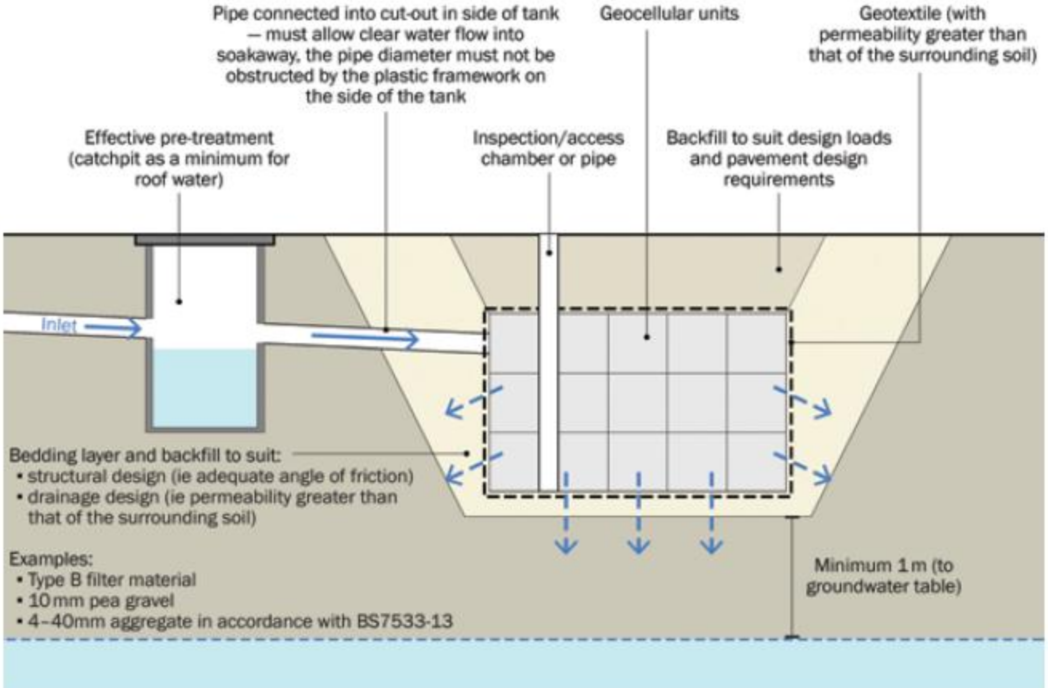

Figure 7 Soakaway – Backfill soil type [28]

Soakaways are considered an infiltration system, it mean that the rainwater will be infiltrated into the ground and finally arrive at the ground water, therefore, the quality of the water infiltrated must meet some quality requirements. To meet these requirements, the infiltration systems usually they have pre-treatments systems to remove pollutants and solid particles before to infiltrate the water into the ground.

Benefits

Soakaways have multiple objectives and their installation produces several benefits such as peak flow attenuation, volume control design, reduction of pollutants, and biodiversity.

Peak flow attenuation: This system could produce good peak flow attenuation in function of how big it is the bioretention and the permeability of the surrounding material, the bigger and more permeable it is the bigger attenuation is produced. In this system, the capacity of the inlet pipe limits the maximum inflow therefore the maximum attenuation per second. [29]

Volume control design: The soakaways volume control is limited by the maximum intern volume that the system could storage and the maximum outflow generated by it, as is explained in the *Basic design*. In the same way, that the Peak flow attenuation as the bigger and more permeable, it is the bigger is the volume control.

Reduction of pollutants: Soakaways could produce a reduction of several pollutants such as TSS, lead or zinc. To have an accurate data of reduction of pollutants it is necessary to do a specific study for each system because in function of the pre-treatment systems, the soil composition and backfill material the reduction of pollutants could change. From the analysis made it by Barraud could be estimated an average of reduction of pollutants, made by soakaways.[30]

Table 7.Soakaways, Reduction of pollutants

	% Removal
TSS	80
Pb	98
Zn	54-88

Amenity: Soakaways are nature-based solutions that don't need an especial space to be installed. It means that if it is desired to install a soakaways is possible to use green areas that already exist, and only is necessary restrict the pass of heavy machinery beyond it to don't compact the backfill.

A soakaway could be designed with a double objective, the hydraulic benefit and the social aim. In this case, it is possible to create a green space where the surface is used as a green area with multiple recreational uses and a soakaway is placed into the ground below it.

Basic design

The soakaways usually are designed to manage the rainfall of 1:10 to 1:30 years of return period or bigger, the largest ones manage 1:100 years event. This system should discharge the storage water in a reasonable time, if the components are designed to 1:10 event it should discharge all volume on it in 24 hours, however if the components are designed to 1:30 event is enough to have half discharge in 24 hours (in this case, the volume of discharge could be very large, the empty time could be larger if it is performance an analysis of risk and consequences)

Below, it is a simple design guideline proposed. In the first one the aim is to obtain a pre-design of the size necessary in a soakaway to manage a specific rainfall. In the second one, it is proposed a guideline to design a 3D soakaway, and determine the empty time.

Design of soakaway volume

The volume of the soakaway and the water storage volume (S) it is obtained as the difference between the inflow (I), the rainfall event from the return period selected, and the outflow (O), the volume that the soakaway can infiltrate into the soil.[31]

$$I - O = S \tag{Eq. 7}$$

The inflow is calculated as the area that has to be drained (A_D) multiplied by the duration of the storm of design (D) and the intensity of this storm (i)

$$I = A_D \ D \ i \tag{Eq. 8}$$

The outflow is calculated as the half part of the soakaway area, that can infiltrate water into the ground ($A_{50\%}$), multiplied by the infiltration coefficient of the ground around the soakaway (Ks) and the duration of the rainfall event (D)

$$O = A_{50\%} K_s \ D \tag{Eq. 9}$$

$$A_{50\%} = 2(L + W) * \frac{H}{2}$$

(Eq. 10)

Finally to calculate the storage volume it is calculated by the difference between the inflow and the outflow, divided by the porosity of the backfill material (n)[32].

$$S = n \ L \ W \ H$$ (Eq. 11)

$$\frac{I-O}{n} = V$$ (Eq. 12)

<u>Design of maximum height and the base area of a soakaway</u>

The equation to calculate the necessary soakaway base area (A_b) is a function of the maximum height of water allowed in to the soakaway.

$$A_b = \frac{A_D \ i \ D}{n \ h_{max} + q \ D}$$

(Eq. 13)

First of all it is obtaining the infiltration coefficient divided by the infiltration factor (q), and the porosity of the backfill material (n), having this data it is selected an intensity (i) and duration of the storm of design (D) finally with all of these data is possible calculate the maximum height (h_{max})

$$h_{max} = \frac{D(R \ i - q)}{n}$$

(Eq. 14)

Where ¨R¨ is the ratio between the area that has to be drained (A_D), and the soakaway base area (this one should be estimated in this step).

$$R = \frac{A_D}{A_b}$$

(Eq. 15)

To calculate the maximum height and the base area it is necessary to do an iteration process giving values of the area that has to be drained and check when both formulas have the same results. If the maximum height or the base area are too big, have to be considered to reduce the rainfall return period (D,i) or the area that have to be drained.

<u>Design of infiltration system and time to empty</u>

The equation to calculate the half empty is:

$$\frac{n\ A_b}{q\ P}\log_e\left[\frac{h_{max}+\frac{A_b}{P}}{\frac{h\_max}{2}+\frac{A_b}{P}}\right] \qquad \text{(Eq. 16)}$$

In addition, if the half empty time is 24 hours the infiltration coefficient (q) must meet the next inequation.

$$q > \frac{n\ A_b}{24\ P}\log_e\left[\frac{h_{max}+\frac{A_b}{P}}{\frac{h\_max}{2}+\frac{A_b}{P}}\right] \qquad \text{(Eq. 17)}$$

Variables

Soakaway Inflow m^3(I)

Soakaway outflow m^3(O)

Water storage volume m^3(S)

Area to be drained m^2 (A_D)

Base area m^2 (A_b)

Perimeter m^2 (P)

Duration of the storm of design *h* (D)

Intensity storm of design *m/h* (i)

Infiltration coefficient *m/h* (Ks)

Porosity of the fill material m/h (n)

Infiltration area m^2 ($A_{50\%}$)

Modifications in the design, to reduce the long term maintenance cost and extend the life cycle.

Reduction of Infiltration coefficient or porosity of fill material because compaction of fill material or the terrain around the soakaway.

- Use materials that don't suffer big settlements with low loads
- Place the soakaway at enough depth to avoid the influence of the compaction
- Use machinery that exert a low ground pressure
- Plant some vegetation with short roots over the soakaway to avoid the circulation of vehicles over them. The reason use of vegetation with short root is because it should not arrive until the void space where it is storage the water.

Decreasing of filtration coefficient or Porosity of fill material, by clogging.

- Replacing the material around the soakaway by a filter material well graduated to prevent the wash of fines therefore the clogging.
- Using pre-treatments systems that remove the silt and clay materials from the water before that it enters in the soakaway.
- In the soakaways that use geocelular structures, it is possible to place at the deeper part, a collector of fine materials to prevent the clogging.

Erosion process into the soakaway or in the inlet because the inclination is too big.

- Reduce the inlet inclination. Less than a 5% of inclination reduces the velocity of the flow in the inlet and therefore the erosive energy.
- Place materials like gravels, before the entrance in the soakaway to reduce the erosive power of the water.

Maintenance proposed

Table 8.Soakaways, Schedule of maintenance

Type of maintenance	Actions	Frequency
Regular inspections	Inspect all the components looking for big damages, or differences between the actual situation and the initial one.	Annually or After severe storms
	Inspect the pre-treatment systems to prevent the clogging of it.	Annually
	Inspect the drainage inlets and drainage screens to ensure that are not clogged.	Annually or After severe storms
	Inspect backfill soil that covers the soakaway to find possible erosion or erosion channels.	Annually or After severe storms
Regular maintenance	Remove the litter and debris from drainage screens and vegetation to prevent the clogging of the inlet drainage.	Six monthly or as required
	Remove the roots that could cause blockages	Annually
Occasional maintenance	Remove sediments from pre-treatment components, tubes or concert chamber (if it exists)	As required, based on inspections
Remedial actions	Reconstruct the soakaway structure and/or clean the fill material (will require a complete reconstruction)	As required
	Reconstruct and/or replace geocellular structures if it is deteriorated (will a complete reconstruction)	As required
	Replace or clean the geotextile (if it exists) (will require a complete reconstruction)	As required
Monitoring	Check the emptying behaviour of soakaway and control the emptying time.	Annually

Swales

Description

Swales are shallow channels where the flow is conveyed through of a layer of vegetation or crushed rocks, to reduce the velocity of the flow, and produce a sedimentation or precipitation of pollutants and sediments dissolved in the water. The lateral slopes are inclined and usually the upper part is lined with rock to reduce the erosion in the extreme events. The base of these channels should be rock lined or uniform vegetated to protect the soil.

The main objective of a swale is to slow down the velocity of the water that flows through it. To achieve it, the flow should be shallow, to maximize the water contact and the friction with the vegetation. In the normal rainfall events The water should not exceed the vegetation or the lined stones, in this way the coefficient of roughness will be enough to reduce the velocity of the water and produce sedimentation of pollutants desired.

The most common designs of swales are designed to have a non-erosive flow with the rainfall event of 2 years of return period and the maximum capacity of the swale is raised with the rainfall event of 10 years of return period.[33]

There are two main group of swales:

- **Wet swale:** This type of swale usually has a wider base covered by vegetation. The fill material could be the original material or a compost to enhance the plant growing. This system provides, water quality benefits using the residence time and nature growth of vegetation to treat the stormwater.[34]

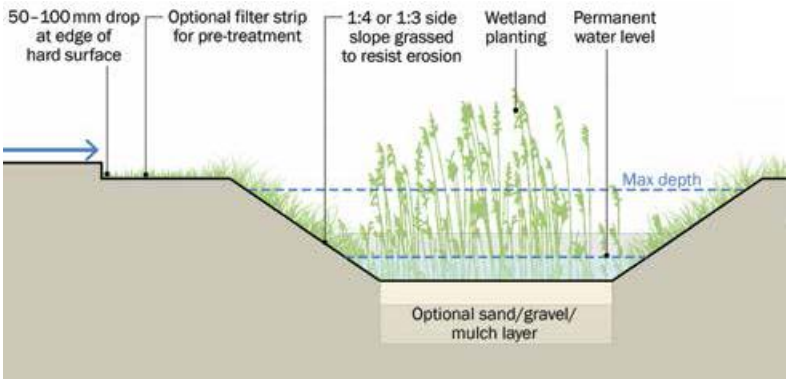

Figure 8. Wet swale type [35]

- **Dry swale:** This type of swale usually has a base excavated in the original soil and filled with a layer of high permeable material. Inside of this impermeable material it is placed a perforated pipe to collect the water and convey it to the release point. Usually, the perforated pipe and the fill material are separated by a geotextile or a filter layer made of graduated materials. This type of system facilitates the water infiltration into the grown, increasing the available infiltration area.

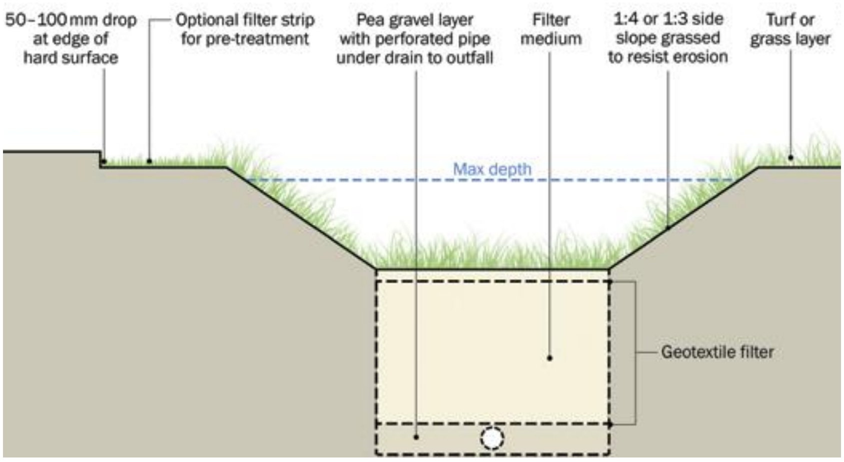

Figure 9. Dry swale type [36]

Benefits

The swales are usually placed near to longitudinal structures such as roads or railways. These types of structures generate pollutants derived from the use of it, such as salt, TSS, or heavy metals. Therefore is necessary treat this runoff that has a concentration of pollutants unacceptable, but it is complicated, because they are long structures with a uniform contamination. Applying a local treatment to reduce the pollutant concentration will be very expensive, for this reason, one of the most suitable solutions are the swales. They could be placed near to these structures and usually they have the best cost-effectively ratio in this scenario because this systems have a low cost per longitudinal meter. In addition,swales can produce a small peak flow attenuation and produce an amenity benefit.

Peak flow attenuation: The peak flow attenuation could be calculated using standard hydraulic assessment. The infiltration contributions can be only included in the dry swales and if the longitudinal slope is lower than 1.5 %. The attenuation will be calculated as:

$$Attenuation = \sum Volume\ of\ each\ layer * Porosity\ of\ each\ layer$$

(Eq. 18)

Volume control design: The volume control design that could produce the swale is not significant in the runoff generated by the big rainfall event, but in the small rainfall events, this reduction could be significant.

Reduction of pollutants: The vegetated swales could produce a reduction of some pollutants like TSS, Copper or Zinc that are suspended in the runoff. The swales can improve the water quality removing particles with a size bigger than 6 to 15 µm. On the other hand, it is not very effective removing dissolved pollutants in the water, like the nitrogen. The reduction of pollutants varies in function of the planted vegetation and the concentration of pollutants in the runoff. Some approximations of the pollutants removal percentages are:[37]

Table 9.Swale, Pollutants removal

	% Removal (SWAMP)	% Removal (J.F. Sabourin& Associates)
Pb	75	99
TSS	24	81
Cu	96	66
Zn	93	90

Amenity: Swales can be placed in many different landscapes providing vegetated corridors in streetscapes, enhancing the landscape vision. These corridors should avoid the sharp bends to reduce the erosion and with not steep slopes to don't be dangerous for the people that could fall inside on it. The seeded plant species should be local species if it is possible to suit the local landscape and prevent plant invasions.

Biodiversity: Swales can include a big variety of plants preferably native plants species, and sometimes wildflower grass if it requires have not, a big maintenance. This vegetation has a positive contribution to the biodiversity, providing food and suitable habitat for insect, birds, and invertebrates. The use of native plant species will do easier create a sustainable area suitable for indigenous species

Basic design

In the design of swales, the most important variables are which type of vegetation will cover the channel, the longitudinal inclination, and the shape of the swale. With this data it is possible to calculate the flow that could be treated by the swale(WTR). This flow should be minor or equal than the runoff estimated in the designed rainfall event. The other design criteria derived than the last one, it is the velocity. The excessive flow velocity could damage the swale vegetation, producing erosion and an incorrect treatment of the runoff. Before to start with the basic design formulation, it will be provided some advice, about which typical ranges of design variables are.

The trapezoidal section is the typical cross section shape in swales, it is because is easier to construct and easier to maintain than other shapes like the parabolic section. In this trapezoidal sections the typical inclinations for the lateral slopes are 4H:1V, and the maximum inclination recommended is 3H:1V, because use a steeper slope could produce erosion and damage the vegetation.

The recommended horizontal slope usually it is around 1% to 2.5%, to prevent the vegetation erosion. The maximum possible inclination is 5% but should be checked the possible problems of erosion. On the other hand, the minimum inclination allowed is 0,5 % to prevent the possible water ponding in the swale.

Regarding with the swale dimensions the bottom width can vary between 2.5 meters to 0.5 meters. The minimum of 0.5 meters of width is because try to construct a narrower channel would be difficult, because would be required special machinery. The maximum width of 2,5 meters is because if it is wider could be possible that appears channelling in the flow, producing a not regular treatment in the flow.

Also, the flow depth should be no greater than 70% of vegetation height and never should exceed 0.6 meters.

The maximum velocities that the flow could raise should be controlled too. The maximum velocity could be determined in function of the type of vegetation and the longitudinal inclination of the swale, it is possible use the table 10, it has been obtained from the study of Chow in 1959 [38]

Table 10.Swale, Maximum velocities allowed

Permissible velocity (m/s)			
	Slope range, %	Erosion-resistance soils	Easily eroded soils
Bermuda grass	0-5	2.4	1.8
	5-10	2.1	1.5
	>10	1.8	1.2
Buffalograss, Kentucky bluegrass, smooth brome, blue grama	0-5	2.1	1.5
	5-10	1.8	1.2
	>10	1.5	0.9
Grass mixture	0-5	1.5	1.2
	5-10	1.2	0.9
	>10	Do not used	Do not use
Lespedeza sericea, weeping lovegrass, ischaemum (yellow bluestem), kudzu, alfalfa, crabgrass	0-5	1.1	0.8
	>5	Do not used	Do not used
Annuals—used on mild slopes or as temporary protection until permanent covers are established, common lespedeza, Sudangrass	0-5	0.1	0.8
	>5	Not recommended	Not recommended

Taking into account all of the recommendations suggested above, it will be presented the design calculations. The first one is the calculation of the maximum flow that could be treated by the swale (WTR) and the second one is the remaining time calculation.

Design for swale capacity:

The first objective is ensuring that the WTR is equal or smaller than the runoff generated by the design rainfall event, to calculate that is possible use the equation:

$$WQT = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

(Eq. 19)

Where the hydraulic radius for a trapezoidal section it is calculated such as:

$$R = \frac{(b + zy)y}{b + 2y\sqrt{1 + z^2}}$$

(Eq. 20)

When the WTR is calculated, it is necessary does another checking to verify that the velocity of the flow is slower than the maximum velocity resisted by the swale, these maximums could be found in the table 10, and the velocity in the swale could be calculated as:

$$V = WQT/A$$

(Eq. 21)

Also to calculate the total height of the swale, it is assumed that the swale shouldn't have overflow with the runoff generated by the rainfall event of 10 years of return period. To calculate that, it is possible to use the formula number 19, but in this case, the height of water will be the total swale height instead of the 70% of the vegetation height. In these calculations, the erosion is not important because it is designed to manage an extreme event.

Variables

Water treatment rate *m^3/s* (WTR)

Manning's roughness coefficient (n)

Flow depth *m* (y)

Swale bottom width *m* (b)

Hydraulic radius *m* (R)

Longitudinal swale slope *%* (S)

Area covered by the flow in the cross-section [(b+zy)y] *m^2* (A)

Side slope, ratio of horizontal distance respect to vertical distance ¨***z***¨*H:1V* (z)

On the other hand, swales remove the pollutants by sedimentation and to achieve this, it is necessary to have a hydraulic residence time (HRT) this time usually is around 5 to 9 minutes. Knowing the velocity of the flow and the desired residence time is possible to calculate the minimum swale length using the next equation.[39]

$$HRT = 0.014\left(\frac{L}{V}\right)^{1.003}$$

(Eq. 22)

Variables

Hydraulic residence time *min* (HRT)

Length of the swale *m* (L)

Velocity at the designing flow *m/s* (V)

Modifications in the design, to reduce the long term maintenance cost and extend the life cycle.

Superficial erosion produced by the excessive velocity of the flow.

- Increasing the width of the bottom of the swale will be reduced the height of the flow, producing an increment of friction between vegetation and flow. Therefore, the velocity will be smaller and the erosive energy too. Also, the vegetation height could be incremented, but it only can be modified in a couple of centimetres, therefore, the change will not be very significant.

- Reducing the longitudinal slope inclination, it affects directly to the flow velocity, therefore, to the erosive energy. In addition, if the inclination is flatter the vegetation can assume a higher velocity before suffering erosion as can be observed in table 10.

- In the case that the longitudinal slope inclination could not be modified, it is possible to construct check dams. Check dams are structures constructed by coarse aggregate (100-600mm) or wooden boards, usually are placed every 10-20 meters, when the inclination is bigger than 5%. These structures allow the pass of water in the centre of the structure, where is placed energy dissipation material (as gravel stone spreader, or washed stone of 3-10 mm in diameter) which it is extended 1-2 m downstream to protect the original soil and the vegetation. Also it is necessary to ensure that the water does not bypass the sides of the dam. With this system is possible to reduce the inclination between check dams

Pounding of water that could produce damage to the vegetation or hypoxia

- The longitudinal slope inclination could be modified to ensure a minimum inclination of 0,5% in all points of swale, to prevent the pounding of water.

- Changing the type of vegetation by one adapted to this pounding condition, such as the wetland grass species.

Erosion channels and meandering flow

- Pay attention to the plant coverage, and reseed if the percentage of coverage is lower than the 90%. If the plant coverage is not correct, exists more risk to damage the swale soil. It could produce erosion channels, therefore, an unequal treatment of the water.

- Designing the swale without sharp bends to prevent the meandering flow. The sharp bends can force the flow to be concentrated on a side of the swale, producing an unequal treatment and higher erosion.

Clogging in the perforated pipe, (if it exist) it produces a not correct evacuation of water, and could produce pounding.

- If the system is designed to evacuate part of the runoff through a perforated pipe, it is necessary to ensure that it does not exist clogging in the holes of the pipe. One solution to prevent the clogging is placed a filter layer or a geotextile between the original soil and the perforated pipe.

- Another possible problem is the accumulation of sediments into the perforated pipe, reducing the useful diameter to convey water. To avoid this, it is possible to place a filter layer or a geotextile between the original soil and the perforated pipe.

Swale erosion, when the vegetation is not completely installed.

- When the vegetation doesn't cover at least 90% of the swale and the height is not the designed yet, to reduce the erosion and allow the correct growing of the vegetation; the swale should be protected and don't allow the entrance of runoff on it. It can be protected placing barriers as a gravel trench that doesn't allow the entrance of water in the swale, or covering the vegetation with a geotextile until it raises the height of design.

Maintenance proposed

Table 11.Swales, Schedule of maintenance

Type of maintenance	Actions	Frequency
Regular maintenance	Remove debris and litter from the surface.	Monthly, o as required
	Cut the grass till the design height (around 75-150 mm)	Monthly during growing season, or as required
	Remove intrusive plant species.	Monthly during growing season, or as required
	Clean the inlets and outlets to prevent possible blockages.	Monthly
Regular inspections	Inspect the infiltration surface where it could be produced pounding or silt accumulation.	Monthly
	Inspect the inlets and surfaces where it is produced the sedimentation to establish an appropriate silt removal frequency (max sediment depth 25 mm)	Every 6 months
	Inspect the initial growth of vegetation	Monthly during the firsts 6 months, 4 times during the 2 next year then twice a year
	Inspect the perforated pipe to avoid possible clogging (If perforated pipe exists)	Annually, or as required
Occasional maintenance	Inspect presence of the pollutant in the swale, to detect not expected pollutants.	Every 6 months, or as required
	Reseed areas with poor vegetation.	As required, where the soil has a 10% of exposed area
Remedial actions	Repair the vegetation erosion by reseeding.	As required
	Repair erosion channelling by backfilling with similar soil to the original one.	As required
	Repair or replace inlets and overflow systems damaged or clogged.	As required

	Levelling and realigned of slopes to the original level	As required
	Scarifying and spike topsoil layer to improve the infiltration ratio, to prevent compaction of the soil surface	As required
	Remove the sediment accumulation in the upstream systems such as, filter strips or flow spreaders	As required

[40]

Vegetated strips

Description

Strips are surfaces densely vegetated, covered by grass, installed in slopes with a little inclination, next to the impermeable surface. Their function is collect the water from the impervious zones, and convey it until a swale, or other Suds components. In addition, the strips do a pre-treatment of the water. Basically, strips enhance the sedimentation of solids and pollutant suspended into runoff, before to release it into principal SuDS systems. The water should flow in sheet flow and in a thin sheet to maximize friction between the grass and the water, to reduce the velocity of the water, thereby enhancing sedimentation process[41]

Vegetated strips are composed basically of three elements, the vegetation, the topsoil layer and the engineered soil layer

- **Vegetation:** The vegetation planted in strips is usually turf grass and the height of the vegetation, should be higher than the water flow height in the strip produced by the rainfall design event. The main function of the vegetation is protect the strip from erosion and allows the sedimentation process.

- **Topsoil:** This is the layer where is planted the vegetation, usually it is made by compost to allow the correct vegetation growing. Topsoil should have at least a 150 mm of depth to meet this function.

- **Engineered soil:** This layer is composed of different grain size, this composition depends on of the grain size of the topsoil and the material bellow the engineered soil, this layer actuates as a transition between these two layers, acting as a filter avoiding the fine washing from the topsoil. The minimum depth of this layer is 300 mm.

The strips can have a silt trap placed in the transition between the hard surface and the strip itself, this trap enhances the pollutant removal, preventing the entrance in the strip. Another possible variation in the typical strips construction, it could be placing a geomembrane 0,5 m below the surface to protect the groundwater from the possible infiltrations of pollutants. This geomembrane could be impervious or only act as a filter.

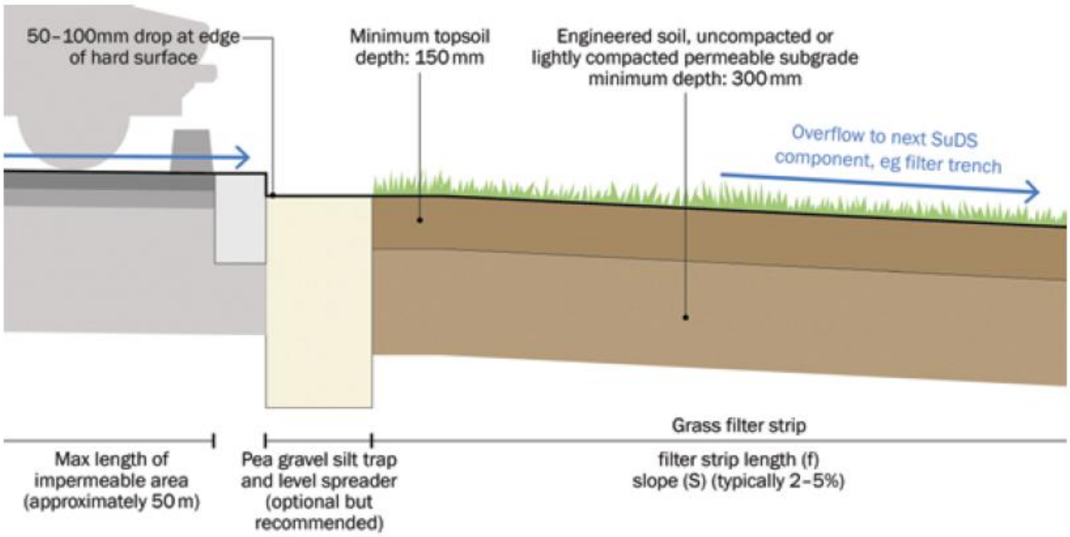

Figure 10. Vegetated strip parts [42]

Benefits

The strips are usually placed near to the longitudinal structures such as roads or railways providing some beneficial impact on these structures. These types of structures generate pollutants, as TSS, or heavy metals. Therefore, it is necessary to treat the runoff generated by them. Strips do a pre-treatment removing some pollutants before to release the water to the main treatments systems. Sometimes it is not possible to construct the principal treatment structures next to the linear structures, in these situations, the strip could be used to convey the water to the final destination. Also, the strips can generate other hydraulic and social benefits such as:

Peak flow attenuation: The peak flow control produced by this system is minimal, it only affects to the small rainfall events and it doesn't have any influence in the big rainfall events. The possible reduction is produced by percolation or evapotranspiration but usually it is not included in the calculations.

Volume control design: The storage volume is minimum. The only volume control that could be made it is by infiltration, it means that the only storage volume available, it is the void spaces of the terrain that it is minimal and it is not usually included in the analysis

Reduction of pollutants: Vegetated strips could produce a reduction of pollutants principally TSS suspended in the runoff. The pollutant reduction percentage is really variable and depends on of a lot of factors as, the slope inclination or the type of vegetation, but roughly the reduction of TSS it is around 80% [43]

Amenity: Vegetated strips can be placed into many different landscapes, providing vegetated areas next to the hard surface, enhancing the landscapes, and improves the perception of people when they are using these linear structures. Plant species should be local species if it is possible to suit with the local landscape and prevent plant invasions.

Biodiversity: Vegetated strips allow the growing of a big variety of plants and it creates a suitable place to some invertebrates and a foraging area for reptiles, amphibians, and birds. Vegetated strips produces an increment of pollination/biological control in the surrounding fields.[44]

Basic design

Basically, the effectiveness of the strip depends on the area available to construct the strip, the inclination of the slope where is placed the strip and the species of planted vegetation. Now it will be provided some recommendation of these variables mentioned before to design a suitable strip.

Typically, vegetated strips are placed on inclined slopes, this inclination usually varies from 1 to 15%. The slopes with more than 10% of inclination, they are only allowed in regions with middle rainfalls, it means that it is only allowed in places where the extreme events are not common. On the other hand, the minimum slope is 1% because with less than it, could appear pounding problems.

The width of the strip is only conditioned by achieving that the runoff has a sheet flow.

The typical values of roughness could vary between 0.2 to 1, in function of the type of vegetation and the length of it. The roughness and the inclination factors should be modified until achieving that the maximum velocity of the flow, be as maximum 0,3 m/s and the maximum height of the flow 50 mm.

Regarding the impervious zone, that discharges water into the vegetated strip, should have a maximum length of 15 to 50 meters. This length could vary in function of the inclination of it and the rainfall intensity. On the other hand, the length of the strip should have 4.5 meters in the same direction than the impervious zone, to ensure that the flow maintains the sheet flow. The typical length of the strips is 90 meters in the muddy slopes and 30 to 45 in the develop areas. To check which is this maximum length that maintains the sheet flow, could be multiplied the length of the strip by the inclination of the impervious zone and check if the result is minor than 0.3 as can be observed in the equation 23. [45]

$$L_I S_I \leq 0.3$$

(Eq. 23)

Another important thing that should be checked is the velocity of the flow, to check if it is acceptable and it doesn't produce erosion. To do this calculation the first of all is necessary calculate which will be the water treatment rate (WTR)

$$WQT \quad = \frac{RvIA_i}{3.6 * 10^6}$$

(Eq. 24)

When the WTR it is knowned it is possible to calculate which will be the height of the flow in the strip (y). (Equation 25)

$$y = \left[\frac{nWQT}{WS_s^{1/2}}\right]^{3/5}$$

(Eq. 25)

At this point when all of this data are obtained, it is possible to calculate which will be the velocity in the strip, it is easy, only is necessary divide the total flow by the flow area as could be observed in the equation 26

$$V = \frac{WQT}{y\,W_s}$$

(Eq. 26)

The calculated velocity must be under the limit of 0.3 m/s, to prevent the erosion.

Variables

Length of the strip, same direction than the flow *m* (L_S)

Wide of the strip perpendicular to the flow *m* (W_s)

Wide of the impervious area that drainage to the strip *m* (Wi)

Length of the impervious area that drainage to the strip *m* (Li)

Longitudinal inclination of impervious zone (S_I)

Water treatment rate m^3/s (WTR)

Runoff coefficient (Rv)

Rainfall intensity mm/h (I)

Drainage area of the impervious area that drainage to the strip L_i* W_i m^2 (A_i)

Manning's roughness coefficient (n)

Wide of the strip perpendicular to the flow m (W)

Flow height m (y)

Longitudinal inclination of strip (S_S)

Modifications in the design, to reduce the long term maintenance cost and extend the life cycle.

Superficial erosion produced by the excessive velocity of the flow.

- Increasing the vegetation height if it is possible. It will increase the friction between the water and the vegetation, reducing the velocity ,therefore the erosive energy.

- Reducing the longitudinal slope inclination, it affects directly to the flow velocity, reducing it, therefore, the erosive energy will be lower too.

- Pay attention to plant coverage and reseed if the percentage of coverage is lower than the 80%, if the plant coverage is not correct the velocity can be higher than the design velocity, and the strip can suffer erosion.

Pounding of water, produces damage in the vegetation or hypoxia

- Modifying the longitudinal slope inclination, to ensure a minimum inclination of at least 0,5% in the strip, it will prevent the pounding.

- Change the vegetation planted by one adapted to these ponded conditions, as the wetland grass species.

Reduction of cover vegetation in dry climate

- In some dry climates it is necessary to use specific vegetation that doesn't need big amounts of water, to avoid the reduction of cover vegetation by the deficit of water as could happen in the Mediterranean climates.

Strip soil erosion produced when the vegetation is not completely installed.

- When the vegetation doesn't cover at least 80% of the strip area, to reduce the erosion and allow the correct growing of the vegetation; the strip should be protected and don't allow the entrance of runoff on it. It can be done placing barriers as a gravel trench that doesn't allow the entrance of water in the swale, or covering the vegetation with a geotextile until it raises the height of design.

Clogging or erosion in the transition between the impervious zone and the strip

- The strip should be constructed 50-100 mm bellow the impervious zone, to have a drop where the sediments could be retained and prevent the clogging in the transition between them, because the difference of velocity from the impervious zone where the flow velocity is higher respect the strip where the flow velocity is slower, could produce sedimentation of material.

Maintenance proposed

Table 12.Vegetated strips, Schedule of maintenance

Type of maintenance	Actions	Frequency
Regular maintenance	Remove debris and litter from the surface of the vegetated strip	Monthly, o as required
	Cut the grass till the design height	Monthly during growing season, or as required
	Remove intrusive species of plants	Monthly during growing season, or as required
	Clean the inlets, outlets to avoid possible blockages	Monthly
Regular Inspections	Inspect the infiltration surface, to detect the water pounding or silt accumulation	Monthly
	Inspect inlets and surfaces where is produced the sedimentation, to establish appropriate silt removal frequency (max sediment depth 25 mm)	Every 6 months
	Inspect the growth of the vegetation	Monthly during the firsts 6 months, 4 times during the 2 next year then twice a year
	Inspect the silt trap to remove the silt accumulation and avoid possible clogging (If it exists)	Monthly, or as required
Occasional maintenance	Reseed areas with poor vegetation	As required, where the soil has a 20% of exposed area
Remedial actions	Repair the vegetation erosion by reseeding	As required

	Repair the soil erosion by backfilling with soil similar to the original	As required
	Remove the sediments and oils or petrol residues from the impervious zone.	As required
	Leveling and realigned of slopes to the original state	As required
	Scarify and spike topsoil layer to improve the infiltration ratio, prevent compaction of the soil surface	As required

Bioretention

Description

Bioretention is a shallow vegetated depression in the landscape that can attenuate the peak flow storing water on it. It could be constructed excavating into the ground or in a natural depression and later filling this space with a backfill material, and covering this backfill material with vegetation. This system produces a reduction of runoff by evapotranspiration, interception, and infiltration. In addition,these systems are usually used to reduce the pollutant dissolved in the water.

Bioretention is a nature-based solution that is easy to adapt to any place because it is very flexible. This type of solutions could be installed in parks and recreational areas, having the function of green areas in the dry periods and during the storms, it will provide reduction and attenuation of runoff. These should have an overflow system to manage the bigger rainfall events, the water that could not be treated, should be transported out of the system to avoid possible damages on it.[46]

As it is illustrated in the figure 11 a typical Bioretention system is composed of these parts:

- **Inlet**: This part collects the water to convey it until the storage surface part. It should be designed with a maximum inclination limit, to prevent the erosion.

- **Surface storage part**: In this part, the water is temporally stored until the filter medium can infiltrate the water. It could have hard edges to increase the storage volume and reduce the erosion produced when there is overflow. Normally the maximum depth of storage is around 150-300 mm.

- **Vegetation**: Vegetation, it influences in the majority of the process that happens in Bioretention, in function of the installed vegetation, it is possible to reduce different types of pollutants, and also it prevent the erosion of the surface. The vegetation can have a strong influence on the amenity and biodiversity , for this reason, should be designed by landscape architects and for an interdisciplinary group of experts.

- **Filter medium**: This part is composed of a sand filter that removes or reduces the concentration of pollutants. It is made of different materials that could absolve or adsorb pollutants, the reduction of pollutants varies in function of the backfill soil composition. Normally it has 750-1000 mm of depth. The smallest catchments can reduce this depth till 400 mm.

- **Transition layer**: This layer is necessary to prevent washing of fines from the filter layer to the drainage layer. This layer needs at least 100 mm of height to achieve this aim. It is usually composed of geotextiles or nature materials like gravel or sand. This layer should have enough permeability to allow water go through it.

- **Drainage layer**: The objective of this layer is to collect the water from transition layer. It must have enough permeability to allow the water enter into the perforated pipes. The drainage layer has to cover the drainage pipes and ensure that it has higher flow rate entrance into the pipes, than the flow rate entrance into the drainage layer to prevent possible pounding in this layer.

  The drainage layer must cover the drainage pipes at least 50 mm, to prevent the entering of sand or silt into the perforated pipes. In addition, this layer can be used as storage, but it should have more storage volume than the surface storage part. It should be checked that after some rain events, the filter medium, is not always saturated, to ensure that the bioretention is working properly.

- **Perforated pipes**: This part collects the water from the drainage layer and conveys it until the release point. If the system aims to infiltrate water, this part is not necessary, because the drainage layer will infiltrate the water into the ground. The minimum diameter of this part should be at least 100 mm.

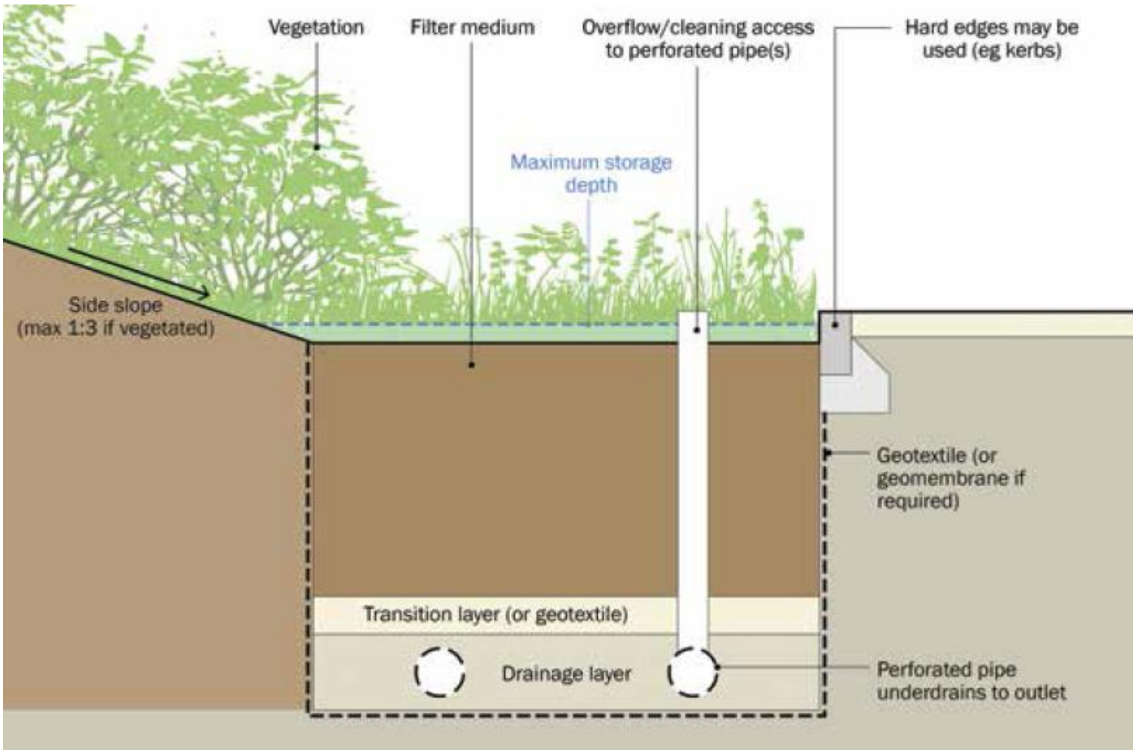

Figure 11. Bioretention parts [47]

There exists a small modification in the Bioretention systems that consists of including an anaerobic system as could be observed in the figure 12, in this system the outlet pipe is above then the perforated pipe. This cause that the water only can be drained when the height of water into the drainage layer is higher than the outlet pipe. This kind of system requires that drainage part be lined with a waterproof layer to ensure the storage of water. With this system is possible to maintain always a small storage of water which is accessible to the plants in the dry periods.

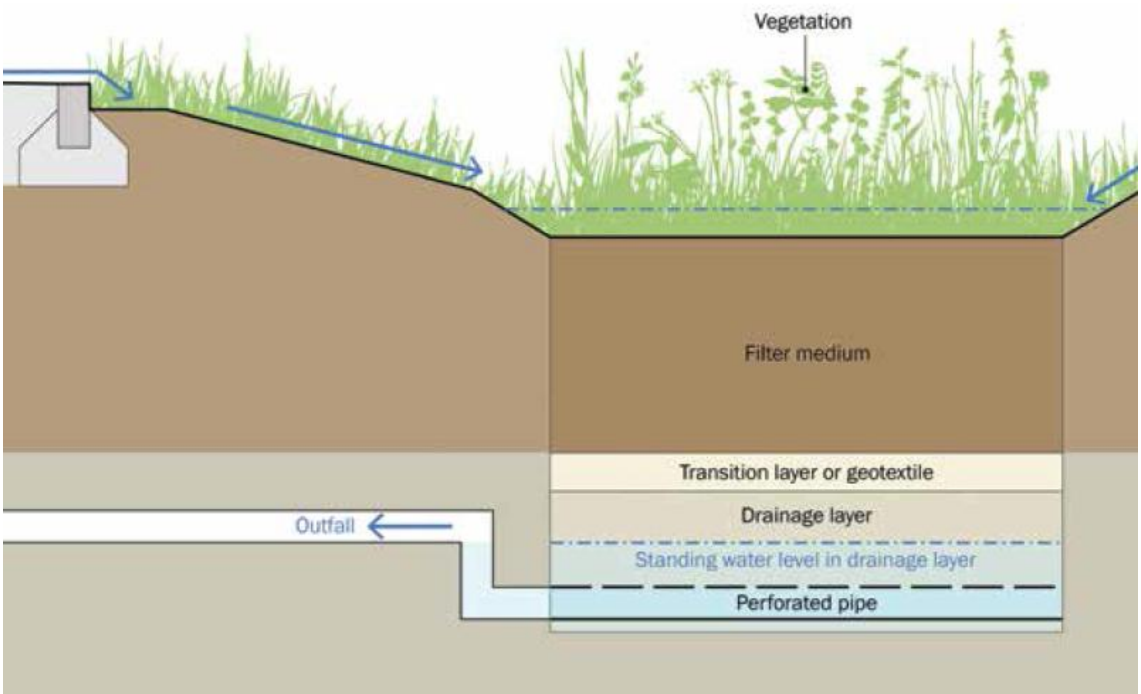

Figure 12. Bioretention with anaerobic system[48]

Benefits

Peak flow attenuation: This system could produce good peak flow attenuation in function of how big and deep it is. The permeability of the surrounding material is another factor that influence in the peak flow reduction, the more permeable it is, the bigger the attenuation is. The peak flow attenuation could be estimated as it is explained in the *Basic design* section.

Volume control design: The contribution of bioretention to the volume control, should be based on which is the expected infiltration. The bigger and more permeable it is the bigger is the volume control.

Reduction of pollutants: Bioretention systems are one of the most utilized to reduce the pollutant concentration, because the combination of vegetation and filter medium produce a reduction of several pollutants. The pollutants removal should be designed to treat the volume of rainfall of 1 year return period. The vegetation should be designed and selected properly to treat the desired pollutants. In the table 13 could be observed a study of New Zealand University where it is studied which concentration of pollutants into the maximum inflow and in the medium inflow. Finally are showed which the respective concentrations are, at the outputs and which the percentages of reduction for each one are.

Table 13.Bioretention, Pollutant removal

	Median inflow	Median outflow	Max inflow	Max outflow	Reduction	Reduction
Pb (μg/L)	11	1	210	180	90.91	14.29
TSS (mg/L)	30	3	375	42	90.00	88.80
	Median inflow	Median outflow	Dissolved inflow	Dissolved outflow		
Cu (μg/L)	37	10	23	15	72.97	34.78
Zn (μg/L)	659	355	29	24	46.13	17.24

[49]

The reduction of pollutants in the bioretention is not constant because the vegetation and the soil composition produce a different percentage of reduction of pollutants. But this New Zeeland study can be compared to another study of the snowmelt pollutant removal in bioretention areas. It could be observed that the percentages of removal are similar.

Table 14.Bioretention, Pollutant removal

	% Removal Snowmelt	% Removal New Zealand Study
Pb	90	100
TSS	90	99
Cu	73	89
Zn	46	96

[50]

Amenity: The bioretention has a good adaptability and it could provide a green area in a big number of spaces, including, in the city. In addition, it could be installed in spaces with green areas already constructed. When the bioretention systems are installed it could be used in the same way than before of the installation and it is only necessary to restrict the pass of heavy machinery above it.

Basic design

The bioretention systems could have multiple shapes and length but the typical width is around 0.6 to 20 meters. Excavate a trench with less than 0.6 meters of width could present construction problems, because it is necessary specialized machinery. On the other hand construct a bioretention with more than 20 meters, could produce problems in the uniformity of treatment around the system. Taking into account this recommendation, it will be presented the required equations to calculate a sizing the bioretention system.[51]

To calculate which area of filter medium, it is possible to use the next equation:

$$\mathrm{WTR} = k\, A_f\, h\, t$$

(Eq. 27)

In the use of this equation is necessary to have some considerations, the volume of water to be treated included in the formula should be the rainfall event of 1 year of return period if the aim is the pollutant reduction. The evacuation time is the time that needs the system to percolate through the filter bed, this time, should be minor than 24-48 hours. Regarding the permeability of the filter, it should be between 100-300 mm/h and it should retain the water enough time to support the vegetation growth.

The drainage layer and the filter layer could be used as attenuation system. To calculate the peak flow control design it is applied a simplification, using an elemental formula:

$$Attenuation = \sum Volume\ of\ each\ layer * Porosity\ of\ each\ layer$$

(Eq. 28)

Of course, with this formula is only possible to calculate the global volume reduction, not the reduction in function of the time. To calculate the attenuation in each step of time is necessary to study how percolates the water through each layer in function of the permeability and which is the maximum water content for each layer.

Variables

Surface filter area *m*^{2}(A_f)

Volume of water to be treated *m*^{3} (V_t)

Filter bed depth *m* (Hf)

Permeability of filter medium *m/s* (k)

Half maximum height of water above filter bed *m* (h)

Evacuation time, percolation *s* (t)

Water treatment rate m3/s (WTR)

Modifications in the design, to reduce the long term maintenance cost and extend the life cycle.

Erosion in the inlet:

- Reducing the slope of the inlet until achieve, that the velocity of the water in the inlet is not higher than 0,5 m/s, for the rainfall event of design. For the extreme rainfall event, the maximum velocity is 1,5 m/s (1:100 years of return period)

- If the bioretention is designed as the end of a swale and it is not possible to reduce the inlet slope, the problem could be solved installing small dams that reduce the speed of the water before to enter in the bioretention.

- Planting dense vegetation with deep roots in the inlet, it could reduce the water speed and reinforce the ground against the erosion.

- If it is not possible to reduce the inclination in the inlet it is possible to install energy dissipater. (not recommendable)

Unequal water treatment.

- Constructing a bioretention with more than 20 meters of wide could affect to how the water is distributed around the filter medium, causing a not uniformly treatment. It means that some zones will require more maintenance than other and the most efficient way to work is to apply the maintenance to all the system at the same time, have different maintenance will reduce the effectiveness.

Clogging of filter media or transition layer

- Using a properly grain size distribution, in the design of the filter media, to avoid the clogging during the water treatment. An example of material size grading for bioretention filter medium could be:

Table 15.Bioretention, Filter layer size grain graduation

Material (Sieve size)	% of material
Clay and silt (< 0.063 mm)	< 5%
Fine sand (0.063–0.2 mm)	< 20%
Medium sand (0.2–0.6 mm)	35% to 65%
Coarse sand (0.60–2.0 mm)	50% to 60%
Fine gravel (2.0–6.0 mm)	< 10%

- Graduating the transition layer according to the filter media, to avoid the wash of fines. To ensure that wash of fines does not occur is possible use "*Steps in filter design*" the appendix 26A from *Gradation design of sand and gravel filters* (National Engineering Handbook) to design the transition layer.

Perforated pipes design

- In the description part was commented, that the perforated pipes should have more permeability than the drainage layer to ensure the correct drainage. If the perforated pipe doesn't have enough permeability the filter media could arrive to be always saturated. For this reason, the holes in the perforated pipe should be designed properly.

Precautions in the construction to prevent over-compactions.

- In the filter media collocation takes care to do not over-compact the soil. Use light machinery and prevent that the machinery runs along planting bed, because it can reduce the permeability.
- If the system is designed to produce infiltration in the low part, it should be prevented that the machinery runs along the trench in the excavation process to prevent the reduction of permeability.

Maintenance proposed

Table 16.Bioretention, Schedule of maintenance

Type of maintenance	Actions	Frequency
Regular inspections	Inspect the infiltration surface, to detect possible silt accumulations or pounding and determine the maintenance frequency.	Quarterly
	Inspect the inlet and outlets systems to prevent the clogging.	Quarterly
	Inspect the surface to detect possible erosion in the soil surface.	Annually or After severe storms
	Inspect the perforated pipe to prevent clogging	Annually
Regular maintenance	Remove the litter and leave from the surface	Quarterly or as required
	Replant original vegetation and remove the intrusive species.	Annually
	Remove sediments from pre-treatment components (if it exists)	As required, based on inspections
Occasional maintenance	Cleaning drainage layer	As required, based on inspections
Remedial actions	Replace the perforated pipe if it is damaged or clogged.	As required
	Reconstruct and/or replace the drainage layer (It will require reconstructions of the bioretention)	As required
	Replace or clean the geotextile (if it exists) (It will require reconstructions of the bioretention)	As required

Excel sheet explanation

The final objective of this excel sheets is create a tool to group all information collected from the 5 systems analysed in the solution approach part . The function of these excel sheet is to do a compendium of all NBS and green solutions installed in a specific area, to can monitor the state of these systems and have a historical record. Whit this tools it is possible to do management and maintenance of these systems, in the most efficient way. In addition, these tools could help in the design and development of new NBS, being based on the experience of others constructed before.

In the picture 13 is possible to observe a capture of one of these excel sheet:

	N°	1				
	Date	[illegible]	12.05.2016	13.05.2016	14.05.2016	15.05.2016
	ID					
System characteristics	Bottom width of the swale m (b)	2.4	2.4	2.4	2.4	2.4
	Total swale height m (H)	1.5	1.5	1.5	1.5	1.5
	Side slope, ratio of horizontal distance respect to vertical "z"H:1V (z)	4	4	4	4	4
	Length of the swale m (L)	50	50	50	50	50
	Manning's roughness coefficient (n)	0.2	1	1	1	1
	Vegetation height m (Vh)	0.2	0.1	0.2	0.2	0.2
	Vegetation type	Grass mixture	Grass mixture	Grass mixture	Grass mixture	Grass mixture
	Longitudinal swale slope % (S)	0.02	0.02	0.02	0.02	0.02
	Hydraulic radius m (R)	0.071110156	0.124533802	0.124533802	0.124533802	0.124533802
	Cross-section area covered by the flow m² (A)	0.2176	0.2176	0.2176	0.2176	0.2176
Hydraulic characteristics	Rainfall intensity mm/h (I)	17	17	17	17	17
	Rainfall duration h	0.2	0.2	0.2	0.2	0.2
	Flow depth m (y)	0.00	0.00	0.00	0.00	0.00
Hydraulic Calculations	Water treatment rate (WTR) m³/s	0.026441775	0.007660675	0.007660675	0.007660675	0.007660675
	Velocity of the flow m/s (V)	0.121577651	0.035242074	0.035242074	0.035242074	0.035242074
	Hydraulic residence time min (HRT)	5.072241062	20.29902572	20.29902572	20.29902572	20.29902572
Velocity limits	Maximum velocity limit m/s	1.5	1.5	1.5	1.5	1.5
	Recommended velocity limit m/s	1.2	1.2	1.2	1.2	1.2
	Minor velocity limit m/s	0.060600016	0.017621037	0.017621037	0.017621037	0.017621037
Maintenance data	% of vegetation coverage	50	00	50	50	50
	height of silt accumulation mm	10	26	10	10	10
	Accumulation of silt per day mm	-	0.121212121	-16	0	0
	Presence of check dams N/Y	N	N	N	N	N
	Distance between check dams m	10	10	10	10	10

Figure 13. Excel sheet capture

Every excel sheet are divided into four parts:

Identification data and dates: In this first part it is indicated the number of the system inside the excel sheet, the identification code for the currently studied system, and different dates. The first date is the installation date, and in the next cells are indicated the date of when the inspections have been done.

	N°	1				
	Date	01.01.2016	12.05.2016	13.05.2016	14.05.2016	15.05.2016
	ID					
System characteristics	Bottom width of the swale m (b)	2.4	2.4	2.4	2.4	2.4
	Total swale height m (H)	1.5	1.5	1.5	1.5	1.5
	Side slope, ratio of horizontal distance respect to vertical "z"H:1V (z)	4	4	4	4	4
	Length of the swale m (L)	50	50	50	50	50
	Manning's roughness coefficient (n)	0.2	1	1	1	1
	Vegetation height m (Vh)	0.2	0.1	0.2	0.2	0.2
	Vegetation type	Grass mixture	Grass mixture	Grass mixture	Grass mixture	Grass mixture
	Longitudinal swale slope % (S)	0.02	0.02	0.02	0.02	0.02
	Hydraulic radius m (R)	0.071118156	0.124399802	0.124399802	0.124399802	0.124399802
	Cross-section area covered by the flow m^2 (A)	0.2176	0.2176	0.2176	0.2176	0.2176

Figure 14. Excel sheet, identification and date

System characteristics: in this part are listed the main characteristics of each system. It is possible to monitor these characteristics and to estimate, the water that could be treated or managed by the system. Sometimes, in this part are included some characteristics about the design rainfalls and return period, such as intensity and duration of the rainfalls; this part is useful to design the system size.

	N°	1				
	Date	01.01.2016	12.05.2016	13.05.2016	14.05.2016	15.05.2016
	ID					
System characteristics	Bottom width of the swale m (b)	2.4	2.4	2.4	2.4	2.4
	Total swale height m (H)	1.5	1.5	1.5	1.5	1.5
	Side slope, ratio of horizontal distance respect to vertical "z"H:1V (z)	4	4	4	4	4
	Length of the swale m (L)	50	50	50	50	50
	Manning's roughness coefficient (n)	0.2	1	1	1	1
	Vegetation height m (Vh)	0.2	0.1	0.2	0.2	0.2
	Vegetation type	Grass mixture	Grass mixture	Grass mixture	Grass mixture	Grass mixture
	Longitudinal swale slope % (S)	0.02	0.02	0.02	0.02	0.02
	Hydraulic radius m (R)	0.071118156	0.124399802	0.124399802	0.124399802	0.124399802
	Cross-section area covered by the flow m^2 (A)	0.2176	0.2176	0.2176	0.2176	0.2176
Hydraulic characteristics	Rainfall intensity mm/h (I)	17	17	17	17	17
	Rainfall duration h	0.2	0.2	0.2	0.2	0.2
	Flow depth m (y)	0.08	0.08	0.08	0.08	0.08

Figure 15. Excel sheet, System characteristics

Results: In this part are presented the results such as the maximum amount of water that could manage the system or the maximum amount of water that could storage a system.

Hydraulic Calculations	Water treatment rate (WTR) m^3/s	0.026411773	0.007668675	0.007668675	0.007668675	0.007668675
	Velocity of the flow m/s (V)	0.121377631	0.035242074	0.035242074	0.035242074	0.035242074
	Hydraulic residence time *min* (HRT)	5.872241062	20.29982572	20.29982572	20.29982572	20.29982572
Velocity limits	Maximum velocity limit *m/s*	1.5	1.5	1.5	1.5	1.5
	Recommended velocity limit m/s	1.2	1.2	1.2	1.2	1.2
	Minor velocity limit *m/s*	0.060688816	0.017621037	0.017621037	0.017621037	0.017621037
Maintenance data	% of vegetation coverage	90	80	90	90	90
	height of silt accumulation *mm*	10	26	10	10	10
	Accumulation of silt per day *mm*	-	0.121212121	-16	0	0
	Presence of check dams N/Y	N	N	N	N	N
	Distance between check dams *m*	10	10	10	10	10

Figure 16. Excel sheet, Results

Maintenance data: In this part are listed some important assets of each system that should be monitored to ensure the properly behaviour of the system. To ensure the correct behaviour, there are provided some advises with the recommended values for different variables. With these recommended values is possible to monitor if the requirements are fulfilled and if it is not, it give an alert to plan a maintenance action or fix the problem.

Hydraulic Calculations	Water treatment rate (WTR) m^3/s	0.026411773	0.007668675	0.007668675	0.007668675	0.007668675
	Velocity of the flow m/s (V)	0.121377631	0.035242074	0.035242074	0.035242074	0.035242074
	Hydraulic residence time min (HRT)	5.872241062	20.29982572	20.29982572	20.29982572	20.29982572
Velocity limits	Maximum velocity limit m/s	1.5	1.5	1.5	1.5	1.5
	Recommended velocity limit m/s	1.2	1.2	1.2	1.2	1.2
	Minor velocity limit m/s	0.060688816	0.017621037	0.017621037	0.017621037	0.017621037
Maintenance data	% of vegetation coverage	90	80	90	90	90
	height of silt accumulation mm	10	26	10	10	10
	Accumulation of silt per day mm	-	0.121212121	-16	0	0
	Presence of check dams N/Y	N	N	N	N	N
	Distance between check dams m	10	10	10	10	10

Figure 17. Excel sheet, Maintenance data

The using of the excel sheet is easy; the green cells should be filled with the system characteristics, automatically will be to obtain the results. In addition there are some cells with small red triangles in the upper right corner, in these cells there are some advice or recommendations with important information about maximum and recommended values for this variable.

When all data are implemented some result cells changing of colour in function if the value is appropriated or not, in the excel sheet exist 5 different colours and the meaning of each one is:

The white cell indicates that these cells are only informative

The green cell indicates that the value is appropriated

The yellow cell indicates that the value could have problems of maintenance

The red cell indicates that the value is not appropriated

The light green colour indicates that this value should be filled by the user

Application at Trondheim

In this part it is developed an analysis of how to implement a stormwater management whit the point of view of the nature-based solution in a specific place, using the excel sheets provided in the last part and applying all advice provided in this master thesis.

The study place is located at Norway in the city of Trondheim that it is inside of the Sør-Trøndelag region. In the next picture could be observed which selected area is. It is marked with a yellow colour. This area is located at the district of Steinan in the south of Trondheim.

Figure 18.Trondheim NBS application, General view of location [52]

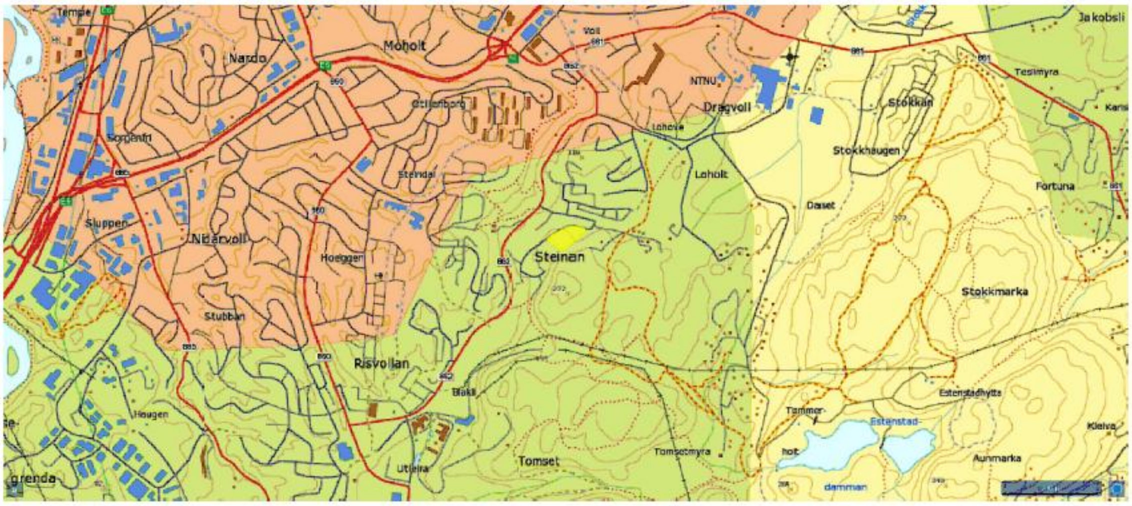

Figure 19.Trondheim NBS application, Focus view of location [53]

In the selected area were checked the different land uses, in function of the land use it is assigned a runoff coefficient to know which percentage of precipitation it will become in runoff. These uses could be observed in the next picture where the green colour represents the green areas, the grey colour represents the asphalt parts and the red colour represents the roof area and impermeable areas.

Figure 20.Trondheim NBS application, Location

In the next picture is illustrated the area model obtained by the software *AutoCAD 2015*

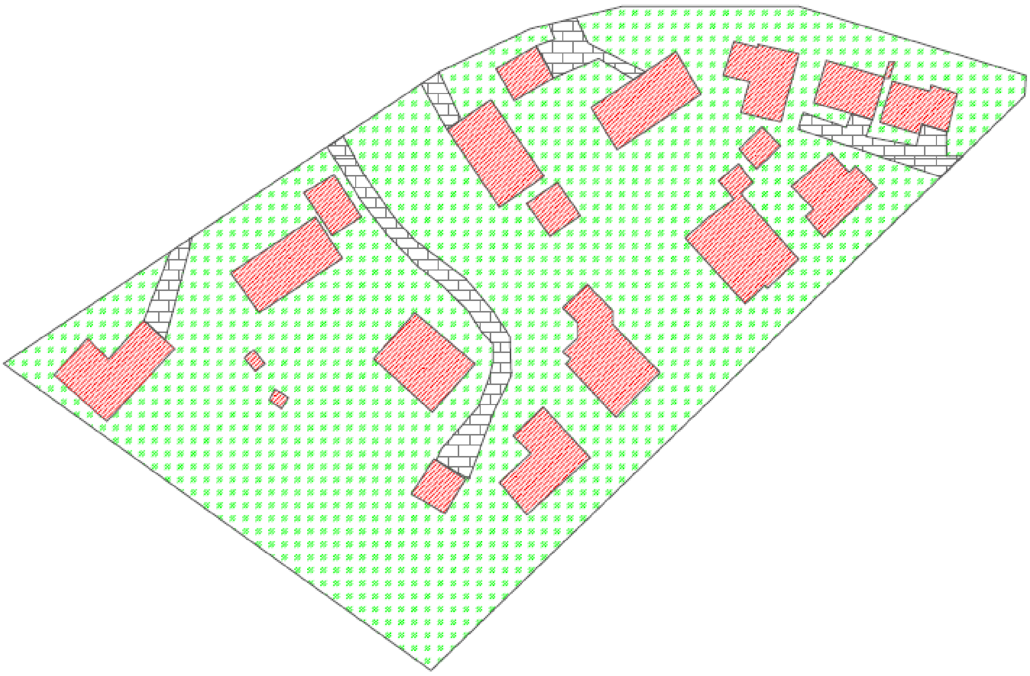

Figure 21.Trondheim NBS application, Distribution of areas

The results from this study are grouped in the table 17 where are indicated the percentage of the area destinated for each land use and the runoff coefficient for each area group.

Table 17.Distribution of areas

Land Types	Total Area within Site (m^2)	Runoff Coefficient (C)
Roof with standard membrane or blue roof	2480	0.95
Green roof with less than 4 inches of growing media	0	0.95
Pavement	680	0.85
Porous asphalt / concrete and permeable pavers	0	0.7
Green roof with 4 or more inches of growing media	0	0.7
Synthetic turf fields with gravel bed and underdrain	0	0.7
Gravel parking lot	0	0.65
Undeveloped areas	0	0.3
Grassed areas	9840	0.2
Rain gardens and vegetated swales	0	0.2
Other surface green infrastructure practices	0	0.2
Other*	0	0.00
Unassigned land area	0	Runoff coeficient average
Total site area (A):	13000	0.377076923

The result of this study it is that the runoff coefficient is 0.377 it will be necessary afterwards.

Once that the study area is selected and the runoff coefficient it is known, it should be characterized the climate conditions; it means that should be calculated the daily precipitation and the specific rainfall for the return period selected. On the other hand, it should be calculated the minimum, maximum,and the average temperature to can calculate the evapotranspiration.

This process starts analysing the daily precipitation in the study place. The period of time that has been analysed is from 1961 to 1990. In the table 18 and 19 are exposed the results of average daily precipitation and the average daily temperatures:

Table 18.Daily precipitation average

Date	Daily precipitation average (mm)
1961-1990	2.425155666

Table 19.Temperature data

Average temperature (Cº)	Maximum temperature (Cº)	Minimum temperature (Cº)
4.857142857	13.38571429	-3.457142857

When it is calculated the daily precipitation average, to calculate which rainfall intensity has a return period of 5 years it is used the next method:[52]

The first step is to calculate the average rainfall intensity during the period 1961-1990 (It is showed in the table 17).

$$\bar{x} = \frac{\sum_{n} x_1}{n}$$

(Eq. 29)

The second step is to calculate the standard deviation.

$$S_x = \sqrt{\frac{\sum(x_n - \bar{x})^2}{n-1}}$$

(Eq. 30)

The third step is to calculate the ¨alpha¨ and ¨u¨ factors

$$\alpha = \frac{\sqrt{6} * S_x}{\pi}$$
(Eq. 31)

$$u = \bar{x} - 0.5772 * \alpha$$
(Eq. 32)

The last step is to use the two last calculated factors to calculate the ¨Y_t¨ to finally calculate ¨X_t¨ it is the rainfall intensity for the design return period.

$$Y_t = -\ln\left[\ln\left(\frac{T}{T-1}\right)\right]$$
(Eq. 33)

$$X_t = \alpha \, y_t + u$$
(Eq. 34)

The results of this analysis are presented in the following table 20:

Table 20.Temperature data

Daily precipitation average (mm)	Standar deviation	Life cycle
2.425155666	2.667671233	50
alfa	u	Return period(years)
2.079974727	1.224594254	5
Yt	Xt(mm)	Not ocurrence pobabiliy
1.499939987	4.344431518	0.001427248
Rainfall duration	Specific rainfall intensity (mm)	
20	2.907091813	

As could be observed in the table 19, the specific rainfall intensity is 3.35 mm per square meter and hour, for a rainfall event duration of 20 minutes.

The other important thing that should be characterized is the soil from the study place. To do an estimation of which soil and the compositions is, has been used the data provided by the ¨The Geological Survey of Norway¨(NGU). From the web page of this institute has been obtained maps with the soil origin in function of a legend of colour as can be observed in the figure 19. From this map was obtained that the soil is composed of a sandstone, with a porosity around 53 % and a soil permeability around $5*10^{-6}$ m/s.

Once that the place is completely characterized, it will be proposed 3 different systems to reduce the amount of runoff generated in this area. The solutions proposed are: green roofs, bioretention, and soakaways.

The results for each system are presented as a capture of the excel sheet presented before. In these images, the upper part describes the system characteristics; and in the lower part are showed the results. All calculations and important data are in the first column, the other ones are reserved to the future inspections.

Soakaways

In this system,it is proposed use soakaway with a 30 m x 20 m area and 2 m of depth. The backfill material selected is sand to maximize the storage capacity (Porosity 55%; Permeability 5E-3). The most important results from this part are the reduction of runoff provided, that it is 1.8 m^3 and it is produced by infiltration; and the total volume of storage, it is 660 m^3.

The other important results are showed in the next table (table 21):

Table 21.Trondheim NBS application, Soakaway solution

System characteristics	Soakaway lenght *m* (L)	20	20	20	20	20
	Soakaway width *m* (W)	30	30	30	30	30
	Soakaway height *m* (h)	2	2	2	2	2
	Base area of infiltration system m^2 (Ab)	600	600	600	600	600
	Porosity of fill material *m/h* (n)	55.00%	0.55	0.55	0.55	0.55
	Permeability coeficient of backfill medium *m/h* (kb)	5.00E-03	0.005	0.005	0.005	0.005
	Infiltration area m^2 ($A_{50\%}$)	100	100	100	100	100
	Area to be drained m^2 (A_D)	13000	13000	13000	13000	13000
	Runoff coefficient (Rv)	0.377	0.377	0.377	0.377	0.377
	Sourronding soil permeability *m/s* (Ks)	5.00E-06	5.00E-06	5.00E-06	5.00E-06	5.00E-06
	Inlet pipe diameter *m* (Di)	0.4	0.4	0.4	0.4	0.4
	Inlet pipe velocity *m/s* (Vdi)	0.1	0.1	0.1	0.1	0.1
Hydraulic characteristics	Duration of the storm of design *h* (D)	1	1	1	1	1
	Intensity storm of design *mm/h* (i)	3.35	50	50	50	50
Hydrauclic Calculations	Inflow *m* (I)	16.41835	16.41835	16.41835	16.41835	16.41835
	Outflow *m* (O)	1.8	1.8	1.8	1.8	1.8
	Total storage volumen *m* (S)	660	660	660	660	660
	Storage volumen required *m* (Sr)	14.61835	14.61835	14.61835	14.61835	14.61835

Green roofs

In this system it is proposed to cover 600 square meters of roofs with extensive green roofs, the substrate is a mix of clay and organic material with 0.4 m of depth (Porosity 60%; Permeability 6E-6). It is a soil with a low response, the objective is to retain the maximum quantity of water inside the roof to evapotranspire this volume of water. The vegetation selected to prevent the erosion and produce this evapotranspiration is high grass because it doesn't need a high level of maintenance and usually it have a good evaporation rate.

The most important results from this part are that the green roof could produce a reduction of 1.3m3 /day. In this model, the reduction it is indicated per day because the runoff reduction is produced by evapotranspiration. It is done the assumption that the slow response of the soil is enough to slow to retain the water one day into the green roof, this time is enough to allow the vegetation produce the evapotranspiration.

In this system, the amount of water that could be storage is not significant.

The other important results are showed in the next table (table 22):

Table 22.Trondheim NBS application, Green roof solution

System characteristics	Surface area m^2 (As)	600	600	600	600	600
	Heigth of substrate m (hs)	0.4	0.4	0.4	0.4	0.4
	Vegetation height *m* (Vh)	0.2	0.2	0.2	0.2	0.2
	Vegetation type	High grass	High grass	High grass	High grass	High grass
	Type of soil	High plasticity clays	High plasticity clays	High plasticity clays	High plasticity clays	High plasticity clays
	Permeability coeficient of the soil mm/min (Ks)	6.00E-06	6.00E-06	6.00E-06	6.00E-06	6.00E-06
	Porosity	60.00%	60.00%	60.00%	60.00%	60.00%
	Soil response (β)	0.5	0.5	0.5	0.5	0.5
	Roof inclination %	2	2	2	2	2
Hydraulic characteristics	Extra-terrestrial radiation MJ/m^2day (Ra)	3.6	3.6	3.6	3.6	3.6
	Average temperature (T_{ave})	4.85	4.85	4.85	4.85	4.85
	Minimum temperature (T_{min})	-3.45	-3.45	-3.45	-3.45	-3.45
	Maximum temperature (T_{max})	13.39	13.39	13.39	13.39	13.39
	Evapotraspration $mm/m^2\ day^{-1}$ (ET)	7.696080234	7.696080234	7.696080234	7.696080234	7.696080234
	Precipitation $mm/m^2\ day^{-1}$ (P)	2.91	2.91	2.91	2.91	2.91
	Actual soil water storage mm/m2 (SM)	10	100	100	100	100
	Field capacity mm/m2 (FC)	240	240	240	240	240
	Runoff mm/m2 day^{-1} (dUZ)	0.594001263	1.878396923	1.878396923	1.878396923	1.878396923
	Change soil water storage mm/m2 day^{-1} (SM)	4.619918503	93.33552284	93.33552284	93.33552284	93.33552284
	Green roof runoff m3/day	0.356400758	4.658424369	4.658424369	4.658424369	4.658424369
	Total runoff m3/day	12.96252076	12.96252076	12.96252076	12.96252076	12.96252076
	Runoff reduction m3/day	1.302299242	1.302299242	1.302299242	1.302299242	1.302299242

Bioretention

In this system,it is proposed to use a bioretention with a 30 m x 20 m area and 2 m of depth. The filter medium is composed of a silt sand (Porosity 50%; Permeability 1E-4) it is 1.8 meters depth, and the drainage layer is composed by a fine gravel (Porosity 40%) it has 0.2 meters depth.

The most important results from this part are the reduction of runoff provided is 0.87 m^3 produced by infiltration, and the total volume of storage is 588 m^3

The other important results are showed in the next table (table 23):

Table 23.Trondheim NBS application, Bioretention solution

System Characteristics	Filter medium lenght *m* (L)	20	20	20	20	20
	Filter medium width *m* (W)	30	30	30	30	30
	Filter medium height m (Hf)	1.8	1.8	1.8	1.8	1.8
	Surface filter area m^2 (A_f)	600	600	600	600	600
	Volume filter area m3 (Vf)	1080	1080	1080	1080	1080
	Porosity of filter medium % (kf)	50.00%	50.00%	50.00%	50.00%	50.00%
	Permeability coeficient of the filter medium m/s (kf)	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
	Drainage layer height m (Hd)	0.2	0.2	0.2	0.2	0.2
	Volume drainage layer area m3 (Vd)	120	120	120	120	120
	Porosity of drainage layer % (kd)	40.00%	40.00%	40.00%	40.00%	40.00%
	Impervious area m2 (A)	3160	3160	3160	3160	3160
	Runoff coefficient (Rv)	0.377	0.9	0.9	0.9	0.9
Hydraulic charactetistics	Rainfall intensity *mm/day* (I)	2.91	32.96	32.96	32.96	32.96
	Evacuation time, percolation h (t)	48	48	5	5	5
Hydraulic calculations	Water treatment rate m3 (WTR)	0.864	5.184	0.540	0.540	0.540
	Area necesay m2 (Af)	545.625	540	540	540	540
	Area deviation %	91%	90%	90%	90%	90%
	Total runoff m3/day	13.40082	156.38592	161.02992	161.02992	161.02992
	Attenuation m3	588	588	588	588	588

Systems comparison

In this part will be studied the benefits of each solution proposed and which solution is the most effective. The area used in all systems is the same to obtain comparable data.

Regarding which is the system that produces the bigger reduction of runoff it is the soakaways. The second system that has a good attenuation is the green roofs, but this system doesn't have available storage volume. This is a bad point because other methods such as the bioretention or the soakaways can storage water and infiltrate it along the time. For this reason attending only to the attenuation of runoff the soakaways are the most suitable system.

Regarding the pollutant reduction, looks like the green roof produces an increment of some pollutants but it is because the water that treats it only comes from the precipitations and usually this water is cleaner than the runoff produced by the impervious zones (this phenomena it is explained in the green roof part). Leaving aside this, the percentages of reduction are:

Table 24.Pollutant reduction comparison

	Green Roof	Bioretention	Soakaway
TSS (mg/L)	69.54	88.8	80
Pb (µg/L)	-162.31	14.29	98
Cu (µg/L)	-164.1	34.78261	-
Zn (µg/L)	-82.54	17.24138	70

Attending only to the pollutant reduction the most suitable systems are the soakaways and the bioretention. The bioretention could produce a reduction concentration of pollutant of a bigger number of pollutants than the soakaways and usually, it doesn't need a pre-treatment system, for this reason, this is the most suitable system.

Regarding the amenity aspect, the bioretention and the soakaway could use the subsoil of the green areas. With these 2 systems is possible to use the surface area as a park or recreation area. On the other hand, the green roofs use areas that usually don’t have any secondary use. The green roofs analysed in this study are installed in inclined roofs, it reduces the possibilities to use this roofs with a social objective , but it produces a landscape enhancement that it is really positive for the human well-being.

To continue with the analysis it is necessary to talk about the cost of maintenance. The cost of maintenance between these 3 systems is really different. There are 2 groups, the excavated systems, bioretention and soakaway; and the superficial systems, green roofs.

The excavated systems usually have a lower cost of maintenance but the costs of replacement or reconstruction are higher than in the superficial system. On the other hand, the green roofs have a lower cost of replacement because they are more accessible but they need a periodic maintenance to keep the height of vegetation at the right height or reseed the eroded parts.

Attending to these two last criteria, it is difficult to select a system because each one has their positive and negative aspects. But the bioretention systems usually have a better adaptability.

To conclude with this analysis, if it is only possible to install one system, is necessary taking into account all collected data and results and give to all criteria commented before the same weight in the final decision.

The system that produces the better attenuation of the peak flow and a reduction in the total volume of water are the soakaways. Regarding the reduction of pollutants, Soakaways have a good reduction of pollutant, similar to the bioretention, these two systems have a big variability in function of the backfill material but soakaways need in addition a pre-treatment to remove some pollutants, especially the TSS. Not like the bioretention that does all treatment for themselves. Regarding the maintenance cost, all excavated systems have more or less the same cost and this criteria it is not decisive in the decision. To conclude, regarding the amenity, as it was said before the bioretention have the better adaptability. At this point the bioretention and soakaways are the most suitable systems, but because the bioretention doesn't need any auxiliary system, it is the selected system.

Bioretention systems are selected as the most suitable for this place, but the point of view of NBS it is not only to use one method. The ideal solution to manage the storm water is to used a combination of systems, using green roofs to reduce the runoff generated by the roofs. Them the water not absorbed by the green roofs, could be conveyed by strips until a swale. With these two systems,the amount of pollutants will be reduced and the peak flow will be reduced a bit by the infiltration in the swale. Finally, the remaining water will be conveyed by the swales until a bioretention to conclude the treatment, it will provide a good quantity reduction a wide reduction of different pollutants. The global combination of these systems will provide a green vision and produce an enhancement of the human well-being at the same time that is done a green and sustainable stormwater management.

Final remarks

Currently, the nature-based solution is a new concept that should be developed more and it is necessary to do a deeper researching in this field, to do that in the future this point of view will be more integrated in the society. The development of this concept could produce benefits to the society, such as green cities, or a management of stormwater in a sustainable way and being friendly with the environment.

NBS have a big potential to improve the life quality of the humanity, addressing one of the most important problems that concern the humanity nowadays, the climate change. With NBS is possible help to reduce the impact of climate change in the stormwater management because the systems that compose the NBS have a good adaptability if the amount of precipitations changes therefore the stormwater that should be treat.

It is necessary to have a long-term planning and extend the scope of the society, starting to give value to more things than only the construction cost, when a stormwater project is being planned. There should be taken in account things as the long term maintenance, the adaptability to the environment and the most important point, the impact produced in the environment, because some environmental damages, or contaminations could not be fixed with money. For these reasons it is important, change the actual mentality and starts to use more the natural-based solutions.

But there are some problems when it is applying the point of view of the NBS. It is that there are not many systems that have followed this philosophy in the past. So don't exist standardized guidelines to design systems according with this point of view. The behaviour of this systems are not so well known such as piping systems that have been used for a long time. This entail that, when a stormwater system it is being designed, usually the designers opt for a traditional system instead of a NBS system.

Besides there is another reason why these NBS systems are not more used; the reason is that the future behaviour of the system and the required maintenance are not well known. In other systems such as the pipe systems these two things are really well known, even they have, asset management techniques to estimate the breaks probability or optimized the maintenance. This master thesis aims to illustrate what are the most important assets in each NBS system, and also it provide small maintenance guidelines. This two things along whit the excel sheets that have been developed, they can help to monitor and to maintain these systems effectively and in a sustainable way.

To finish with this thesis are propose some ways to continue developing and investigating the NBS field. One of them is continue investigating NBS systems with real models to study how the maintenance in a long term period can be reduced. Another study is which sensors can be installed in these systems to have real time monitoring and detect possible problems in the behaviour of the system. Finally to do a compendium of NBS applied around the world to study which are the most suitable in function of the climate characteristics.

References

[1] Ackerman, D. and Stein, E. Evaluating the Effectiveness of Best Management Practices Using Dynamic Modelling. (2008); 134:8(628), 628-639.

[2] K. Vijayaraghavan. Greenrooms: A critical review on the role of components , benefits, limitations and trends. Renewable and Sustainable Energy Reviews (2016); 57: 740–752.

[3] https://en.wikipedia.org/wiki/Sustainability_accounting

[4] A.E. Barbosa*, J.N. Fernandes, L.M. David: Key issues for sustainable urban stormwater management (2012).

[5] D. Joksimovic, Z. Alam: Cost Efficiency of Low Impact Development (LID) Stormwater Management Practices. *Procedia Engineering*(2014); 734 – 741

[6] Michael R. Bloomberg, Mayor Carter H. Strickland, Jr., Commissioner: Developed by the New York City Department of Environmental Protection in consultation with the New York City Department of Buildings. *Guidelines for the Design and Construction of Stormwater Management Systems* (2012)

[7] PDSWRS: Workgroup and AISWCD for submission to Illinois Environmental Protection Agency: Stormwater Performance Standards Recommendations (2013)

[8] Final Report of the Horizon 2020 Expert Group on Nature Based Solutions and Re-Naturing Cities. *Nature- Based Solutions & Re-Naturing Cities*(2015)

[9] Michael R. Bloomberg, Mayor Carter H. Strickland, Jr., Commissioner: Developed by the New York City Department of Environmental Protection in consultation with the New York City Department of Buildings. *Guidelines for the Design and Construction of Stormwater Management Systems* (2012)

[10] A.H. Elliott . S.A. Trowsdale: A review of models for low impact urban stormwater drainage (2006)

[11] INGRA, international green roof association (2015)

[12] B. Woods Ballard: Green roofs *CIRIA SuDS Manual* (2015) chapter 12; 236

[13] Michael R. Bloomberg, Mayor Carter H. Strickland, Jr., Commissioner: Guidelines for the Design and Construction of Stormwater Management Systems Developed by the New York City Department of Environmental Protection in consultation with the New York City Department of Buildings (2012); Chapter 2.4.

[14] University of Toronto: Assessment of Life Cycle Costs for Low Impact Development Stormwater Management Practices Toronto and Region Conservation University of Toronto (2013)

[15] INGRA, international green roof association (2015)

[16] Sajedeh Sadat, GhazizadehHashemi, Hilmi, Bin Mahmud: The performance of green roofs with respect to water quality and reduction of energy consumption in tropics: A review. Renewable and Sustainable Energy Reviews (2015); 52: 669–679

[17] Roger Norris Hilten, M.S. and Thomas Mark Lawrence: Using Green Roofs and Other BMPs to Reduce the Need for Stormwater Retention Capacity Requirements (2007)

[18] Qianqian Zhang, Liping Miao, Xiaoke Wang, Dandan Liu, Liang Zhu, Bing Zhou, JichaoSuna, Jingtao Liu: The capacity of greening roof to reduce stormwater runoff and pollution. Landscape and Urban Planning (2015); 144:142–150

[19] QianqianZhanga, LipingMiaob, XiaokeWangc,∗, DandanLiua, Liang Zhua, Bing Zhoua, JichaoSuna, JingtaoLiua: Landscape and Urban Planning (2014)

[20] Nichaou et al (2001)

[21] IUCN Red List of Threatened Species: www.iucnredlist.org

[22] Roger Norris Hilten, M.S. and Thomas Mark Lawrence, Ph.D., P.E. University of Georgia, Athens, Georgia: Using Green Roofs and Other BMPs to Reduce the Need for Stormwater Retention Capacity Requirements (2015)

[23] Hargreaves and Samani, (1985)

[24] AnundKillingtveit and Nils Roar Saelthun: Hydropowedevelopment Volume No 7 Norwegian institute of technology (1995)

[25] AnundKillingtveit and Nils Roar Saelthun: Hydropowedevelopment Volume No 7 Norwegian institute of technology (1995)

[26] A J Pickett; J Howison: Design of Soakaways volume *4 GEOTECHNICS AND DRAINAGE* (2006)

[27]B. Woods Ballard: Infiltration systems *CIRIA SuDS Manual* (2015) chapter 13; 286

[28]B. Woods Ballard: Infiltration systems *CIRIA SuDS Manual* (2015) chapter 13; 286

[29]http://www.susdrain.org/delivering-suds/using-suds/suds components/infiltration/soakaways.html

[30] Barraud et al. Valence, France (1999)

[31] Garston, Watford :Bre Bookshop (2003) .

[32] Roseberry Avenue: Soakaway design Digest 365 BRE Bookshop (2003).

[33] Water Environment Federation American Society of Civil Engineers Enviornmental& Water Resources Insitute: Design of urban stormwater controls. Swale and strips (2012); chapter 7.

[34] U.S. Department of transportation, Federal Highway Administration: https://www.environment.fhwa.dot.gov/ecosystems/ultraurb/3fs10.asp

[35] B. Woods Ballard: Swale*CIRIA SuDS Manual* (2015) chapter 17; 314

[36] B. Woods Ballard: Swale*CIRIA SuDS Manual* (2015) chapter 17; 314

[37]J.F. Sabourin& Associates: SWAMP New York, Ontario (2008)

[38] Permissible velocities for channels lined with grass Chow (1959)

[39] American Society of Civil Engineers/ Enviornmental& Water Resources Insitute: Design of Urban Stormwater Controls, MOP 23. Water Resources and Environmental Engineering Series); 266-271

[40] Department of Engineering, University of Aberdeen, Fraser Noble Building, Aberdeen A: Modelling of water and sediment transport over grassed areas; Journal of Hydrology (2001); 168-182

[41] Water Environment Federation American Society of Civil Engineers/ Enviornmental& Water Resources Insitute: Design of urban stormwater controls. Swale and strips;(2012) chapter 7 .

[42] B. Woods Ballard: Strip*CIRIA SuDS Manual* (2015) chapter 15; 292

[43] J.F. Sabourin& Associates Nepal,Ontario (2008)

[44]-Neal Robert Haddaway , Colin Brow , Sönke Eggers3, Jonas Josefsson , Brian Kronvang, Nicola Randall , JaanaUusi-Kämppä: Impacts of vegetated strips in and around agricultural fields, Mistra Council for Evidence-Based Environmental Management (EviEM), Stockholm,(2015)

[45] American Society of Civil Engineers/ Enviornmental& Water Resources Insitute.: Design of Urban Stormwater Controls, MOP 23. *Water Resources and Environmental Engineering Series;* 271-287

[46] Sam A. Trowsdale , Robyn Simcock: Urban stormwater treatment using bioretention. Journal of Hydrology (2011); 167-174

[47] B. Woods Ballard: Bioretention systems*CIRIA SuDS Manual* (2015) chapter 18; 334

[48] B. Woods Ballard: Bioretention systems*CIRIA SuDS Manual* (2015) chapter 18; 339

[49] Sam A. Trowsdale , Robyn Simcock: Urban stormwater treatment using bioretention; Journal of Hydrology (2011) 397, 167–174

[50] Tone Merete Muthanna, Maria Viklander, GodeckeBlecken, Sveinn T. Thorolfsson: Snowmelt pollutant removal in bioretention areas (2007) ; 41 ,4061 – 4072

[51] Department for environment Food and rural affairs: The SuDS manual (2015); 257-269

[52] The Geological Survey of Norway (NGU)

[53] The Geological Survey of Norway (NGU)

[54] http://www.ugr.es/~iagua/LICOM_archivos/SolucionProblema1.pdf