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The effects of Green Street implementation on runoff flow in developing urban scenarios compared to conventional system

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Table of content

List of figures

List of Tables

List of equations

Summary

The concept of “Green Street” is elaborated in this thesis both theoretically and practically. Thesis tries to study how Green Street practices (which are solutions towards sustainable stormwater management) can be applied in urban development. Green Street addresses stormwater runoff treatment and brings other benefits to both environment and society. In order to study Green Street efficiency on flow reduction, four scenarios (two conventional system scenarios and two Green Street scenarios) have been developed in Teckomatorp which is a small town in Sweden. Teckomatorp is a peasant society with a good location in Skåne province which makes Teckomatorp a potential town for further development. Four thought-out urban scenarios are presented in this thesis in order to create a sample for further studies of Green Street in urban development. The two Green Street scenarios have different density and in each of them two Green Street practices (stormwater planter and permeable pavement) are implemented to reach a higher sustainable system. These two scenarios are competing with two conventional system (using the traditional drainage system in urban area) scenarios with the same density. First literature review will introduce different social and environmental benefits (i.e. aesthetic view of streets, biodiversity, improving social activity and etc.) of using Green Street practices. Second, calculations of peak discharge (peak flow during a rainfall) and the comparison between results will show the effectiveness of applying Green Street practices on runoff flow in urban development. For all four scenarios rational method will be used to calculate the peak flow (discharge). The comparison of flow reduction in both Green Street scenarios and conventional system scenarios is presented and discussed in this thesis to show how density and Green Street practices can affect flow reduction.

1. Introduction

Urban development and population growth make a need for human to protect water quality as well as water quantity. Global warming, reduction of precipitations make a shortage in water resources and require a great attention in order to prevent drought and water environment damage (Donofrio *et al.*, 2009). Increase in impervious surfaces due to the recent development cause different damages to the water resources such as; carrying pollutants directly and indirectly to drainage basins and also intensify velocity of runoff which cause soil erosion of downstream (Chester *et al.*, 1996). Due to the high cost city expansion all around the world by developers, flooding which is caused by higher rainfall intensity can be resulted in high costs for municipalities as well as environmental damages (Welker *et al.*, 2010). In addition to that, rain that cannot be infiltrated to groundwater level (due to impervious surfaces) during a rainfall, flows to creeks and pipes with high speed (result of conventional system) and eventually drained to streams and rivers with high velocity and pollutants which can cause natural hydrology cycle disruption and make a high flood risk (Welker *et al.*, 2010).

In this thesis the concept of Green Street (an approach towards sustainable stormwater management) which is a sub category of green infrastructure approach, will be more elaborated. Different definitions such as stormwater, stormwater management, conventional drainage system and etc, are described in the following chapters to make the Green Street concept more understandable.

1.1. What is stormwater and why does it need management?

Stormwater or stormwater runoff (Council, 2008) & (Peterson *et al.*, 2009) is the water pile-up from precipitation that runs on the surface and washes over landscape (i.e., runoff from melting snow, surface runoff, drainage and etc.) and eventually discharges to a waterway, such as river or any other drainage basins (Horsley & Durham, 2010).

Stormwater runoff is important because it has a big effect on hydrology cycle (also known as water cycle which means the journey of water from land to sky and back to land) as it is a part of hydrological cycle (Horsley & Durham, 2010). It washes sediments and pollutants especially in urban areas and cause major damages to water bodies (LEE & BANG, 2000). It can also cause flooding when it is a heavy storm. In another words in urban areas, stormwater runoff and downstream overflow can cause major damages to both cities (high cost damage) and environment (McGuire *et al.*, 2010).

1.2. Conventional drainage system

In order to control stormwater runoff, pipe system has been designed and used for many years in cities (Coffman, 1999). Conventional system carries out runoff from rainfall and waste water (such as human waste from toilet and bathroom, liquid coming out from washing machine and etc.) as fast as possible through underground pipe systems. This “out of sight out of mind” approach (NNASDE, 2009) has shown its deficiencies during years.

Some problems of a conventional drainage system were presented by (Hoyer *et al.*, 2011) , (Woods-Ballard *et al.*, 2007), (EPA, 2000) as following;

- Decrease in drinking water sources in cities, by preventing water from infiltrating to groundwater layer (because of impervious area of lands) and consequently reduction of ground water level.
- Loss of infiltration due to stormwater runoff rate caused by pipe systems. Moreover conventional drainage system does not let stormwater be evaporated which results in dryness of weather.
- Conventional drainage system is not capable of taking care of pollutants neither filter them which makes water resources contaminated.
- Increase in velocity of stormwater runoff in conventional approach takes up the risk of soil erosion in downstream catchment (Bryan *et al.*, 2005).
- Risk of flooding in conventional drainage system is high when it comes to a heavy rain due to many factors such as overflowing the receiving downstream, lack of infiltration and etc.
- In conventional drainage system runoff drains to river or downstream as quickly as possible which can have a bad effect on the ecosystem, especially habitats of river or downstream as it changes the rate of flow so quick.

Conventional system of urban drainage is neither addressing sustainability nor amenity for the neighborhood. In addition to that, it cannot increase quality of water environment which can be added to all its deficiencies.

1.3. Sustainable stormwater management approach

One of the important components that has been implemented recently as a solution of flooding in urban areas is sustainable stormwater management. Sustainable stormwater management is considered as an effective approach to control overflow of runoff and prevent downstream from degradation by filtrating pollutants and decreasing rate and volume of stormwater runoff. This topic has been studied in different parts of the world and has got different names such as in UK, SUDS– Sustainable Drainage Systems, LID – Low Impact Development in USA, WSUD – Water Sensitive Urban Design, particularly in Australia (Roy *et al.*, 2008), BMP–Best Management Practices in Globe (Hoyer *et al.*, 2011) and LOD (acronym for local stormwater treatment) in Sweden (Persson *et al.*, 2009). These studies have provided solutions to address stormwater runoff both in quality and quantity (Ellis, 2008). In sustainable stormwater management, stormwater runoff is treated on-site or as close as possible to the source (Hoyer *et al.*, 2011) by providing the opportunity to infiltrate into groundwater which raises groundwater level, storage and increase evaporation as well as reducing the rate and volume of runoff which prevent overflow and soil erosion of downstream (Niemczynowicz, 1999). Furthermore, sustainable stormwater management promotes health and quality of aquatic ecosystems (Echols

& Pennypacker, 2008) & (Cairns, 2006). The purpose of sustainable stormwater management is to reduce the quantity and volume of runoff by applying different sustainable techniques such as pervious surfaces, green infrastructure and etc. Increase in ecosystem health and improve amenity in cities are other advantages of sustainable stormwater management approach as well as addressing natural hydrology cycle (Woods-Ballard *et al.*, 2007). Although local traditional detention facilities such as pond and constructed wetlands can help to address the natural hydrology cycle but by all means they are not sufficient and adequate especially during a heavy rainfall when infiltration through soil will reduce and contaminated runoff will go directly to local detentions or nearby streams which can also cause degradation of water resources (TRCA, 2009). Whereas the measures in sustainable stormwater management aim to control runoff in a small-scale lot close to its source. This approach is a cost-effective way, using different techniques (such as bioretention/filtration, open green swales, permeable pavement and etc.) that address storage capacity, pollutant removal and rate/volume reduction as well as conveyance and flow control (Coffman, 1999).

Green Street, an approach towards sustainable stormwater management helps to protect and preserve the water environment and the landscape itself as well as the water resources for our grandchildren and next generation (McGuire *et al.*, 2010)

This thesis tries to elaborate on the topic of Green Street as one of stormwater treatment measures theoretically and practically.

1.4. Green infrastructure

Green infrastructure refers to different natural elements such as vegetations and soil that can be applied in a range of ways to manage and control stormwater runoff in a sustainable way as well as providing the community aesthetic neighborhood (Wise, 2008) & (Foster *et al.*, 2011). United State Environmental Protection Agency (EPA) in its publications and also Grumble (2007) recommend using green infrastructure as an approach to decrease stormwater runoff volume and separating from sewage system using natural landscape elements (soft materials such as soil, vegetation) rather than hard elements (i.e. pipes, concrete channels,…). Green infrastructure basically focuses on reusing, infiltrating and storage stormwater runoff which is improving the natural hydrology cycle (Grumble, 2007). Some other advantages of using green infrastructure especially in hot regions that can be gained through evaporation and evapotranspiration are improved air quality, reduced air cooling cost and eased negative effect of city heat islands (EPA, 2010). Another study submitted by EPA in 2010 prepared by (Dill *et al.*, 2010) shows other advantages of using green infrastructures, which is related to physical activities and social interaction as well as economical benefit that living in a Green Street will have for inhabitants (Farnham, 2010).

2. Aim and Objectives

One of the aims is to calculate peak flow (discharge) from 15 minutes intensive rainfall by rational formula. The idea is to calculate peak discharge during 15 minutes rainfall and figure out how to control and reduce the volume and rate of flow using Green Street concept. Another purpose is to show how Green Street implementation affects flow reduction in urban scenarios and compare the results with conventional street scenarios.

Questions to be answer in this thesis;

- What is a Green Street and how does it treat and control stormwater runoff?
- What are the benefits and disadvantage of Green Street concept?
- What is rational method and how it can be used to calculate peak flow?
- How will density rate (exploitation rate) affect peak discharge (also water volume) for both conventional and Green Street scenarios?

2.1. Research method and borders

The search for literature review is mainly based on google search engine. Some of the main references used in this thesis are stormwater manual books such as CIRIA's stormwater manual (2007) and Portland storrmwater manual (2004). Searching tips can be summarized in "Green Street", "sustainable stormwater management", "Bioretention or biofiltartion", "permeable pavement" and etc.

The main focus in this thesis concerns "Green Street" concept (more sustainable views such as water quality) and 2 practices used in Green Street scenarios as well as rational method. General description of some Green Street practices are provided in thesis however detailed information about cost or economical view is not a concern.

3. Green Street

Before defining a Green Street, it is important to mention the role of streets in urban areas. Recently streets have become more essential in urban development because they should take care of more responsibilities. It is not only people and traffic now which needs to be accommodated in streets but also internet, electronic lines, optic fiber, sewer system and telephone connection and etc (Walker, 2009). Furthermore, streets are the place for markets, social interaction, physical activity, demonstration and revolution, a playground for kids. These requirements from streets and many other activities that can take place in a street in urban areas make a need for landscape architect to revise their plans for designing not only a street but a perfect street that can address all these needs.

A Green Street is a concept that has been studied to answer all these needs with its thought out plan and design as well as engineered structured to address sustainable environment and friendly ecosystem.

Green Street defines as a street compounded of natural elements mainly soil and vegetation to manage or control stormwater runoff in a sustainable way and as close as possible to its source (EPA, 2009), (Dill *et al.*, 2010), (Wise, 2008). Green Street improves the quality of stormwater in urban areas as well as improving the capacity of existing and future conveyance of sewer system (Portland 2012). Green Streets filter pollutants, lower down the rate, reduce the volume, capture and in some areas infiltrate stormwater before stormwater can flow to an approved drainage system (NNASDE, 2009). Jason King (2009) defines Green Street, a street that uses vegetation and soil in order to control stormwater in its source. This sustainable stormwater strategy uses natural system to enhance health of watershed, improve amenity and address biodiversity as well as reduce and control stormwater (King, 2009)

Figure 1 – Impervious street (Chris Maser, 2012)

San Mateo country sustainable Green Street and parking lots (2009), introduced five levels of design for a Green Street:

Level 1: First step and level of design is to minimize impervious surfaces of street and sidewalk and maximize greenery along the street using trees or vegetation (figure 1).

Figure 2 – Canopy tree (EPA, 2012)

Level 2: Canopy[1] tree has a significant effect on stormwater by absorbing stormwater runoff (figure 2). Canopy reduces soil erosion and volume of runoff by improving infiltration and also through evapotranspiration (CRWA, 2009).

[1] - Canopy tree refers to outer layer of tree's leaves which can block the light and make shade on the ground.

Level 3: Sidewalks, streets and driveways runoff should be fully managed in a sustainable way. It means that by applying soil and vegetations or greenery, runoff should be managed. Biodiversity and aesthetic are two important factors that must be gain through using greenery or soft material instead of hard material or conventional system (figure3).

Figure 3 – Green Street (swale) (Clean Water Services, 2012)

Level 4: Green Street's great attention is on different transportation modes such as bike lane, motorways and walking path (Figure 4).

Figure 4 – A Green Street including bike lane and sidewalk (Green Works, 2012)

Level 5: The last level is to integrate spaces of buildings and street frontage and design a proper system for their stormwater management. In addition to that private and public stormwater runoff is managed through Green Street approach.

Figure 5 – Rainwater harvesting (EPA, 2012)

University of California points out three main features of a Green Street in a publication about Green Street (Das, 2006) as following;

First is to reduce the impervious areas of land which has negative effects on sustainability in our cities. Heat island is one of its negative effects that can be mitigated and improved by reducing impervious lands. Using landscape, trees or vegetation and integrate them with streetscape is a sustainable way of controlling stormwater and a good substitute for impervious areas.

Second is to improve the runoff quality. This goal is achieved by implementing different Green Street practices such as biofiltration and trees to remove pollutants from stormwater. In addition to that these practices are designed to reduce volume and rate of stormwater.

Third is to use public natural resources and public spaces for multiple purposes. Green Street practice respects public natural resources and addresses multiple purposes by integration of public space and landscape to create recreation and other share uses for a society.

The City of Portland is an urban area which is one of the leaders in applying Green Street has another definition for Green Street (Portland, 2008b) as; Green Streets totally changes the appearance of streets by cutting down the amount of impervious surfaces and uses green landscape to control stormwater runoff by letting runoff to infiltrate to groundwater and removing pollutants from runoff using soil and vegetation. This on-site and visible method does not let the whole amount of stormwater to flow to streams and river which can cause soil erosion. Instead it reduces the volume of stormwater and prevents soil erosion of downstream as well as improving ecosystem services and natural hydrological cycle.

Some Green Street photos are presented in Figure 6, 7 and 8.

Figure 6 – Curb extension (Portland bureau of Environmental Services, 2009)

Figure 7 –Planter (Portland bureau of Environmental Services, 2009)

Figure 8 – Planter (Portland bureau of Environmental Services, 2009)

Green Street concept can be integrated with urban design and urban planning to provide a lively beautiful city which can take care of its stormwater in a sustainable way as it also provides different other advantages (Hoyer *et al.*, 2011). Figures 6, 7 and 8 are some examples showing how Green Street techniques can improve the amenity in urban areas. This potential in Green Street concept needs to cooperate with urban planning process to make cities more attractive as it also promotes space use in an effective way in urban areas.

3.1. Some benefits of Green Street

Green Street as it is been mentioned is not only a technique to improve stormwater management but it a concept that provides human and environment different advantages such as;

- Increased water quality by removing pollutants from stormwater using infiltration as well as other techniques (Grumble, 2007).
- Decreased risk of flooding in urban areas by reducing impervious surfaces, instead implementing bioretention, swale and other green techniques (Grumble, 2007).
- Increase in water supply by infiltrating stormwater to groundwater layer and replenish the ground water supply (Grumble, 2007).
- Improved air quality by removing pollutants carried through the air (airborne) using vegetation and trees (Grumble, 2007).
- Cooling down air temperature by increasing evaporation and shade that can be gained through applying vegetation and trees or bioretention and etc (Grumble, 2007).
- Reduce the heat island effect by cutting down impervious surfaces and creating green landscape. Using trees in urban areas also help to reduce the bad effect of heat island because of tree's shade. In addition to that tree's shade can cool down runoff (Grumble, 2007).
- Improve in amenity of neighborhood by beautifying streets using green structure in combination with blue. Furthermore, increasing the biodiversity which is gained through using trees, vegetations and soil in urban areas (Grumble, 2007).
- Green Street is a cost effective technique because it saves all the costs for conventional drainage system such as using different hard materials i.e. pipes, concrete ponds (digging and etc) and etc as well as the cost for the maintenance.
- Different researches have shown the fact that incorporating green and blue into street design will improve physical activities and social interaction (Walker, 2009), (Farnham, 2010) and (Dill *et al.*, 2010).
- Some other social benefits of Green Street are connected to a better inhabitant's mental well-being and psychological health (Farnham, 2010).
- A study conducted by University of Delaware connect Green Street with crime reduction which is also considered as a social benefit of Green Street (Barton & Pineo, 2009).
- Green Street increases safety as it decreases the risk of accident. According to (Barton & Pineo, 2009) drivers are tend to drive more carefully in Green Street.
- Green Street concept can easily cooperate with urban design and urban planning to make cities more attractive (Hoyer *et al.*, 2011).

- Green Street concept repair and improve urban ecology by improving greenery and integrating the landscape in urban areas (Hoyer *et al.*, 2011).

3.2. Some limitations of Green Street

- In cold climates, many consideration should be incorporated with Green Street design in order to prevent freezing and less efficiency (EPA, 2008). One of the examples is infiltration trench which does not function good in cold climate. Snow plough and freezing the surface of permeable pavement are also some concerns for cold climate that should be taken into account (Lukes & Kloss, 2008).

- According to a case, some of Green Street inhabitants complain about lack of parking space (Dill *et al.*, 2010). Figure 9 shows a street before and after Green Street implementation. As it is obvious, street gets narrower as they get greener so result will be fewer parking spaces.

- Trees and their leaves can make the street dirty. Furthermore using pesticide and herbicide is dangerous for the environment which is used in some of Green Street techniques (Cappiella *et al.*, 2006). Using these kinds of chemical substances to help trees and vegetations can increase the risk of spreading toxic waste in our environment which is also considered as a negative point.

- Birds can cause dirt on cars and also on street.

- Some other disadvantages of Green Street will be more elaborated in following chapter (Green Street practices). Maintenance, risk of clogging (i.e. bioretention), insects especially in pond and some limitation of usage for practices are considered as other disadvantages of Green Street (Woods-Ballard *et al.*, 2007).

Figure 9 – Coolidge road, before and after implementation of Green Street (CRWA, 2012)

3.3. Some Green Street practices

3.3.1. Bioretention

Bioretention, also called bioretention strip or rain garden is a Green Street practice that refers to a shallow landscape covered by engineered soil and vegetation/plants on top which helps to drain runoff from below and reduce the volume of stormwater (Woods-Ballard *et al.*, 2007). It is a technique that suits frequent rainfall (Woods-Ballard *et al.*, 2007). Bioretention is also a stormwater treatment that is based on vegetation and engineered soil and is used in some other practices such as planters, rain garden, swale and infiltration basin with some adjustments to improve the quality of water by its high filtration capability (Hoyer *et al.*, 2011). This technique is in the subcategory of filtration as it does not encourage infiltration because of the lining layer in the bottom of bioretention which does not allow any infiltration.

Bioretention practice has been developed since 1990s and the origin of this technique is Prince George's County, Maryland, Department of Environmental Resources (Coffman, 1999).
Bioretention area can be implemented in number of places such as along highways, roads residential areas, industrial areas, parking lots and etc. This technique is rather flexible in size and shape and can be landscaped and used in urban areas to improve aesthetic and biodiversity. In addition, a good bioretention design can make it possible for visitor to see water in the bioretention after a heavy rain (Hoyer *et al.*, 2011).

In this approach lining layer as a ground level layer is require which makes the technique not suitable for areas with infiltration capacity so industrial area can be completely suitable for bioretention practice. Figure 10 is a bioretention strip used in a parking lot and figure 11 shows a section of a bioretention practice.

Some advantages of bioretention

- Bioretention area is very practical at filtering pollutants and increasing the quality of water. Bacteria, suspended solids, metal such as copper and organic materials can be reduced and purified up to 90% with this practice (CASQA, 2003).
- Bioretention landscape can reduce the volume of runoff (Woods-Ballard et al., 2007).
- It improves amenity of landscape as well as biodiversity and also mitigate and block wind by the vegetation (CASQA, 2003).
- Bioretention areas have flexible features so they can be applied in different places (Woods-Ballard *et al.*, 2007).

Some disadvantages of bioretention (Woods-Ballard *et al.*, 2007)

- A bioretention area cannot be applied in a very steep slope.
- A bioretention landscape needs landscaping and management.

- A bioretention can easily be clogged if it is located in a poor landscape**.**

Figure 10 – A bioretention strip (City Of Owatonna, 2012)

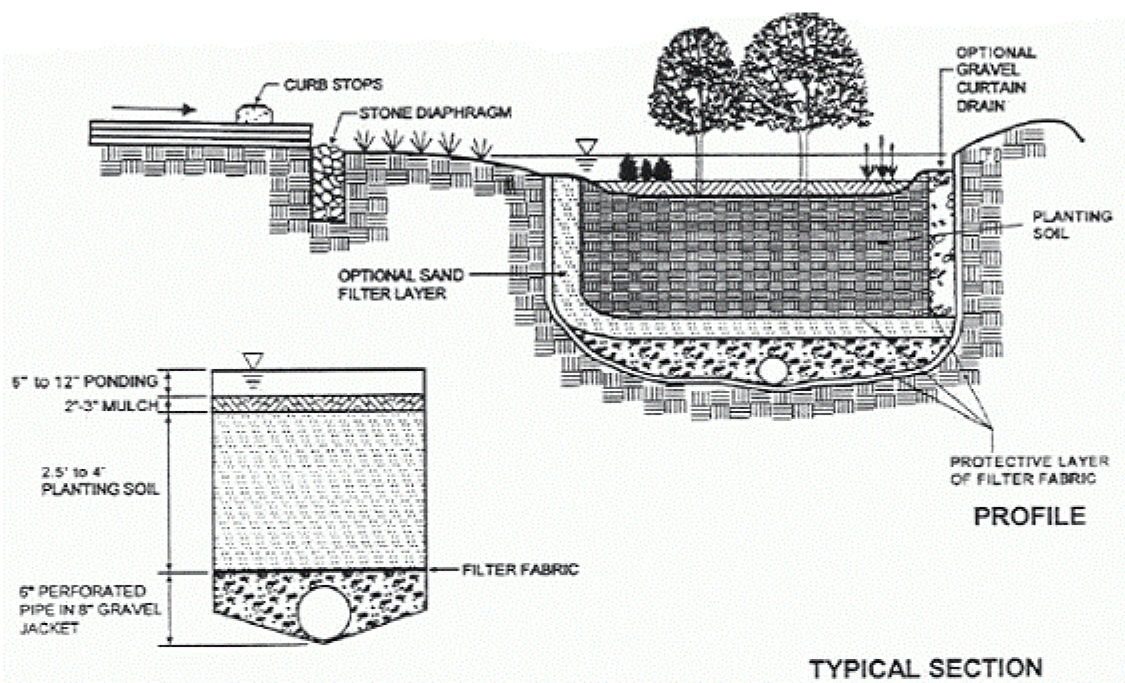


Figure 11 – Section of bioretention practice (MDE, 2000)

3.3.2. Green roofs

Green roofs, rooftops greening or eco-roofs is a technique that comes from Germany by Strodthogff & Behrens with multi benefits (Coffman, 1999). A green roof is basically composed of multi layer system including a drainage layer underneath which is placed on roof of buildings to control and reduce the volume of stormwater in the source of it. Figure 12 and 13 show different layers of a green roof and figure 14 is an implementation of a green roof. This technique is in subcategory (stormwater management) of source control because in this practice rainfall comes directly on green roof and filters through the layers. This practice promotes urban ecology and biodiversity in urban areas. It is also considered as a positive element that can be integrated with urban planning by landscape architect to improve the view of cities. A building with a green roof can be seen as a part of landscape and it also address physical human health by promoting evaporation and decreasing the negative effect of heat island (Hoyer *et al.*, 2011).

Some advantages of green roof

- Reduction of stormwater runoff volume; It can store 30% to 100% of the yearly rainfall (Coffman, 1999).
- Improved quality of stormwater and consequently water environment by filtering the pollutants from the rain.
- Cooling the air and increasing the humidity by improving evaporation of stormwater runoff.
- It can insulate the building from heating and temperature as well as noise pollution.
- Increased amenity of neighborhood by its green structure and biodiversity.

Some disadvantages of green roof

- Maintenance cost of green roof is considered as a barrier (Gedge & Frith, 2004). This issue can be more explained with cost of maintaining vegetation and preventing leakage from the roof which can cause higher cost of repair (Belan & Otto, 2004).
- Installation issues especially for an already constructed building (installing green roof can be expensive) (Belan & Otto, 2004).
- Green roofs do not always look perfectly green which is considered as a negative effect on aesthetic view of a building (Gedge & Frith, 2004).
- Applying fertilizers and pesticide to improve vegetation of green roof can result in a lower water quality in combination with rainfall (Gedge & Frith, 2004).

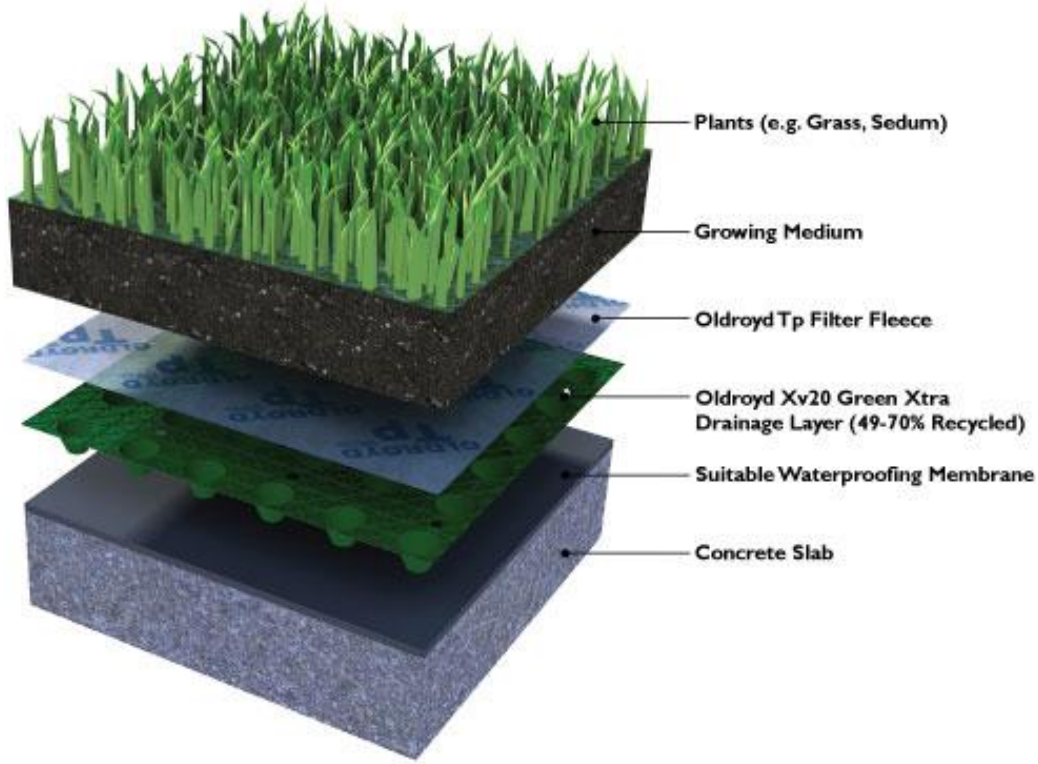


Figure 12 – Different layers in a green roof (Safeguard Europe Ltd, 2012)

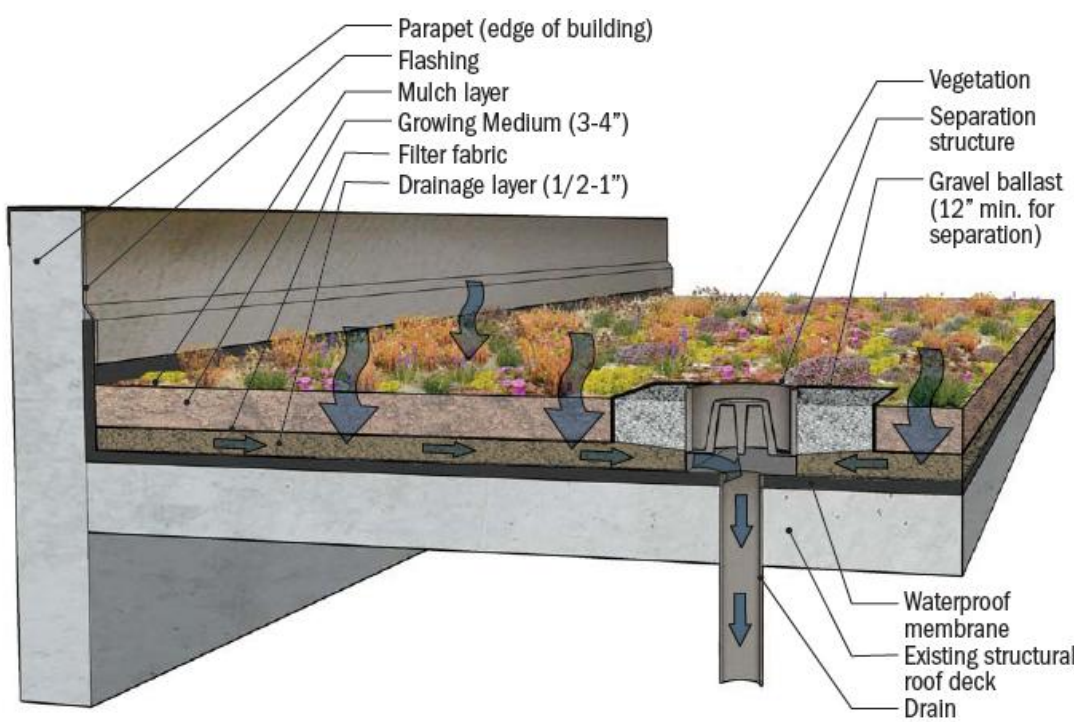


Figure 13 – Green roof and how water flows through the system (Services, 2009)

Figure 14 – Implementing green roof on a building (American Rivers, 2012)

3.3.3 Swales

Swales are vegetated channels that promote conveyance and pollution removal of stormwater and eventually drain runoff to downstream. Infiltration in swales is depended to the condition. Sometimes base layer of a swale is a permeable surface which allows infiltration and sometimes it is impermeable. Swales can be considered as very effective substitute for drainage pipes and gullies in urban areas (Woods-Ballard *et al.*, 2007). Swales are subcategory for open channels (Woods-Ballard *et al.*, 2007) as figure 16 and 17 show dry and wet swale.

Swales can fit in open spaces or parks to create a more beautiful landscape and also they can be utilized as recreation when swales are dry. Landscape architects can take advantage of slope of swales and incorporate it with the delicate design to make a beautiful landscape in urban areas (Hoyer *et al.*, 2011).

Some advantages of swales (Woods-Ballard *et al.*, 2007)

- Swales are very efficient in reducing the velocity and volume of the stormwater.
- Swales are quite flexible and can be applied in different landscape.
- Swales are cost effective in comparison with conventional approach as well as easy maintenance.

Some disadvantages of swales (Woods-Ballard *et al.*, 2007)

- It is hard to apply this method in a steep slope landscape area.
- It is hard to plant trees in swales.
- The connection between swale and drainage pipe can be clogged with pollutants so the connection between swale and pipe can work poorly.

Woods-Ballard et al (2007) divides swales to three different types;

3.3.3.1 Conveyance swales

A shallow wide vegetated swale is basically called a conveyance swale or grass swale (Coffman, 1999) as its main function is to convey stormwater runoff from a drained area to another. Figure 15 shows a conveyance swale.

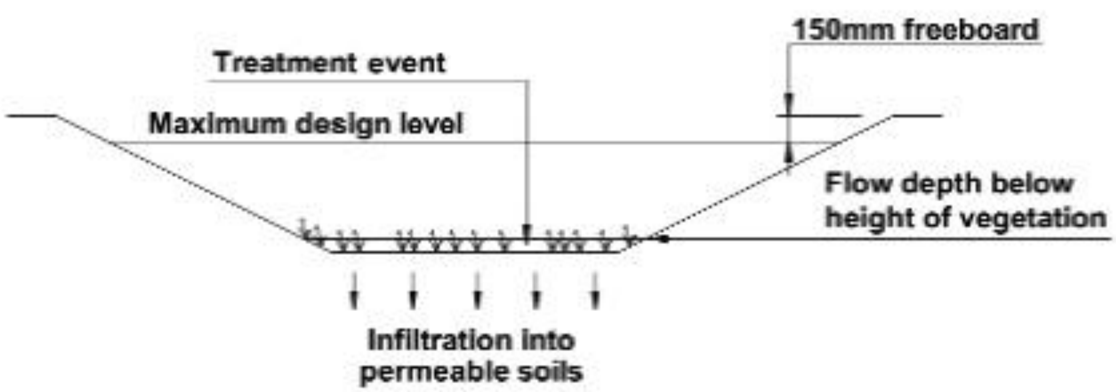


Figure 15 – Conveyance swale (Woods-Ballard *et al.*, 2007)

3.3.3.2 Wet swales

The structure of wet swale is close to conveyance swale, however the vegetation layer has been improved to treat pollutants more than conveyance swale (Woods-Ballard *et al.*, 2007). Vegetation in wet swale must have the quality to be tolerant towards water since it can be water always remaining in the wet swale. Wet swale is usually used along highways (Coffman, 1999). Wet swale is not effective in volume reduction of stormwater whereas it promotes pollutant removal. Figure 18 shows a wet swale section and figure 17 is an implementation of wet swale practice.

3.3.3.3 Dry swales

In dry swales the engineered soil filter underneath of vegetated layer and the drainage layer under the soil filter increase the capacity of drainage as well as improve pollutants removal capability. In another word dry swale address quantity as well as quality control (Coffman, 1999). Both dry and wet swale are designed for 48 hours stormwater quality treatment (MDE, 2000). Figure 19 shows a dry swale section and figure 16 is an implementation of dry swale.

Figure 16 – Implementation of dry swale, source HW Group File Photo (Horsley & Durham, 2010)

Figure 17 – Implementation of wet swale by (VIRGINIA, 2011)

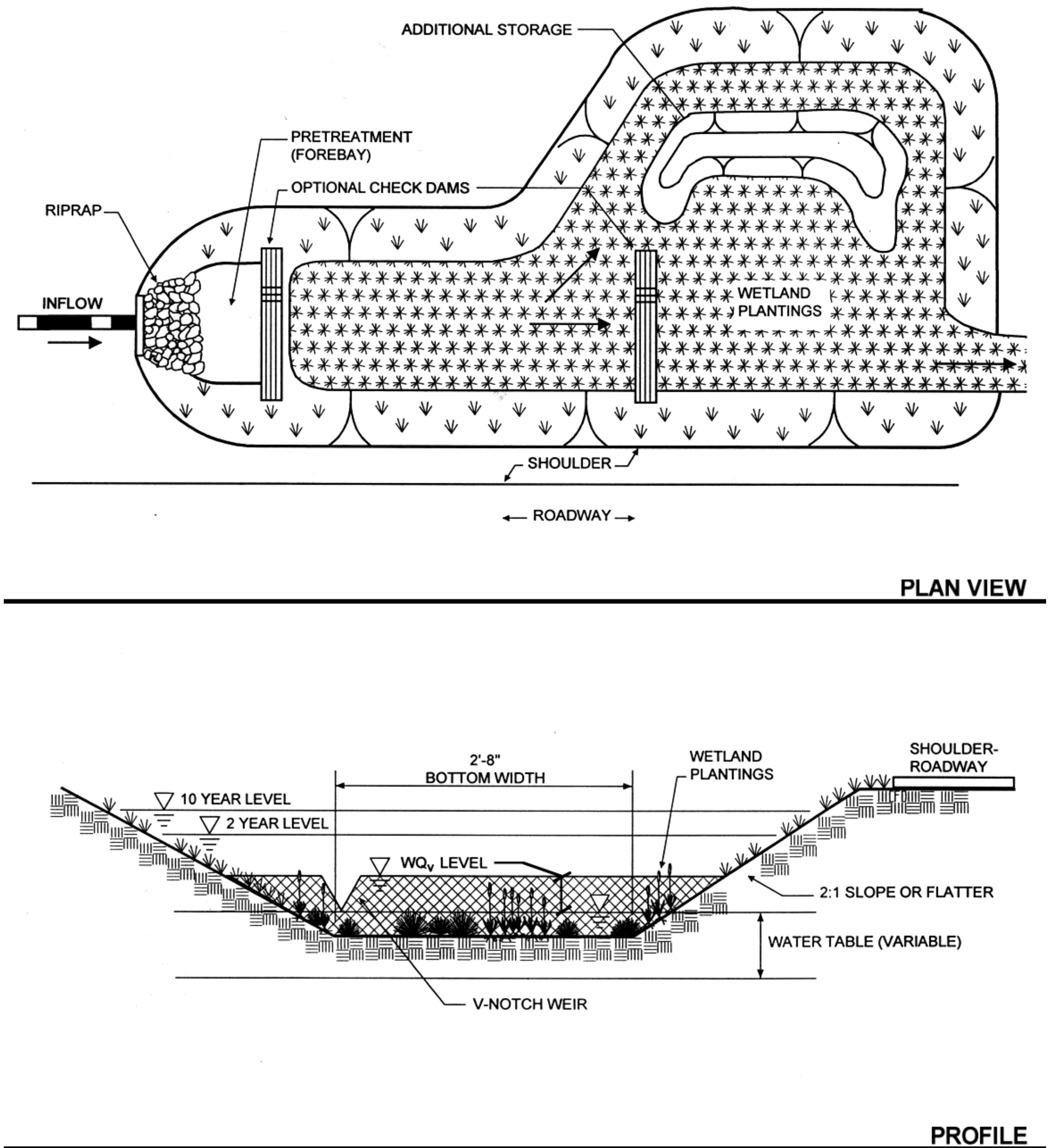


Figure 18 – Wet swale (MDE, 2000)

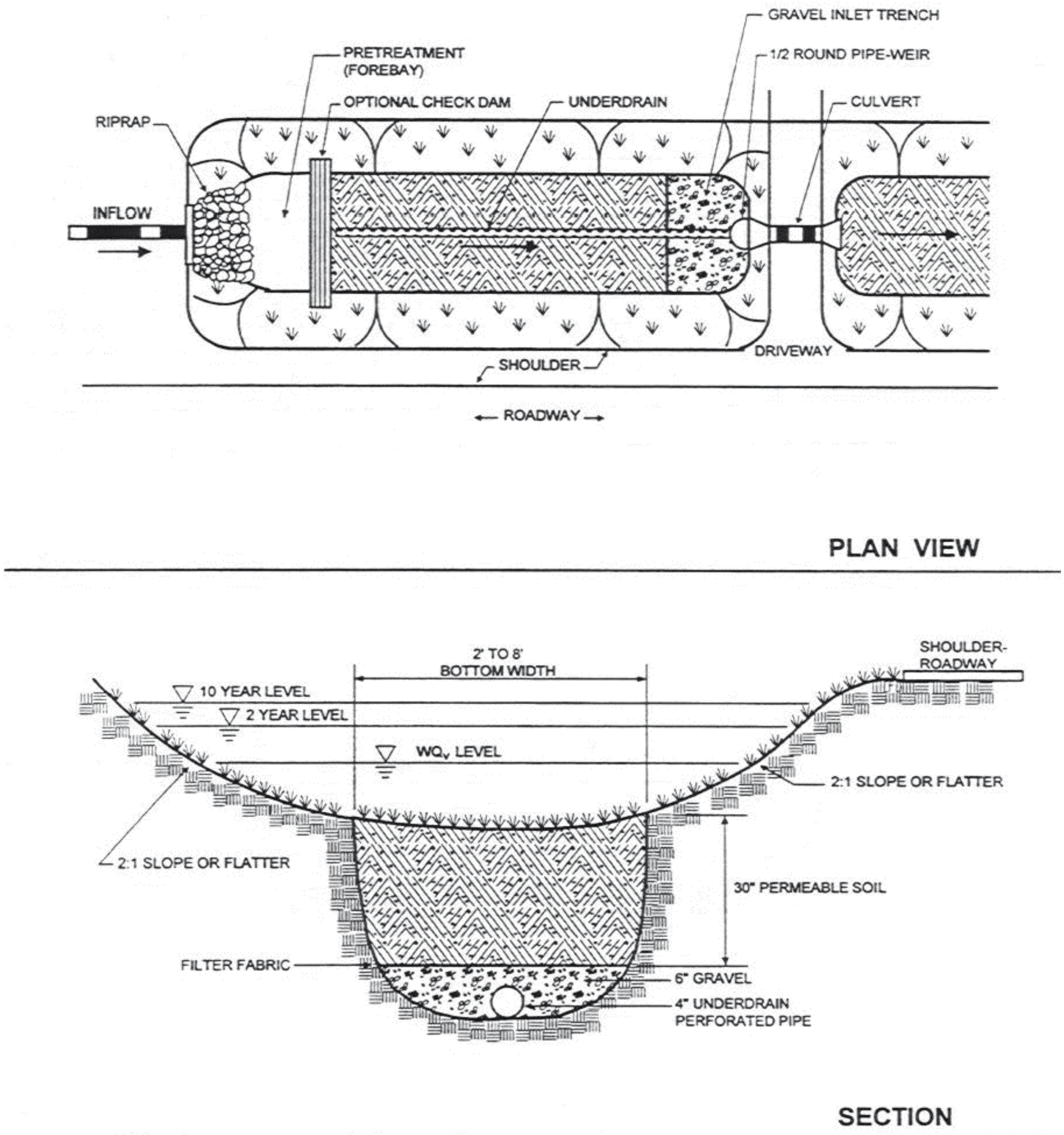


Figure 19 – Dry swale (MDE, 2000)

3.3.4. Rainwater harvesting

Rainwater harvesting method is designed to intercept and store the rainfall for reusing the rainwater in future. Rainwater harvesting is considered as a subcategory of stormwater source control. This practice can both address the reduction of runoff volume and prevention of downstream contamination. The stored water in the tank or barrels can be used for different non-potable purposes such as irrigation, toilet flushing, car washing and etc. Although a sophisticated treatment on the stored water can provide potable use. Figure 20 shows a rainwater harvesting system in a house (Woods-Ballard *et al.*, 2007). Rainwater harvesting addresses sustainability in cities. Landscape architects may not be able to use this technique to beautify cities as it is more applicable for small scales or single houses. However usage of this technique should be encouraged by developers and landscape architect to improve sustainability as well as help water resource by saving stormwater and reuse it for many purposes.

Some advantages of rainwater harvesting (Woods-Ballard *et al.*, 2007)

- It is considered as a source control practice which means, the rainfall from roofs directly drains to barrels or tanks to be stored.
- By providing stored water, rainwater harvesting can reduce the need of water.

Some disadvantages of rainwater harvesting (Woods-Ballard *et al.*, 2007)

- It can be risky for the public health as the stored water can be used for potable consumption.
- The maintenance and install of a barrel or a tank for rainwater harvesting can be costly.
- The risk of water freezing and being unsteady for the above ground barrel is high therefore is better to have the tank or barrel underground which can be problematic in some places.

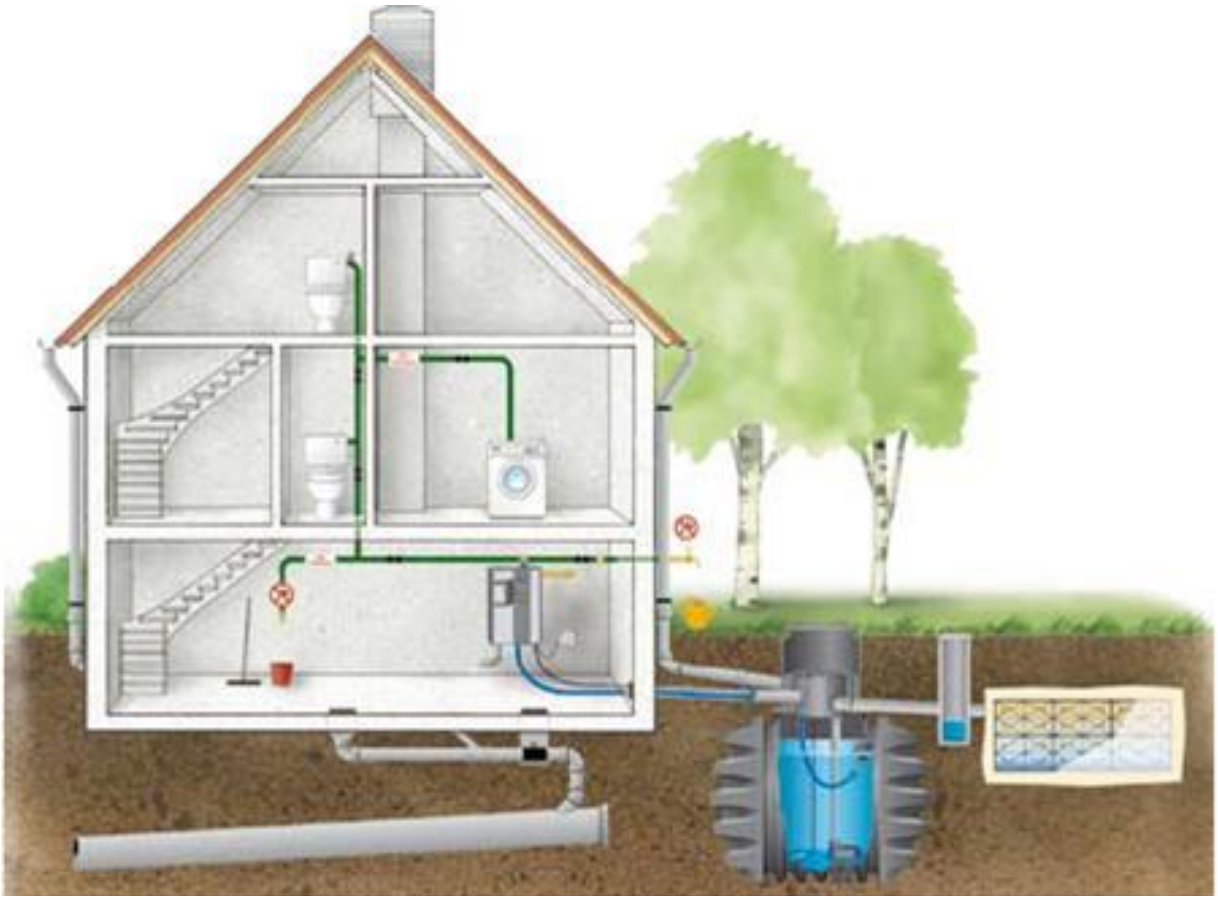


Figure 20 – Rainwater harvesting (Woods-Ballard *et al.*, 2007)

3.3.5. Vegetated filter strip

Vegetated filter strip or vegetated filters (Portland, 2004) are gently sloping areas to receive sheet stormwater runoff (flows) from upstream development (Services, 2009). Vegetated filters usually situated between impervious land and streams and the function of vegetated filters is to slow, filter and infiltrate stormwater runoff (Woods-Ballard *et al.*, 2007). stormwater can travel in vegetated filter strip and be temporarily stored, infiltrated and eventually drained to an approved drainage system. Figure 21 shows different parts of a vegetated filter strip and figure 22 is an implementation of this practice in a Green Street.

This practice can be applied both in private and public areas such as pocket parks as well as offices. Existing residential areas or sidewalks can be integrated with this technique to be more applicable to control stormwater as they also become more attractive. Vegetated filter strip can be integrated with the existing urban landscape to improve the street aesthetic view especially if it is utilized along roads and paved sidewalk (Hoyer *et al.*, 2011).

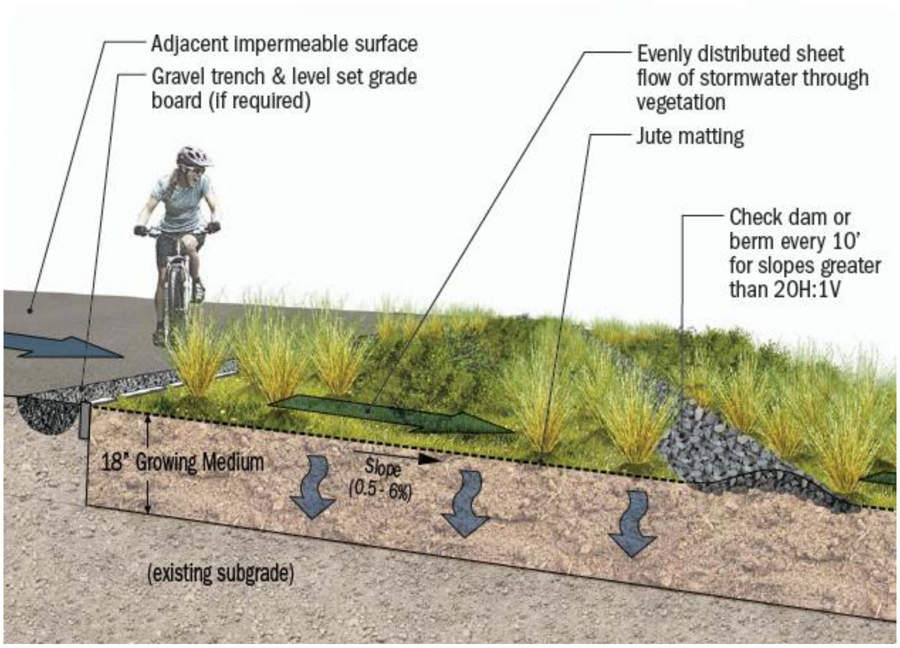


Figure 21 – Vegetated filter stripe (Services, 2009)

Figure 22 – Implementation of vegetation filter stripe (Portland bureau of Environmental Services, 2009)

Some advantages of vegetated filter strip (Woods-Ballard *et al.*, 2007)

- Filter strips can receive stormwater runoff from a large impervious piece of land.
- It can be considered as low-cost treatment.
- It is easy to incorporate it within the landscape and improve aesthetic view of street.

- Vegetated filter strips improve infiltration and evaporation.

Some disadvantages of vegetated filter strip (Woods-Ballard *et al.,* 2007)

- Vegetated filter strips require a large piece of land to be implemented.
- It cannot be applied in steep slope landscape.
- Using this technique for high risk areas is problematic since infiltration can be dangerous for groundwater unless the filter strip is provided with permeable lining.
- This technique is not effective for high intensive rain.

3.3.6. Trees

Trees intercept precipitation, directly rainfall can be taken up by the roots and go through the trunk of a tree (Day & Dickinson, 2008). There are different types of trees that can be applied for managing stormwater such as oak however canopy tree (the outer layer of tree made by leaves) is very effective in intercepting stormwater (EPA, 2004). Figure 23 shows some oak trees (an example of canopy tree) in a street in Pennsylvania Avenue, Washington, D.C. Landscape architects can encourage utilizing trees in planning and design process for urban areas to improve public appeal (Hoyer *et al.*, 2011). Trees provide different benefits in managing stormwater as following:

Some advantages of trees

- Trees control flow with their leaves and branches and allow the rainfall to evaporate which is important for natural hydrological cycle. Trees also improve infiltration and replenishment of groundwater (Portland, 2004).
- Trees make shade on impervious surfaces which mitigates the negative effect of heat islands. By reducing the effect of heat island, runoff will have less temperature when it flows on shade surface. Less temperature runoff is more healthy for the environment (Portland, 2004).
- Trees remove pollutants from air which also can facilitate pollutants reduction of rainfall and in result, runoff will carry less pollutants to downstream (Day & Dickinson, 2008).
- Trees improve the aesthetic view of streets as well as biodiversity.

Some advantages of trees

- Younger trees cannot control stormwater very effectively as older and bigger trees. In another words, it can take some years for a street to benefit newly planted trees for stormwater management (Belan & Otto, 2004).

- Trees are less effective in controlling stormwater in cold seasons when they lose their leaves (Belan & Otto, 2004).

Figure 23 – Applying trees for managing stormwater (Day & Dickinson, 2008) *Photo by Nina Bassuk*

Note: Two Green Street practices that are used in the case study of this thesis are; 1- A flow-through planter 2- A permeable pavement. More details about these two Green Street practices are presented in the following chapters.

3.3.7 Planters

Planters are rather small, vegetation covered landscape which have vertical walls, made of stone, concrete or bricks, plastics and etc (Portland, 2004). Generally planters use bioretention treatment for pollution removal from stormwater runoff since it contains the vegetation and engineered soil structure to remove the pollutant and reduce the volume and velocity of the stormwater.

Planters are flexible in size and shape and can be used in different areas such as no-residential and residential or along the street.

Some advantages of planters (CRWA, 2008)

- Planters help to decrease the stormwater velocity, temperature and volume.
- Planters increase the quality of stormwater by removing pollutants.
- Increase the amenity and aesthetic of neighborhood.
- It is a cost-effective Green Street practice.
- Planters are flexible in size and can be applied in different landscape.

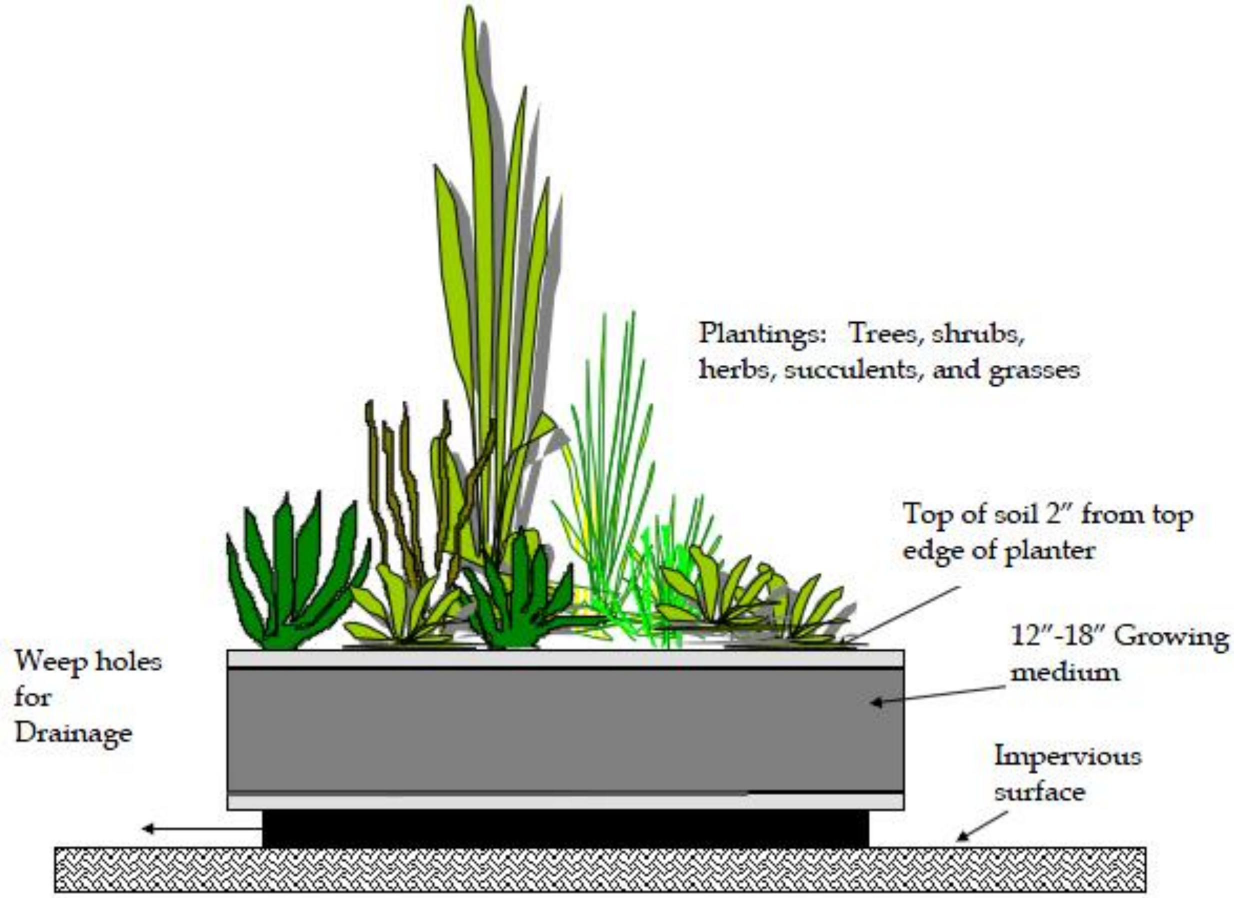
Some disadvantages of planters (CRWA, 2008)

- Planters are rather small and not proper for large impervious landscape.
- They can effectively work for 25 years.
- Planters need to be maintained due to the weed growing, drying the vegetation (watering) and soil replacement.
- Planters cannot be applied in the steep slope landscape.

Planters are divided into three main categories; contained, infiltration and flow-trough (Portland, 2004).

3.3.7.1 Contained planters

Contained planters are covered with an impervious base layer that is constructed on an impervious landscape where the infiltration to the ground water is not allowed due to the soil condition or in pollutant hot-spot. Contained planters are covered by shrubs and trees, rather small and the function is mainly to filter, reduce the volume of stormwater by evaporation and transpiration (TT, 2010). Eventually drainage is allowed from the bottom layer to a pipe or other stormwater systems.(Portland, 2004). Figure 24 shows a contained planter.



Figures 24 – Contained planter (Portland, 2004)

3.3.7.2. Infiltration planters/rain gardens

Infiltration planters are designed to collect, filter and infiltrate stormwater runoff as well as increase groundwater level. Infiltration planter (also known as rain garden) can be designed in different shape and size with or without wall (Services, 2009). However rain gardens are bigger in size and without surrounding walls, though, the same technique is applied in both to filter and infiltrate stormwater runoff. Figure 25 shows an infiltration planter. There is less pipe used in infiltration planter in comparison with flow-through planter.

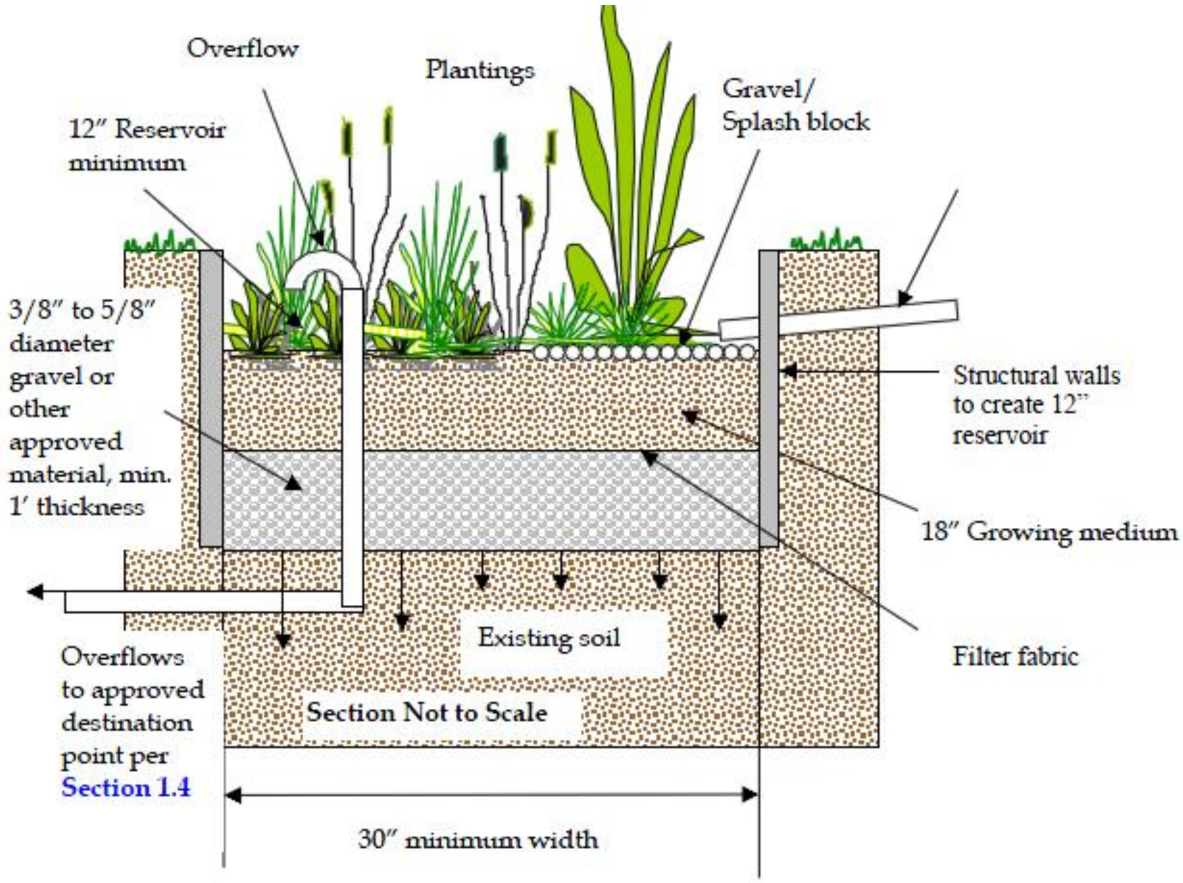


Figure 25 – Infiltration planter (Portland, 2004)

3.3.7.3. Flow-through planters

Flow-through planter are designed to treat and eventually convey the stormwater to another stormwater practice or to a drainage system. Flow-through planters have an impervious layer at the bottom which does not allow any infiltration of stormwater to groundwater but just filter/remove the sediment as well as reduce the rate of stormwater and finally treated stormwater will be conveyed to a pipe system. Figure 26 shows a flow-through planter.

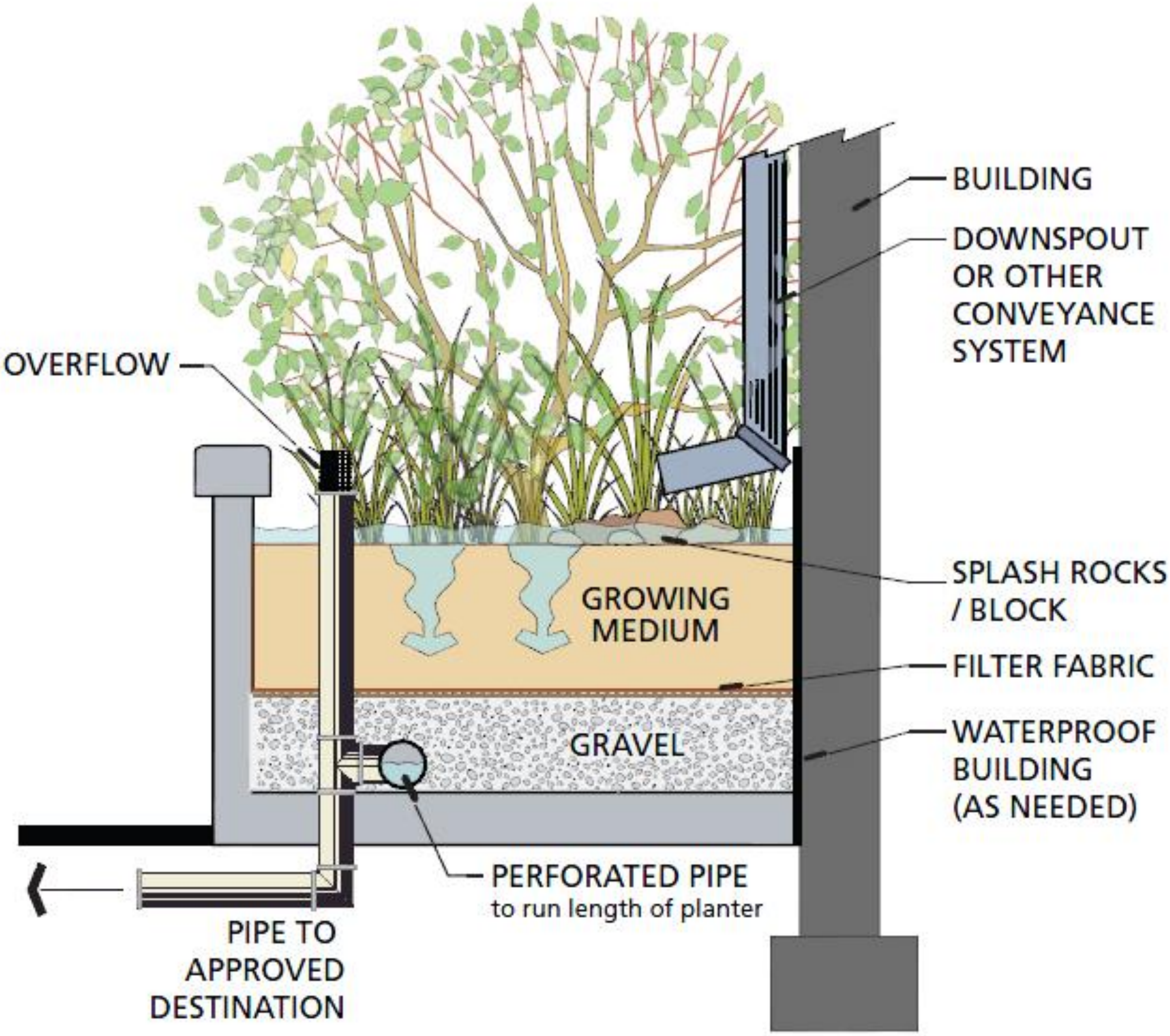


Figure 26– Flow-through planter (Portland, 2006)

3.3.7.4. A flow- through planter as a choice of Green Street practice

A flow-through planter is chosen as a Green Street practice that is going to be used for the green scenarios both dense and not dense. Among 3 different types of planters; contained, infiltration and flow-through planter, flow-through planter has been chosen based on the goals of the project;

First, infiltration in this area according to the risk of groundwater contamination is not a choice. BT Kemi (is a pesticide factory that made the area contaminated) and its remaining pollutants in the soil increase the risk of groundwater contamination that can be so dangerous for both environment and inhabitants. Infiltration planter which is one of the practices of a Green Street that allows the runoff to infiltrate to the ground and eventually reach the groundwater is excluded from the choice of selection in this project. Therefore infiltration planter practice is omitted from the choice of selection.

Second, the goal of the project is to control the flow (runoff), by reducing the rate and volume as well as pollutants. These goals cannot be achieved by a contained planter. A contained planter's goal is to storage runoff not to convey it (Portland, 2004). Therefore the contained planter is also excluded from the choice of selection as a Green Street practice in our green scenarios.

3.3.7.5. A flow- through planter's detailed properties

A flow-through planter is one of the Green Street practices for managing and controlling stormwater. The main function of a flow-through planter is to filter pollutants by its vegetation on top and engineered soil structure underneath of that and eventually convey the treated stormwater to the drainage pipe (Portland, 2004). A flow-through planter has other functions such as reducing the rate and volume of the runoff. Flow-through planters are flexible in size and shape and can be applied in many different situations and places. Figure 27 shows a flow-through planter different parts in detail and figure 28 is a plan view and figure 29 is an implementation of a flow-through planter.

3.3.7.6. Some design considerations (Portland, 2004)

In designing the flow-through planter some factors should be taken into consideration;

- It is possible to incorporate the walls of the planter into the building's foundation.
- Walls of the planter should be waterproof - especial consideration when the wall and the building's foundation are incorporated.
- The flow-through planter's topsoil can be made by different type of soil and is flexible however the topsoil and the filter fabric or the facility shouldn't have more than 18 inches or almost 45 centimeter distance.
- There are some consideration about the dimension and slope as flowing; first, slope shouldn't be more than 5 percent (5%). Second, the flow-through planter's width is not less than 45 centimeter or (18 inches). Lastly, the section lying underneath of topsoil which is called storage facility shouldn't be less than 12 inches or 30 centimeter.
- The flow-through planter needs setback[2] from the line of a lot, land use or properties. The setback for a flow-through planter should be at least 1.5 meters. However for planters with a height less than 76 centimeter (30 inches) the setback can be less than 1.5 meters.
- Different materials such as bricks, concrete, stone and wood (wood needs some consideration as it can chemically contaminate stormwater so it should be treated wood) can be used for making the walls of a planter.

[2] Setback is a distance a structure should have from a building or other land use (Wikipedia 2012)

- Flow-through planter is best applicable for an area less than 1400 m^2 or 15000 ft^2. A flow-through planter sizing can be gained in different ways however SIM approach (simplified approach) which is based on a method called (SBUH) stands for the Santa Barbara Urban Hydrograph method developed by the Santa Barbara Flood control and Water Conservation District. This method can address runoff hydrograph in a simple way and without using many equation and steps.

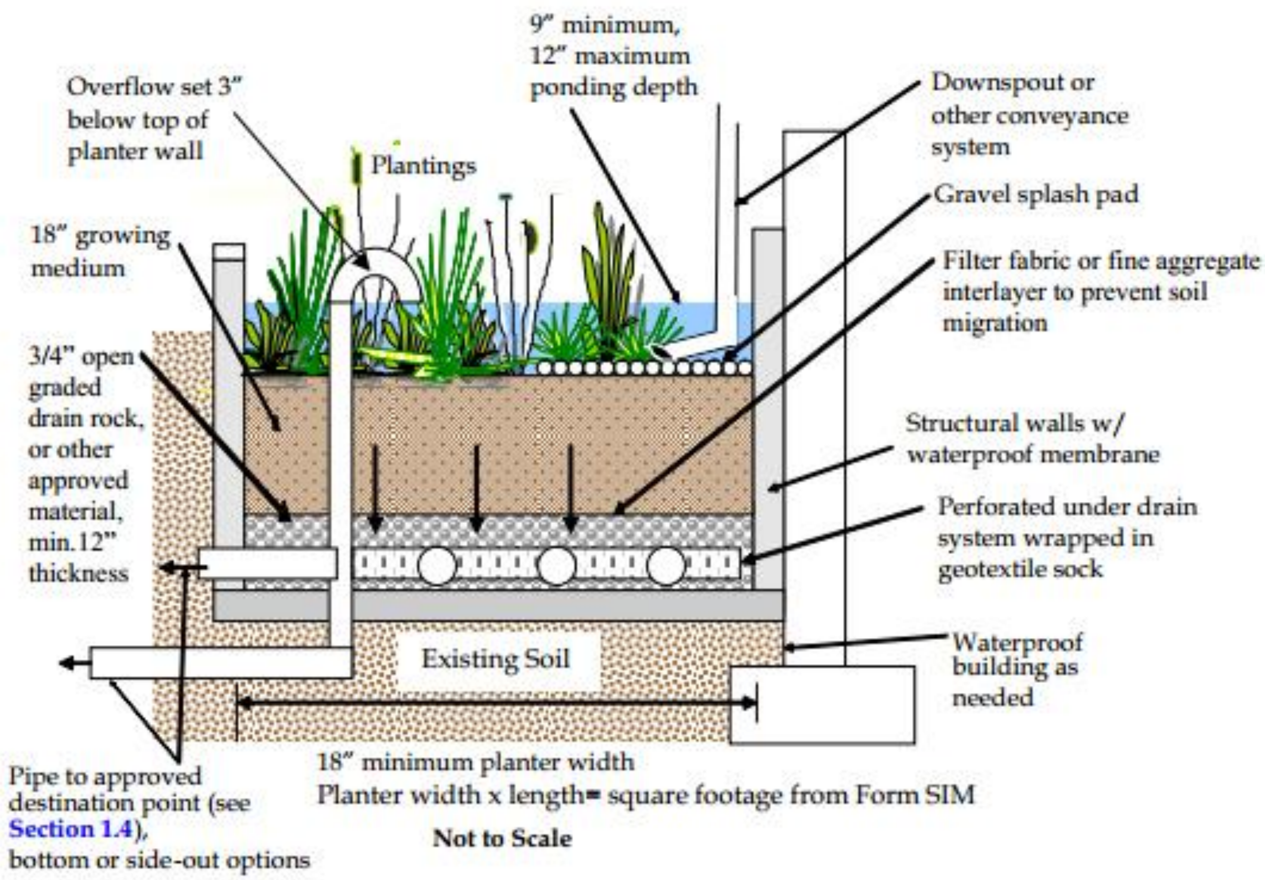


Figure 27 - A flow-through planter's detailed section (Eugene, 2008), adopted from (Portland, 2004)

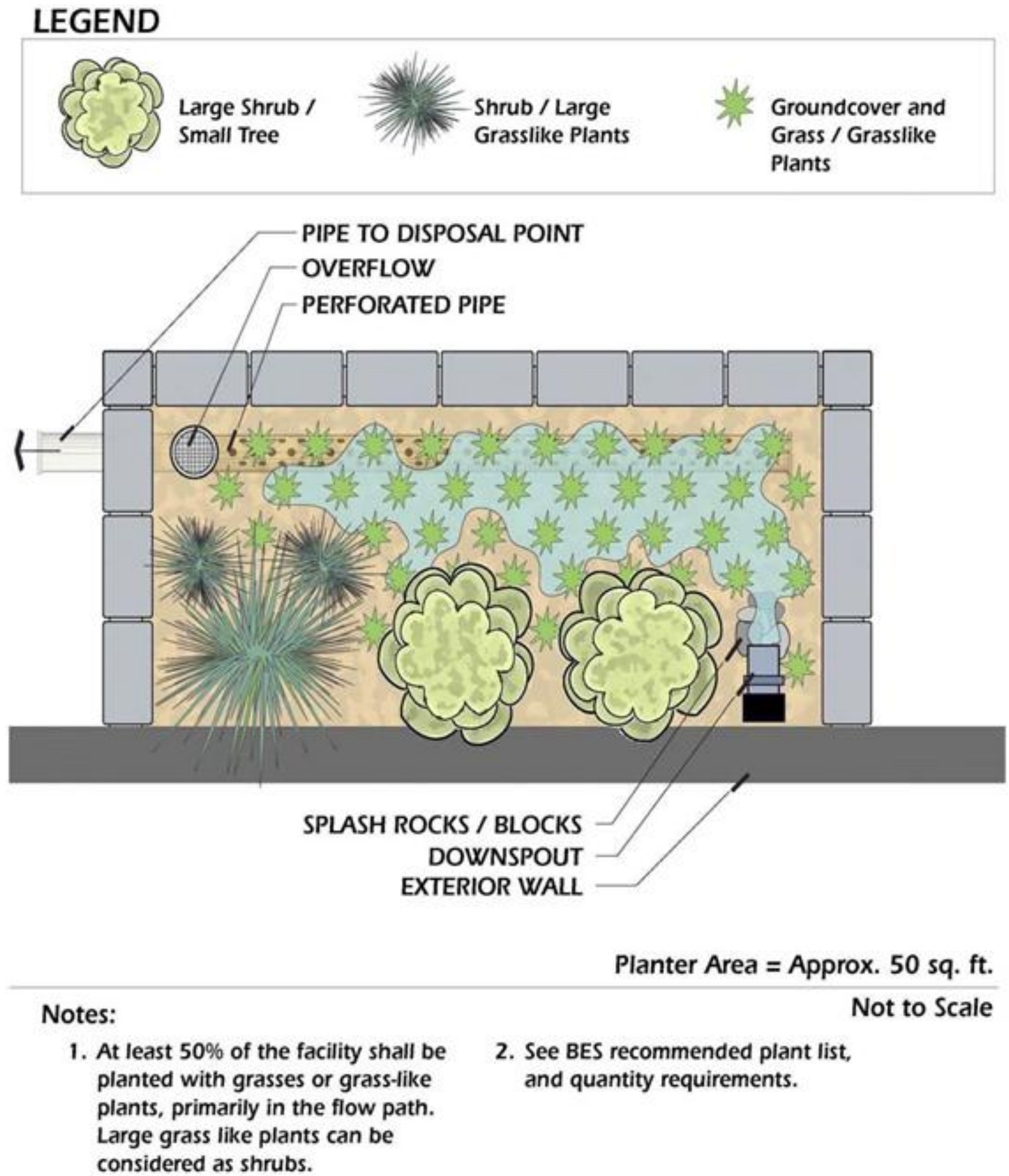


Figure 28 – A plan of a flow-through planter (Portland, 2004)

Figure 29 – An implementation of a flow-through planter (Center for Community Progress and City Parks Association, 2012)

3.3.7.7. Calculation for the size of a flow-through planter

For the calculation of a flow-through planter two different approaches are presented in this chapter. First, using SIM approach by (Portland, 2008a) and the second is a formula from SUDS manual by (Woods-Ballard *et al.*, 2007) which is used for estimating the area of a bioretention. According to (Boscacci, 2010), a bioretention's size calculation can be applied for a flow-through planter. However some consideration should be taken into account such as time of dewatering which is 48 hours in bioretention (Woods-Ballard *et al.*, 2007) whereas in flow-through planter is 3 to 4 hours (SEMCOG, 2008). Recommended soil for bioretention according to SUDS manual is silty loam with 0.000002 m/s hydraulic conductivity (permeability value) but for a flow-through planter a sandy filter in recommended by (FAWB, 2009) which has 0.00002 m/s hydraulic conductivity. Table 1 introduces some different permeability values for different soil.

3.3.7.7.1. SIM approach

SIM approach or simplified approach is a simple way of estimating the size of different stormwater facilities. In this approach, the area of impervious land or rooftop is multiplied by a sizing factor. Whereas each stormwater facility has its specific sizing factor (Portland, 2008a).

For a flow-through planter a sizing factor of 0.06 by Portland (2004) was introduced.

3.3.7.7.2. SUDS approach

Second approach is a formula by Woods-Ballard et al (2007) for calculation the surface area of bioretention which can be also applied to a flow-through planter (Boscacci, 2010). The formula is as following;

$$A_f = \overline{\hspace{2cm}} \qquad (1)$$

Where;

A_f is the surface area of bioretention (flow-through planter) in m^2

V_t is the total volume of water that is going to be treated (m^3)

L is the depth of soil layer (m)

k is the coefficient for the capacity of passing water through the soil in (m/s)

h is the average height of water level on the top (above the soil) in (m)

t is the time for the water to travel through the filter medium in (s)

Note: Different values of “k” are presented in appendix 5. Soil permeability or “k” has a significant role in the equation for flow-through planter area. Gravel or sandy soils for instance have greater permeability value compare to loam or silty loam. Therefore, the area for a flow-through planter will be smaller using gravel or sandy in comparison with loam or silty loam. A recommendation soil type for planter is gravel or sandy soils (SEMCOG, 2008).

Another important parameter in area calculation for planter is “t” (time of dewatering) which is 48 for bioretention according to SUDS manual whereas it is 3-4 hours for flow-through planter (SEMCOG, 2008).

3.3.8. Permeable pavement

The pervious pavement or permeable pavement is another practice to control and reduce the volume of stormwater. Permeable pavement allows the stormwater to penetrate top layer, filter the pollutants through the soil layer and eventually infiltrate to the groundwater level, drain the treated stormwater to downstream or reuse and storage temporarily. According to EPA (Environmental Protection Agency), permeable pavement is the subcategory of infiltration practice. Porous concrete (figure 30), porous asphalt (figure 31) and bricks that are made of porous concrete (figure 32) are the most used material in permeable pavement (Scholz & Grabowiecki, 2006).

Permeable pavement can be utilized in urban areas especially in very dense urban areas to improve sustainability as it addresses stormwater quality and also to reduce traffic noise (Hoyer *et al.*, 2011). Recently different types of permeable pavement are available in market, which can be applied by landscape architects to improve amenity of city. Permeable pavement can also be planted with vegetation on top layer in some places which increase amenity (Hoyer *et al.*, 2011).

Some advantages of permeable pavement (Woods-Ballard *et al.*, 2007)

- Pervious pavement removes a huge amount of pollutants from stormwater.
- Using pervious pavement is an efficient way of reducing stormwater volume as well as velocity of runoff.
- It can also be considered as a cost saving method since it utilizes the urban space for multiple purposes (such as traffic passage and stormwater management practice).
- It is a cost effective way since it eliminates the use of pond, gully pots, manhole and etc.
- It does not need high maintenance.

Some disadvantages of permeable pavement (Woods-Ballard *et al.*, 2007)

- Grass or weed can grow through the layers if the landscape condition is poor or the maintenance is weak.
- This practice cannot be applied for all conditions especially when the rate of pollutants is high or the soil condition is not suitable for infiltration (due to the risk of groundwater contamination).
- It can be problematic when it comes to a heavy traffic road due to the heavy weight.

Figure 30 – Porous concrete (VDC, 2012)

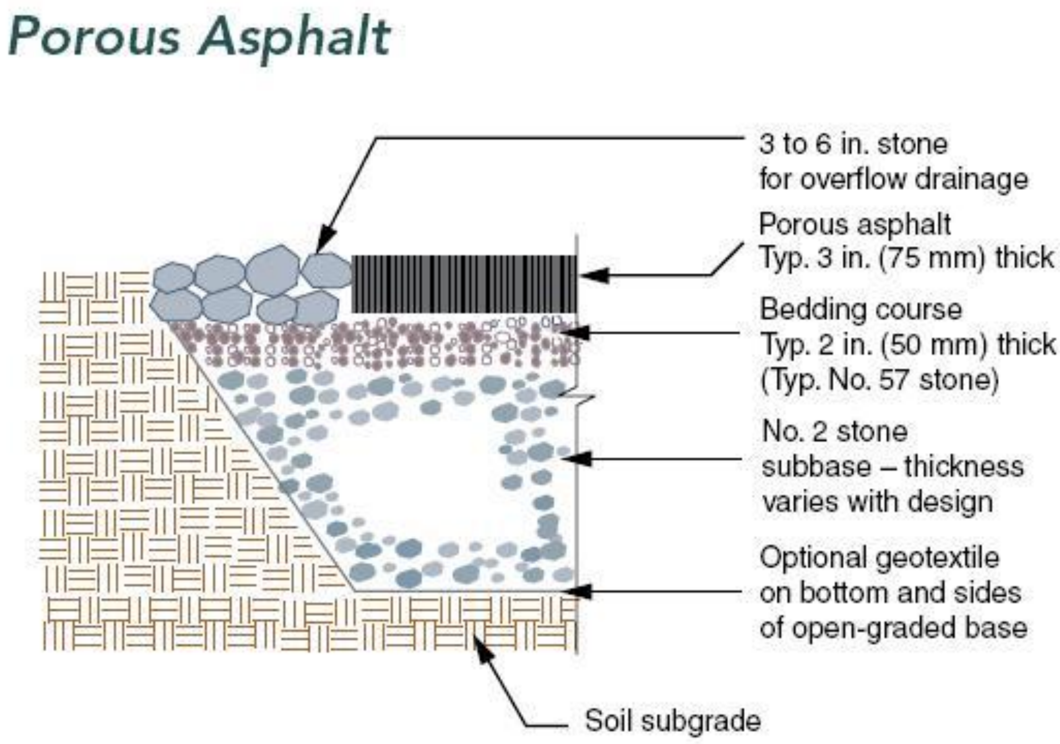


Figure 31 – Porous asphalt (EPA, 2012)

Table 1 introduces the capacity of passing stormwater through porous asphalt (Adams & Cahill, 2003);

Table 1 – Porous asphalt

Sieve size	Passing in %
12.7 mm	100
9.5 mm	95

Figure 32 – A parking lot with a permeable pavement (Urban Drainage and Flood Control District, 2012)

In the case study of this thesis, both green scenarios will have “No infiltration permeable pavement” as a choice of Green Street practice.

Different types of permeable pavement

Three different permeable pavements are presented in following section. Figures 33, 34 and figure 35 respectively present fully infiltration permeable pavement, partially infiltrate permeable pavement and no infiltration permeable pavement.

3.3.8.1. Fully infiltrate permeable pavement

Fully infiltration permeable pavement is a suitable solution for an area where soil has the capacity to infiltrate stormwater runoff. In this approach the stormwater cannot flow to a drainage pipe or other drainage system because it is infiltrated to the groundwater layer. This technique is considered as an economic approach among all three types of permeable pavement (Vanstone 2012)[3]. Figure 33 shows a fully infiltration permeable pavement.

[3] - www.vanstone.co.za

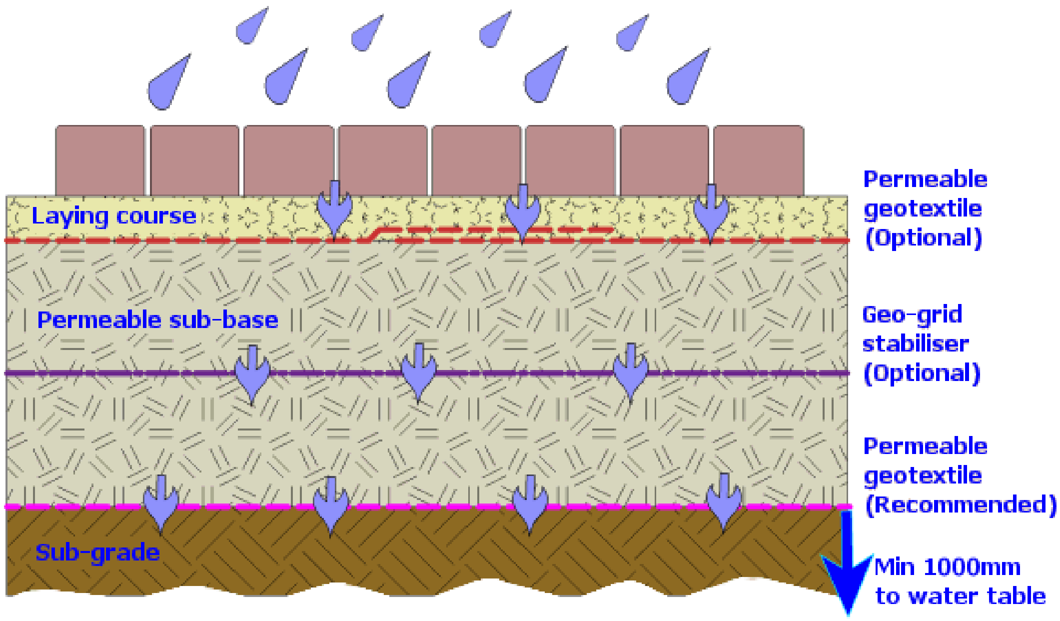


Figure 33 – Fully infiltration permeable pavement Adopted by SUDS manual, drawing by (Tony McCormack ~ Pavingexpert.com, 2012)

3.3.8.2. Partially infiltrate permeable pavement

Partially infiltrate permeable pavement is a technique which is more suitable for an area where the sub-grade does not have enough capacity to infiltrate stormwater or the risk of excess stormwater due to a heavy rain is highly noticeable. In these situations a perforated pipe is placed on top of sub-grade layer to convey the excess stormwater to another stormwater practices such as swale or pond or directly drain treated stormwater to a pipe system (Vanstone 2012). Figure 34 is a partially infiltrate permeable pavement.

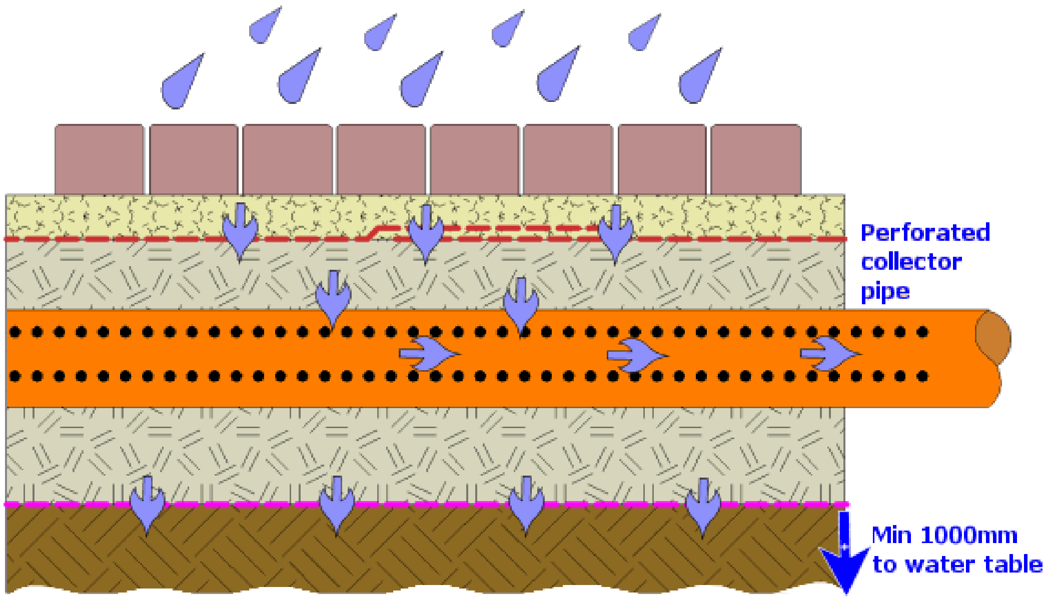


Figure 34 – partially infiltrate permeable pavement Adopted by SUDS manual, drawing by (Tony McCormack ~ Pavingexpert.com, 2012)

3.3.8.3. No infiltration permeable pavement

No infiltration permeable pavement which does not infiltrate stormwater to the sub-grade layer or groundwater level. This technique is used for areas where the risk of groundwater contamination is highly considerable. In this approach a drainage pipe in the permeable level collects and conveys all the stormwater to an approved drainage system. One of the advantages of this system is that it does not need a big pipe and a small pipe would be able to collect the stormwater to the drainage point. Figure 35 shows no infiltration permeable pavement. This Green Street practice is used in green scenarios.

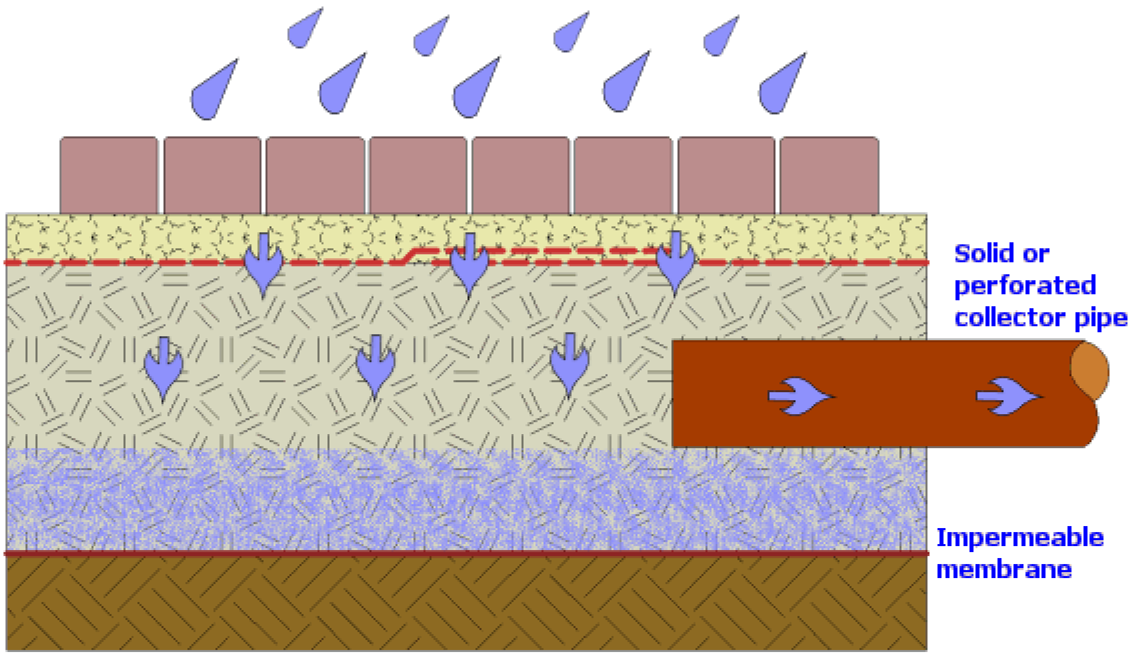


Figure 35 – No infiltration permeable pavement adopted by SUDS manual, drawing by (Tony McCormack ~ Pavingexpert.com, 2012)

3.3.8.4. Permeable pavement as a Green Street practice

The second practice which is going to be implemented in the case study is the permeable pavement. Permeable pavement is a widely used technique as it can be applied in a range of areas such as residential, commercial and etc (Scholz & Grabowiecki, 2006). This technique as it is been introduced previously, allows stormwater to pass through the top layer and filter pollutants through the soil layer and finally infiltrate/convey/storage the treated stormwater. Permeable pavement is one of the most important techniques in the Low Impact Development (LID) program especially for the highly dense urban areas (ICPI 2012)[4]. This technique can fit into all different municipalities such as an old municipality where the capacity of stormwater runoff is low (i.e. an old highly constructed area). Applying permeable pavement can help to address the stormwater in such a municipal (ICPI 2012).

In Teckomatorp (the area of case study), risk of groundwater contamination due to the BT Kemi is highly considerable (chapter 5). Hence the stormwater cannot be infiltrated to the groundwater level as it might contaminate the groundwater. In this case or similar cases permeable pavement should include a thin impermeable layer to prevent stormwater from infiltrating to the groundwater layer (no infiltration permeable pavement). In such a case stormwater that has been treated can be stored in another facility or conveyed to a drainage system (Scholz & Grabowiecki, 2006).

[4] - www.icpi.org

4. An introduction to the calculation

In the last chapter some of Green Street practices were introduced in order to increase the knowledge about "sustainable stormwater management" and also "Green Street". In the following chapter a method which is used in this thesis to calculate discharge will be described. Peak flow calculation is a part of the methodology chapter in this thesis. Peak discharge or peak flow is the basic data that is used to estimate the efficiency and performance of using planters as one of Green Street practices instead of conventional system (i.e. pipes,).

Rational method is selected among different methods (i.e. SCS, USG) for the peak discharge calculation because it is a fast, easy, applicable and commonly used equation to calculate peak flow in a small drainage basin.

4.1. Rational method

One of the most commonly used formulas, developing in 19th century (Snider, 1972) in Ireland (Hua *et al.*, 2003) for calculation of peak discharge in a small watershed (Brown *et al.*, 2001) is rational method.

The rational formula is marked by: (NCTCOG, 2010)

- Looking at the whole area as one unit.
- Calculating runoff at the lowest point.
- Assume that runoff is distributed in an area uniformly and time of distribution is constant. In another word in the rational method the consumption is that the intensity of rainfall and loss (i.e. infiltration) of rainfall in both time and space is distributed uniformly (Hua *et al.*, 2003).

4.2. Application

The rational method is mainly used and applicable for small watershed or drainage basin up to 81 hectares or 200 acres. This method can be applied to calculate peak of stormwater runoff flow for designing more a conveyance hydraulic structure such as culvert, gutter, drainage pipe or a small ditch (NCTCOG, 2010). In rational method, best result can be gained when the drainage basin has impervious surface (NCTCOG, 2010).

The result of discharge from rational method shouldn't be used to design the storage facilities, whereas modified rational method is more suitable and accurate for the storage facility such as detentions or contained planters (NCTCOG, 2010).

In general the output or results from the rational method equation is not most accurate when more details should be taken into account in discharge calculation process. These details can simply be defined as different factors that can have impacts on peak flow such as pervious surfaces which cause runoff storage (NCTCOG, 2010).

4.3. Equations

The rational method formula is given as (Brown, Stein et al. 2001);

$$\mathbf{Q} = \text{——} \qquad (2)$$

Where:

Q = Discharge in m^3/s, (cfs)

C = Runoff coefficient which is dimensionless

I = Rainfall intensity mm/hr, (in/hr) for a time period called t_c or time of concentration.

A = Watershed area or drainage basin area, ha, (acres)

K_u = is a unit conversion, for SI unit (metric unit) is 360 whereas for English system (CU) is just 1.

The runoff coefficient parameter in rational method equation is for a rainfall with a return period of 10 year and less. When the return period is more than 10 years, higher rainfall intensity may occur. Consequently infiltration or other losses of runoff might not happen due to the more speed and volume of stormwater runoff. Therefore a new parameter has been introduced to the main rational method equation called frequency factor (NCTCOG, 2010). Table 2 shows different values of C_f.

$$Q = C_f \text{ ——} \qquad (3)$$

It is important to notice that the multiply of C and C_f cannot exceed 1. $\mathbf{C_f}$ is introduced in the following table.

Table 2 - C_f (frequency factor)

C_f (frequency factor for the rational method)	
Rainfall return period (years)	C_f
10 or less	1.0
25	1.1
50	1.2
100	1.25

4.3.1. Time of concentration (T_c)

Time of concentration is basically defined as the time or period that runoff travels from hydraulically most distance point of drainage basin to the point of interest or concentration (Brown *et al.*, 2001).

T_c or time of concentration is very critical in the rational method formula and should be calculated for every design point in the watershed. Basically T_c can be estimated from the figure 36 when the runoff is flowing on the land, by determining three parameters;

first, average slope in a distance (ft/100ft) second, the runoff coefficient (C), third, distance (D) (in urban areas 50 - 100 ft or 15-30 meters is a reasonable distance)

One of the accurate formulas describing figure 36 is:

$$T_c = 1.8(1.1 - C)(D)^{0.5}/(S)^{(1/3)} \tag{4}$$

Where:
Tc = Time of concentration in (min)
C = Average or composite runoff coefficient
D = Distance or hydraulically most distance point to the point of interest (ft)
S = Average slope along the distance “D”, in (ft/100 ft)

In some cases the time of concentration should be generated from another formula by applying another nomograph. Normograph is mainly used to calculate the time of traveling water in a pipe, swale or channel. In these cases the velocity of water (i.e. channel) can be generated from the figure 37 and regarding the velocity, the T_c can be easily calculated by dividing the velocity into the distance of traveling (NCTCOG, 2010).

In some cases the time of concentration is a combination of overflow traveling time on the land or surface plus the water traveling time in a channel or swales. In this case the time of concentration for each part should be calculated according to the corresponded figure, eventually the result can be gained by adding all the outputs together (NCTCOG, 2010). Table 3 introduces the borders of T_c for some land uses.

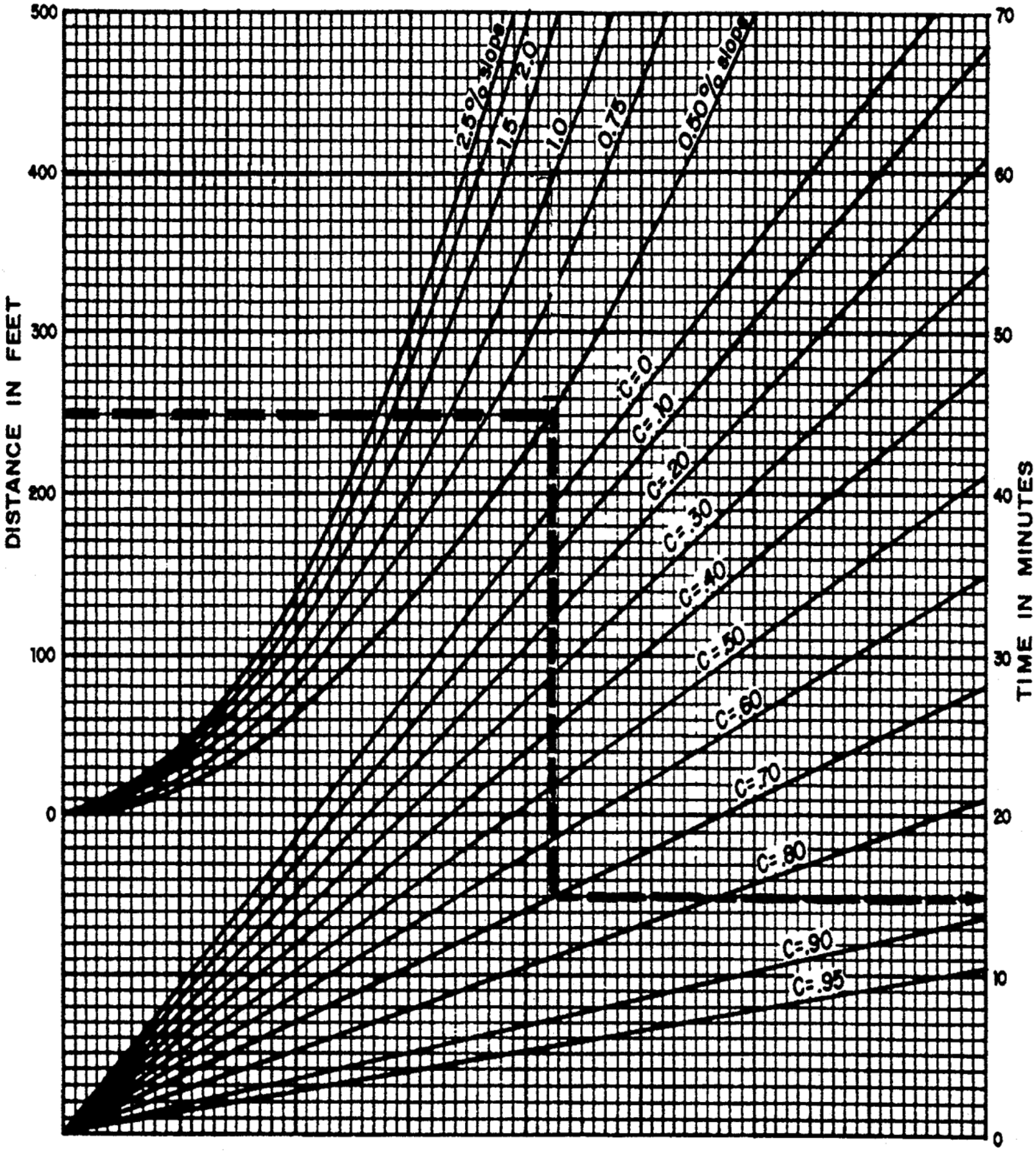
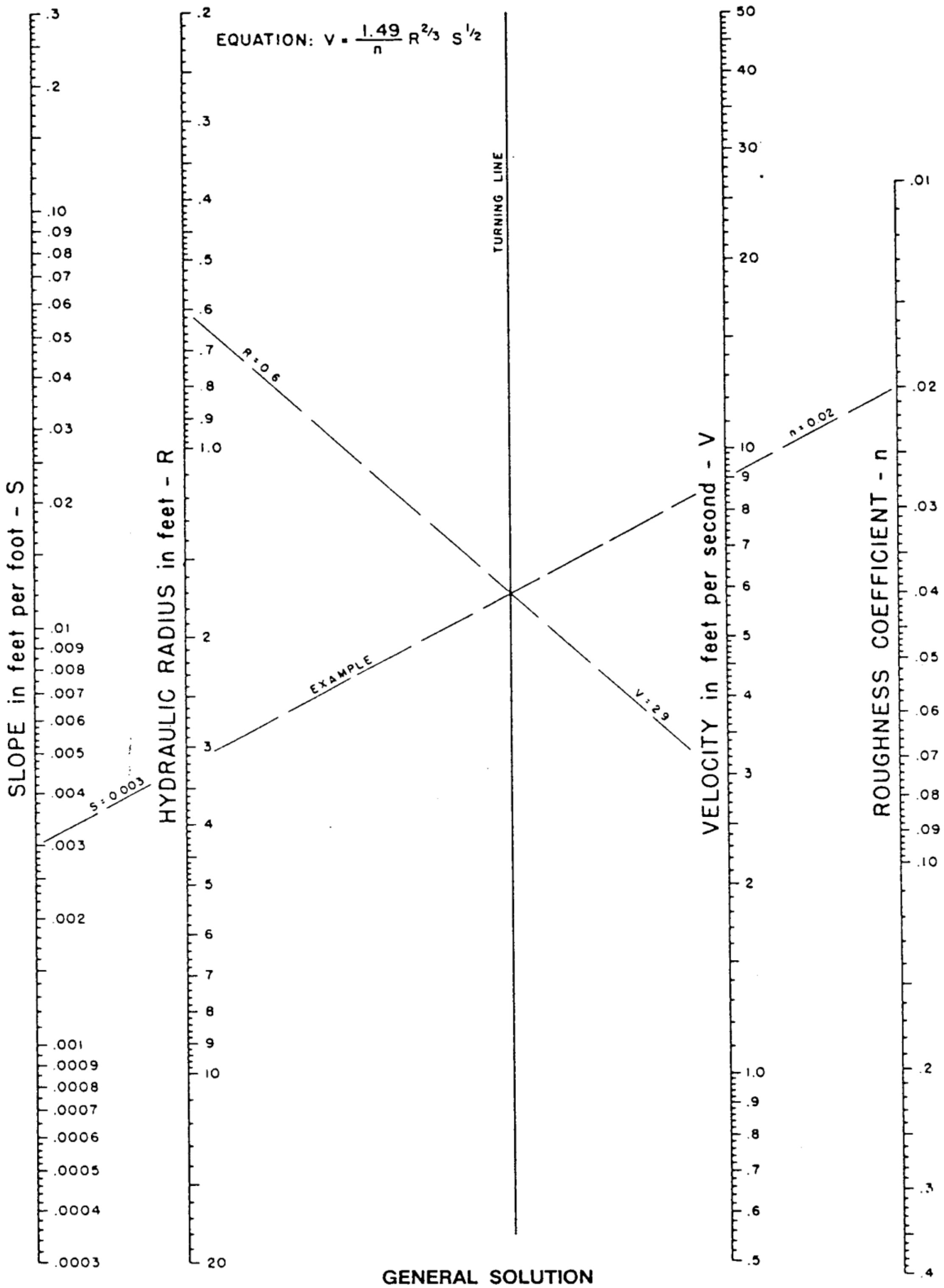


Figure 36 - Overland flow nomograph (NCTCOG, 2010)

(Source: Airport Drainage, Federal Aviation Administration, 1965)



Reference: USDOT, FHWA, HDS-3 (1961).

Figure 37 - Manning equation nomograph **(NCTCOG, 2010)**

Table 3 – Time of concentration

Time of concentration T_c		
Land use	Minimum (min)	Maximum (min)
Residential area	15	30
Commercial and industrial	10	25
Business area	10	15

4.3.2. Rainfall intensity (I)

Rainfall intensity is defined as the average of rainfall rate (in/hr) or (mm/hr) for a duration equal to the time of concentration (T_c) in a selected return period (i.e. 10 years). When the return period is selected (i.e. 10 years) and the calculation of T_c is done, the rainfall intensity can be generated easily from a simple table. Table 4 is an example of rainfall intensity tables.

Table 4 – Stockholm rainfall intensity (Dahlström, 2010)

Rainfall intensity values (mm/hour)	
Return period and duration (T_c)	**Stockholm (Sweden)**
10 years	
10 minutes	**82.2**
15 minutes	**97.8**
30 minutes	**124.8**

4.3.3. Runoff coefficient (C)

Runoff coefficient is a changeable parameter in the rational method equation which increases the precision of results and needs to be determined by designers or engineers according to their judgments and understanding of the area (drainage basin) (NCTCOG, 2010). It also defined as a parameter which is calculated from the function of drainage slope and soil type. Runoff coefficient should be constant during the rainfall event (NCTCOG, 2010). Runoff coefficient is a parameter depended on different factors of watershed (drainage basin). Appendix 6 introduces the runoff coefficient values, recommended by NCTCOG (2010).

In some cases the combination of different surfaces in a drainage basin or a watershed makes designers to combine different runoff coefficient and create a composite runoff coefficient. Composite runoff coefficient makes the results from rational method more accurate. Creating a composite runoff coefficient can be done, using appendix 6 by taking out the values and combining with the percentage of different land uses in a watershed (NCTCOG, 2010).

It is important to mention that the rational method should be applied only in cases where the distribution of land use in a watershed or drainage basin is uniform. However, putting a specific type of land use in a drainage basin requires other type of hydrological equation (NCTCOG, 2010).

In addition to that, the drainage basin or watershed should be divided into smaller basin if there are different land uses in the area (i.e. area with high infiltration capacity and impervious area should be divided). In this case results from the rational formula will be more reasonable.

5. Method and materials

5.1. Case study:

Teckomatorp is located in the southern part of Svalöv municipality in Skåne province in Sweden. Teckomatorp has an area of 113 hectare and the population was around 2363 in 2007. Teckomatorp rail station makes the area very accessible by train to main cities in the region such as Lund, Malmö and Helsingborg (figure 38). In addition to that, an overview of the region shows that Teckomatorp has a good accessibility to Copenhagen which is the biggest city in the region. Teckomatorp has been a distinctly working and peasant society. There are also various businesses and a business center as a result of the railroad[5].

The municipality of Svalöv is planning on developing an area in Teckomatorp (figure 39), constructing buildings and greenery. The idea and purpose of development is to make Teckomatorp more attractive in the region. The good location of Teckomatorp (good accessibility) on one hand and closeness to some important places such as ESS and Max Lab IV in Lund (almost 20 km) on the other hand, increases the importance of Teckomatorp. Teckomatorp has the potential to develop and become more attractive in the region.

But what Teckomatorp is best known for, today, is BT Kemi that was a herbicide factory which contaminated the area due to its chemical waste. This scandal in the mid 70's causes a lot of environmental damage and shook their own society, Sweden and also other countries. Even in these days, more than 30 years after the event, still Teckomatorp's name comes up when talking about environmental pollution and harmful substances in soil and environment. The main polluted substances of the waste material from the factory contain mainly phenoxy acids (herbicides), chlorophenols (pesticides), chlorocresol (chemical disinfectant) and dinoseb

[5] - Information from "www.teckomatorp.org"

(herbicide) (Brobeck & Ståhl-Gustafsson, 2007). These are different types of toxics chemical substance which caused the scandal. The northern part has been cleaned up, however, the process of cleaning up the soil and the environment is still in progress[3] in some other parts of the area (mainly the southern part which is going to be developed).

Teckomatorp has been through challenges which are preventing this town from growing and development in the region. However, the sanitation activity and a development plan from the municipality, brings forth a growing hope of making Teckomatorp more attractive.In Teckomatorp, increasing the sustainability would be considered as an important factor to create a new identity for the area and improve its attraction. Green Street concept in Teckomatorp can achieve biodiversity as well as sustainability and amenity which consequently will increase the attraction in Teckomatorp.

Figure 38 - An overview of Teckomatorp in Skåne province[6]

[6] - Map from www.eniro.se

5.2. A schematic map of the area

Figure 39 shows an overview of Teckomatorp including the area of development, river, remaining polluted area and Vallarna (park). Railroad and train station are respectively indicated with white line and a black box. The black area in the south of the railway shows the remaining polluted area that is going to be cleaned up by government before future development. Yellow area is called “Vallarna” which is a recreational park which used to be a part of polluted area. The river is called “Braån” which is shown on the map that can be considered as a positive natural element, used to be also polluted due to BT Kemi. The area of development is shown on the map which is situated in the south of railway. The blue arrows show the direction of runoff flow according to topographic map of the area.

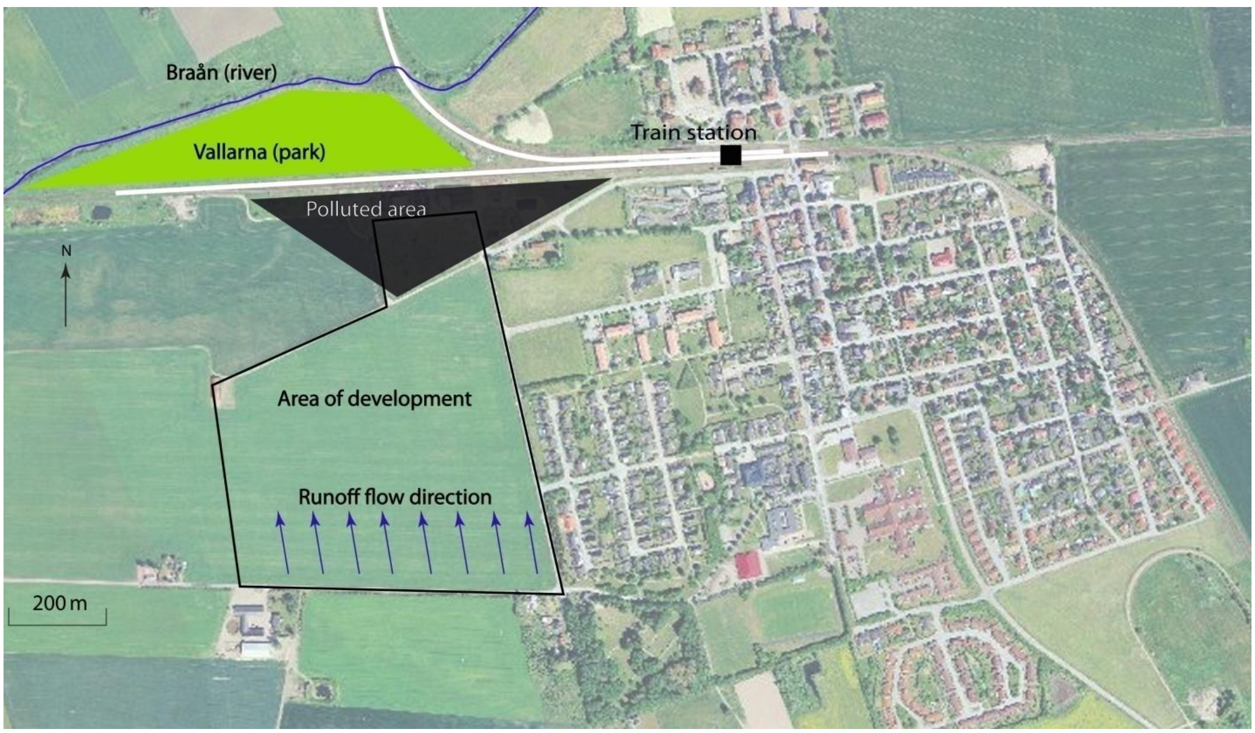


Figure 39 – An aerial map of Teckomatorp including the area of development (schematic)

5.3. A diagram for new development in Teckomatorp

Figure 40 indicates a diagram for new development in Teckomatorp. As it is shown in the diagram red color represents high density, yellow represents low density and green is a park. In new development in Teckomatorp a green corridor (park) is proposed to increase attraction and sustainability as well as recreation in the area. High density area in the north of new development or south of the railway is situated to function as a noise barrier for the park and low density area. The purpose of the high density area is to integrate the new development into the old area. Low density areas are mainly villas. The high density area in the west of the new development can be considered as a wind barrier. The noise and wind barriers are improving the quality of living for inhabitants of the new development in Teckomatorp. There are some villas in the west of the new development that are exposed to open landscape which can provide an appealing condition for those who like to live in an open land.

Figure 40 – A diagram for new development in Teckomatorp

5.4. A rough plan for new development in Teckomatorp

Figure 41 shows a rough plan for Teckomatorp's new development. The park as one of the main part of this plan is a combination of blue and green to improve the aspects of biodiversity, sustainability and also biotopes. A creek is designed in the park to take care of some part of stormwater runoff that is connected to Braån (river). It can also be considered as a positive natural element to improve biodiversity and ecosystem service.

The park in new development in Teckomatorp has connections to the rest of Teckomatorp from north and south. "Connection to park" (shown on the map in north east of new park) and also the existing park in the south east are two main connections of new park to the rest of Teckomatorp.

Bigger rectangular (figure 41) shows high density which is mainly situated in the east, north and west part of new development. The idea of having more density in the east consisting of mainly four floors residential buildings and offices is to integrate the new development with the rest of Teckomatorp. There is a sport complex (shown on the figure 41) in the north of new development that functions as a noise barrier (noise from the railway). Hence, park and other residential building in the new development can enjoy a calmness and pleasant condition.

Small buildings are two floor-villas and mainly situated in the centre to have less wind and noise. The only exception is the line of villas on the western part of the new development which is designed to provide some villas exposed to open landscape. These villas can provide a privilege for those who like to live in open landscape.

A school is situated in the west of park which has the privilege of the closeness to the park as well as calmness. Moreover, the distance from railway and closeness to villas and other residential area can provide convenience for inhabitants.

Streets are all planned to become Green Street (points along streets in new development show trees and shrubs) to improve sustainability, amenity and biodiversity of the new development. In addition to that streets are mainly designed vertically in order to function as stormwater conveyance tools. In heavy storm, street can take stormwater runoff to the river which increases safety in the new development's plan.

The circle in figure 41 is a street in the new development that has low and high density buildings on each side. This street is going to be more elaborated on, in the following chapters.

This thesis mainly deals with stormwater treatment in two units (a two floor-villa and 4-floor building) and compares the effectiveness in flow reduction in conventional system compared to Green Street practices.

Figure 41 – A rough plan for new development in Teckomatorp

5.5. Green infrastructure for new development in Teckomatorp

Figure 42 introduces green infrastructure in new development in Teckomatorp. Green Street concept is implemented in all streets in new development in Teckomatorp. The ponds in the park will improve both sustainability aspect as well as biodiversity. All the green elements including trees and shrubs improve biotopes in new development in Teckomatorp which is significantly important for improving the landscape characteristic of an area. These biodiversity, sustainability and biotopes address amenity and a new identity for Teckomatorp. Teckomatorp needs to be improved and become more attractive in order to both attract people to this area and also remove the bad reputation of BT Kemi.

Green Streets in new development in Teckomatorp are encouraged to convey stormwater runoff in case of heavy rain when stormwater management system (Green Street practice) is not adequate or capable of controlling the stormwater runoff. In this situation another duty of the streets is to convey runoff to downstream (Braån).

Figure 42 – Green infrastructure for new development in Teckomatorp

5.6. Project description

This master project aims to elaborate on the topic of Green Street concept which is a strategy of sustainable stormwater management, by applying two Green Street practices in two units (buildings) in Teckomatorp's new development. The two practices are stormwater planter (flow-through planter) and permeable pavement (no infiltration). In doing so, four scenarios have been developed in Teckomatorp. These four scenarios are divided into low and high density, conventional system and Green Street scenarios. These four scenarios are; First, low density – Green Street, Second, low density – conventional system, Third, high density – Green Street, 4-high density – conventional system.. Peak discharge in each scenario is calculated by rational method formula, based on a rainfall pattern. The rainfall is 15 minutes intensive rainfall with a return period of 10 years. 15 minutes of rainfall is a recommendation for residential area by table 3. Eventually results of flow reduction in all scenarios (conventional street versus Green Street) will be discussed in the discussion chapter. Rational formula which was introduced in the previous chapter is chosen to calculate the peak flow in all scenarios because of following reasons;

- The area of the case study is highly impervious since greenery is excluded from the unit for the calculation of peak flow. The area of impervious land which is rooftops in Green Street scenarios where in conventional system scenarios parking lot is also added to the area of impervious land. Therefore rational method can give accurate estimation of discharge (SEMCOG, 2008).
- Peak discharge calculation by rational method is more accurate for storm sewer design or conveyance facility (PWD, 2011). In this thesis all the runoff is eventually drained to drainage system and the designed creek. However a flow-through planter is designed to capture pollution and reduce flow rate and volume before runoff goes partly to sewer pipe system and partly to the designed creek. Therefore it functions mainly as a conveyance facility. A flow-through planter is designed to drain stormwater in 3 to 4 hours and is not considered as storage system like contained planter.
- In this thesis the purpose of calculation of peak flow is just to show how a planter can be functional and applicable to control runoff flow. So any formula that estimates peak discharge could be appropriate. However rational method was chosen due to its simplicity and applicability.

Peak flow in all scenarios will be calculated to show how much water flows in each scenario. This amount of water will be drained out in 15 minutes in the conventional system scenarios (scenario 2 and 4) whereas in Green Street scenarios flow is given 4 hours to be filtered through the flow-through planter and eventually drain to drainage pipe. In Green Street scenarios permeable pavement is also taking care of rainfall on parking lot. The parking lots in both Green Street scenarios have permeable pavement which can pass the rainfall in 15 minutes through its top layer (table 1). Therefore the area of parking lot in both green scenarios is excluded from the calculation of peak flow.

Rational method estimates water volume in each scenario to make it more understandable how reduction of impervious land will affect the water volume. According to the results from rational formula a flow-through planter in both Green Street scenarios will be designed to take care of runoff from the rooftop. The area of flow-through planter can be calculated by two different methods as it is already mentioned. Finally, both Green Street scenarios will have a flow-through planter (which mainly takes care of rooftop runoff) and permeable pavement for their parking lots. The greenery in all scenarios are also excluded from the calculation of peak flow because it is assumed to take care of its own runoff. Furthermore, including greenery to rational method will make the results less accurate.

Another calculation is the flow reduction calculation which shows the effectiveness of a flow-through planter in reducing flow and flow rate. Flow rate has an important influence on water environment as well as soil erosion of downstream. Another goal of this project is to show how Green Street approach effects flow reduction.

At the end the thesis points out some of advantages and disadvantages of each approach (conventional system and Green Street) to make it more clear how each approach can affect runoff flow.

5.7. Scenarios - density

Scenarios are divided based on their densities; low density and high density. However each of them will be divided into conventional system scenario and Green Street scenario. Figure 43 and 44 show low density scenarios, respectively scenario 1 and scenario 2. Figure 45 shows scenario 3 and figure 46 show high scenario 4. Schematic figures of scenarios are presented just to visualize and make the calculation more understandable. These scenarios are divided based on their density and each scenario is considered as a unit. In each unit there is a building and a parking lot and the rest of the area is greenery. In Green Street scenarios (scenario 1 and 3) two stormwater practices (permeable surface and planter) are applied to gain a higher sustainability. However, two other scenarios (scenario 2 and 4) will have conventional systems for its stormwater management.

The idea of having different densities in this case study is to compare the effect of density on flow (peak discharge). Increase density will cause more peak discharge in urban areas. Especially impervious areas, cause more runoff in urban development and consequently increase risk of flooding. In this case study 4 units with different densities (low and high) are exposed to the same rainfall pattern. In another words, calculation of peak discharge will indicate how much more runoff flow will be generated in the high density scenarios. The other purpose is to compare the results in same density scenarios (i.e. scenario 1, 2) but with different stormwater management strategies (Green Street versus conventional system). Green Street approach tries to reduce the peak flow by reducing the impervious land (using permeable pavement for the parking lot) and reducing the flow by attenuate stormwater runoff (using a flow-through planter). Eventually a comparison between the results (peak discharge and flow reduction) of each scenario will show the effectiveness of Green Street practices on flow reduction and the effect of density on peak discharge.

5.7.1. Scenario 1, 2 (low density)

The first and second scenario (Figure 43 and 44) represents residential houses, two floors with the whole area of 500 m^2 and the constructed building inside the units are 187.5 m^2 and the parking lots have an area of 25 m^2. Both scenarios are villa houses in the new development in Teckomatorp. Parking lot in conventional scenario is constructed with impervious material whereas in Green Street scenario a permeable pavement is used instead which makes a change in peak discharge.

Rooftops in all scenarios are made of concrete. The lines on the roof of the building show slope of rooftop that is towards the parking lot. Greenery in all scenarios is taking care of its runoff. Soil and vegetation on the yard will filter, infiltrate and attenuate stormwater runoff flowing on the greenery. The focus of calculation is on impervious surface which is the rooftop in Green Street scenario and in conventional scenario both rooftop and parking lot.

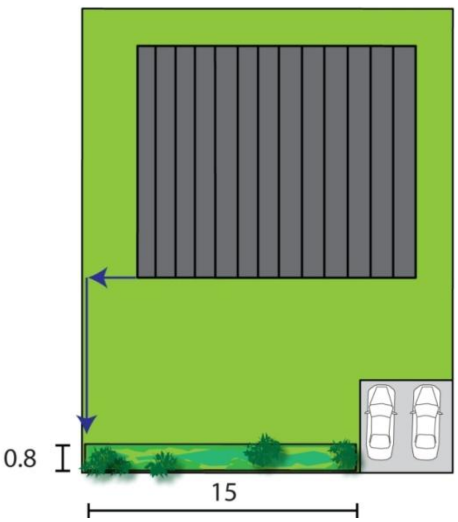


Figure 43 - Scenario 1

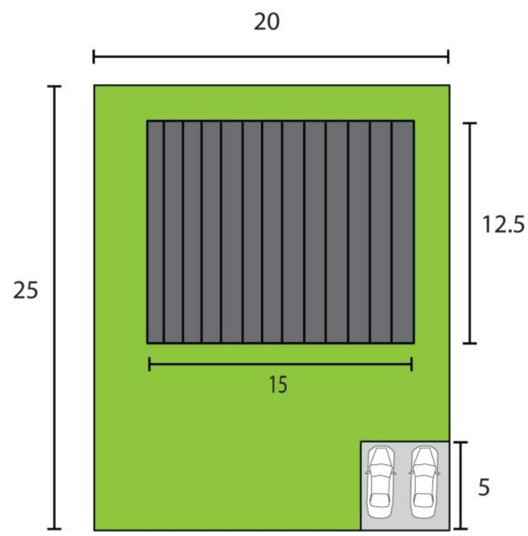


Figure 44 - Scenario 2

5.7.2. Scenario 3, 4 (high density)

The third and forth scenario (figure 45, 46) have an area of 50 m^2 of parking lot and the constructed building is 300 m^2 (4 floors residential apartment), the greenery part of the unit has an area of 150 m^2. These scenarios have a higher density in comparison with the previous scenarios. These scenarios are situated in a street with high density in new development in Teckomatorp. The parking lot in the high density – conventional scenario (scenario 4) is with impervious surface whereas in Green Street scenario the parking lot has permeable pavement. Slope of the rooftop is towards the parking lot. Lines are presenting the slope direction on the rooftop. As it is mentioned, both scenarios have the whole area of 500 m^2, however the density is different. In the low density scenario – conventional system 212.5 m^2 is the whole constructed area whereas 350 m^2 is the constructed area in high density scenario - conventional system. In scenario 1 only rooftop 187.5 m^2 is considered as constructed area and this number in scenario 3 is 300 m^2.

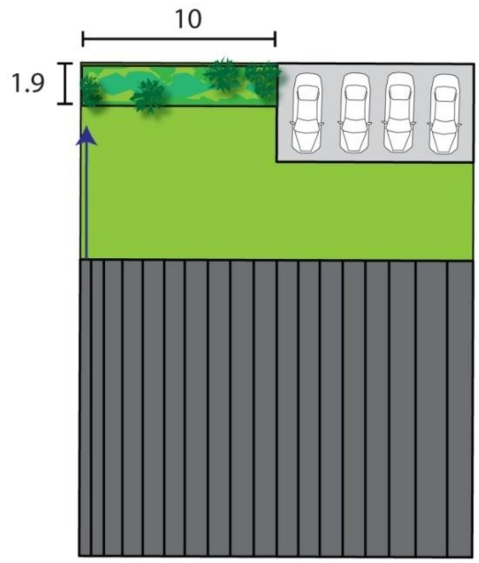


Figure 45 - Scenario 3

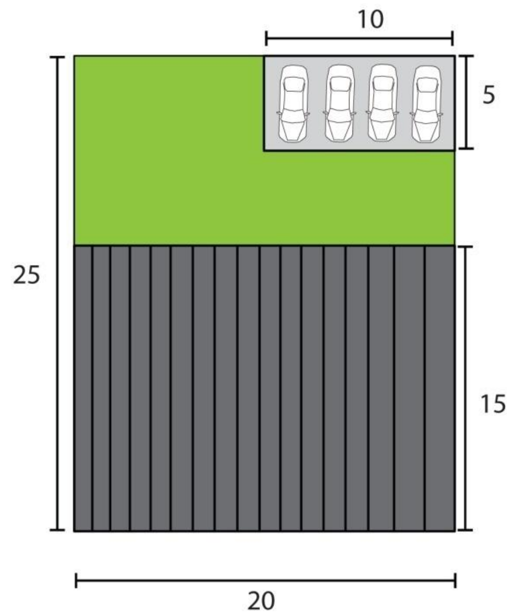


Figure 46 - Scenario 4

5.7.3. An overview of both scenarios – conventional street

Figure 47 refers to the circle on the figure 41 (rough plan for new development) which shows an overview of both scenarios (low and high density scenario) in a conventional street. Figures 47 and 48 are presented to illustrate a conventional street. This example is a typical conventional street can be seen in any urban area. Both sidewalk and bike lane in one side and only sidewalk on the other side is how a conventional street can look like. These figures are shown to visualize the difference between a Green Street and a conventional street. Both conventional scenarios are presented in both figures 47 and 48. As it is obvious in figure 48 the slope of rooftop is towards the street (or parking lot). One of the ways that Teckomatorp's new development can implement to control its stormwater is to use conventional street. Both high density and low density scenarios are respectively situated on right and left side of the conventional street.

It is important to mention that a conventional street is fairly wider that the same street but green. The two parked car on figure 48 indicate the width of a conventional street. However a though-out plan might mitigate this deficiency (lack of parking space in Green Street).

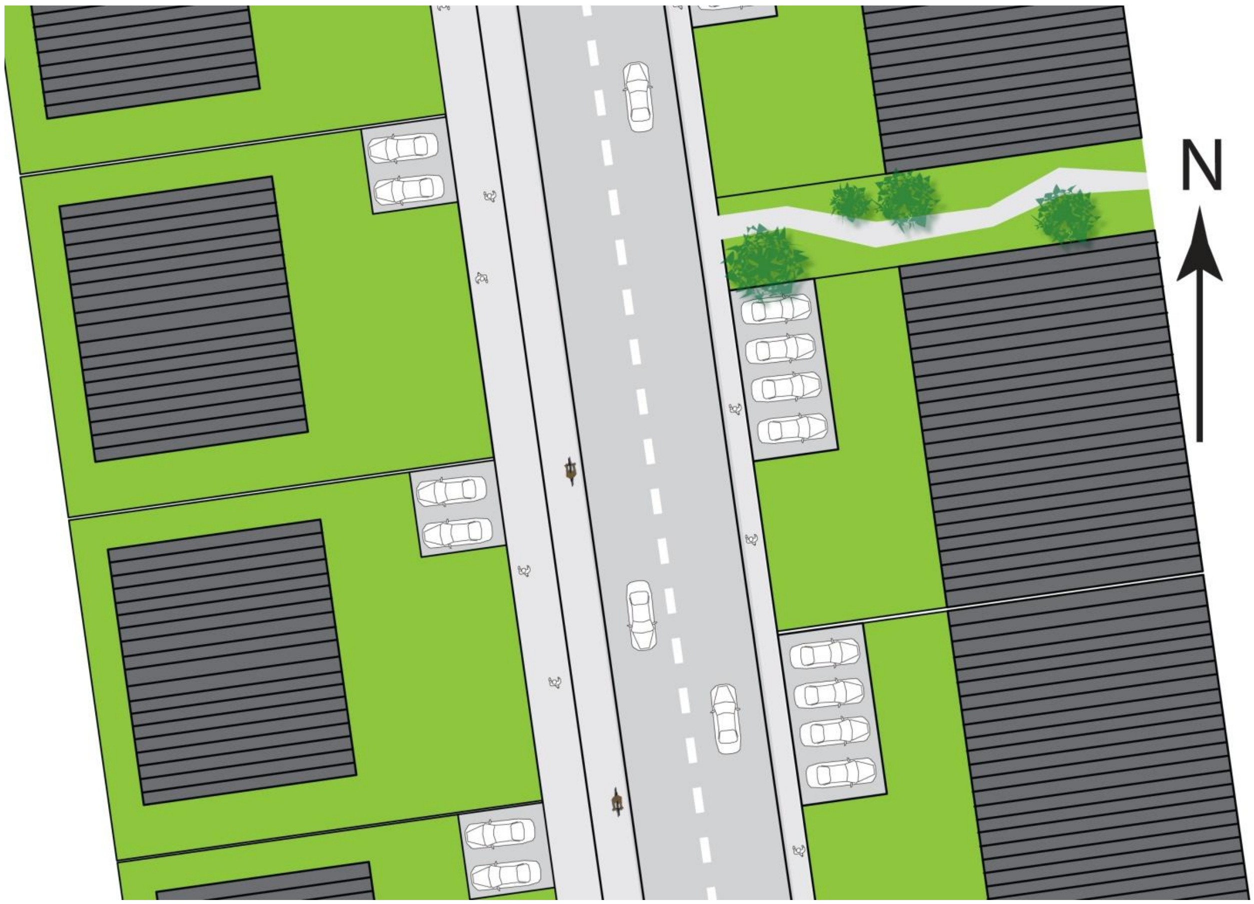


Figure 47 – An overview of both scenarios - conventional street

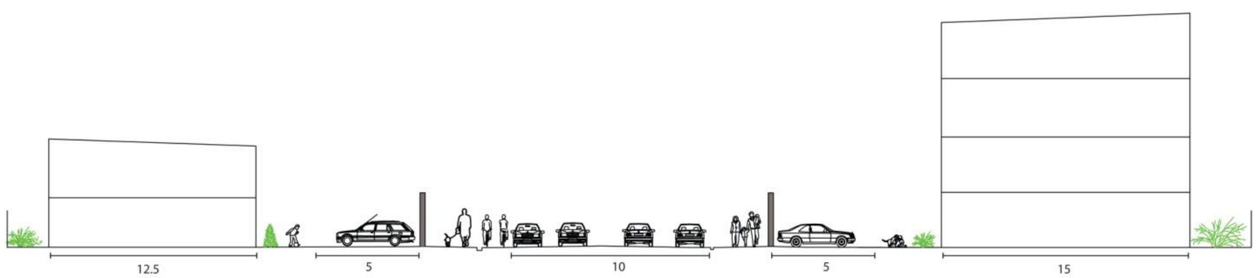


Figure 48 – A section of conventional street (sizes are in meter)

5.8. Calculation of peak discharge

Detailed of peak discharge calculations are presented in appendix 2. In this chapter the results of discharge (peak flow) calculation for each scenario are presented. Scenarios are; 1- low density – Green Street 2- low density - conventional system 3- high density - Green Street 4- high density - conventional system. There are some considerations for the peak flow calculation;

Consideration 1: Greenery in all scenarios is excluded from the area of calculation. Rational formula is more accurate for impervious land so greenery cannot fit into the equation. Therefore greenery is assumed to take care of its rainfall. In addition to that, SIM approach which estimates size of flow-through planter based on impervious land.

Consideration 2: Permeable pavement is included in conventional system scenarios (scenario 2, 4) whereas it is excluded from Green Street scenarios (scenarios 1, 3). As it has been mentioned permeable pavement can pass 100 percent of rainfall (table 1).

Consideration 3: Time of concentration for all scenarios according to table 3 is 15 minutes which is appropriate for residential area.

Consideration 4: Rainfall intensity for 15 minutes is 16.3 mm (appendix 1). Therefore for one hour rainfall intensity will be (16.3*6 = 97.8 mm/h). 97.8 mm/h of rainfall will be used as the rainfall intensity (I) in peak discharge calculation for all scenarios.

Consideration 5: Rooftop in all scenarios is made of concrete. Runoff coefficient (C) is 0.95 (appendix 6) for concrete and asphalt surface. C (runoff coefficient) is the same in all scenarios.

Consideration 6: C_f is 1 because the return period is 10 years for the rainfall intensity (table 2).

So results from the calculations will be as following;

5.8.1. Scenario 1 – Low density - Green Street

The result for 15 minutes intense rain shows 4.4 m^3 volume of water in the first scenario.

5.8.2. Scenario 2- Low density - conventional system

In this scenario 25 m^2 of parking lot has an impervious surface which will be added to the total area so the result from calculation will be 4.95 m^3 volume of water in the second scenario.

5.8.3. Scenario 3 – High density - Green Street

The result for 15 minutes intense rain shows 6.9 m^3 volume of water in the third scenario.

5.8.4. Scenario 4- High density - conventional system

In this scenario 50 m^2 of parking lot is also considered in the calculation because the parking lots in both conventional scenarios have impervious surface.
So the result for 15 minutes intense rain shows 8.1 m^3 volume of water in the forth scenario.

Note: Results from calculation of 4 different scenarios show that impervious land cause more volume of water in landscape. This fact has been studied in many different literatures that more impervious land generate more runoff in urban areas (Chester *et al.*, 1996).

5.9. Calculation of flow-through planter area (Green Street scenarios)

Calculation of flow-through planter size is presented more in detail in appendix 3 at the end of this document. In this chapter size of flow-through planter will be determined by two different methods (section 3.3.7.7) SIM and SUDS methods. There are some considerations as it is mentioned that should be taken into account for calculation of size of planter using SUDS equation. These considerations are:

Consideration 1: Time of dewatering which is 4 hours which is 14400 seconds.

Consideration 2: Soil filter is sandy soil with 0.00002 m/s permeability (hydraulic conductivity) value (appendix 5).

Consideration 3: The height of soil filter is 0.75 m.

Consideration 4: The average height of water above planter is 0.15 m.

5.9.1. Scenario 1 – Low density - Green Street

Calculation of flow-through planter using SIM approach (appendix 3)

Area of flow-through planter = 0.06*187.5 = 11.25 m^2

Calculation of flow-through planter using SUDS formula (appendix 3)

Af = 12 m^2 (according to equation number 1)

Result: An average area of **12** m^2 is needed for the flow-through planter surface area.

Figure 49 shows a flow-through planter on the left side of the parking lot. The treated stormwater from the planter can easily flow to an approved drainage system or to the designed creek. The parking lot has a permeable pavement (no infiltration) which also collects and filters stormwater runoff through the soil medium and eventually the drainage pipe in the permeable pavement will convey the treated stormwater to an approved drainage system.

The idea of using planter on the edge of the unit (close to the street) is to use the vegetation on the planter as a divider wall of the unit. A flow-through planter with width of 0.8 m can fit in this scenario. Consequently, the new Teckomatorp development can get an identity. In addition to that it improves aesthetic of the area by using more natural elements rather than hard and elements (i.e. pipes).

Note: Runoff from the roof is shown on the figure 49 that flows from the left of the roof and can be conveyed directly to the flow-through planter by a pipe or open channel.

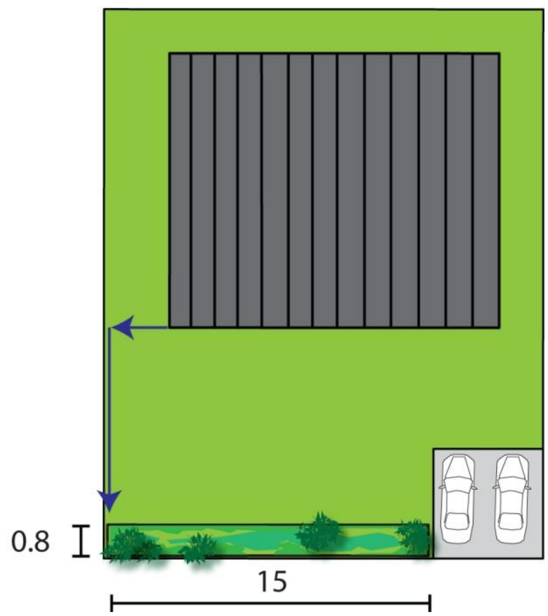


Figure 49 – Scenario 1 including a flow-through planter

5.9.2. Scenario 3 – High density - Green Street

Calculation of flow-through planter using SIM approach (appendix 3)

Area of flow-through planter = 0.06*300 = 18 m^2

Calculation of flow-through planter using the SUDS formula (appendix 3)

A_f = 20 m^2 (according to equation number 1)

Result: An average area of **19** m^2 is proposed for the flow-through planter surface area

In this scenario a flow-through planter with 1.9 m width can fit on the edge of the building and the same as scenario 1, it can play the role of a divider wall for the unit.

The parking lot has an area of 50 m^2 with no infiltration permeable pavement and the treated stormwater both from planter and permeable pavement will flow partly to an approved drainage system and partly to the designed creek.

Figure 50 shows scenario 3 (high density – Green Street) with a flow-through planter.

Note: The long straight arrow shows runoff from the roof that can be conveyed to the planter through a pipe or a narrow open channel.

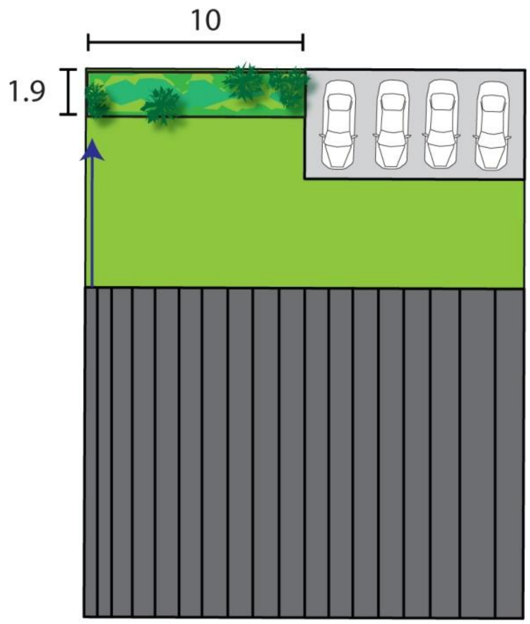


Figure 50 – Scenario 3 including a flow-through planter

5.10. Calculation of flow reduction (all scenarios)

Detailed calculation is presented in appendix 4 at the end of this document.

The results from the calculation of flow reduction are presented in this chapter which shows the difference between flow in Green Street scenarios and conventional system. In conventional system all the flow (discharge) should be drained in 15 minutes (rainfall duration) whereas in Green Street flow has 4 hours to be drained from planter.

There are some considerations that should be taken into account for the calculation of flow reduction;

Consideration 1: For Green Street scenarios time of dewatering is 4 hours or 14400 seconds.

Consideration 2: For conventional system time of dewatering is equal to the time of rainfall duration which is 15 minutes or 900 seconds.

5.10.1. Flow reduction in scenario 1:

Q = 0.3 liter/s

5.10.2. Flow reduction in scenario 2:

Q= 5.5 liter/s

Comparison 1: Results show that flow in Green Street scenario is 18 times less than conventional system.

5.10.3. Flow reduction in scenario 3:

Q = 0.5 liter/s

5.10.4. Flow reduction in scenario 4:

Q= 9 liter/s

Comparison 2: Results show the flow in Green Street scenario is 18 times less than conventional system.

Note: The comparisons between the results show the effectiveness of using a flow-through planter in comparison with conventional system. 4 hours delay in dewatering, make a great difference in flow which is 18 times less than conventional system in this case study. This reduction of flow is promoting different advantages to environment, water environment and ecosystem. Less flow as it is been studied prevents downstream from flooding and soil erosion.

5.11. An overview of both Green Street scenarios (scenario 1, 3)

Figure 51 shows an overview of both high and low density scenarios in a Green Street. The circle in figure 41 is elaborated with more details on figure 51 and a section of it is provided on figure 52. This Green Street can be applied in new development in Teckomatorp to improve biodiversity and sustainability as well as aesthetic value of the area.

A comparison between figure 51 and figure 47 indicates that green street is narrower than a conventional street. This difference was described previously as a disadvantage of Green Street according to a survey. The survey shows that some people who live in a Green Street complain about lack of space for parking lot (Dill *et al.*, 2010). This deficiency can be improved and mitigated by better planning and more thought-out design. A comparison between figure 48 and 52 shows that in conventional street each side a car can park whereas, in Green Street only one side is possible to stop and park a car.

Figure 48 (a section of conventional system) and figure 52 (a section of Green Street) on the other hand, show other aspects such as:

- Improve in aesthetic value of the street in Green Street compared to conventional street.
- Using more natural elements such as soil and vegetation in Green Street. Hence, Green Street promotes sustainability.
- Improvement in biotopes by increasing the natural elements in the area such as water, vegetation and soil.
- Reduce the risk of flooding by attenuating stormwater runoff.
- Promote biodiversity through the use of soft material instead of hard material. Soft material refers to soil and vegetation which is the main elements in Green Street, whereas hard material such as pipe are used in the conventional system.
- In Green Street, stormwater will be filtered through soil medium before it is drained to an approved drainage system. This desedimentation will improve the health of watershed.
- Green Street reduces flow and flow rate which promotes river shore by preventing soil erosion as well as improving the ecosystem in river and downstream. Fast runoff (high velocity) can have a great negative impact on fish and other animal life in the river due to a sudden change in their life condition.
- Although Green Street is narrower than conventional street but it should be also mentioned that in Green Street usually drivers drive more slowly than in conventional or in this case wider street. This can promote safety for inhabitants especially kids living in Green Street (Barton & Pineo, 2009).

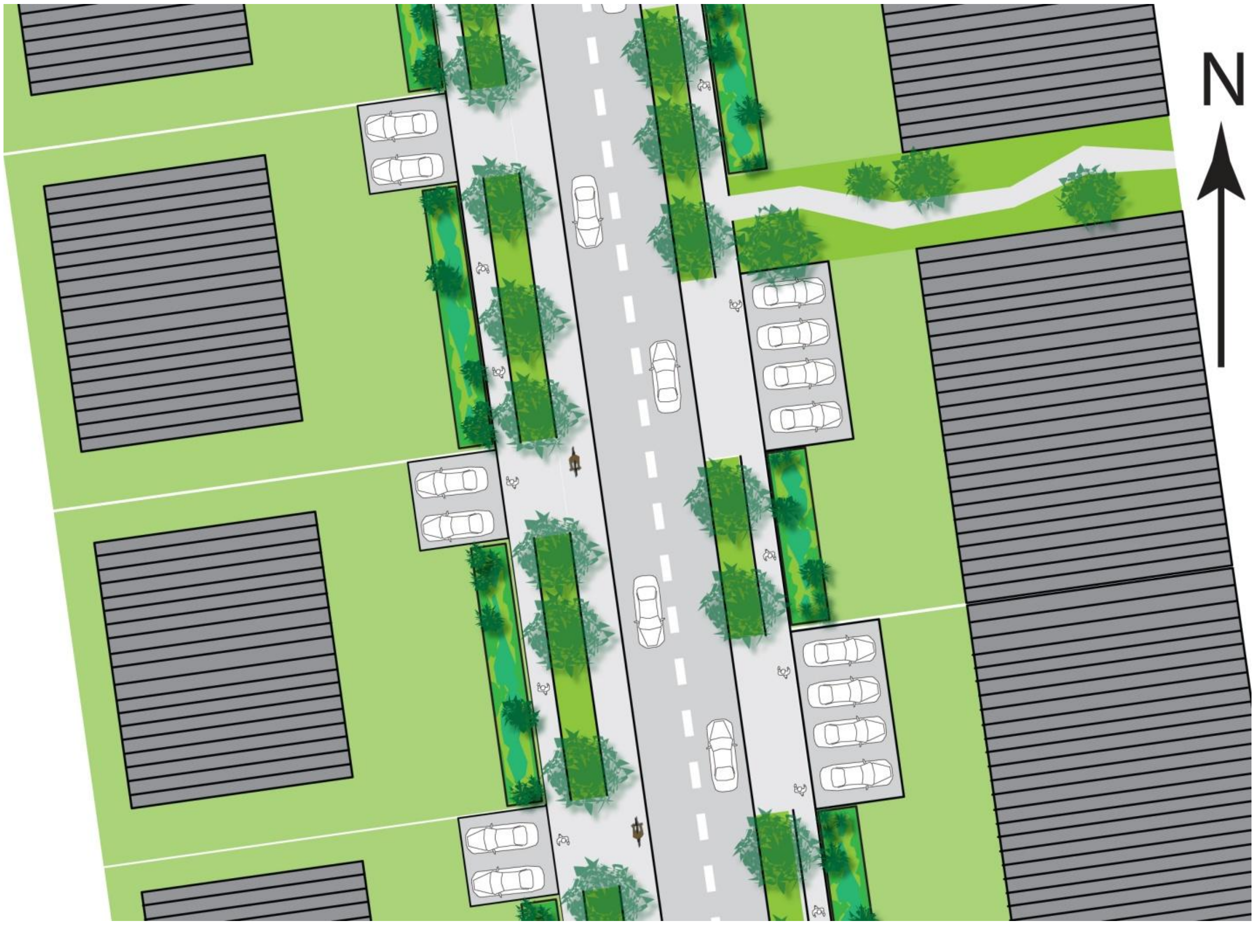


Figure 51 – An overview of both scenarios – Green Street

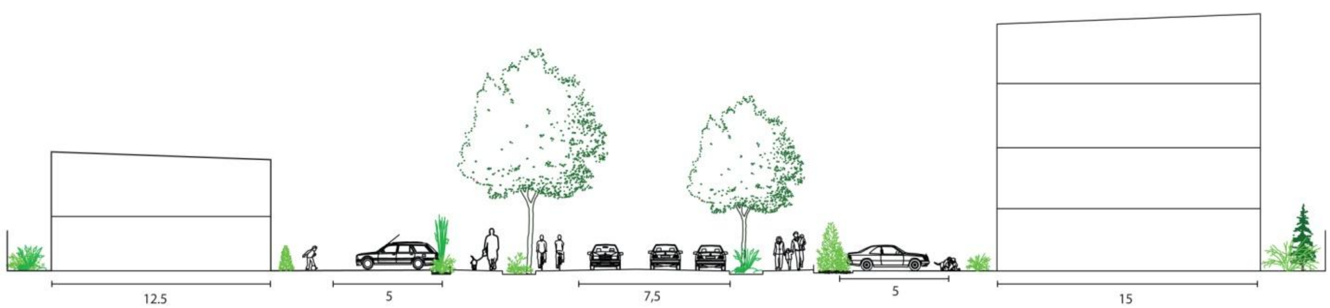


Figure 52 – A section of Green Street (sizes are in meter)

6. Discussion

6.1. Green Street, benefits and its barriers

Green Street is a street that uses soil and vegetations to control stormwater runoff on-site and close to its source (King, 2009). Green Street is an approach towards sustainable stormwater management and its main purpose is to reduce volume and rate of stormwater runoff and enhance quality of runoff as well as health of watershed (King, 2009).

Jason King in *Green Streets, Green Infrastructure* (2009) introduced some benefits of Green Street;

- Improve in the quality of stormwater runoff.
- Decreased the impervious areas of land.
- Replenish groundwater level by promoting infiltration.
- Enhancement of bicycle lane and pedestrians.
- Increased the greenery in urban areas.
- Promote ecosystem benefit through biodiversity (using vegetation and soil).
- Reduced risk of flooding.
- Improve market opportunity by increasing amenity of streets.
- By filtering pollutants in Green Street, negative effect of combined sewer overflows will be reduced (CSOs).
- Different social benefits that are connected to greenery which Green Street concept offers such as physical activity, reduction of stress, social interaction, more safety etc.
- Economical benefits of long term application of Green Street approach instead of pipes for controlling stormwater runoff.

Some of the barriers of Green Street concept are as following;

- One of the considerable barriers is to retrofit existing street with Green Street which can be costly (Belan & Otto, 2004).
- Another disadvantage of Green Street practices is the initial cost of implementing Green Street practices. Although Green Street approach has long term financial benefits, the initial installation can be costly (Gedge & Frith, 2004).
- Some limitations and constrains of using Green Street practices such as steep slopes that can be facilitated with many green street practices. In addition to that, cold climate poses other limitations.
- Streets get narrower when they turn greener, as visible in a comparison between figure 48 and figure 52. According to a previous survey, this has lead to complaints from people living in a green street area (Dill et al., 2010).

In this thesis, the case study consists of four scenarios where two of them are Green Street scenarios. In the calculation of flow reduction Green Street scenarios show the effectiveness in reducing the flow. Calculations of peak discharge (appendix 1) show how applying permeable pavement can reduce the amount of water in each unit. Other advantages of Green Street can be more understood by comparing figure 51 and 47 as well as figure 48 and 52 with each other.

This comparison shows how a Green Street concept (by using vegetation and soil) can improve biodiversity, sustainability as well as biotopes. Using vegetation in the figure 52 compared to figure 48 shows that Green Street look nicer and more beautiful because of the trees and vegetation along the street.

There are some deficiencies that were listed such as lack of parking space which can be improved by better design and plan for Green Street. Figure 48 show that one car can park on each side of the conventional street whereas only one side of Green Street can be used as parking space. It is important to mention the safety of Green Street compared to conventional street. Using vegetation and trees along streets decrease accidents in urban areas (Barton & Pineo, 2009). Drivers are more tend to drive slowly in narrower street compared to a wider one (Barton & Pineo, 2009).

On one hand Green Street provides a perfect condition for bird and insects and butterflies and some other type of animals which can be considered as an improvement in biotopes and animal life. On the other hand sound of birds or insects as well as nitrogenous bird's waste on car and on street can be considered as negative points of Green Street.

The thesis focus is on how a Green Street can control the flow compared to a conventional system. Hence some of significant advantages of Green Street concept which can improve the quality of life in urban areas are listed and visualized in this thesis. As landscape architect, sustainability, biotopes, biodiversity and social aspects that have been listed and mentioned before in the text are essential items for planning an urban area. The Green Street concept promotes all these aspects.

6.2. Rational formula

Rational formula is a common and simple method used for calculating of peak flow in urban and rural area. By applying this method discharge (peak flow) can be estimated to design a drainage system. This formula is applicable for urban areas with maximum area of 5 km^2 where in rural area 25 km^2 are the maximum acceptable size of a drainage basin (Queensland, 2007). In Teckomatorp case study, 4 different scenarios have been developed and rational formula was used to estimate peak flow in each scenario. The results of peak flow showed density and impervious land increase water volume or flow.

Greenery was excluded from the calculation of peak discharge because it can make the result less accurate. However taking the whole greenery into account will not make so much difference in results from rational method. Greenery gets around 0.2 to 0.3 as the runoff coefficient value and that will not make a big difference in the result for peak flow.

In this thesis the results from rational method differ in all scenarios according to the impervious land which proves the effect of impervious land on peak discharge.

There are many different methods that can be used to calculate peak flow and runoff in urban area, but rational method was chosen because of its simplicity and applicability.

Conventional system and Green Street practices are two different ways of controlling stormwater runoff. In conventional system the most important purpose is to get rid of stormwater as quick as possible by using and applying mainly hard materials such as pipes. However in Green Street practices, stormwater are treated on-site. Furthermore, in Green Street, the main purpose is to improve quality of stormwater by removing pollutants and also decrease the rate and volume of stormwater to avoid flooding and also improve water cycle (natural hydrology cycle). Green Street practices are different structures that control and manage stormwater in a sustainable way. Using different kind of soft or natural materials mainly vegetation and soil in Green Street practices are not only improving the sustainability aspect but also increasing aesthetic view of a street. Density and the amount of impervious land in each scenario affect the results. Results mean the amount of discharge or volume of water flows on landscape that needs to be controlled and managed. In this thesis, four different scenarios present different results in the peak flow depending on their properties. The comparison between the results is presented as following:

6.3. Density and its impact on peak flow

Density means constructed part in each scenario which is 187.5 m^2 (37.5 % of the whole unit) in the first, whereas in second scenario, area of parking lot is also added so the area is 212.5 m^2 (42.5 %). 300 m^2 (60 %) in the third scenario (high density - Green Street) consider as the constructed area where in high density – conventional system scenario the area of calculation is 350 m^2 (70 %). As the results show, increased density or constructed part of each scenario will increase peak flow (discharge). The impact of impervious land on peak flow and its negative impact on water cycle has been studied in different literature (Chester *et al.*, 1996). Constructed area such as roads and roofs, create hard material surfaces i.e. concrete or asphalt. As it shows in the appendix 6 (runoff coefficient values), concrete and asphalt that are used for a roof of a building get the highest value (0.95) in the table whereas grass and greenery in general have a value around 0.3. When the percentage of constructed area increases the result from rational formula will consequently increase.

Another important point to be considered is the rate of discharge which is also affected by the density. It is obvious that, water can travel with more speed on concrete surface than grass field. Figure 37, shows how roughness coefficient (n) (friction between runoff and surface) can affect velocity of stormwater runoff. Increase in rate of runoff and its negative impacts on downstream soil erosion as well as water environment has been studied. In conventional system scenarios all runoff should be drained from the roof top to drainage pipe in 15 minutes however in green scenarios runoff has 4 hours to be filtered and cooled down before it goes to a pipe system. This reduction of speed and pollutants as well as reduction of temperature and volume of runoff in Green Street practices address different benefits to the environment.

6.4. Green Street and flow reduction

Green Street has a significant effect on flow, by attenuating, filtering and storing stormwater runoff. For instance in scenario 1 (low density – Green Street), the flow-through planter was designed to dewater in 4 hours whereas in conventional scenario this time is only 15 minutes (rainfall duration). Runoff flow in Green Street scenarios according to the results (section 5.10) is around 18 times less than conventional system. This reduction of flow promotes natural hydrology cycle and prevents soil erosion of downstream. According to different literature, flow rate and pollutants have a great negative effect on water cycle. Therefore, purifying stormwater runoff and reducing flow rate improves hydrology cycle or in another word cleaner water for human and wildlife.

6.5. Applying permeable surface and its impact on peak flow

In both Green Street scenarios, parking lots get permeable pavement (no infiltration permeable pavement). This practice in the first scenario has less effect since the parking lot in the first scenario is just 25 m^2 which is around 11% of the whole area of calculation (212.5 m^2), whereas between the third and forth scenarios the difference is more obvious. In Teckomatorp case study, permeable pavement has the ability to pass 100% of runoff (table 2) during the 15 minutes rainfall. So the area of parking lots has been neglected from the calculation of peak flow in green scenarios. More obvious difference appears in high density scenarios where in high density – conventional system, 15% of the area (350 m^2) is parking lot. 6.9 m^3 water in the third scenario where in the forth one 8.1 m^3 shows exactly the impact of permeable pavement on the water volume. It shows, how density can increase peak flow. When both impervious area and runoff coefficient increase the amount of discharge will get a higher number. Impervious area such as concrete and asphalt get the highest value of runoff coefficient (appendix 6) and consequently increase the amount of peak flow. This more water volume can increase risk of flooding especially in urban areas which can cause huge expenses for municipals.

6.6. Green practices versus conventional system

Two Green Street practices, implemented in Green Street scenarios in new development Teckomatorp are a flow-through planter and a no infiltration permeable pavement where in the other scenarios (2 and 4) conventional system is applied to control stormwater runoff. According to the results from calculation, both conventional system scenarios get higher discharge whereas in Green Street scenarios same density generates less peak discharge. This excess water volume will have different negative effects such as increasing risk of flooding, distributing pollution to water environment and increasing soil erosion of downstream.

Shortage of clean water resources urges human to preserve water quality as well as water quantity. In another word, conventional system is not a sophisticated way of controlling stormwater runoff.

Green Street practice is an approach toward sustainable stormwater management that helps to fulfill these deficiencies caused by conventional system. These green techniques point out volume, rate and quality of runoff. These goals are achieved by implementing natural elements such as soil and vegetation that improve beauty of our streets. Stormwater runoff goes to a flow-through planter, vegetation and engineer soil filter the pollution and decrease the velocity of runoff as well as the volume and eventually treated stormwater runoff can be used or drained to a drainage system. Permeable pavements also treat stormwater runoff and then infiltrate it to the groundwater level or convey it to a drainage system. Treated stormwater with lower velocity is no longer dangerous for water environment but also improves natural hydrological cycle. Less water volume on landscape because of applying green practices is causing less risk of flooding.

7. Conclusion

The results of calculations show that higher density increases the amount of water volume in landscape. In addition to that comparisons between conventional system scenarios and Green Street scenarios, show that more runoff volume will be generated using conventional system which is by all means bad for both economy (risk of flooding) and water cycle. However applying a flow-through planter and a permeable pavement in Green Street scenarios not only improve the aesthetic view of our scenarios but also generate less discharge and consequently less risk of flooding. Furthermore, treated stormwater runoff which has better quality (less polluted), less velocity and decreased volume (i.e. storage, evaporation and etc.) in Green Street scenarios will improve the natural hydrological cycle as well as aquatic ecosystem.

Municipalities should encourage Low impact development (LID), Best Management Practices (BMP), Sustainable Drainage Systems (SUDS) and etc, approaches into their planning for neighborhoods. These approaches will bring different benefits to our societies and environment. Sustainability is an important goal for all these approaches which is also significantly important for landscape planners and designers as well as developers and municipalities to promote in their projects.

Sustainable stormwater management in new development in Teckomatorp can be considered as a starting point for removing the notoriety of the area due to BT Kemi, instead giving the area a new identity. Using vegetation and soil as the most important elements of all Green Street structures, will also improve the view and beauty of Teckomatorp.

8. Appendix

Appendix 1 - Rainfall intensity in (l/s ha) that means liters (s) per second and hectare- in Sweden- Stockholm

Return period in year	Duration of rain fall (Dahlström, 2010)									
	Unit	5 min	10 min	15 min	30 min	60 min	120 min	360 min	720 min	1440 min
0.5	l/s ha	116.8	85.2	67.8	43.9	27.6	17.2	8.4	5.6	4.0
0.5	mm	3.5	5.1	6.1	7.9	9.9	12.4	18.0	24.2	34.7
1	l/s ha	146.6	106.9	84.9	54.8	34.2	21.1	10.0	6.5	4.5
1	mm	4.4	6.4	7.6	9.9	12.3	15.2	21.6	28.2	39.2
2	l/s ha	184.2	134.1	106.5	68.5	42.6	26.1	12.1	7.7	5.2
2	mm	5.5	8.0	9.6	12.3	15.3	18.8	26.1	33.3	44.9
5	l/s ha	249.3	181.3	143.8	92.3	57.1	34.7	15.7	9.8	6.3
5	mm	7.5	10.9	12.9	16.6	20.6	25.0	33.9	42.1	54.8
10	l/s ha	331.5	228.0	180.6	115.7	71.4	43.1	19.2	11.8	7.5
10	mm	9.4	13.7	16.3	20.8	25.7	31.3	41.6	50.8	64.6

Appendix 2 - Calculation of peak discharge

Scenario 1 – Low density - Green Street

Area (A)	$A_{Impervious} = A_{roof} = 187.5\ m^2 = =0.01875$ ha
C (runoff coefficient)	C = 0.95
I (rainfall intensity)	I = 97.8 mm/h
C_f (frequency factor for rational method)	**C_f = 1**
K_u (Unit conversion)	**K_u = 360**
Q (flow) = C_f	Q = = 0.0048 m^3/s Q = 0.0048 m^3/s *1000 = 4.8 liter/s
V_{water} (volume of water) in 15 minutes 15 minutes = 15 * 60 second = 900 s	$V_{Water\ in\ 15\ minutes} = 900 * 0.0048\ m^3/s = 4.4\ m^3$ V_{Water} = 4.4 * 1000 = 4400 liters

Scenario 2 - Low density - conventional system

In this scenario 25 m^2 of parking lot has an impervious surface so it will be added to the total area so the calculation will be;

Area (A)	$A_{impervious} = A_{roof} + A_{parking} = 187.5 + 25 = 212.5\ m^2 = 0.02125$ ha
C (runoff coefficient)	C = 0.95
I (rainfall intensity)	I = 97.8 mm/h
C_f (frequency factor for rational method)	**$C_f = 1$**
K_u (Unit conversion)	**$K_u = 360$**
Q (flow) = C_f	Q = = 0.0055 m^3/s Q = 0.0055 m^3/s *1000 = 5.5 liter/s
V_{water} (volume of water) in 15 minutes 15 minutes = 15 * 60 second = 900 s	$V_{Water\ in\ 15\ minutes} = 900 * 0.0055\ m^3/s = 4.95\ m^3$ $V_{Water} = 4.95 * 1000 = 4950$ liters

Scenario 3 – High density - Green Street

Area (A)	$A_{impervious} = A_{roof} = 300\ m^2 = 0.03$ ha
C (runoff coefficient)	C = 0.95
I (rainfall intensity)	I = 97.8 mm/h
C_f (frequency factor for rational method)	**C_f = 1**
K_u (Unit conversion)	**K_u = 360**
Q (flow) = C_f	Q = = 0.0077 m^3/s Q = 0.0077 m^3/s *1000 = 7.7 liter/s
V_{water} (volume of water) in 15 minutes 15 minutes = 15 * 60 second = 900 s	$V_{Water\ in\ 15\ minutes}$ = 900 * 0.0077 m^3/s = 6.9 m^3 V_{Water} = 6.9 * 1000 = 6900 liters

Scenario 4 - High density - conventional system

In this scenario 50 m^2 of parking lot has an impervious surface so it will be added to the total area, the calculation will be;

Area (A)	$A_{impervious} = A_{roof} + A_{parking} = 300 + 50 = 350\ m^2 = 0.035$ ha
C (runoff coefficient)	C = 0.95
I (rainfall intensity)	I = 97.8 mm/h
C_f (frequency factor for rational method)	**$C_f = 1$**
K_u (Unit conversion)	**$K_u = 360$**
Q (flow) = C_f ——	Q = ———— = 0.009 m^3/s Q = 0.009 m^3/s *1000 = 9 liter/s
V_{water} (volume of water) in 15 minutes 15 minutes = 15 * 60 second = 900 s	$V_{Water\ in\ 15\ minutes} = 900 * 0.009\ m^3/s = 8.1\ m^3$ $V_{Water} = 8.1 * 1000 = 8100$ liters

Appendix 3 – Calculation of flow-through planter size (only Green Street scenarios)

Scenario 1 – Low density - Green Street

Calculation of flow-through planter using SIM approach

Area (Area of impervious land)	$A_{impervious} = A_{roof} = 187.5\ m^2$
SIM sizing factor	0.06
Area of planter = $A_{impervious} * 0.06$	$0.06 * 187.5 = 11.25\ m^2$

Calculation of flow-through planter using SUDS formula

L (depth of soil layer (m))	0.75 m
V_t is the total volume of water (m^3)	$4.4\ m^3$
k is the hydraulic conductivity of soil (m/s)	0.00002 m/s
h is the average height of water level on the top (above the soil) in (m)	0.15 m
t is the time for the water to travel through the filter medium in (s)	t= 4 hours = 4 * 3600 second = 14400 s
(area of planter) $A_f = \frac{}{}$	$A_f = \frac{}{} = 12\ m^2$

Scenario 3 – High density - Green Street

Calculation of flow-through planter using SIM approach

Area (Area of impervious land)	$A_{impervious} = A_{roof} = 300\ m^2$
SIM sizing factor	0.06
Area of planter = $A_{impervious}$ * 0.06	0.06 * 300 = 18 m^2

Calculation of flow-through planter using the SUDS formula

L (depth of soil layer (m))	0.75 m
V_t is the total volume of water (m^3)	6.9 m^3
k is the hydraulic conductivity of soil (m/s)	0.00002 m/s
h is the average height of water level on the top (above the soil) in (m)	0.15 m
t is the time for the water to travel through the filter medium in (s)	t= 4 hours = 4 * 3600 second = 14400 s
(area of planter) A_f = ———	A_f = ——————— = 20 m^2

Appendix 4 - Calculation of flow reduction in all scenarios

Calculation of flow reduction – Low density - Green Street (scenario 1):

V_{water} (m^3) or liter	4.4 m^3 = 4400 liter
Time of dewatering	4 hours = 4 * 3600 = 14400 seconds
Q = ———	Q = ——— = 0.3 liter/s

Calculation of flow reduction – Low density - conventional scenario (scenario 2):

V_{water} (m^3) or liter	4.95 m^3 = 4950 liter
Time of dewatering	15 minutes = 900 seconds
Q = ———	Q = ——— = 5.5 liter/s

Calculation of flow reduction – High density - Green Street (scenario 3):

V_{water} (m^3) or liter	6.93 m^3 = 6930 liter
Time of dewatering	4 hours = 4 * 3600 = 14400 seconds
Q = ———	Q = ——— = 0.5 liter/s

Calculation of flow reduction – High density - conventional scenario (scenario 4):

V_{water} (m^3) or liter	8.1 m^3 m^3 = 8100 liter
Time of dewatering	15 minutes = 900 seconds
Q = ——	Q = —— = 9 liter/s

Appendix 5 – Soil permeability coefficient values, "k" (Woods-Ballard et al., 2007)

Type of soil	Permeability coefficient (m/h)
Good infiltration media	
Gravel	10-1000
Sand	0.1-100
Loamy sand	0.1-1
Sandy loam	0.05-0.5
Loam	0.001-0.1
Silt loam	0.0005-0.05
chalk	0.001-100
Sandy clay loam	0.001-0.1
Poor infiltration media	
Silty clay loam	0.00005-0.005
Clay	≤ 0.0001
Till	0.00001-0.01
Rock	0.00001-0.1

Appendix 6 – Runoff coefficient value

Runoff coefficient value recommended by (NCTCOG, 2010)	
Type of areas	**Runoff coefficient (C)**
Lawns:	
Sandy soil, flat, 2%	0.10
Sandy soil, average, 2 - 7%	0.15
Sandy soil, steep, > 7%	0.20
Clay soil, flat, 2%	0.17
Clay soil, average, 2 - 7%	0.22
Clay soil, steep, > 7%	0.35
Agricultural	0.30
Forest	0.15
Streams, Lakes, Water Surfaces	1.00
Business:	
Downtown areas	0.95
Neighborhood areas	0.70
Residential:	
Single Family (1/8 acre lots)	0.65
Single Family (1/4 acre lots)	0.60
Single Family (1/2 acre lots)	0.55
Single Family (1+ acre lots)	0.45
Multi-Family Units, (Light)	0.65
Multi-Family, (Heavy)	0.85
Commercial/Industrial:	
Light areas	0.70
Heavy areas	0.80
Parks, cemeteries	0.25
Playgrounds	0.35
Railroad yard areas	0.40
Streets:	
Asphalt and Concrete	0.95
Brick	0.85
Drives, walks, and roofs	0.95
Gravel areas	0.50
Graded or no plant cover:	
Sandy soil, flat, 0 - 5%	0.30
Sandy soil, flat, 5 - 10%	0.40
Clayey soil, flat, 0 - 5%	0.50
Clayey soil, average, 5 - 10%	0.60

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