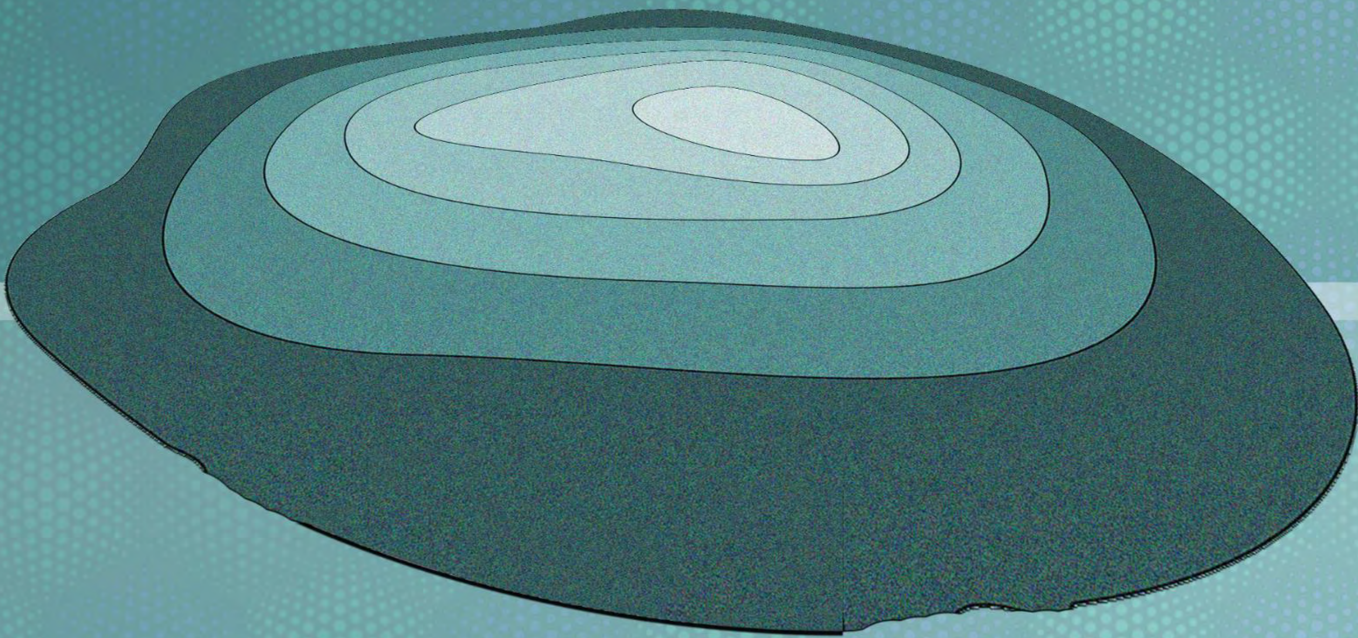
Ministry of Environment
Republic of Maldives

A Guide to Groundwater Improvement Measures in Small Low-lying Islands - Maldives



Part I

Infiltration and Drainage

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PREFACE

The objective of this volume, a part of a series providing guidance on groundwater management and aquifer protection in the Maldives, is to provide guidance on sustainable infiltration techniques of groundwater recharge by illustrating various options that are suitable for groundwater recharge. The complete guide aims to provide specific guidance on improving groundwater based on a number of broad strategies derived from the ‘model’ “Island Climate Resilient Groundwater Management Plan”.

This guide can be used by practitioners, engineers, planners and policymakers (e.g. Island Councils) to assist in the process of design, implementation and management of sustainable groundwater recharge and improvement facilities in the Maldives. It can also be used by academics for educational purposes and for capacity building and training on methods of infiltration drainage applicable to low-lying islands of the Maldives, with context-specific application of the science of groundwater.

The content of this guidance document is mostly self-standing with the references to existing research, guidance, literature review and international best practices provided. However, this guide should be used together with practical experience of similar projects in the Maldives and other small islands. It is recommended that this document be further supplemented with case studies, design tools etc., for design and implementation of infiltration drainage systems. Even though this guide can be used by the general public for guidance on options available for household level infiltration drainage devices, it does not aim to illustrate or explain the fundamental engineering science of groundwater.

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INTRODUCTION

Maldives is a low-lying island nation with 1192 coral islands located in the Indian Ocean, near the equator. Similar to other developing countries around the globe, developments are taking place at a rapid pace throughout the country. Urbanization of the islands have created more impervious ground cover, leading to a growth in number of flood events due to the increase in surface runoff. For instance, the densely urbanized capital city Male' is often seen flooded to approximately 1 foot after a moderate to heavy rain shower. There is no island-wide stormwater drainage system or an adequate drainage facility currently installed in Male'. Roofs and road surfaces in an urban area are usually the first point of contact for precipitation, before it reaches the ground and is drained or infiltrated. Rainwater falling directly onto the road surfaces as well as the rainwater conveyed from roof catchments accumulate on certain areas of the ground, creating flooding issues. Hence, proper drainage methods are vital for minimizing the accumulation of floodwater. The conventional solution for this problem has been to build piped stormwater drainage systems that rapidly convey water away from urban areas, into a nearby waterbody – ocean in the case of the Maldives. Recently, solutions based on infiltration of stormwater to the ground has become popular.

Infiltration-based drainage methods have an added benefit of groundwater recharge when used to manage stormwater drainage. Historically, island communities have not given much attention to manage stormwater by infiltration drainage techniques. One reason for this could be that the islands were less built-up and land surfaces were covered with vegetation and fairly pervious back then. Such a large fraction of pervious surfaces could provide adequate natural infiltration without any dedicated drainage components. However, urbanisation is changing the landscape of the islands with increasing density of buildings and paved roads. Impact of these changes are felt in two fronts: increased occurrence of small-scale flooding during rainstorms and depletion of the groundwater due to lack of recharge. The most natural and beneficial method of recharging groundwater is primarily by using rainwater as a resource. Therefore, suitable methods of infiltration drainage techniques can be implemented to manage stormwater runoff in developing islands, which should also allow for the maximum possible recharge of groundwater. These methods and techniques should be adopted and promoted in order to conserve and recharge groundwater aquifer system in the Maldives.

This guide discusses and illustrates various options and types of infiltration-based solutions for the drainage of stormwater from roofs and road surfaces that help in recharging groundwater, and are suitable to be adopted in the Maldives. The following section provides background information and explains the basics of storm run-off generation in the context of the Maldives islands. Then two chapters are presented; first focusing on infiltration drainage methods that are suitable for building roofs and rainwater harvesting systems, and the second focusing on methods applicable for road drainage infrastructure. Finally, at the end of each chapter, a conclusion has been drawn and recommendation are presented for the appropriate use of these solutions in the islands of the Maldives.

BACKGROUND

General Overview of Maldives Islands

The Maldives is formed by a chain of carbonate coral reef islands resulting from prehistoric volcanoes and has un-weathered coral rock and a coralline sandy soil structure with good permeable soil properties. It is one of the flattest countries in the world, with 90% of land area at a surface elevation of less than 1 m from mean sea-level (Deng & Bailey, 2017). A freshwater lens is formed on top of the underlying saltwater within the subsoil layer, with the groundwater table located at a shallow depth in most of the islands (see Figure 1). In addition to pluvial flooding, low-lying atoll islands are especially vulnerable to sea-level rise and coastal flooding. However, saline or brackish water should not be allowed to infiltrate into the groundwater. One of the most important factors when selecting a drainage scheme is the amount of precipitation or rainfall that the island experiences, which is dictated by the local hydrology.

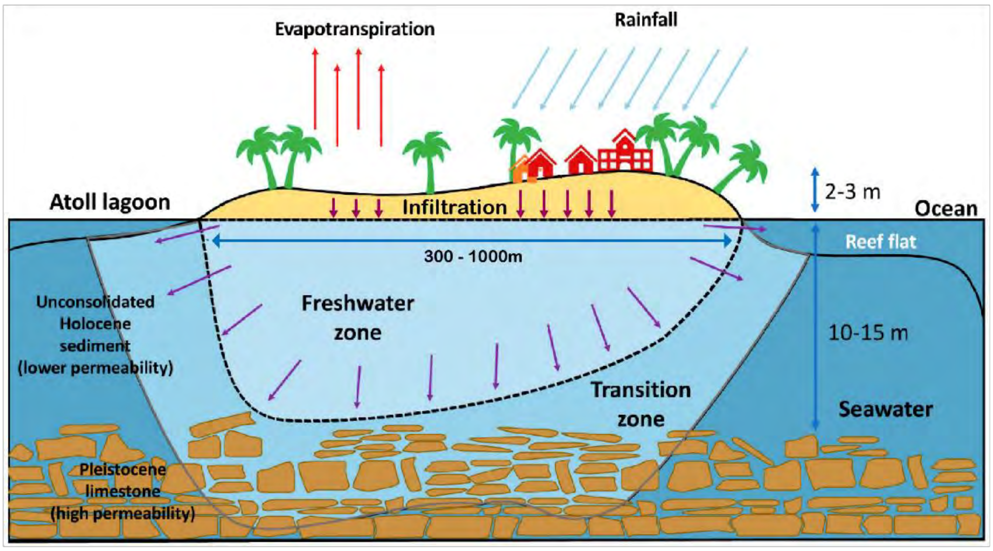

Figure 1: Hydrogeological cross section of a typical atoll island in the Maldives showing the freshwater lens (Jaleel, et al., 2020)(Illustrated with a highly exaggerated vertical scale)

Rain falls everywhere, on land surfaces and on the vast ocean that surrounds the islands. This natural weather phenomenon is illustrated by the principles of the hydrologic cycle, which is best described by the water recycling system on earth. Hydrologic cycle (continuous movement of water between land and earth) is governed by different processes of water movement between the atmosphere and the earth, mainly by; evaporation, condensation and precipitation.

The water received from precipitation is divided between infiltration into the ground, evaporation and runoff (see Figure 2). Stormwater is the precipitation that falls from the sky and turns to surface runoff. Water that is conveyed through an underground stormwater drainage system is also known as stormwater. Maldives experiences only rainfall as precipitation since it has a tropical climate (see Figure 3). Natural surfaces usually absorb surface runoff until the subsurface soil is saturated, as opposed to hard surfaces that does not absorb water as they are not often designed to soak water into the ground.

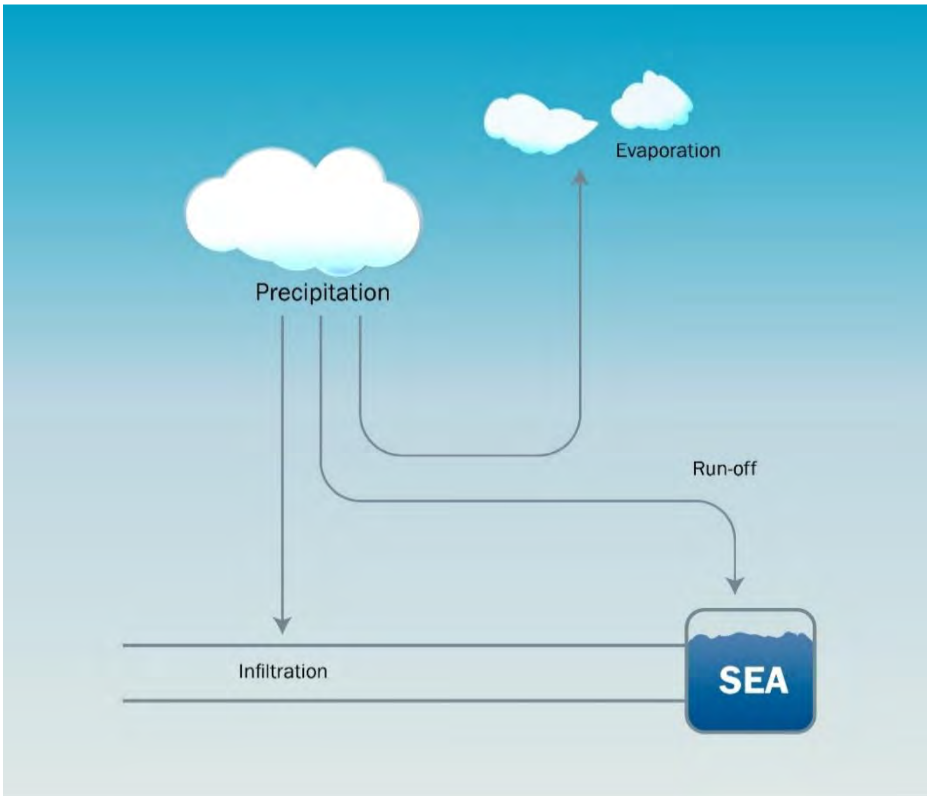

Figure 2: Important processes of the hydrologic cycle that governs the process of groundwater infiltration.

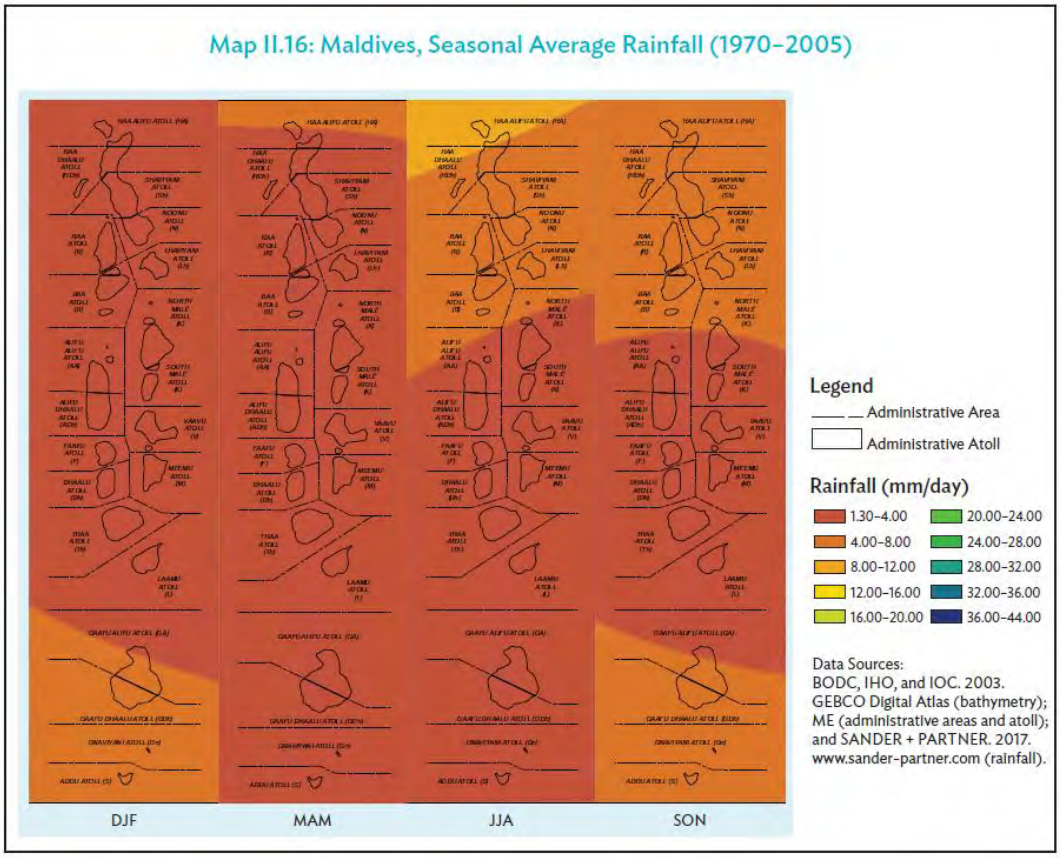

Figure 3: Maldives, Seasonal Average Rainfall (1970-2005) (Maldives does not experience snowfall as precipitation) (ADB, 2020)

Surface Water-balance in the Maldivian Setting

Infiltration and storm runoff primarily depend on the number of permeable and impermeable surfaces and the degree of soil permeability. Rainwater that falls on impermeable surfaces such as building roofs are usually discharged to surrounding empty lands within the plot and is sometimes allowed to drain into the streets. In general, most of the roads in the islands are unpaved, with surfaces in its most natural state, allowing the infiltration of rainwater which can practically be considered pervious (see Figure 4). However, urban development has led to an increasing number of impervious surfaces such as paved asphalt roads and concrete buildings with terraces or corrugated roofing that does not allow infiltration of water.

Figure 4: Surface runoff will infiltrate into the groundwater through sandy soil in the islands (Shown here is a typical unpaved sandy road in an island) (Source: raajje.mv/4062)

When land surfaces of the islands get covered with more artificial impervious surfaces (roofs, roads and parking lots etc.), the process of natural infiltration become increasingly reduced (see Figure 5). Nearly 50% of water is infiltrated into the ground in a natural setting compared to 15% in an urban setting (Saraswat, et al., 2016). Hence, the rate and amount of infiltration of rainwater through the soil column is significantly impacted when a city is urbanized (see Figure 6). Greater Male' region when compared to the less built-up outer islands, can be considered as an urban catchment. A recent study found that 39.9% of rainfall contributes to groundwater recharge in the island of Gdh. Fiyoari, an island with less infrastructure and sandy roads (see Figure 7). Mechanisms for managing storm runoff should be established in islands with both pervious and impervious land areas.

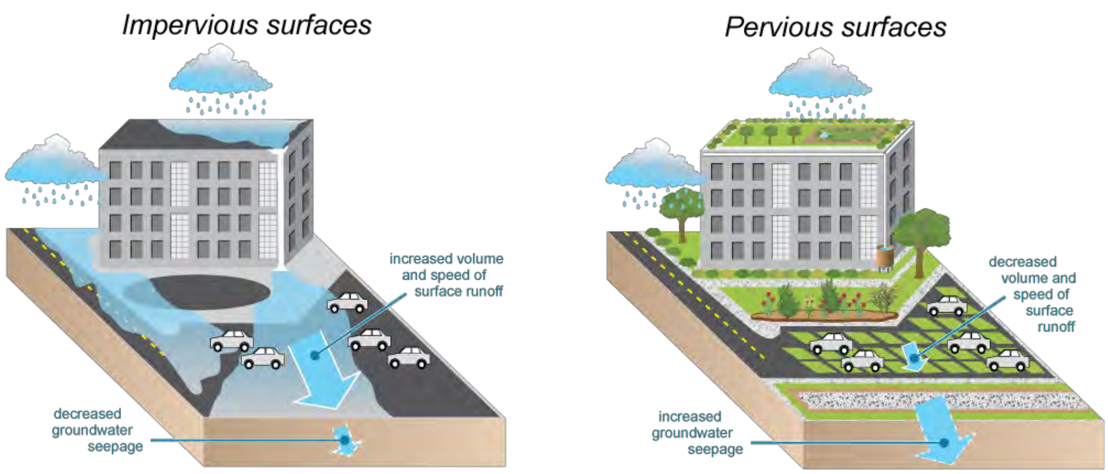

Figure 5: A conceptual diagram showing the difference between pervious and impervious surfaces (Adapted from Source: umces.edu/ian/library/impervious-versus-pervious-surfaces)

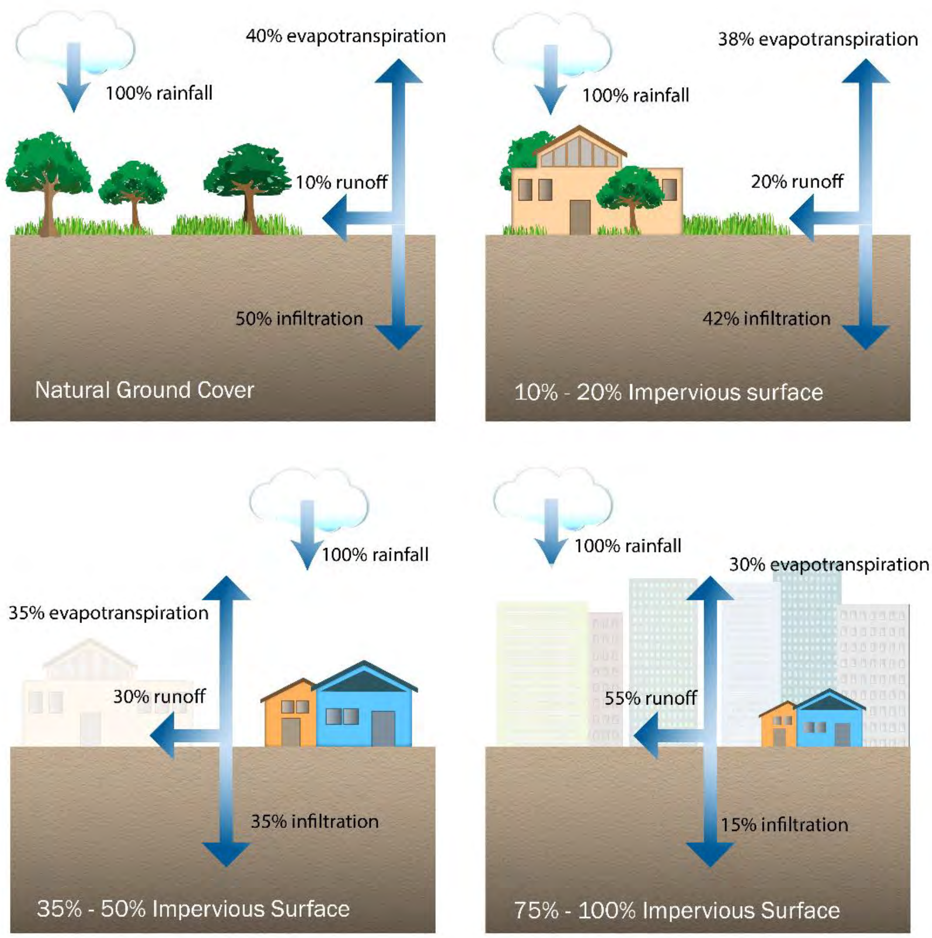

Figure 6: Comparison of the percentage of absorption of rainfall and surface runoff in a natural and an urban setting (Adapted from FISRWG, 1998, pp. 3-23)

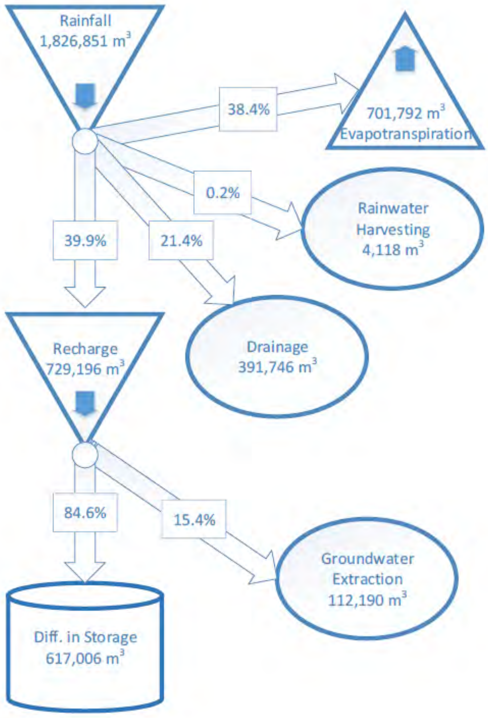

Figure 7: Schematic of water balance in Gdh.Fiyoari Island (Ministry of Envionment, 2020)

Stormwater Drainage in the Islands

Appropriate practices of stormwater management and drainage is required in the islands, in order to reduce the impact of storm runoff. Most of the islands does not have a dedicated stormwater drainage system or a natural system for drainage, to connect the outlets of roof downpipes, in case of heavy rain and flooding (Ministry of Environment, Energy and Water, 2007). As a result, roof drainage is often discharged directly into surrounding land areas and road surfaces via downspouts connected to household roofing (see Figure 8). When roof run-off is discharged into impermeable road surfaces, it causes flooding and erosion, leading to undesirable environmental hazards. Further problems may persist especially if more household roof drainage is allowed to be discharged into road surfaces.

Figure 8: A downpipe connected to the roof gutter has been left to discharge rainwater directly to the ground surface (a common practice in the islands) (Source: Authors)

Drainage systems and low impact development components or infiltration drainage devices can be utilized to manage stormwater and to reduce storm runoff. Roofs and road surfaces are excellent catchments for collecting rainwater suitable for groundwater recharge. Furthermore, infiltration drainage methods are essentially green and sustainable methods utilized to manage surface run-off. However, ponding due to soil compaction and reduced infiltration capacity can also be observed in some of the built-up areas and sandy natural roads of the islands.

Reduction in infiltration capacity of the sub-surface soil layer will reduce the recharge of the freshwater lens of the islands and increase its salinity. Reduced infiltration capacity has two important consequences. The first is increased ponding, surface runoff and high runoff introduced into the drainage systems (where such systems are available). The second is related to water supply security due to reduced groundwater recharge by infiltration. Infiltration drainage systems can be utilized to increase the infiltration capacity of sub-surface soil.

Sustainable Urban Drainage (SuDS)

Under the collection of stormwater management approaches that are commonly known as SuDS[1] (Sustainable Urban Drainage Systems), there are many different infiltration techniques. SuDS has been successfully utilized on small on-site developments for a number of years in several developed countries. As discussed previously, conventional road drainage, in general, involves removal of excess water from surrounding areas in a controlled manner to open channels or a series of underground pipes. However, in SuDS schemes, runoff is allowed to soak into the top soil and percolate directly into the lower layers of the ground. Examples of such systems include; soakaways, infiltration trenches, bio-retention systems, swales, pervious pavements etc. These infiltration systems should not generally cost more than the traditional drainage (piped) systems. Due to the number of inherent co-benefits of SuDS systems, the necessity for incorporating and promoting these components in drainage schemes cannot be understated. However, extra care should be taken when designing and implementing infiltration drainage components in low-lying islands.

There are various technical challenges and difficulties that could be encountered when implementing SuDS schemes in low-lying islands such as in the islands of Maldives. Due to the low elevation and shallow water table in the Maldives, the sub-soil layer saturates quickly, and the total volume of free storage space available above the water table for any additional quantity of water is low. Moreover, unlike hard engineering drainage solutions, these components aim to mimic the surrounding nature, and are extremely sensitive to the environment in which they are placed. Hence, the hydrogeology and the topography of the site in concern should be properly studied and understood well before implementing these components. Particular attention should be given to the land surface elevation, depth of water table below ground level and the properties of the soil cover. For example, some sites may require excavation and removal of existing soil, backfilling with good permeable soil to a certain depth/ height. It may not be practical to elevate existing ground level of an island for the sole purpose of implementing SuDS schemes. However, these are excellent drainage options that can be successfully implemented, for example, as an urban drainage solution for reclaimed islands and elevated parks. Therefore, it is important that a site-specific design be

[1] Sustainable Urban Drainage Systems: Approaches to manage surface water that take account of water quantity (flooding), water quality (pollution) biodiversity (wildlife and plants) and amenity. (Source: susdrain.org)

prepared and that the designers have adequate flexibility for site adjustments/ modifications required for implementing the chosen method/ type of infiltration device. Moreover, as these components are susceptible to clogging by garbage and debris, care should be taken for regular cleaning and maintenance to ensure they work as intended.

CHAPTER 1:

Roof Capture and Infiltration

1.1 Introduction

Rainwater Harvesting Systems (RWH) are used to collect rainwater from impermeable catchments such as roofs, and store in containers for human consumption. In case there are no RWH systems connected to the roof, roof runoff is drained directly to the ground via downpipes.

Oftentimes, downpipe connections from roof catchments to the sanitary sewer system have been encountered in islands where there are existing sewerage networks. Sewerage networks are designed to a certain capacity, and it shall not be overloaded beyond the limit by an input for which it has not been designed. Hence, roof connection to sewer network is not a recommended practice.

Building roofs can be connected to infiltration drainage components for recharging the groundwater aquifer of the island. This can be achieved in two ways; by integrating existing or new RWH systems with infiltration drainage components or by direct discharge of roof run-off into infiltration drainage components. SuDS devices should be adopted in roof catchments, particularly in RWH systems for infiltration drainage and recharging groundwater aquifer in the islands.

This chapter is a guidance for property owners and developers of existing and new buildings; houses and commercial buildings on sustainable infiltration components that can be integrated with building roofs and RWH systems for groundwater recharge. A brief description of roof capture and RWH systems followed by suitable SuDS devices suitable for land plots with varying degrees of free space have been presented. In the end of the chapter, a conclusion has been drawn about the methods proposed.

1.2 Roof Capture & Rainwater Conveyance

Building roofs act as catchment surfaces for rainwater collection during a rainfall event. Any type of building, regardless of its size, shape and usage will be have some kind of roof (see Figure 1.1). Pitch roofs or gable roofs made of corrugated steel sheets sloping to two sides, to the gutters are very common in the islands. Most of the existing buildings are already equipped with gutters and downspouts. Rainfall runoff mainly depends on the area and type of catchment over which it falls, as well as its surface features. A catchment component is required for any system that is used for groundwater recharge, which is the roof in case of a building.

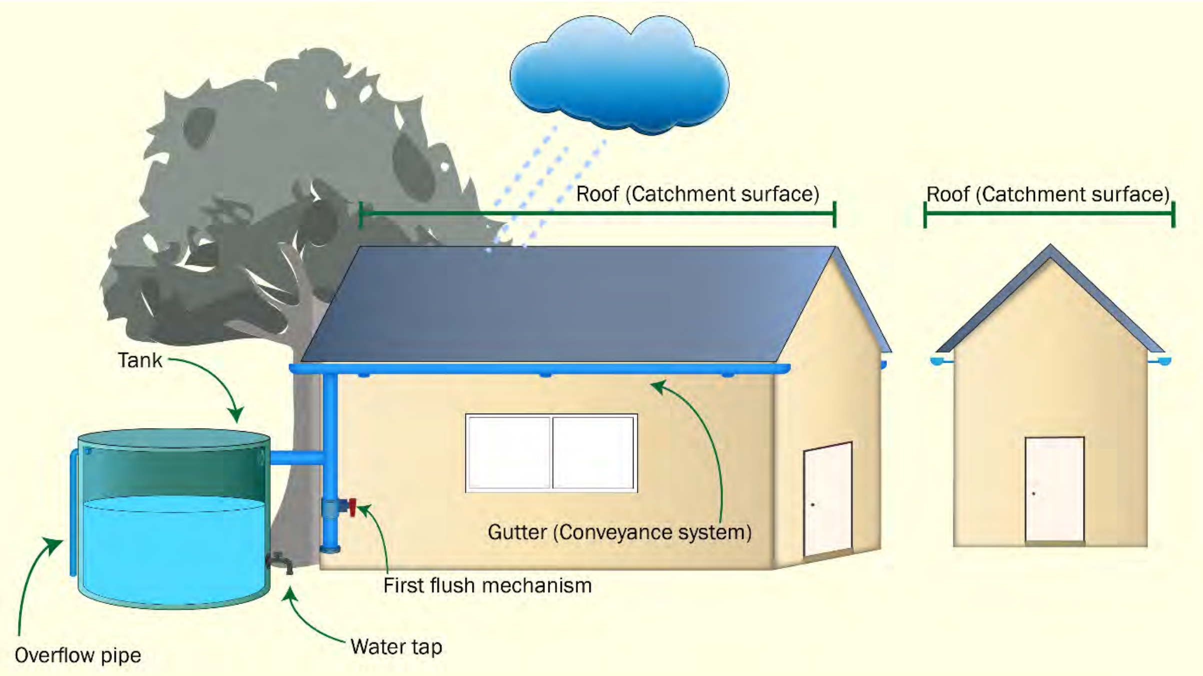

Figure 1.1: Building roofs are used as rainwater catchment surfaces

Runoff from roof catchment is intercepted, redirected and conveyed via special components fixed to the roof (see Figure 1.2). Rainwater collected at the roof gutters is transported down to the ground via conduits known as downpipes. The method used to convey water to the ground is similar to the way in which a RWH system conveys water to a storage tank, as explained in Section 1.3 - Rain Water Harvesting Systems. Once the roof run-off reaches the ground, it is dispersed to nearby surfaces, evaporates or finds its way to the groundwater.

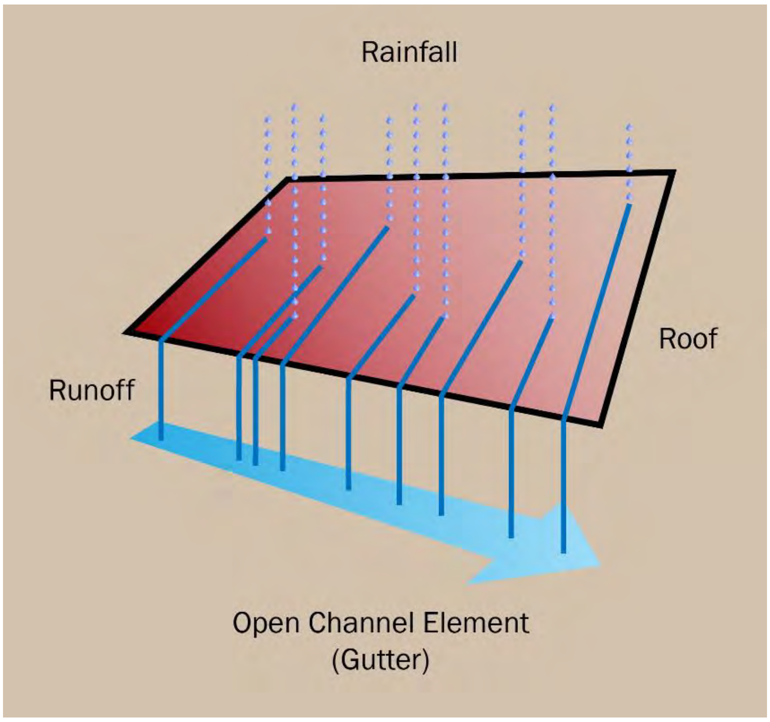

Figure 1.2: A simplified model showing the flow path of rainfall from a roof to the gutter

1.3 Rain Water Harvesting Systems in Maldives

Rainwater harvesting is the process of collecting rainwater from a surface on which it falls and storing for use when needed. This method of rainwater collection, treatment and storage, instead of discharging to the ground is encouraged or preferred as an alternative means for bottled drinking water. Additionally, harvested rainwater can be considered a sustainable source of drinking water. This is important especially for those islands that does not have a piped water supply system and for those that experience water shortages during dry periods. Since rainfall varies monthly and is unpredictable, water required for dry months is stored in containers for later consumption. As such, several household roofs in islands are often connected to RWH systems for collection and storage of rainwater (see Figure 1.3). To understand the connection between infiltration drainage systems and RWH systems, it is important to appreciate the basic working principles of a RWH system.

Figure 1.3: A simple Rainwater Harvesting setup in a mosque in GDh. Rathafandhoo (The most common method of Rainwater Harvesting system in islands) (Source: Authors)

In a typical RWH setup, rainwater is collected from roofs and diverted into the gutters to be drained down to a storage tank via conduit pipes. The size of the catchment area or roof affects the volume of runoff that can be collected. Therefore, it is important to have an adequate size of roof available as catchment surface and storage capacity to accommodate the volume of water. Water demand is based on the usage and number of people in the household, which is compared to the available quantity of rainwater calculated according to the size of roof, rainfall intensity and rainfall pattern for the specific locality. Adequate size of gutters and downpipes that are properly sized should be fixed to the roof to divert rainwater from rooftop to the storage tank (see Figure 1.4). In addition to roofs, gutters and tanks, a RWH is made up of several other components.

Roof area m^2	Gutter width. mm	Down pipe. mm
17	60	40
25	70	50
34	80	50
46	90	63
66	100	63
128	125	75
208	150	90

Figure 1.4: Required gutter width and down pipe size for RWH systems, calculated according to the roof area. (Environmental Protection Agency, n.d.)

The major components of a typical RWH system are explained below (see Figure 1.5).

- Catchment: Roofs and gutters are used as catchment surfaces which are made of PVC or galvanized structures commonly in the Maldives. Sufficient gradient should be provided to the gutters for the water to freely flow down to the pipe, which is usually 1:200.
- Conveyance: Downpipes are made of PVC material of appropriate diameter and is based on the rainfall intensity and catchment area. An automatic or a manual first flush device is attached to the downpipes to divert the first rain before it enters the storage tank.
- Storage: A tank or cistern of suitable size used to store the rainwater for future use, determined based on the required volume of water. Black PE tanks are commonly used in the Maldives.
- Treatment: Filter units consisting of filter media or other pre-treatment methods such as Chlorination, UV, UF disinfection or boiling is commonly used at the household level to treat water before consumption.

- Infiltration: Water from first flush diverters (with filtration) or tank overflow can be discharged to the ground to recharge groundwater. A RWH system can be used to recharge groundwater using various infiltration components as discussed in the next section.

For a comprehensive guidance on setting up a RWH system, readers may refer to the National Rain Water Harvesting Guideline published by EPA in 2012, available on their website for download.

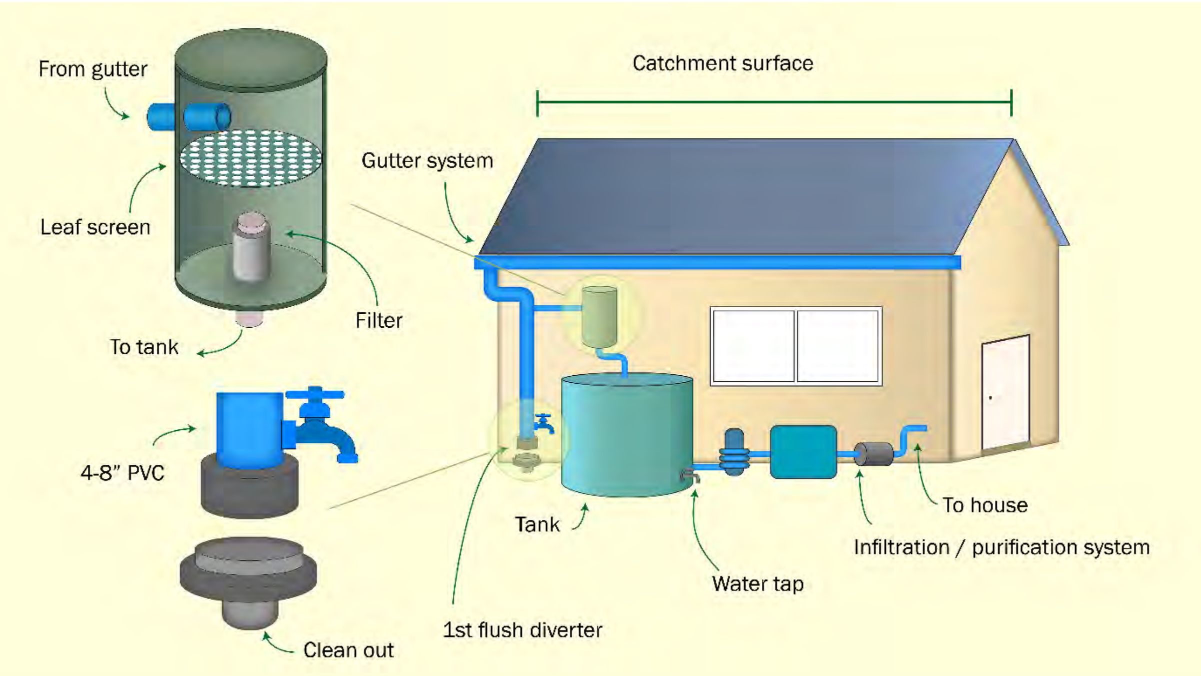

Figure 1.5: The main components of a typical rainwater harvesting system

RWH systems can be used to recharge groundwater by integrating it with an infiltration drainage component. Water collected from roof catchments by first flush devices from first rain of rainfall can be connected (after treatment) to an infiltration drainage component for groundwater recharge. In addition, any volume of water above the storage capacity of a RWH system known as overflow, can also be drained to the ground by directing an overflow pipe from the storage tank to the ground. Properly designed groundwater recharge or infiltration drainage components shall be incorporated into RWH systems and building roofs across Maldives, wherever practicable to maximize groundwater recharge.

1.4 Sustainable Drainage Systems for Roofs and Rainwater Harvesting Systems

SuDS components or infiltration devices are used for groundwater recharge by capturing and infiltrating surface runoff into the subsoil layer. They facilitate the drainage of surface runoff into the unsaturated zone of the subsurface soil and to the groundwater aquifer (freshwater lens) for recharging groundwater. A properly designed infiltration component decreases the volume of runoff, contains potential pollutants, and increases the amount of water entering the groundwater aquifer system.

A range of different types of infiltration components are available for groundwater recharge which can be integrated with roof catchments and RWH systems. These components can be constructed beneath the outlet of a 'point' discharge to the ground, which are downpipes in case of a building (see Figure 1.6). Depending on the area available and the quantity of water collected, infiltration components can be used individually or a number of components can be combined together. It is important to conduct a site investigation of the particular plot of land for site-specific design before designing and implementing these components.

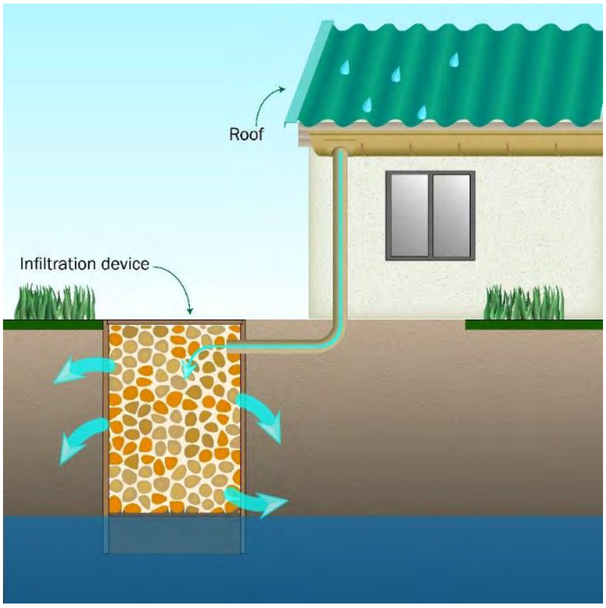

Figure 1.6: Downpipes from Roofs or overflow pipes from RWH Systems can be connected to an infiltration component for groundwater recharge

Infiltration devices should be designed specifically for the site and should be sized based on the technical parameters of the land. A ground investigation has to be carried out before design and construction to verify the type, depths and permeability of the soil layer. In general, parameters related to the topography and hydrogeology of the site should be investigated. This includes; elevation, vegetative cover, water movement and soil characteristics. The rate at which water can be infiltrated depends on the permeability of the surrounding soil, which is mainly sand, in the Maldives. In addition, depth of water table should also be considered. As a general rule, no component should be designed too steeply sloped towards a building. Existing dug wells can also be re-purposed in the long-term for use as a recharge structure when not required as a result of the construction of a water distribution network. If the source water is subject to contamination, a device that has pre-treatment function is required before allowing the water to be infiltrated into the groundwater. The same parameters shall be investigated for all types of land plots regardless of the function of the building; households, private & public buildings, mosques, schools, condominiums, guesthouses and industrial buildings, before choosing a suitable infiltration facility. Space constraints (in terms of the built-up area) within the land plot is one of the main factors that influence the type and design of infiltration devices.

It is important to categorize the land plots available for infiltration devices and evaluate each site individually. Depending on the availability of space within the land area, any plot of land with a building that requires a recharge component can be classified into any one of the three categories given below;

1. Unsaturated land plots: Plots with plenty of space available within the land area. Majority of the land plots in the outer islands fall into this category.
2. Partially saturated land plots: Plots with only a limited amount of space available within the land area.
3. Fully saturated land plots: Fully built-up land plots are single-unit houses or commercial, industrial land plots that are fully covered with infrastructure such as buildings or roads, having insufficient space available to place any type of recharge component within the land area. Most of the housing plots in Male' are developed up to the boundary and there is no adequate space available to construct a recharge structure within the land area except below ground.

Given below is a selected list of infiltration components that are suitable for building roofs and RWH systems:

I. Components suitable for unsaturated & partially saturated land plots:
   a) Soakaways
   b) Infiltration Trenches
   c) Filter Drains
   d) Filter Strips
   e) Infiltration Basins
   f) Infiltration Blankets

II. Components suitable for fully built-up land plots
   a) Underground Recharge wells

These devices are illustrated and further detailed below in Section 1.4.1- Components for Unsaturated & Partially Saturated Land Plots & Section 1.4.2 - Components for Fully built-up Land Plots.

1.4.1 Components for Unsaturated & Partially Saturated Land Plots

Land plots with adequate space for constructing infiltration devices that are suitable for use within the premises and can be constructed close to existing or proposed buildings.

a. Soakaways: Square or circular excavations filled with void-forming materials such as gravel that allows temporary storage of water before it soaks into the ground (see Figure 1.7). Soakaways can be constructed by preparing a shallow excavation in the ground and inserting blockwork, pre-cast concrete rings or polyethylene rings/ perforated storage structures which are backfilled using granular material such as stone rubble fill (see Figure 1.7). Specialist geo-cellular units pre-wrapped in geotextile are also available which provide good overall storage capacity.

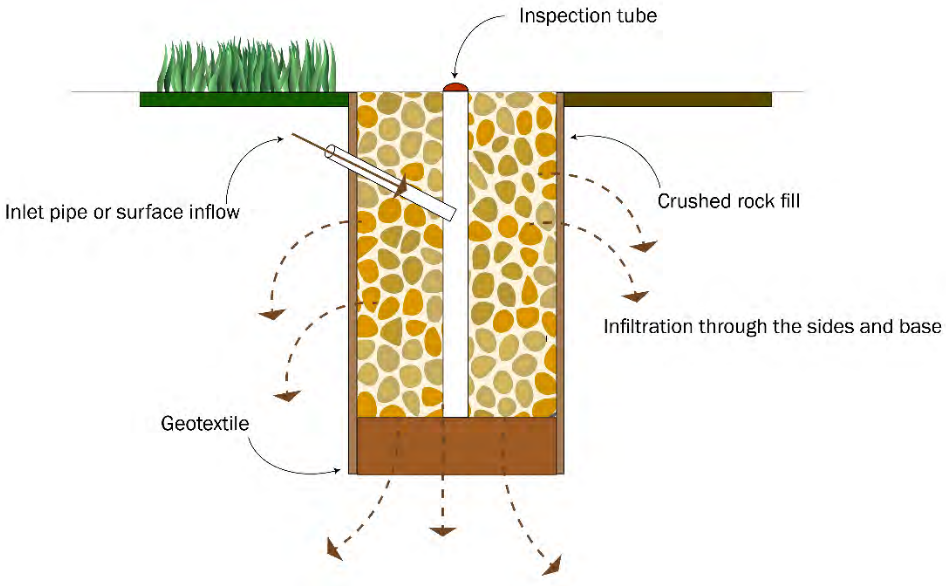

Figure 1.7: Cross-section through a Soakaway

b. **Infiltration Trenches:** Shallow, linear excavations filled with permeable granular material that allows exfiltration of water into the surrounding soils from the bottom and sides of the trench (see Figure 1.8). Water is stored in the pore spaces of the granular material and slowly infiltrates into the soil. Infiltration trenches are fundamentally linear or trench soakaways and can be used in areas where there is adequate space available. Water is diverted to the trench by allowing the adjacent ground to slope into it using another drainage component, such as a filter strip. A perforated pipe, if required can also be provided to distribute water along the trench.

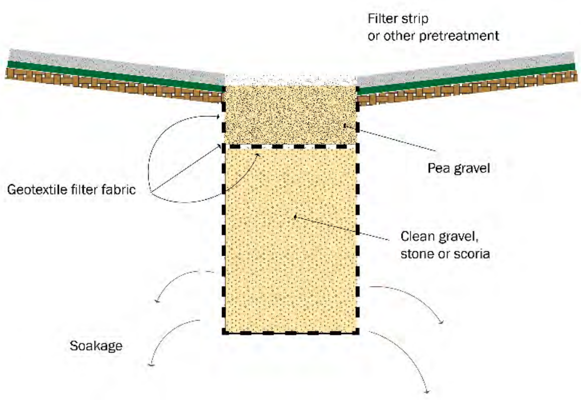

Figure 1.8: Cross-section through an infiltration trench (left). Example photo of an infiltration trench constructed on the road side(right) (Adapted from Source: sswm.info)

c. **Filter Drains:** A linear trench filled with granular material, overlaying a perforated pipe provided near the base of the filter drain to collect and convey water downstream, such as a French drain (see Figure 1.9). Water through the perforated pipe is conveyed down the trench, filtered through the perforations and is stored in the porous gravel. It is lined with geotextile fabric to prevent the ingress of soil and other materials into the structure. Filter drains are constructed above the water table, usually with a total depth of 1-2m. Ideally, water to the drainage device is conveyed via sloping filter strips (see Figure 1.10).

Figure 1.9: A filter drain under construction (Source: edensstructural.com)

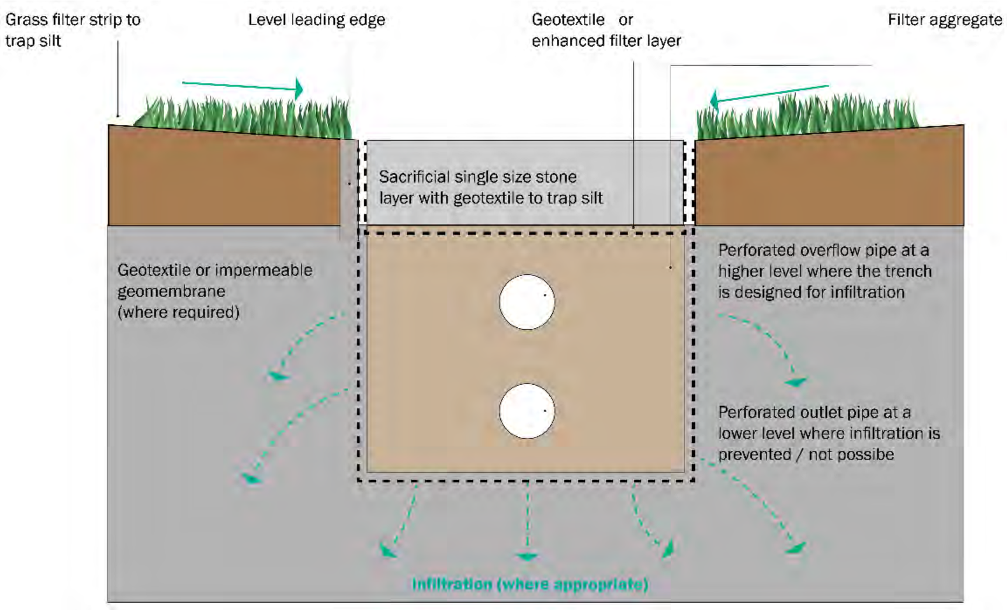

Figure 1.10: Typical section through a filter drain (Adapted from CIRIA, 2015, p. 304)

d. **Filter Strips:** Gently sloping areas of grass or vegetation that drains water evenly off from the edge of impermeable surfaces usually to another drainage component (see Figure 1.11). Runoff is treated by vegetative filtering (where appropriate), and promotes settlement of particulate pollutants and infiltration. Filter strips can be used to connect the falling water to another infiltration device such as filter-trenches or a filter drains and are sometimes considered as pre-treatment components.

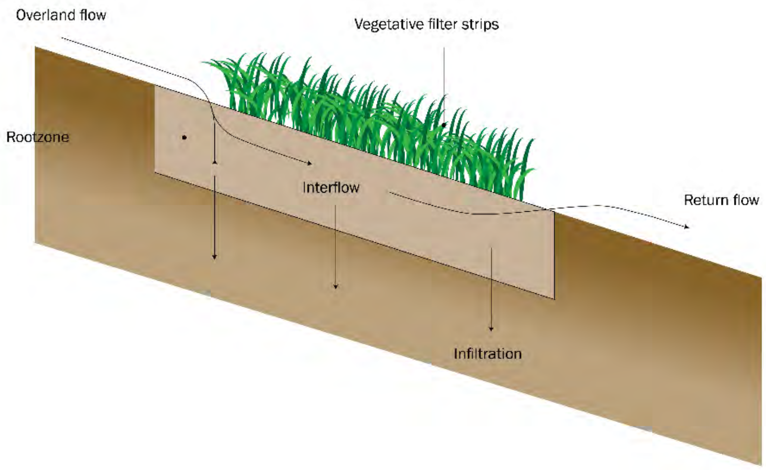

Figure 1.11: Cross-section through a typical grassed filter strip

e. Infiltration Basins: A dry flat-bottomed, shallow vegetated landscape depressions that stores runoff (allowing debris to settle and filter out) that infiltrates water gradually into the ground (see Figure 1.12). Infiltration basins are usually large areas in the landscape with an outlet for draining stormwater (see Figure 1.13). However, it can be of any size in plan or in-depth depending on the available volume of the source water. These depressions can also be sized to drain roof-runoffs.

Figure 1.12: Example of a large infiltration basin suitable for areas with plenty of open free space (Source: cityofoberlin.com)

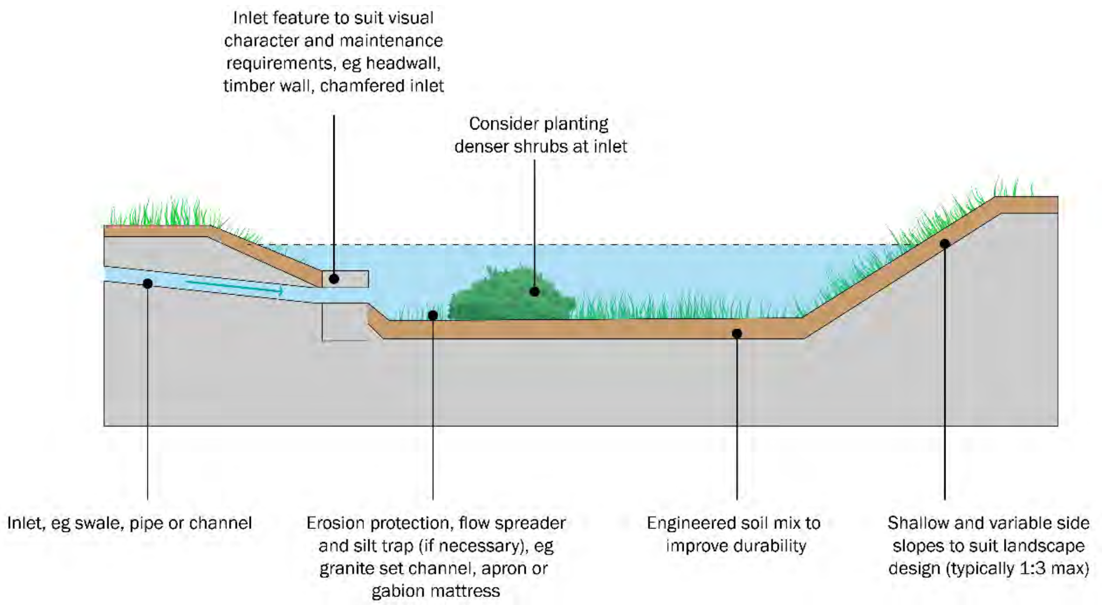

Figure 1.13: Cross-section through a typical infiltration basin (Adapted from CIRIA, 2015, p. 260)

f. **Infiltration Blankets:** Large shallow systems that are typically constructed using permeable aggregate or geo-cellular units that act as extensive soakaway systems (see Figure 1.14). These are subsurface systems constructed below car parking areas or playgrounds etc. Granular materials within the structure may be replaced with perforated pipes and geo-cellular units to increase the water storage capacity without having to increase the size of the component.

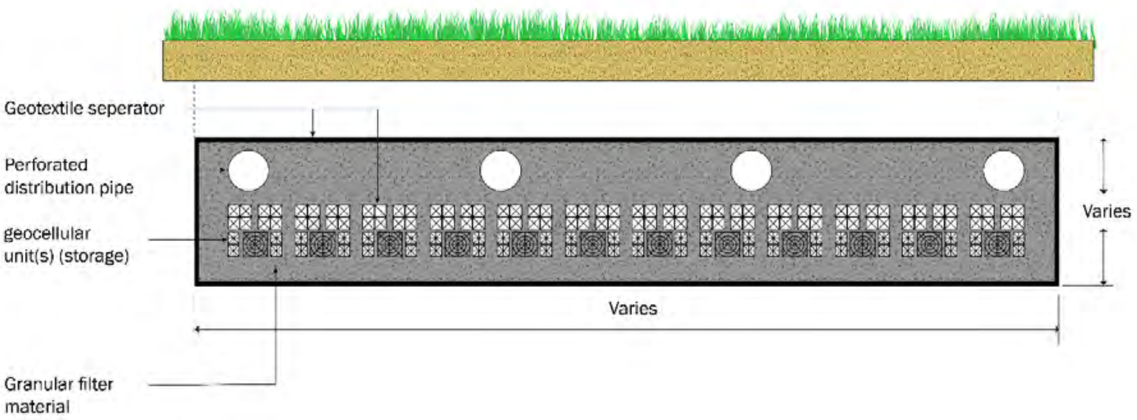

Figure 1.14: Cross-section through an infiltration blanket (Adapted from CIRIA, 2015, p. 260)

1.4.2 Components for Fully built-up Land Plots

Land plots that are single-unit houses or private and commercial lands that are fully covered with infrastructure such as buildings or roads, having insufficient space available to place a recharge component within the land area except for below ground.

a. **Underground Recharge Wells:** Dug-wells made of concrete that are buried below ground and used for groundwater recharge. Downpipe outlets from roof drainage or rainwater tank overflow can be connected to these underground recharge wells (see Figure 1.15). Most of the houses have an existing dug-well constructed below ground and are not usually used for potable purposes. In case the water has to be drawn for other purposes from the well, such as for cleaning, flushing etc., it is important to have a pre-treatment function before discharging water into the well.

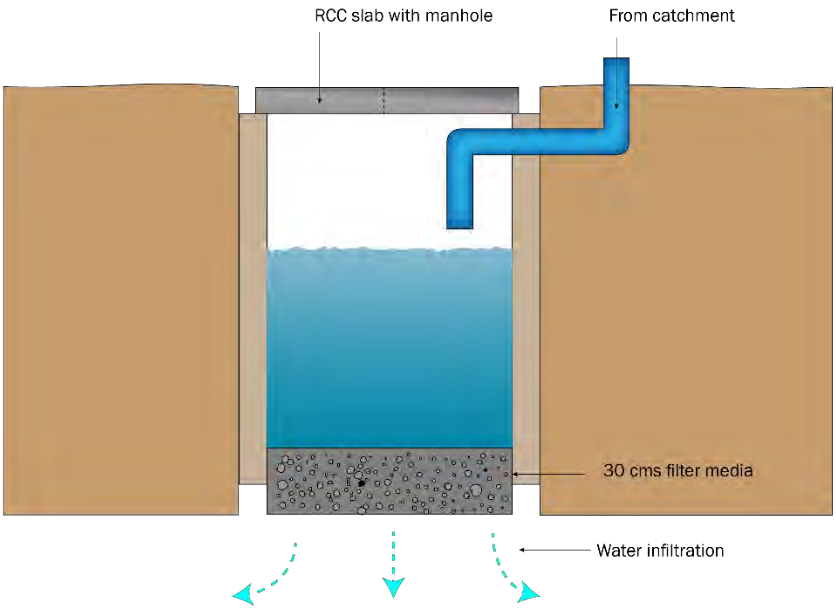

Figure 1.15: Cross-section through an underground dug-well.

Water quality considerations:

1. *Do not allow contaminated water (e.g. sewage) to flow into the infiltration systems.*
2. *Pay attention to potential pollutant sources when locating the infiltration systems. (e.g. toilet pits, contaminated sites)*

3. *After taking common-sense precautions (like above) runoff from residential areas are the most appropriate form of urban water sources for groundwater recharge. Many of the island communities in the Maldives provide good opportunities for this.*

1.5 Conclusions and Recommendations

Groundwater recharge can be achieved through building roofs and RWH systems using infiltration drainage facilities. A brief description of RWH harvesting systems along with various SuDS components that are suitable for household or community RWH systems for infiltration drainage have been presented. However, suitable methods are site-specific and shall be chosen and designed based on the site-context. The degree of free space available within the land area (saturated, partially saturated or fully saturated) needs to be considered when choosing an infiltration component. It is recommended to integrate RWH systems with sustainable infiltration devices as much as possible to maximize the amount of recharge to the groundwater aquifer.

CHAPTER 2:

Road drainage capture, Management & Infiltration

2.1 Introduction

Roof drainage and stormwater inlets are not permitted to be connected to sewer networks in the Maldives in order to avoid the risk of overflow and sewer backup. Hence, both foul water and stormwater cannot be carried in the same pipeline in the Maldives, and combined sewers are no longer adopted in new developments across the world. Two different approaches that are complementary to each other, can be employed in the islands to manage the drainage of excess surface runoff; conventional stormwater drainage and sustainable infiltration drainage techniques.

Conventional stormwater drainage involves collection, conveyance and disposal of stormwater to watercourses, while sustainable drainage methods manage water close to the source (by infiltration, recharge, attenuation, etc.). Due to lack of adequate number of pervious surfaces in an urban catchment or built-up areas, artificial drainage facilities need to be constructed to discharge or infiltrate runoff collected on impervious land surfaces, primarily as road drainage. Stormwater drainage systems are not common in the Maldives (unlike sanitary sewers that has replaced onsite septic tank sanitation technology). Sustainable infiltration drainage methods should be adopted for drainage of water captured from roadways for recharging the freshwater lens of the islands in Maldives.

This chapter is a guidance for road developers and designers on various methods available for sustainable road drainage that can be employed for groundwater recharge in the Maldives. It starts with a brief description of pervious and impervious roads of the Maldives, and then provides details of road runoff & capture followed by an explanation of stormwater management and drainage systems in general. Then, suitable sustainable infiltration drainage methods applicable for roads have been presented. A conclusion has been drawn at the end of the chapter about the components proposed.

2.2 Pervious & Impervious Roads in Maldives

Pervious natural surfaces including natural roads (e.g. vegetation, parks and wetlands) absorb water to the saturation point, then generates runoff which flow by gravity into a discharge location or a drainage inlet. Rainwater infiltrates slowly down to the lower layers of the ground after hours of stagnation on pervious road surfaces, depending on the permeability of soil and rate of evaporation. Moreover, when land surfaces get modified, communities increasingly loose most of its natural state, which would otherwise remain intact. (see Figure 2.1). Hence, a significant amount of water is generated as runoff on impervious surfaces in an urban development. Infrastructure such as buildings, roadways, utility networks etc., required to accommodate the needs of the population are continuously being built in developing urban cities as a way of adapting to the increasing rapid urbanization (see Figure 2.2). Major city infrastructure is often made of concrete and other impermeable material. As a result, urban development’s ultimately leads to a reduction in the capacity for infiltration of water into the ground. Hence, urban developments have a significant ripple effect on the natural systems of the earth, such as the hydrologic cycle. In a fully urbanized setting, rainwater that falls directly onto impermeable surfaces are swept across the land as stormwater runoff.

Figure 2.1: A neighbourhood in a typical island in the Maldives, built-up with houses and unpaved roads surrounded by a dense vegetation cover of coconut palms and evergreen tropical bushes (Source: en.sun.mv/59972)

Figure 2.2: Heavily built-up and densely populated capital Male' is considered a developing urban city, with plenty of impermeable roofs, narrow alleyways with almost no footpaths (in majority of the roads) for pedestrians. (Source: avas.mv/en/40991)

Historically, majority of the roads in outer islands were made of exposed natural earth constructed using layers of levelled and compacted earth (sand), with no specific provisions made for drainage infrastructure (see Figure 2.3). Even for roads equipped with drainage components, inadequate levelling and slopes of road surfaces hinder the transportation of water adequately to drainage facilities. Topography and slopes of unpaved natural roadways are generally inconsistent and difficult to maintain as they are not properly designed. Natural roadways prone to frequent surface ponding are often maintained by filling the potholes with local sand and levelling.

Figure 2.3: Ponding and flooding observed on the surface of an unpaved road in Ga. Maamendhoo after a rainfall event (Source: Authors)

Conversely, road surfaces in some islands (including Male') are paved with interlocking paver blocks that allow some degree of infiltration. One of the key features of a developing urban city or town when compared to a less developed settlement is its transportation system/network, which is usually made up of a combination of interconnected impervious surfaces; roadways, footpaths and parking lots. Road networks are essentially a combination of carriageways, sidewalks and surface drainage components constructed to facilitate the movement of traffic and pedestrians. A range of different materials are available for the design and construction of road infrastructure, based on the type of pavement (flexible or rigid). Nowadays, road wearing courses are made of asphalt concrete in most developing cities due to its durable and robust nature. As such, few asphalt concrete roadways have been constructed recently in populous islands including Male', as part of a recent initiative to improve road conditions. Asphalt roads are primarily impervious and generate a significantly high amounts of runoff. Thus, proper design and construction is crucial for effective road drainage and infiltration. The primary function of a road network is transportation, stormwater collection, conveyance or infiltration is a secondary function.

2.3 Road Run-off & Capture

Impervious elements of an urban road network are essentially open directly to the sky and are subject to rainfall. Road drainage facilities are usually designed to capture and transport stormwater to a designated discharge point via a stormwater drainage system. Properly designed roadways have longitudinal as well as transverse slopes to allow for smooth drainage of stormwater to either side of the road. Drainage infrastructure, such as storm drains are often located at either side of roadways to capture the stormwater. Recent road development projects in the Maldives are being designed and constructed along with stormwater drainage systems.

As surface runoff is captured mainly using road catchments and conveyed via road drainage, stormwater drainage systems and road networks are interdependent. Hence, an integrated urban design (road networks and stormwater systems) approach should be adopted for effective drainage and infiltration of stormwater captured from pervious/ impervious road catchments. If asphalt roads are cut and dug up frequently for installing utility pipes such as sewer lateral lines and electricity cables, road pavements will deteriorate and may encounter long term damages that may also affect road drainage. Thus, retrofitting existing asphalt roads may not be economical. Hence, existing utility services below road pavements should be accounted for (Cable TV, water, sewerage, telephone line services etc.) during the planning and design stage of road drainage.

2.4 Stormwater Management

Stormwater or excess run-off generated on road surfaces by rainfall is a concern in various urban regions around the globe. It is often the source of water responsible for ponding or urban flash floods generated on street surfaces and building rooftops. Floodwater causes erosion, picks up all different types of pollutants and convey them to the nearest watercourse, or may cause property damage by compromising the structural integrity of nearby structures. Therefore, unmanaged stormwater poses various environmental hazards. To protect the health, welfare and safety of tenants, pedestrians and traffic, the build-up of excess surface runoff needs to be prevented by mitigating and controlling stormwater drainage. Owing to the growing number of impervious surfaces in urban regions, unmanaged stormwater will eventually become an inconvenience.

Increasing number of flood events due to rainfall in islands during the past couple of years validates the growing need to prioritize the management of stormwater more than ever before. Currently, there are no proper road drainage or flood mitigation systems installed in most of the islands in Maldives. However, unplanned natural drainage methods in islands will eventually not be adequate as they cannot effectively protect the islands from flooding in extreme weather conditions. Even though there are grated catch basins installed on roadsides in almost every street in the capital city of Male', for collecting and infiltrating road drainage, these systems are clogged with trash and debris due to improper maintenance and does not perform efficiently, resulting in frequent flash floods (see Figure 2.4) after a few hours of moderate rainfall. Hence, runoff captured during storms and excessive/ unexpected amounts of rainfall events is often pumped out manually to the sea. Conversely, during moderate rainfall events, flooding observed in less built-up islands (more pervious land surfaces), except for some localized ponding. Nonetheless, an effective mechanism or a system needs to be utilized that can manage runoff as quickly as possible, to protect the islands from flooding and inundation.

Figure 2.4: A street in Male' city, Maafannu ward is flooded during a recent rain event. (Source: raajje.mv/43385)

2.4.1 Conventional Stormwater Drainage Systems

Most urban cities around the globe are equipped with a stormwater drainage system to manage stormwater, which is similar to a sanitary sewer. Traditionally, stormwater drainage is achieved by connecting roof drainage outlets and road catchments to a dedicated stormwater drainage system constructed without infiltration facilities. Separated stormwater drainage systems are currently under construction in some islands that are prone to flash floods such as N.Holhudhoo and S.Feydhoo, while a localized stormwater drainage system has already been established in Hdh.Kulhudhuffushi. Furthermore, a localized storm water drainage system is built underneath recently developed asphalt ring road in Male' (see Figure 2.5) in order to mitigate flooding. It is expected that stormwater systems will be required in the future to fully mitigate the risks of flood water in Male'.

Figure 2.5: Grating of a road drain inlet installed in the ring road of the capital city Male' (Source: Authors)

In general, a traditional stormwater drainage system is made up of a combination of conduits and open channels for collecting, controlling and transporting surface runoff to the desired location for discharge or infiltration into the ground. Stormwater systems often require elements of artificial drainage such as roadways equipped with street gutters and storm drains (similar to a floor drain in the bathroom) to capture storm runoff. Hence, road surfaces are the most significant impervious surfaces in an urban development responsible for collecting and diverting stormwater via pipelines to pump stations. Eventually, water collected at the pump stations are pumped out mechanically and is discharged to natural water bodies (rivers, lakes, seas etc.) and the ocean by a sea outfall. Stormwater is usually not sent to a treatment facility. Since these systems cover a large area of the island, they cannot be regarded as minor infrastructure development projects. In short, surface runoff is collected by storm drains or street gutters and conveyed to a water body via gravity by an underground pipe network or open channels (either natural or manmade) to a pump station(s) (see Figure 2.6). Hardly any priority has been given in the past to include infiltration facilities in older conventional stormwater drainage systems. Traditional stormwater drainage systems consist of several components combined to function together as one complete system.

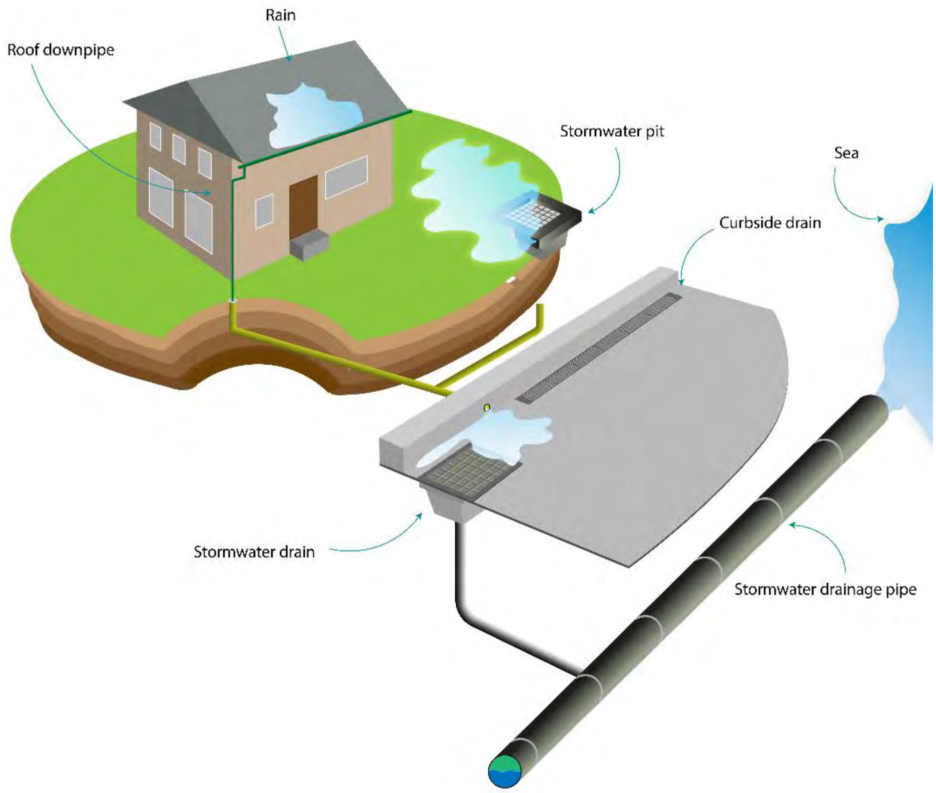

Figure 2.6: Schematic perspective of a separated stormwater drainage system showing the basic processes of the system (collection, transportation and discharging)

Given below are the major components of a conventional stormwater drainage system (see Figure 2.7):

- Storm Drains/ Street Gutters: Several stormwater inlets established at various locations, mostly at the side of streets (on or near street kerbs) to capture runoff from road surfaces.
- Catch Basins: Basins connected to a storm drain for capturing water from roadways.

- Pipe Network: A network of subsurface pipes laid to convey water usually by gravity from catch basins to pump stations.
- Manholes/ Inspection Chambers: Vertical shafts located at pipe junctions and connected to main sewer pipelines. These are usually constructed underground and are wide enough to accommodate a person for maintenance purposes.
- Pump Stations: Pump stations collect water, store them and periodically pump out to sea via an outfall system (Includes pumps that have been connected to electric panel boards for power)
- Outfall: A pipeline laid from a pump station to a natural stream or water body to discharge water (facilities such as culverts have also been used at discharge points in some parts of the world).

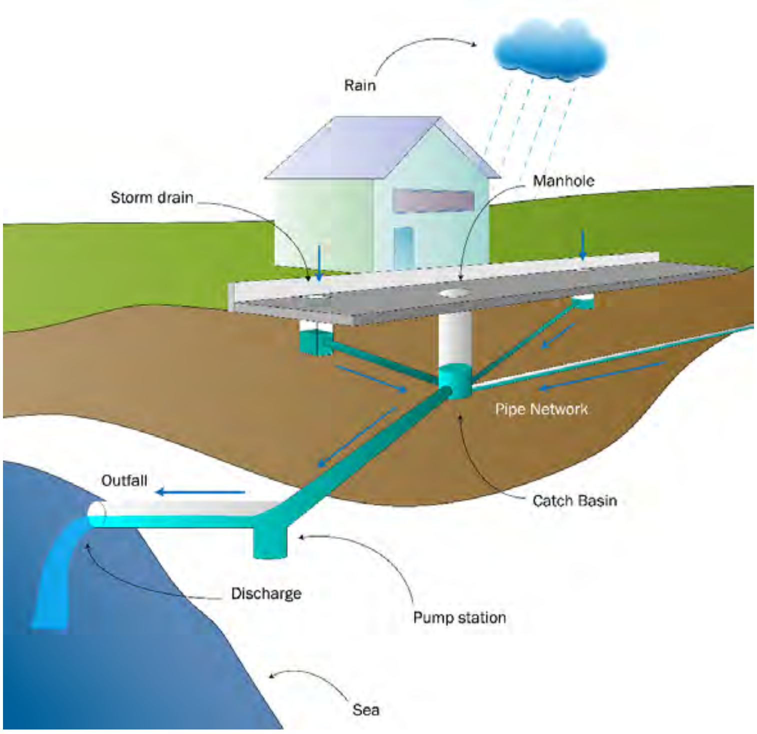

Figure 2.7: Schematic diagram showing the main components of a typical separated Stormwater Drainage System

2.4.2 Design aspects of Piped Stormwater Drainage Systems

Conventional stormwater drainage systems are designed to a set of criteria and are subject to economic, social and environmental constraints just like any other environmental utility. All components in the system shall be able to detain and control the required volume of water safely while achieving the discharge rate. In general, stormwater infrastructure is designed to clear the excess runoff within a given period of time without causing stagnation of a significant amount of water. First of all, the proposed route of the pipe network below road surfaces which will generally follow the road layout and location of the main components, (ideally with a manhole at each pipe junction) are sited on an as-built map of the island.

The size and number of each component in a conventional stormwater drainage system and associated drainage facilities are determined based on the amount of rainfall and the site context, i.e. rainfall-runoff, landscape, soil data etc. Hence, diligent site-specific surveys and investigations are important to estimate the design parameters for the preliminary design of stormwater drainage facilities. In particular, relevant hydrological, topographical and geotechnical investigations of the site needs to be carried out. Rainfall-runoff analysis based on hydrologic and groundwater studies determines the amount of water a drainage system is subjected to and the duration of surface runoff, peak flow rates etc. Rainfall is based on historic metrological data and seasonal variation of monsoon.

Runoff, originating from rainwater is calculated for a certain design horizon selected for the site by considering the return period of the largest rainfall event. It is important to create flood maps by investigating natural flow paths (volume and direction) of water movement across the landscape, site and the surroundings. Topographical charts capture the landscape (spot levels and contour) of the island and any pervious and impervious surfaces including the outline of roadways. Therefore, a large area of the site in concern needs to be investigated for the collection of adequate data. Furthermore, ground investigation of soil is required to obtain infiltration capacity and bearing capacity of the soil (see Figure 2.8). In addition, groundwater studies will also reveal the level and variations in the water table. Relevant soil parameters such as permeability, percolation and infiltration rates are obtained by using various soil testing methods. Data collected from the site are used for the design of stormwater drainage systems and associated drainage facilities.

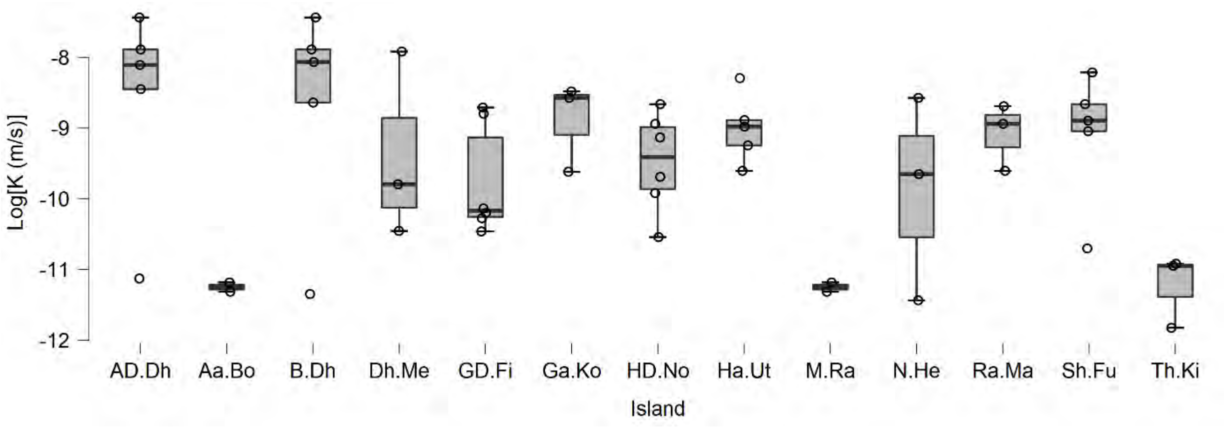

Figure 2.8: A graph of hydraulic conductivity test results from a study conducted on 13 islands across the Maldives

Iterative methods are used to finalize the sizes (pipes, pump stations, catch basins etc.) of each component using hydraulic analysis and flow routing software. For instance, the diameter of pipes, which are designed ideally as gravity systems and pumps size requirements are finalized by carrying out hydraulic analysis using a computer model such as US-EPA SWMM (see Figure 2.9). Finally, electrical panel boards required to power up the systems are designed based on power requirements and the capacity of the chosen pumps. Moreover, once the design has been completed, plans and cross-sections of the proposed system are presented on detailed drawings as output, ready to be constructed on-site (see Figure 2.10). As previously discussed, it is important to plan roadways and stormwater drainage infrastructure together for a more effective drainage system design. Furthermore, to reduce the amount of water discharged to outfalls and maximize the infiltration of water into the soil column, it is encouraged to combine infiltration drainage facilities with the conventional stormwater drainage system or prioritise the use of infiltration drainage methods only.

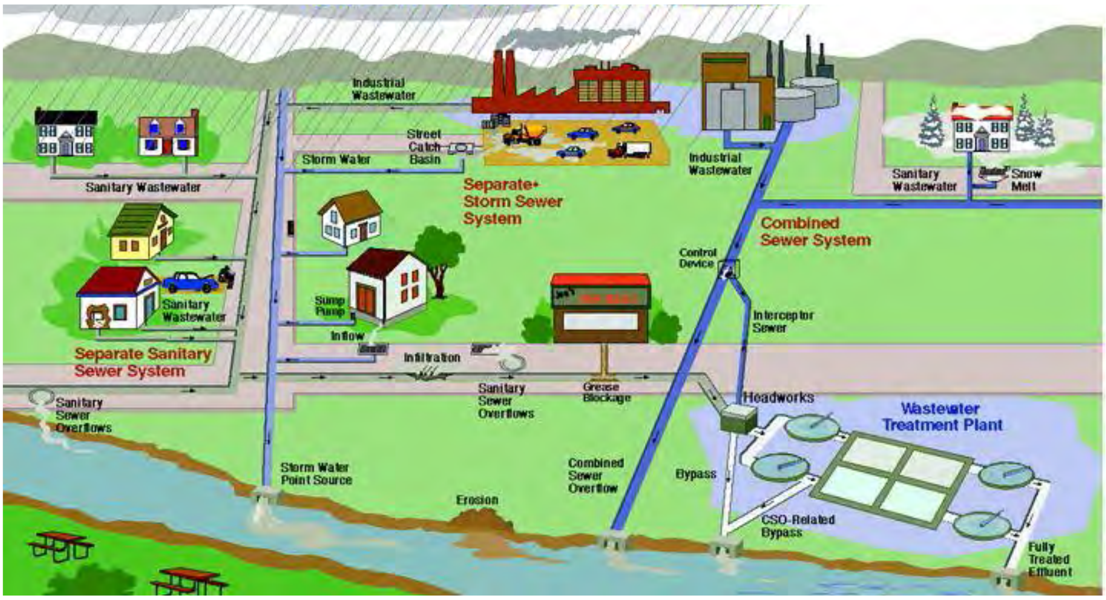

Figure 2.9: Components simulated in US-EPA SWMM (Storm Water Management Model) rainfall-runoff simulation model (Adapted from Source: SWMM User's Manual Version 5.1)

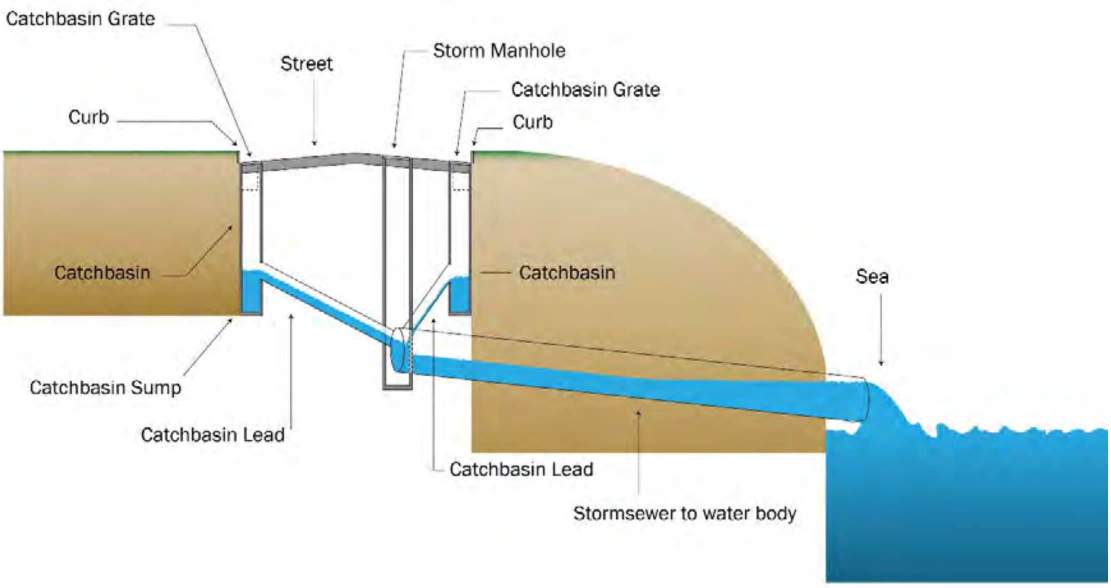

Figure 2.10: Simplified cross-section through a typical stormwater system showing its major components (a similar, more detailed cross-sections will be required for construction)

2.5 Sustainable Stormwater Drainage Systems for Roads

Infiltration drainage systems (natural or artificial) in particular, shall be prioritized and promoted for stormwater drainage schemes. Although in practice, a combination of the two approaches mentioned earlier is often required to achieve realistic road drainage, infiltration drainage has an added benefit of groundwater recharge. Generally, wetlands such as mangroves and inland pond ecosystems etc., are natural retention basins that are important for stormwater management and infiltration. In addition, carefully contoured community facilities (e.g. parks and football fields) can also act as infiltration basins. Run-off captured from road surfaces or through conventional stormwater drainage systems can be used to recharge groundwater resources of the island by utilizing sustainable infiltration drainage techniques. The idea of sustainable drainage is to intercept the hydrologic cycle, catch most of the rain before it reaches a piped drainage system and infiltrate it into the subsoil layer.

SuDS components are the main alternative to conventional underground piped stormwater control and disposal solutions available and is more environmentally friendly. In an urban context, SuDS drainage methods can be utilized by applying to road drainage schemes for stormwater drainage (see Figure 2.11). When combined with a conventional stormwater drainage system, infiltration systems facilitate the primary function of a drainage facility by preventing flooding and inundation. In addition, SuDS methods can be chosen as the on-site drainage solution for small-scale developments, thereby eliminating the need to build a piped stormwater drainage system to cater for the additional runoff. Instead of removing excess water from road surfaces and discharging to local watercourses, drainage by infiltration techniques supports the replenishment of groundwater resources. The most important benefit of sustainable drainage methods is its potential for groundwater recharge when applied to urban road drainage schemes.

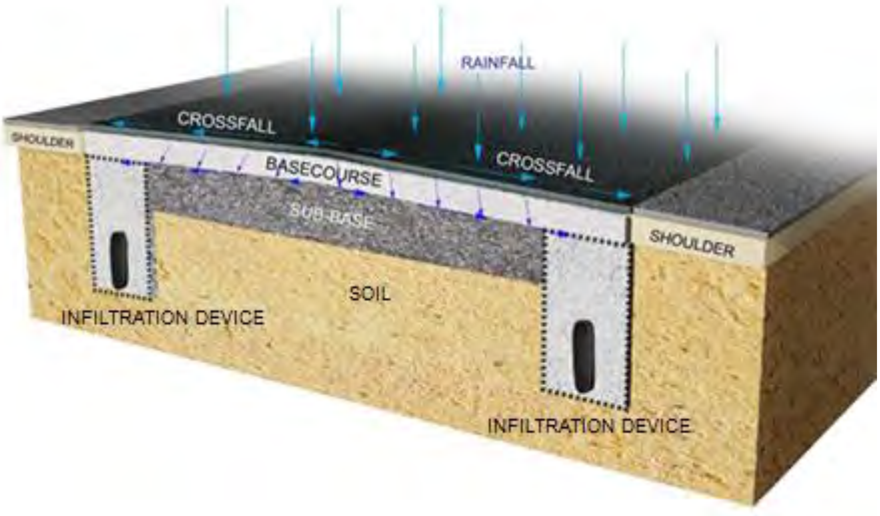

Figure 2.11: Schematic of a cross-section through a road which shows the concept of road drainage using infiltration devices constructed on either side of the road. (Adapted from Source: geosynthetica.com

SuDS devices that capture stormwater from road surfaces functions primarily by capturing and providing detention storage, controlling and releasing water from the base or the sides (below ground) of the device to the unsaturated zone above the water table. These systems are located close to where rainfall falls for maximum efficiency and are built either on the surface or below ground (vertical or horizontal in plan). Thus, it helps in managing water flow, enhances water quality and also provides a habit for wildlife in some cases. Moreover, if operating in conjunction with a piped drainage system, infiltration devices aid in reducing and attenuating storm flows before water enters the system. SuDS schemes are designed for quantity, quality and amenity and can be used in both hard surfaces and soft landscaped areas. In general, infiltration of groundwater from road runoff can be enhanced by using various types/ categories of sustainable infiltration drainage components.

Various SuDS techniques can be used to recharge groundwater using excess water from road runoff. Roadways are designed nowadays for more than just transportation as urban roads play a multifunctional role by interacting with drainage devices. Thus, SuDS components located on other areas of landscape, such as children's parks are ideal places for collecting and diverting stormwater to road SuDS catchments. The idea is to use as many infiltration drainage components as possible for road drainage schemes to facilitate the use of the maximum amount of water for groundwater recharge. For example, infiltration drainage components have been constructed in either side of the streets of Hulhumale' (see Figure 2.12), a reclaimed island without a stormwater drainage system. Groundwater recharge can be improved by using purposefully built sustainable drainage components to infiltrate excess water captured from road surfaces instead of discharging water to the sea.

Figure 2.12: In almost every street in Hulhumale', stormwater is managed entirely by infiltration drainage facilities without using a piped drainage system. (Source: Authors)

Road infiltration drainage components can be categorized into two classes; ground surface and sub-surface types depending on whether storage takes place above or below the ground. All infiltration devices involve some element of storage. Furthermore, ground surface infiltration systems can either be plan or basin type.

I. Ground Surface Components:
   a) Filter Strips
   b) Pervious Pavements
   c) Swales
   d) Infiltration Basins
   e) Retention Basins

II. Sub-surface Components:

a) Infiltration Trenches
b) Filter Drains
c) Bio-retention systems
d) Attenuation Storage Tanks
e) Trees

Based on the site context which best suits the road layout, these systems can be built standalone or several systems combined together. Further details of the methods of infiltration are illustrated below in section 2.5.1- Ground Surface Components & 2.5.2 - Sub-Surface Components.

2.5.1 Ground Surface Components

a. **Filter Strips:** A strip of grass planted on gently sloping ground above engineered soil, to convey water from one area to another (see Figure 2.13 & Figure 2.14). They are usually used to connect impermeable surfaces over which water flows to another impermeable infiltration device. These components allow the velocity of water to be reduced while permitting some degree of runoff infiltration and removal of pollutants.

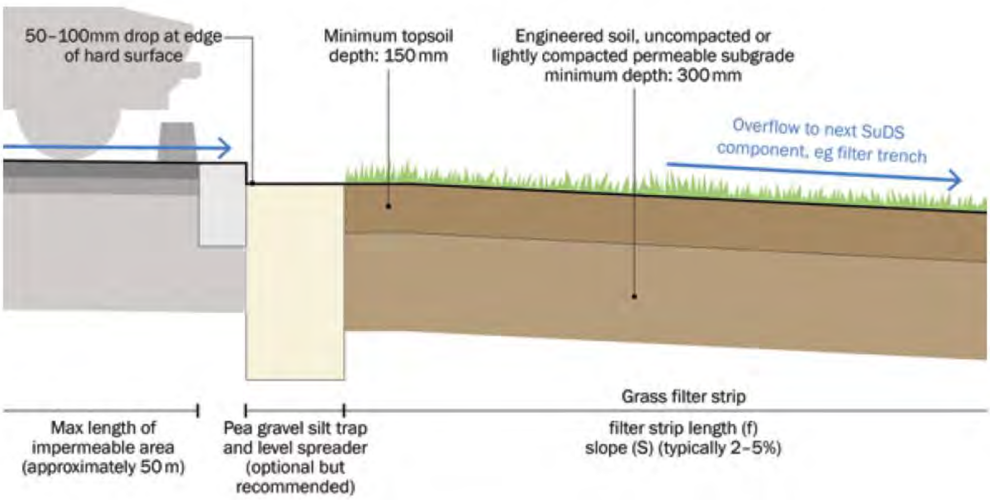

Figure 2.13: Details of a typical filter strip (Adapted from CIRIA, 2015, p. 292)

Figure 2.14*: Cross-section through a typical filter strip connecting to two other components (CIRIA, 2015, p. 323)*

b. **Pervious Pavement:** Engineered pervious pavements (also known as porous pavement) suitable for pedestrians and vehicular traffic (see Figure 2.15). It can be made of a range of different materials (grass, concrete, cement etc.) and has got small openings to let water to pass through to the underlying soil, unlike conventional pavements. Water percolates through the pavement into the sub-structure depending on the voids-ratio (can range between 30 - 95%). Pavements can be lined using geotextile membranes placed immediately below the structure, to protect groundwater from pollution. Groundwater is stored in the sub-base storage zone, below the pavement,

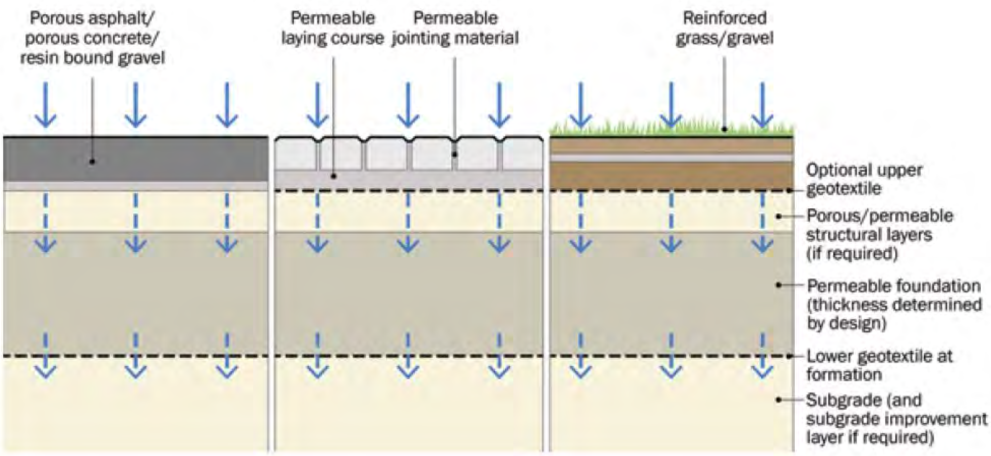

Figure 2.15: Typical features of different pervious pavement systems (CIRIA, 2015, p. 394)

c. **Swales:** Shallow, flat bottomed ditches (or an open channel) vegetated with wetland plants (see Figure 2.16). It can filter and clean water and can also be used as a conveyance system to convey stormwater to another infiltration component. The side gradients are kept to a minimum and are not constructed too deep for safety reasons.

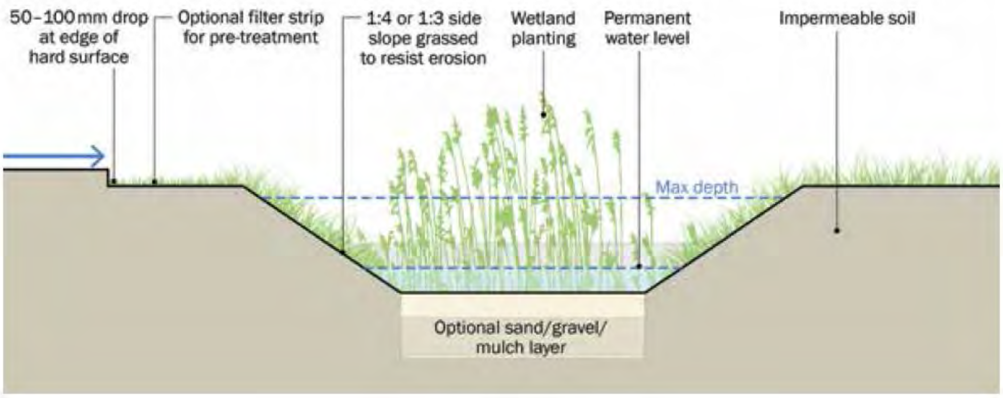

Figure 2.16: Typical section through a swale (CIRIA, 2015, p. 315)

d. **Infiltration Basin:** Open, vegetated depressions in the landscape which are contoured (naturally or artificially) for the temporary storage of water (see Figure 2.17). They are normally dry and can soak surface water into the ground when wet.

Figure 2.17: Picture of an infiltration basin, in dry condition (Source: susdrain.org)

e. **Retention Basins:** Large artificial ponds with a permanent pool of standing water constructed with vegetation around the perimeter (see Figure 2.18 & Figure 2.19). Pollutants are filtered through low permeable soil as the quality of water infiltrated into the ground is enhanced by natural processes. New habitats are allowed to develop in the basin.

Figure 2.18: An example of a retention basin (Source: abertay.ac.uk/business/facilities-and-services-2020/SuDSnet/SuDSnet-photos/retention-ponds/)

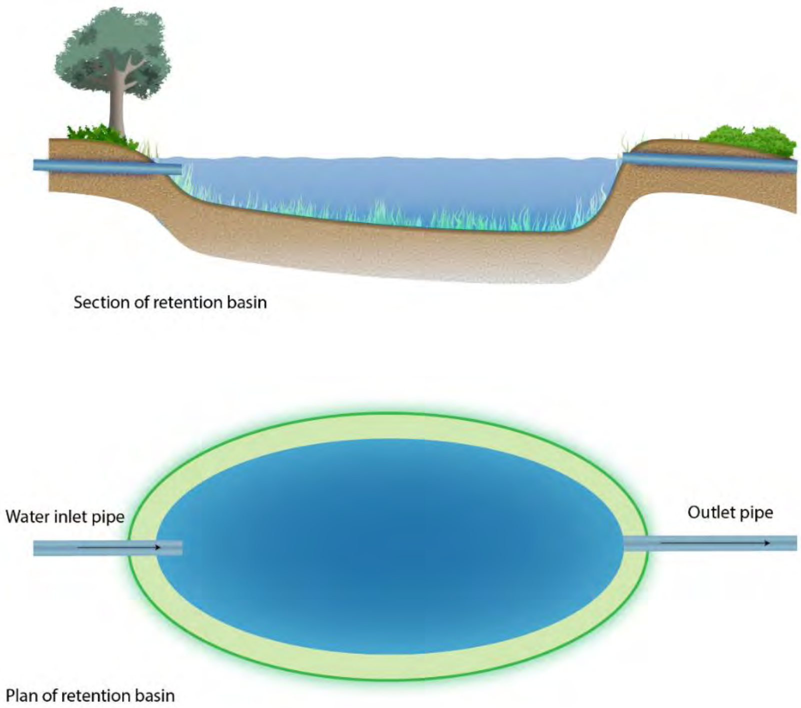

Figure 2.19: Typical details of a retention basin

2.5.2 Sub-Surface Components

a. Infiltration Trenches: Shallow, linear excavations filled with permeable granular material that allows exfiltration of water into the surrounding soils from the bottom and sides of the trench (see Figure 2.20). Water is stored in the pore spaces of the granular material and slowly infiltrates into the soil. Infiltration trenches are fundamentally linear or trench soakaways and can be used in areas where there is adequate space available. Water is diverted to the trench by allowing the adjacent ground to slope into it using another drainage component, such as a filter strip. A perforated pipe, if required can also be provided to distribute water along the trench.

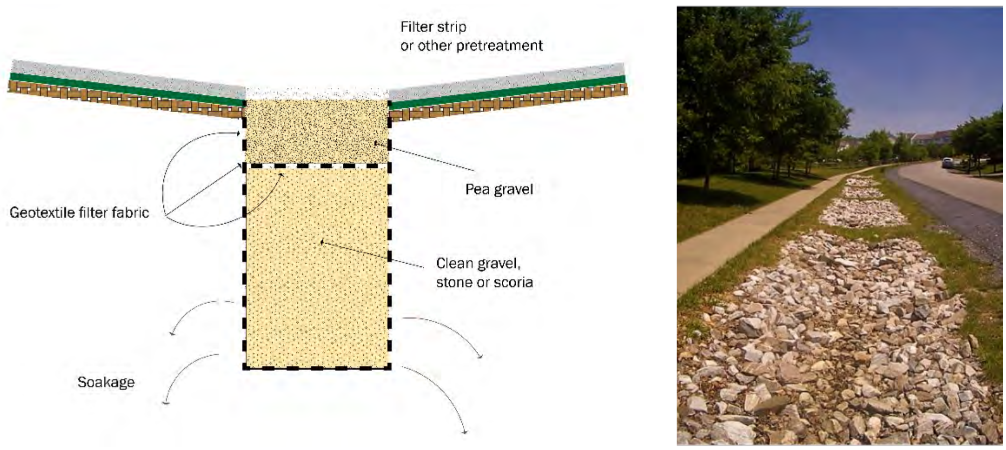

Figure 2.20: Cross-section through an infiltration trench (left). An infiltration trench constructed on the road side(right) (Source: sswm.info)

b. Filter Drains: A linear trench filled with granular material overlaying a perforated pipe provided near the base of the filter drain to collect and convey water downstream, such as a French drain (see Figure 2.21 & Figure 2.22). Water through the perforated pipe is conveyed down the trench, filtered through the perforations and is stored in the porous gravel. It is lined with geotextile fabric to prevent the ingress of soil and other materials into the structure. Filter drains are constructed above the water table, usually with a total depth of 1-2m. Ideally, water to the drainage device is conveyed via sloping filter strips (see Figure 2.13).

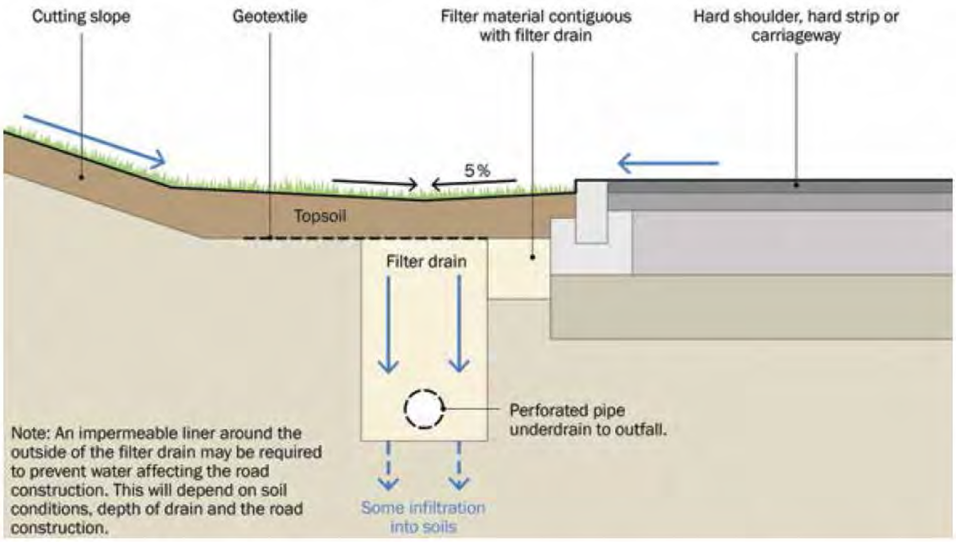

Figure 2.21: Typical section through a road filter drain (CIRIA, 2015, p. 149)

Figure 2.22: A filter drain under construction (Source: edensstructural.com)

c. **Bio-retention Systems:** Shallow, landscaped or planted depressions with engineered soil in the base or filter media with under drainage e.g. rain gardens (see Figure 2.23). They can reduce run-off rates and volumes and can also treat pollution before water infiltrates into the ground.

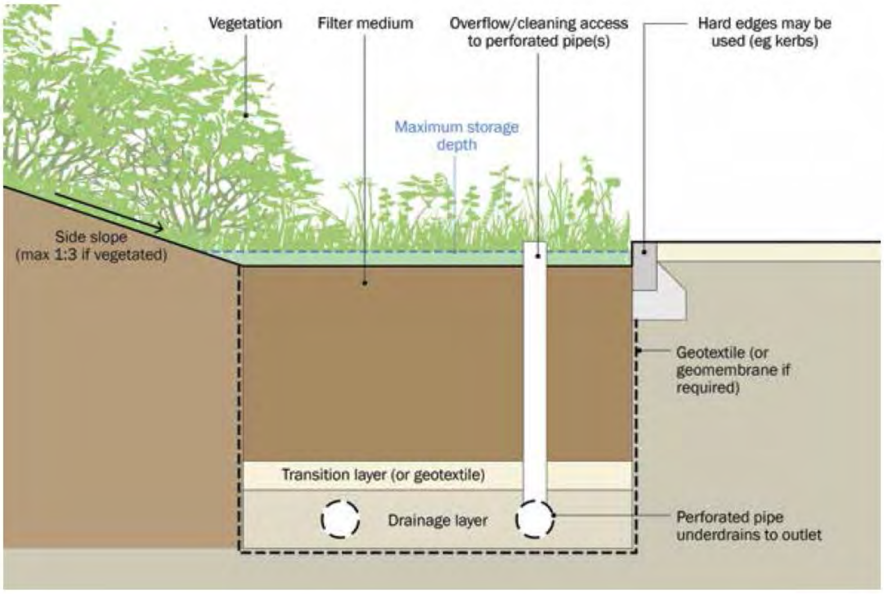

Figure 2.23: Typical features of a bio-retention system (CIRIA, 2015, p. 334)

d. **Attenuation Storage Tanks:** Below ground storage tanks typically made of geo-cellular units (made of plastic, concrete, steel etc.) that infiltrates water to the ground (see Figure 2.24 & Figure 2.25). It provides attenuation without any runoff of treatment.

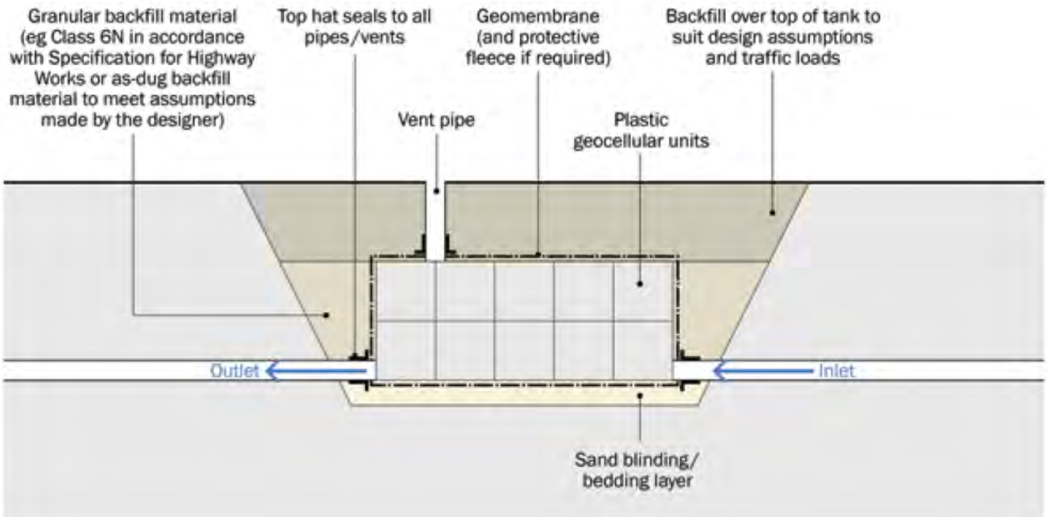

Figure 2.24: Typical details of an attenuation storage tank (CIRIA, 2015, p. 440)

Figure 2.25: Geocellular tank units are being installed in a park (Source: blog.wavin.co.uk)

e. **Trees:** Trees help in reducing runoff volumes and filtering contaminants. Trees are usually planted on pits or planters in urban areas. Groundwater is stored below tree roots (see Figure 2.26 & Figure 2.27). Trees can also be used in conjunction with other devices such as bio-retention systems and swales.

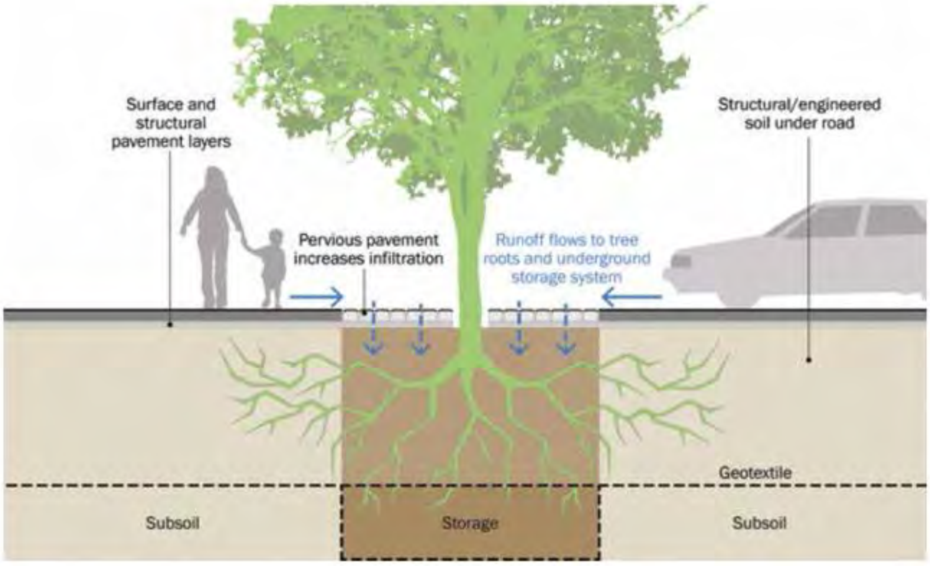

Figure 2.26: Typical details of an infiltration system with a tree where surface water runoff is collected drainage (CIRIA, 2015, p. 363)

Figure 2.27: An example of a tree planted on the road side which can be included as part of a sustainable solution to manage road drainage while providing host of other benefits too. (Source: Authors)

2.6 Conclusions and Recommendations

The thin fresh groundwater layer (freshwater lens) is an important resource of freshwater. Maintenance of the freshwater lens is critically dependent upon adequate and continued infiltration of rainfall into the soil. Urbanization, including the construction of impervious roadways reduce the infiltration capacity of the islands. Conventional drainage systems exacerbate this issue further by rapidly conveying the water away from the island to the sea.

Urban environments often capture road runoff via conventional stormwater drainage systems and discharge it to a watercourse. However, ways to manage drainage largely on or close to the sources has recently become popular around the world. These methods mimic the working of the natural catchments by increasing retention, attenuation and infiltration of water. Such approaches, collectively known as SuDS, provide additional benefits, among which is that of groundwater recharge. SuDS can be used by themselves or as a part, or as a retrofit, of the traditional drainage systems to reduce the amount of stormwater discharged to waterbodies.

Therefore, implementing SuDS, either solely or in combination with a conventional stormwater drainage system is important to reduce the impact of road network on the island water system. The idea is to achieve groundwater recharge as much as possible by minimizing discharge and maximize the percentage of rainfall-runoff infiltrated into the aquifer. Groundwater resource is a valuable commodity. Thus, it is recommended to employ and promote sustainable infiltration drainage techniques in road drainage schemes in islands to maximise groundwater recharge.

GLOSSARY

Aquifer: Underground rocks and sediments that are saturated with groundwater.

Combined Sewer: Sewer systems that collect stormwater runoff, domestic sewage, and industrial wastewater in the same pipe and bring it to the wastewater treatment facility.

Combined Sewer Overflows (CSO): Is the discharge of a mixture of sewage and stormwater from a combined sewer system that is caused by stormwater runoff.

Foul Water Sewer: A sanitary sewer network

Groundwater: Water that is below the surface of ground in the saturation zone.

Impervious Surface: A surface that cannot be penetrated by water and thereby prevents infiltration and generates runoff.

Infiltration (to the ground): The passage of surface water into the ground

Outfall: The point of discharge from the sea, pipe, drain, etc. to a receiving body of water.

Peak Discharge: The greatest rate of flow of stream flow occurring during a storm event.

Rain Water Harvesting: A technique of collection and storage of rainwater into reservoirs or tanks for different uses.

Recharge: The process by which water moves downward through the soil layer from surface water to groundwater.

Runoff: Water from rainfall or other sources that flows across the ground surface instead of infiltrating into the ground.

Rural: Less built-up areas with an adequate number of pervious surfaces that allow rainwater to infiltrate into the ground.

Stormwater: Water derived from a storm event or water conveyed through a stormwater drainage system.

Stormwater Management: The effort to reduce runoff of rainwater into streets, lawns and other sites and the improvement of water quality.

Sustainable Drainage Systems (SuDS): Approaches to manage surface water that take account of water quantity (flooding), water quality (pollution) biodiversity (wildlife and plants) and amenity.

Urban: A city or town with a significant number of pervious surfaces that does not allow infiltration of water into the ground.

Watershed: The land area, or catchment that contributes water to a specific waterbody.

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