MAURITIUS RESEARCH COUNCIL

STORMWATER MANAGEMENT GUIDEBOOK

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STORMWATER MANAGEMENT

GUIDEBOOK

TO ENCOURAGE INFILTRATION

Executive summary

This Stormwater Management Guidebook presents the different ways to reduce and manage stormwater runoff. The past decade or so has seen a very rapid urbanisation of the Mauritian landscape. Commercial buildings and houses have cropped up on agricultural lands. This means an increase in imperviousness resulting in increased surface runoff and hence the flooding of downstream man-made and natural infrastructure. Moreover aquifer recharge has decreased due to lower permeability of the land surface.

In this guidebook, the reader will find detailed information on the design and implementation of those practices which encourage aquifer recharge. Adoption of these practices will undoubtedly mitigate damage to property during periods of intense rainfall.

Throughout the guidebook, a simple language is used so that anyone, be it a house owner or a professional hydraulic engineer, can understand the basic principles of stormwater management and how to implement them. The guidebook is divided in several sections:

- Section 1 gives a brief introduction to the guidebook and contains definitions of technical terms and symbols used in the guidebook.
- Section 2 defines the need for stormwater management.
- Section 3 is a review of the different stormwater management practices worldwide
- Section 4 gives the reader an insight in the detailed design of infiltration practices. Where appropriate, case studies have also been presented to illustrate how to design and compute the costs associated with the practice.
- Section 5 contains a list of references which the reader can consult for further reading. Most of the resources mentioned can be downloaded from the web.
- And finally section 6 is the appendix section which contains more information on certain practices mentioned in the guidebook.

Though this guidebook encourages infiltration practices, it does not in any way undermine the importance of other currently used land drainage practices such as open drains for conveying stormwater. Indeed those open drains can be used together with infiltration practices in order to convey overflows particularly during cyclones or during long periods of sustained rainfall.

Moreover, this guidebook does not have a legal status and the reader should always check with the relevant planning guides and legislations before proceeding with the design of the infiltration practices.

Acknowledgements

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Prodesign is a multidisciplinary firm of consulting engineers. Since 1997, Prodesign has specialised in sustainability and MEP (Mechanical, Electrical and Plumbing) design and consultancy services for building and infrastructure projects.

This guidebook is the outcome of a year long research in stormwater management. A review of international best practices in stormwater management was carried out. Based on the literature review, those practices best suited to Mauritius has been chosen and customised to the local context.

We are profoundly thankful to the following people for their precious advice and guidance.

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Limitations of the guidebook and further work required

This project was conceived with the aim of providing a comprehensive guidebook for Mauritius on stormwater management practices which promote groundwater recharge. Although, all efforts have been made to guide the reader with all the relevant information required for the implementation of stormwater management practices, this guidebook has two major limitations.

For stormwater practices encouraging infiltration, landscaping plays a vital role in the design of the Stormwater management system. Hence, particular attention has to be paid to plant selection, their water requirements and their resistance to extreme droughts and excessive rain. Ideally, this guidebook should have contained a list of plants which could be used in stormwater management practices. However, during the literature review, no search information was found in the public domain. Hence, we believe that a study needs to be carried out on the different plants grown locally and their suitability to stormwater management practices be assessed.

Secondly, the storm data provided by the Meteorological Services has been averaged for the whole island. However, it is a well known fact that rainfall intensity and durations vary all over the island. Using these averaged data can lead to the over sizing of stormwater management practices in some parts of the island. A more accurate approach will be to obtain storm data for representative regions of the island.

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1.0 Terms and definitions

1.1 Notations

Symbol	Definitions
$\dot{Q}$	Runoff volume flow rate (m^3/s)
A	Area of infiltration (m^2)
a_{p50}	Internal surface area of the trial pit up to 50% effective depth and including the base area (m)
a_{s50}	Interfacial surface area of soakaway pit to 50% storage depth (m^2)
C	Runoff coefficient
d	Depth of facility (m)
D	Storm duration (min)
f	Soil infiltration rate (m/s)
G	Hydraulic gradient
I	Rainfall intensity (mm/min)
K	Hydraulic conductivity (m/s)
n	Soil porosity
N	Manning's coefficient ($m^{-1/3}s$)
O	Outflow (m^3)
P	Perimeter (m)
Q	Runoff volume to be treated (m^3)
R	Hydraulic radius (m)
S	Overall slope of channel (m/m)
s	Storage volume (m^3)
t	Time (s)
T	Return period (years)
t_{p72-25}	Time for the water level to fall from 75% to 25% effective depth (s)
t_{s50}	Time taken to empty half storage volume (s)
V	Apparent velocity (m/s)
V_{p75-25}	Effective storage volume of water in the trial pit between 75% and 25% effective depth (m)
V_s	Storage volume (m^3)

Storm Water Management Guidebook to Encourage Infiltration

1.2 Glossary

Term	Definitions
BMP	Best management practices
Check dam	A small dam built across a minor channel, swale or drainage ditch to reduce erosion and gullying
Compaction	Densification of soil by mechanical means
Design storm	A selected storm event, described in terms of the probability of occurring once within a given number of years, for which drainage or flood control improvements are designed and built.
Evapotranspiration	Combination of evaporation of water from wet plant and soil surfaces and the transpiration of water in plants
Grading	Process of changing the ground level to a smooth horizontal or gently sloping surface
Hotspot	Areas with polluting generating activities
Hydraulic conductivity	The ease through which water can move through the soil
Hydraulic gradient	or Darcy Slope, is the vector gradient between two or more hydraulic heads over the length of the flow path
Hydraulic radius	The equivalent circular radius for a rectangular or square flow channel
Hydrologic cycle	General circulation of water from the atmosphere to the ground, seas and back to the atmosphere through various stages or processes such as precipitation interception, infiltration, evaporation and transpiration.
Impervious	That which does not allow water to pass through
Infiltration	Movement of water through the soil surface into the soil profile
Interception	Part of precipitation at the beginning of a storm that is stored in vegetal cover and does not contribute to runoff
LID	Low impact development – management approach and set of practices that reduce runoff and pollutant loading as close to the source as possible
Manning's coefficient	Measure of the roughness of a material
Non-structural practices	Design and planning strategies and policies which help prevent the generation of stormwater runoff
Offline design	Facility designed such that runoff from storms larger than the design storm is bypassed
Online design	Facility designed to receive water from all storms, treat the runoff for the maximum design storm and convey the runoff from larger storms to an overflow
Permanent practices	Strategies implemented to help control the quantity and quality of stormwater runoff during the lifetime of the building

Term	Definitions
Return period	Average length of time between events that have the same duration and volume
Runoff coefficient	Proportion of rainfall falling on a site which will contribute to surface runoff
Sedimentation	Process of accumulation of soil and other particulate matter
Sheet flow	An overland or downslope movement of water in the form a thin, continuous film over smooth soil or rock surfaces and not concentrated into channels larger than rills
Soil erosion	Removal of soil and rock from the earth's surface by the action of water or wind.
Soil porosity	Ratio of the volume of voids in soils over the total volume of soil
Stabilisation	Process of maximising the suitability of the soil for a given construction purpose
Storm duration	Length of time over which rain falls during a storm
Structural measures	Measures that help control and mitigate the impact of stormwater runoff
SUDS	Sustainable urban drainage systems – sequence of management practices and control structures designed to drain surface water in a more sustainable manner than conventional techniques
Surface runoff	Water flow that occurs when the soil is infiltrated to full capacity and excess water from rain flows overland
Temporary practices	Management practices employed during construction
Non-structural practices	Design and planning strategies and policies which help prevent the generation of stormwater runoff
Time of concentration	Sum of overland flow time to the point where the runoff is concentrated or enters a defined drainage feature and the time of flow in a closed conduit or open channel to the design point
Topography	Arrangement of the natural and artificial physical features of an area
Under-drains	A small diameter perforated pipe that allows the bottom of a detention basin, channel or swale to drain

2.0 Why manage stormwater?

2.1 The need for stormwater management

Urbanisation, residential plot development (morcellement), and the conversion of agricultural land to business and industrial development areas are the signs of the economic progress of Mauritius. The downside of this economic modernisation has been the neglect of the natural processes which helped maintain an ecological balance. The past few years have been marked by the flooding of the several regions all over the island particularly during the summer torrential rains. All these floods can, to a large extent, be attribtued to an increase in surface runoff. Surface runoff is the water flow that occurs when the soil is saturated and excess water from rain flows overland.

When rain falls on an undeveloped site, a large proportion infiltrates into the ground. This infiltrated water is taken up by plants and vegetation and helps in recharging ground water table. The rest runs off either overland or by seepage through the grounds into surface water bodies. By developing the site, a lot of impervious surfaces such as roads, footpaths and buildings are created, thereby changing the site characteristics and its ability to absorb rainwater. Figures 2.1 and 2.2 illustrate the effects of increasing imperviousness both on the volume and rate of discharge of surface runoff.

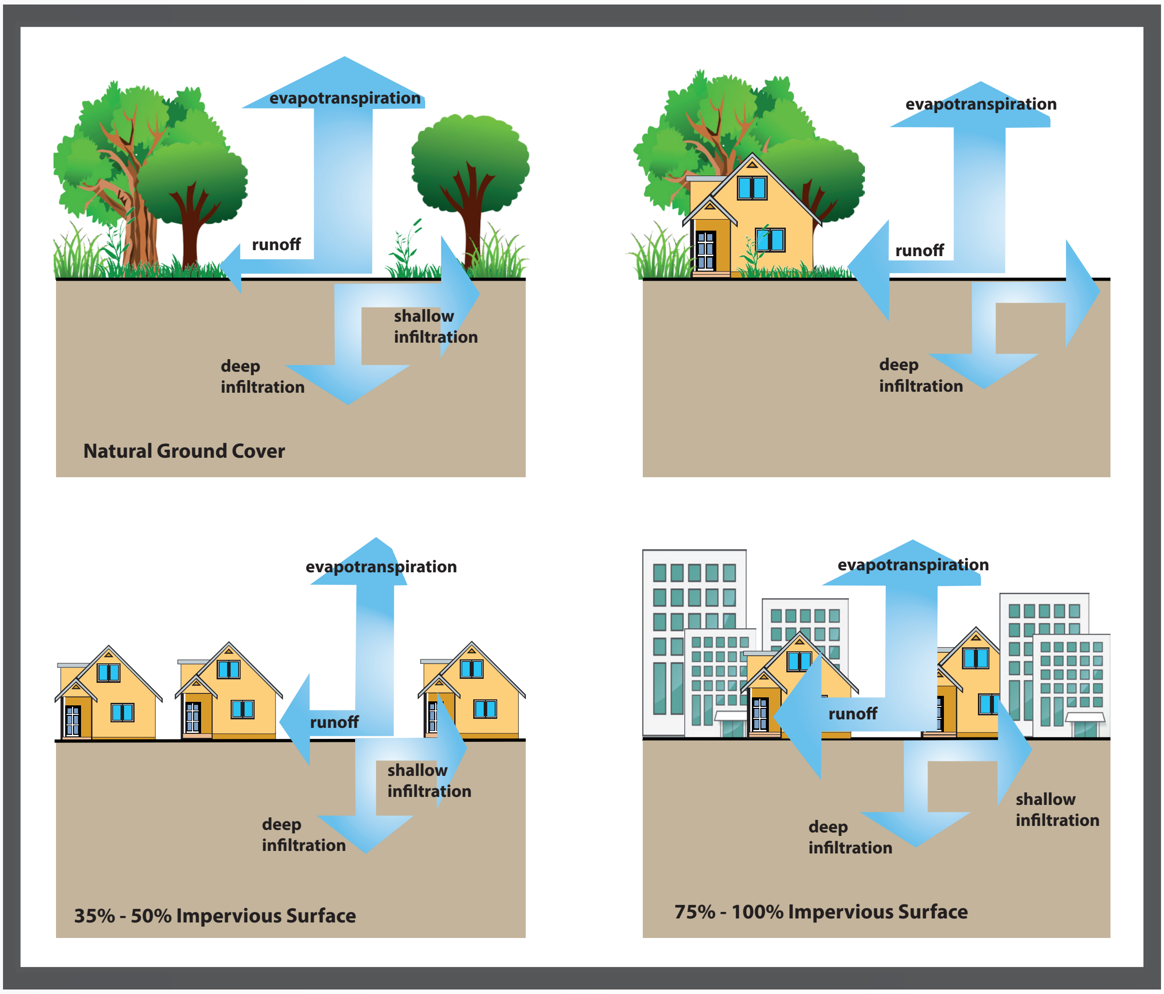


Figure 2.1: Effects of increasing imperviousness on surface runoff

Table 2.1 summarises the changes brought about by urbanisation and its impact on surface runoff.

Table 2.1: Effects of urbanisation on surface runoff

Cause	Effects
Removal of the native vegetative ground cover	Vegetation intercepts precipitation which prevents soil erosion. The loss of native vegetation has also disturbed the water cycle (figure 2.3) due a reduction in evapotranspiration.
Cropping up of new buildings and new road networks	An increase in surface imperviousness leading to a decrease in the amount of water being infiltrated into the soil. The increased imperviousness also produces a smoother surface which increases the amount and rate at which runoff enters the sewer system. Moreover, impervious surfaces such as asphalt absorb a lot of heat leading to an increase in the temperature of surface runoff.
Soil grading, compaction and stabilisation practices	These practices are necessary to obtain a well mixed soil which leads to good ground stability for construction. Well mixed soils are characterised by a uniform distribution of all soil particle sizes. Thus, grading, compaction and stabilisation alter the hydrologic response of soils as well mixed soils have less void spaces in between the particles to allow water to infiltrate.
Changes in the topography of the site	Change the natural course of water: For example, natural surface depressions which would normally have stored storm water could have been filled to provide a uniform ground level.

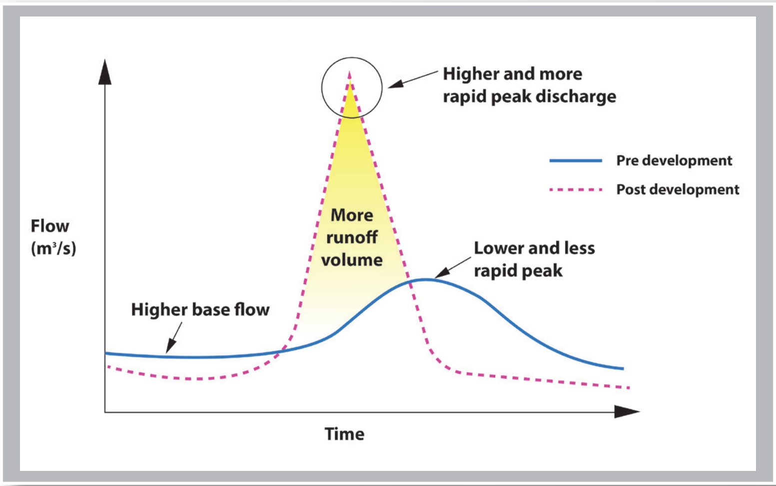


Figure 2.2: Effect of urbanisation on peak flowrate of runoff

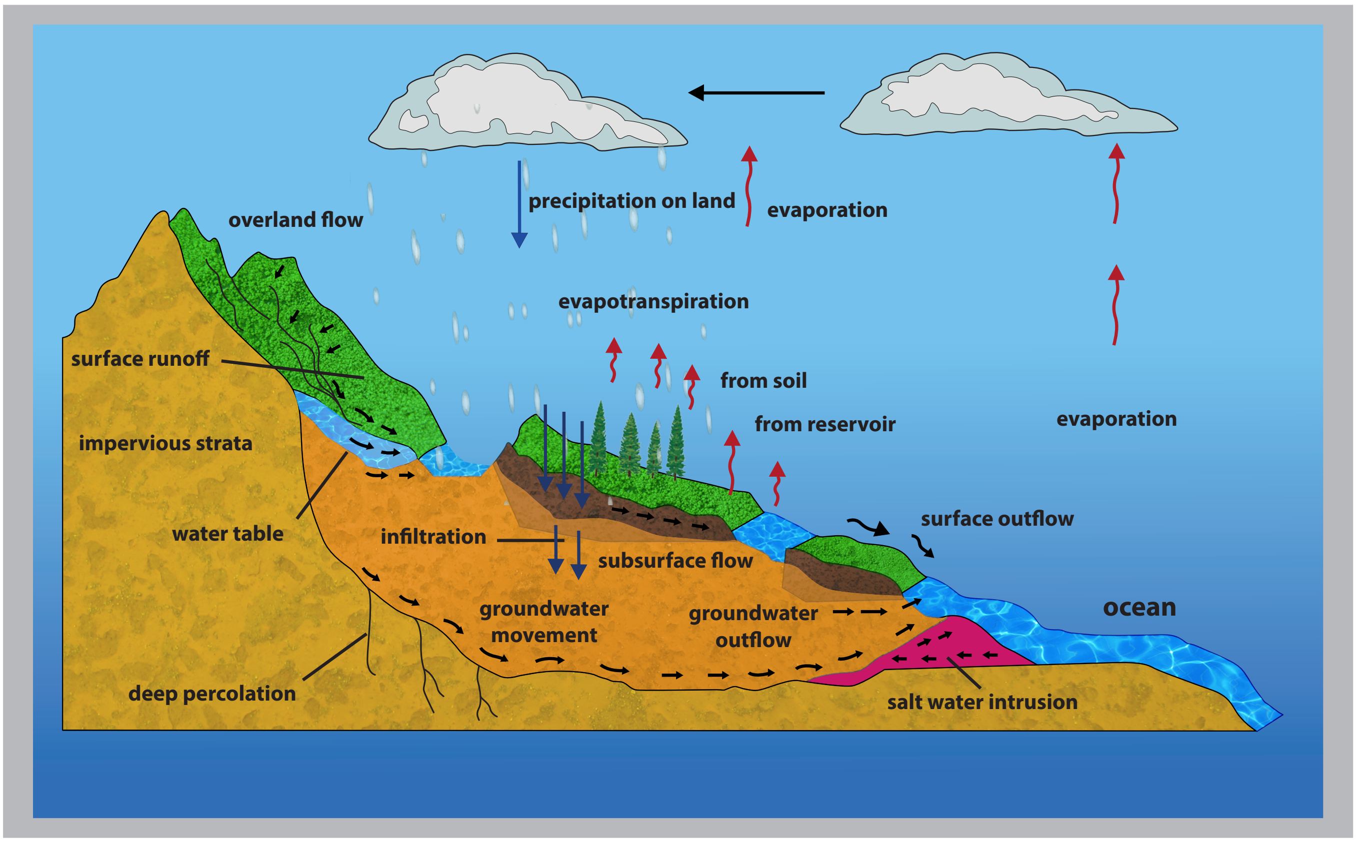


Figure 2.3: The water/hydrologic cycle

An increase in runoff leads to:

- Ground water aquifer and water tables not being recharged
- Floods particularly during short periods of intense rainfall
- Soil erosion and the loss of fertile topsoil
- Damage to the existing stormwater management systems
- Water pollution and degradation of water quality
- Stream widening
- Excess nutrient loading in water bodies
- Increased runoff temperature which could affect the aquatic ecosystem

Pollutants in stormwater:

- Solids: plastics, cans, boxes, leaves, branches
- Sediments/eroded soils – a major concern during the construction phase
- Nutrients such as nitrates and phosphates. These occur mostly from agricultural land runoffs and could lead to algal blooms, or be a public health hazard
- Pesticides
- Metals – leaching of lead, copper, cadmium, mercury, into the ground water would lead to public health hazard
- Hydrocarbons – which are carcinogenic and toxic to humans
- Pathogens – e.g. Salmonella and E-coli

Soil erosion

Soil erosion is the removal of soil and rock from the earth's surface by the action of water and/or wind flow. This results in smooth surfaces which allow water to move more freely and quickly. Topsoil and vegetation provides a valuable filtering mechanism to improve water quality. Hence the process of soil erosion not only increases the peak runoff rate but also the pollutant load in stormwater runoff. (Woods-Ballard et al, 2007)

2.2 Stormwater management plan

The purpose of a stormwater management plan is to minimise and effectively deal with the impacts of surface runoff. International green building codes such as LEED and BREEAM encourage project developers to adopt sustainable urban drainage systems (SUDS) practices such that:

1. Post-development peak runoff rates are the same as pre-development (Greenfield) rates

2. At least 80% of the total suspended solids are removed

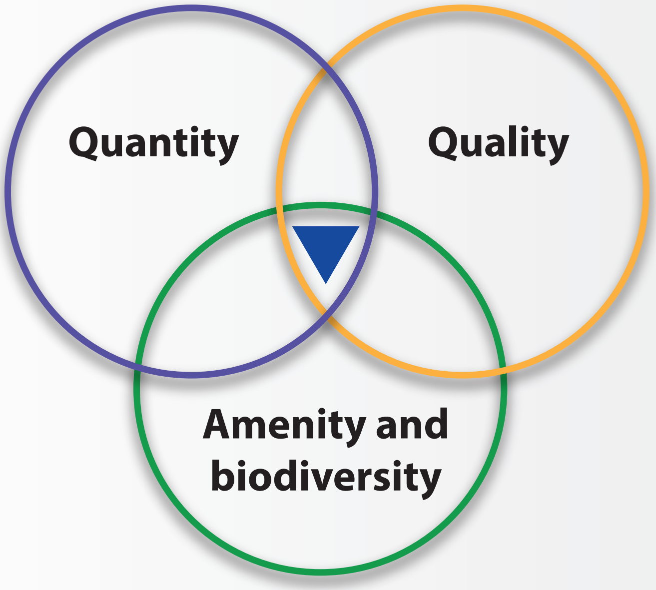


Figure 2.4: Holistic approach to management

Total suspended solids (TSS)

TSS are particles that are too small or light to be removed from stormwater via gravity settling. Suspended concentrations are typically removed by filtration. (USGBC, 2009)

SUDS (Shaffer et al, 2004) have been defined as a sequence of management practices and control structures designed to drain surface water in a more sustainable fashion than some conventional techniques. Conventional stormwater designs aimed at removing surface runoff offsite as quickly as possible: rain falling on the impervious surfaces are collected and conveyed to the sewers before being discharged to water courses (rivers, lakes and sea). The disadvantages of these practices are:

Possible contamination of the stormwater with foul sewer – this could lead to water pollution and could potentially be a public health hazard.

Little scope to reduce and delay peak runoffs – this had led to the over-sizing of drain pipes and hence increased initial costs as drains have been designed to cope with high peak flows.

Poor maintenance of the drains leading to increased flood risks.

SUDS, on the other hand, adopt a holistic approach to stormwater management. The SUDS approach is to prevent and control runoff as close as possible from the source and where possible encourage infiltration. In this manner, SUDS designs control the quality and quantity of runoff while contributing to environmental and biodiversity enhancement.

This guidebook aims at providing an overview of international best practices in stormwater management. Particular attention is paid to permanent practices promoting infiltration and ground water recharge. Where appropriate, the design and associated costs of these stormwater management practices will also be presented for the local context.

2.3 Why infiltration?

When designing a stormwater management system, the following criteria should be considered.

Table 2.2: Stormwater management design criteria

Design criteria	Justification
Interception	To prevent runoff for all rainfall events less than 5 mm
Infiltration	To promote groundwater recharge and support river base flows
Peak flow control	To protect the morphology of receiving water courses
Volume control	To prevent flood risk downstream of the site
Treatment of stormwater runoff	To minimise health and environment risks associated with contaminants
Flow exceedance management	To protect on site and off site properties against extreme flood events (e.g. the 1 in 100 year flood)

These criteria can be met by:

1. Adopting Low Impact Development (LID) practices – LID is a management approach and set of practices that reduce runoff and pollutant loading as close to the source as possible. It includes a variety of practices that mimic or preserve natural drainage processes .

2. Capturing, storing and slowly releasing surface runoff – these practices help in temporarily or permanently diverting runoff from the main drains.

3. A combination of the above mentioned techniques

Infiltration practices help manage stormwater in both ways: they restore the hydrologic response of a site and usually work by capturing and temporarily storing stormwater before allowing infiltration into the soil. In SUDS practices, infiltration is often prioritised as the first option.

Although infiltration practices have several benefits, the designer should bear in mind some of the limitations of this practice. Table 2.3 lists the advantages and disadvantages of infiltration practices.

[1] See appendix A for examples of LID practices.

Table 2.3: Advantages and disadvantages of infiltration techniques

Advantages	Disadvantages
Reduces the volume of runoff and hence the risk of flooding	Potential for ground water contamination especially in hotspot areas[1] or areas with contaminated soils
Increases ground water recharge	Not suitable in areas with steep slopes
Reduces pollutant loading and hence improves stormwater quality	Practices which tend to have shallow ponds could become a breeding place for mosquitoes
Provides thermal benefits by reducing the temperature of surface runoff	Clogging by debris could reduce the infiltration effectiveness
Has to be integrated with the landscape and hence adds to the aesthetic value of the site	Damage to building foundations and ground stability due to seepage and flooding could occur if not designed properly
Mimics pre-development hydrology	Risk of downstream flooding due to the introduction of additional groundwater
Creation of landscaping areas helps maintain and enhance urban biodiversity	
Reduces soil erosion and helps in improving stormwater quality	

[1]Hotspot areas are areas with polluting generating activities. Please see section 3 for examples of hotspot areas.

3.0 Types of stormwater management practices

3.1 Types of stormwater management practices

Stormwater management practices are varied and can be categorised as temporary/permanent measures; structural/non-structural measures; or online/offline strategies.To effectively control and manage stormwater, combinations of these different types of practices are used. A definition of the different stormwater management categories is given in this section. In this guidebook, the different stormwater management strategies have been categorised as temporary and permanent measures.

3.1.1 Temporary v/s permanent

Temporary measures are those stormwater management practices which are employed during the construction phase of the project. These measures help prevent excessive runoff from the site. In practice, these measures should for m part of the erosion and sedimentation control plan of the project. The erosion and sedimentation control plan is developed and implemented in order to prevent soil erosion during construction and to prevent the sedimentation of sewers network or receiving waters (USGBC, 2009). Permanent measures, on the other hand, are those strategies that have been designed to help control the quantity and quality of stormwater runoff during the operational phase of the building.

3.1.2 Non-structural v/s structural

In terms of stormwater management, the definition of structural and non-structural measures is quite ambiguous. This guidebook adopts the same definitions as given by the Pennsylvania Stormwater BMP manual (BWM, 2009). Non-structural practices are defined as those design and planning strategies and policies which help prevent the generation of stormwater runoff while structural measures are those measures that help mitigate the impact of stormwater runoff. In general, practices that fall under low impact development (LID) practices can be categorised as non-structural measures.

3.1.3 Online v/s offline design

Any structural stormwater management strategy can be designed to be either an online or offline system. An online system is one which receives runoff from all storms, treats the runoff for the maximum design storm and conveys runoff from larger storms through an overflow. An offline system is one where most or all of the runoff from storms larger than the design storm bypasses the stormwater management practice (NJDEP, 2004).

3.2 Temporary stormwater management practices

Temporary stormwater management practices are used during the construction phase of the project. During the construction phase, a lot of soil disturbance activities take place, e.g., grading, removal of vegetation, vehicle tracking. These activities adversely impact the hydrological behaviour of the site and lead to an increased runoff and sediment load in the runoff.

This section provides a brief description of the different measures (structural and non-structural) that can be used to manage stormwater during the construction phase. To help identify and implement these practices, a stormwater pollution prevention plan should be developed and maintained. Templates and guidance on how to develop a temporary stormwater management plan can be found on the US EPA website[1].

Maintenance is vital to ensure that the target design criteria are achieved. Maintenance of structural measures requires regular inspection particularly after rainfall events. Moreover any shortcomings in the stormwater management plan revealed during inspections should be remedied immediately.

3.2.1 Vegetated buffers

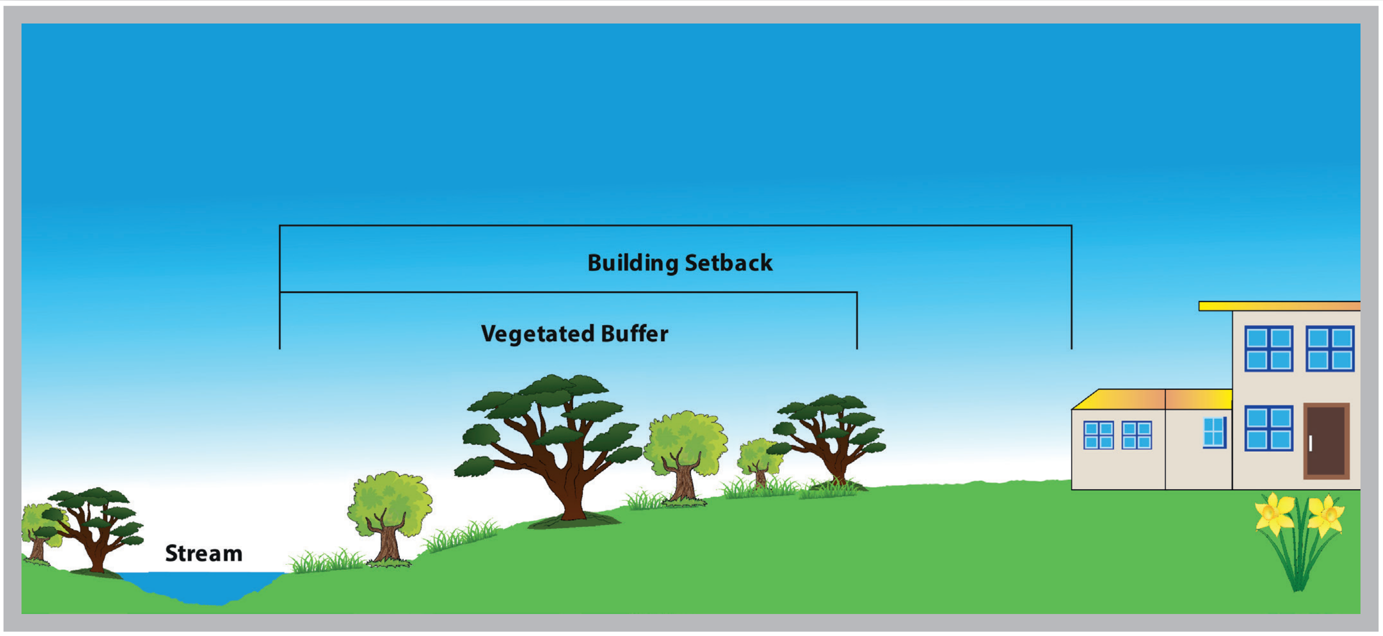


Figure 3.1: Example of a vegetated buffer

Preserving existing vegetation and natural features helps control soil erosion during the construction phase. This erosion control strategy involves identifying areas to be retained in its native state, and locating parking, stockpiles and storage areas away from vegetated areas. This leads to reduced

[1] http://cfpub2.epa.gov/npdes/stormwater/const.cfm (US EPA, 2013).

disturbed areas, protection of nearby streams and water bodies and reduced amount of sedimentation in sheet flow, which is the flow of water as a thin continuous film over a relatively smooth surface. This measure must be implemented right from the start of the project. It can be achieved by clearly marking on a map the areas and trees to be preserved. On site, those features to be preserved should be fenced and signage provided to inform site users.

3.2.2 Mulching

Used to prevent soil and wind erosion on slopes, mulching is the application of a uniform layer of straw, wood or hydraulic mulch to bare soils. Hydraulic mulch is a mixture of shredded wood fibre, water and stabilising emulsion which is applied in areas where equipment access is difficult. Mulch absorbs energy from rainfall and runoff impact and hence helps prevent erosion. It also provides protection and moisture for the establishment of vegetation. On a construction site, mulching will be the preferred option for areas which will be disturbed again after periods of inactivity. This measure can also become a permanent measure for non-vegetated slopes or used together with other stormwater best management practices (BMP).

Figure 3.2: Application of mulch in the US[1]

3.2.3 Temporary seeding

This technique is adopted on graded areas with smooth and hard surfaces as well as on slopes. Erosion and sedimentation control is achieved by the stabilisation of soil through vegetation. Rapid establishment of plant growth and plant density can be achieved through hydro-seeding, which is a mixture of fibre, seed, fertilisers and stabilising emulsion.

[1]Soil facts: mulch options for erosion control on construction site

3.2.4 Soil binders

This is the least recommended erosion and sedimentation control measure. It is the application of soil stabilisers to soils in non-traffic areas. These stabilisers help in preventing water and wind induced erosion. Application of soil binders should be limited as a short term, temporary protection measure. The different type of soil binders which can be used are: plant-material based binders, polymeric emulsion based binders, cementitious based binders. The properties of these different binders are summarised in table 3.1 (CASQA, 2003)

Table 3.1: Properties of soil binders

Property	Plant based (short lived)	Plant based (long lived)	Polymeric emulsion	Cementitious based
Resistance to leaching	High	High	Low to moderate	moderate
Resistance to abrasion	Moderate	Low	High to moderate	Moderate to high
Longevity	Short to medium	Medium	Medium to long	Medium
Minimum curing time before rain	9 to 18 hours	19 to 24 hours	0 to 24 hours	4 to 8 hours
Compatibility with existing vegetation	Good	Poor	Poor	Poor
Mode of degradation	Biodegradable	Biodegradable	Photodegradable and chemically degradable	Photodegradable and chemically degradable
Liquid/powder	Powder	Liquid	Liquid/powder	Powder
Clean up	Water	Water	Water	Water

3.2.5 Erosion control blanket/geo-textiles

Erosion control blankets and geo-textiles work in the same way as mulching. Soil erosion is prevented by the sheltering of bare soil from rainfall and runoff while retaining moisture for plant growth. Typically, blankets and mats are used to stabilise those areas where other control strategies cannot be used. Erosion control blankets and mats are made of netting layered with straw, wood, coconut or man-made fibres. Factors to be considered when selecting mats are:

Figure 3.3: Application of an erosion blanket [1]

- Effectiveness of reducing erosion, flow velocity and run-off
- Compatibility with native plants and wildlife
- Moisture retention capabilities
- Durability
- Maintenance requirements

Site preparation is also essential to ensure proper mat installation.

3.2.6 Temporary pipe downdrain

This method prevents concentrated flows from draining on disturbed slopes. A pipe is used to convey the runoff down the slopes.

Figure 3.4: Example of a temporary downpipe [2]

[1]http://www.paversearch.com/images2/erosgloss2.jpg

[2]http://opcgis.deq.state.ms.us/Erosion_Stormwater_Manual_2ndEd/Volume1/Chap_4_Sections/4_4/V1_Chap4_4_Runoff_Conveyance_TSD.pdf.

3.2.7 Earth dikes, drainage swales and ditches

By intercepting and diverting runoff around or through the site, earth dikes convey runoff towards stabilised drainage systems in a non-erosive manner. Thus, flow on steep slopes is avoided. Runoff velocity is an important factor when choosing this control measure: too high a velocity could lead to erosion and scouring of the drainage swales. To prevent this, check dams, blankets or plastic sheeting are used. Post-treatment of the runoff is required in order to maintain local stormwater quality equirements.

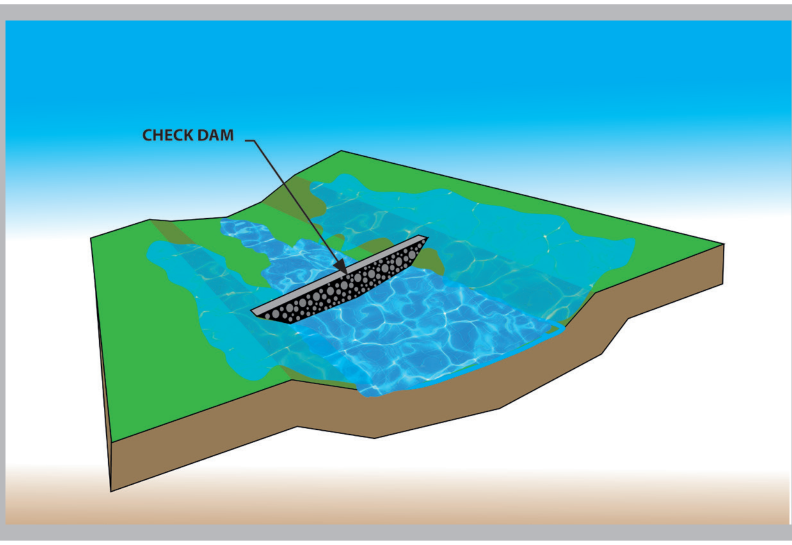


Figure 3.5: Drainage swales

3.2.8 Slope drain

Slope drains are very similar to temporary pipe downdrain with the exception that in this method, no pipe is used. A trench is dug instead and used together with ditches to convey concentrated flows. Slope drains typically have an inlet pipe to converge flows at the top of the slope or at flared discharge. Riprap (appropriately sized rocks that absorb and deflect the energy of fast moving flows) can be used to protect the flared discharge.

3.2.9 Fibre log/rolls

Fibre rolls are tubular cylinders made of straw, flax, coconut, wood or synthetic fibres. These cylinders intercept and reduce runoff velocity and allow sediment to settle out. They are usually used at the bottom of slopes, for inlet protection and as site perimeter control. Eco-friendly and wildlife friendly materials should be used to fabricate fibre logs. Due to unavailability of straw on the Mauritian market, this practice is not popular in Mauritius. Instead silt fences or gravel bag barriers are used.

Figure 3.6: Fibre rolls[1]

[1]http://stormwater.pca.state.mn.us/images/8/8d/Example_of_fiber_log.jpg

3.2.10 Silt fence

Silt fences are linear barriers that capture sediment by retaining runoff and are used where concentrated flows are anticipated. They are available in the form of geo-textiles. Silt fences can be installed at the toe of slopes and around the perimeter of stockpiles or be used for inlet protection. Silt fences should be avoided across intermittent or permanent streams or where concentrated flows are expected.

Figure 3.7: Silt fence around a construction site [1]

3.2.11 Barriers and berms

These temporary linear sedimentation control strategies work by intercepting, slowing stormwater runoff and filtering it before it flows into the stormwater ditch. They are used at the toe of slopes, around the site perimeter and perimeter of stockpiles as well as for inlet protection. However, as with silt fences, these methods are not appropriate across intermittent or permanent streams or where concentrated flows are anticipated. An alternative to barriers are gravel bag berms.

This BMP consists of a row of gravel bags installed end to end to form a barrier across a slope. Gravel bag berms are used to intercept runoff, reduce runoff velocity and release the run off as sheet flow. They are usually constructed along the contour of slopes and the bags should be tightly butted and avoid overlapping. This sedimentation control technique is labour intensive and requires a lot of maintenance.

Figure 3.8: Example of straw bale barrier [2]

[1]http://t1.gstatic.com/images?q=tbn:ANd9GcQMC3U6p1HkHqUzDTTI4Cb_B9FDRTQT1xglSwqJPLpFg2wS5k8tpA

[2]http://www.cecilscd.com/images/E&S%20photo/P1040008.JPG

3.2.12 Stabilised construction exit/entrance

Stabilised construction exit and entrances provide a dedicated route for vehicular traffic. The main aim of this measure is to prevent tracking of soils, sediments or building materials offsite. It uses aggregates, which help remove sediment from vehicle tires, or a rattle plate structure at the entrance and exit points. Water can also be sprayed on vehicles' tyres so as to wash any remaining sediments. This strategy requires that the site personnel be informed and instructed to use site access points only.

Figure 3.9: Rattle plate at site exit [1]

[1] http://www.google.mu/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&docid=jTm_veFxmqxIWM&tbnid=pG3NfZaJZ56ZBM:&ved=0CAUQjRw&url=http%3A%2F%2Fwww.gme-shields.com%2Fsite-suport-products%2Feit-grid%2F&ei=rLjTUvLRG8TnrAe_woHQCQ&bvm=bv.59026428,d.bmk&psig=AFQ jCNFfShFjinmSjovRSwap8tNrEg2W7g&ust=1389693360479777

3.2.13 Sediment trap/basin

A sediment trap temporarily detains sediment laden flow before discharging into storm drains or natural waterways. The controlled release mechanism helps in reducing peak flows, gives time for sediment to settle out and hence acts a pre-treatment measure. Sediment traps are used for small sites (< 2 hectares) while for large sites sediment basins are used. To determine the size of the sediment traps and basins, a suitably qualified engineer should be appointed for the design.

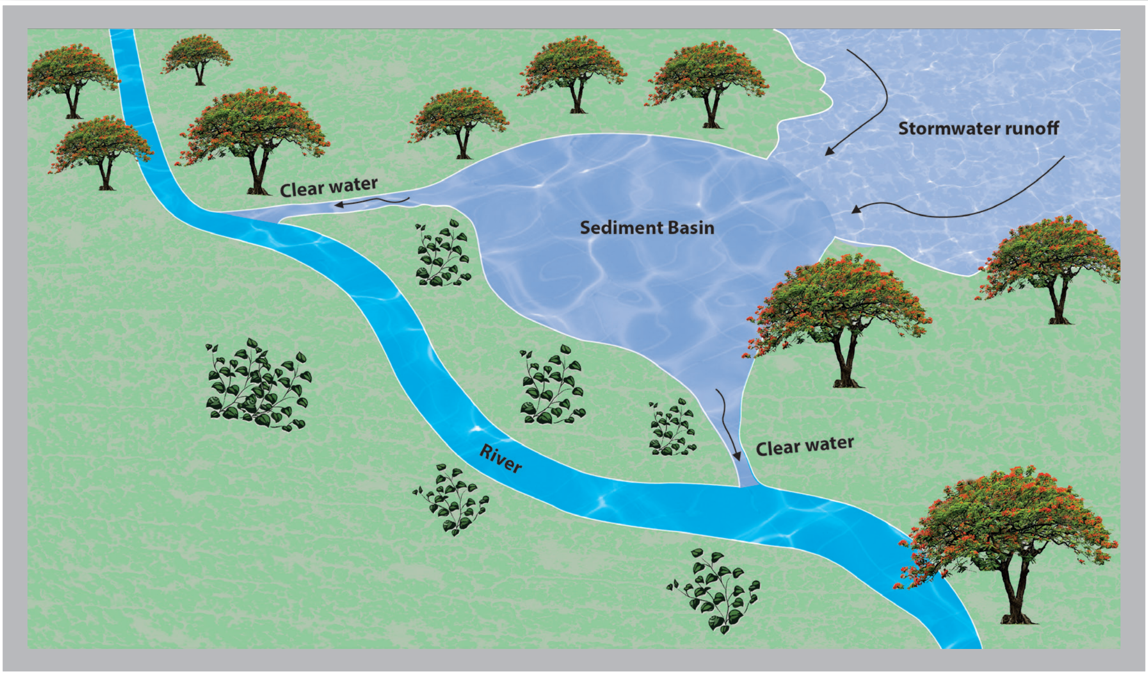


Figure 3.10: Sediment trap

3.2.14 Check dams

Check dams are rock or gravel bag structures placed across a natural or man-made flow channel. Used together with other BMP, check dams help reduce scour and channel erosion in steep channels or large drains by retaining water, reducing peak flow rates and allowing sediment to settle out. The use of check dams can also be extended to permanent BMP strategies. To ensure the proper functioning of check dams, regular inspections are required especially after major storm events so as to repair any damage. Sediment should also be removed once it reaches one-third of the dam height.

3.2.15 Grade breaks

This is a sedimentation control strategy used on long slopes. It is used to stabilise slopes and are changes in slope that break concentrated flows so as to prevent the formation of gullies. Grade breaks are created by gradual changes in the longitudinal grade of a road. Grade breaks are most commonly integrated with road designs but can also be included on construction sites with long slopes. The design of grade breaks depends on various factors such as terrain type, volume of water and many others. Being a specialist design, a suitably qualified engineer should recommend the number and location of grade breaks.

3.2.16 Street cleaning

This BMP requires the removal of dirt, mud, rock and other debris tracked onto public streets and paved areas. This involves daily sweeping of streets and washing of construction vehicles daily to prevent offsite tracking. The use of water for street cleaning should be monitored to prevent the conveyance of pollutants to existing stormwater sewers.

3.3 Permanent stormwater management practices

This guidebook categorises permanent measures for stormwater management practices into those that promote infiltration and those that do not. Practices that promote infiltration are:

1. Infiltration basins
2. Dry well/French drains
3. Infiltration trench/gallery
4. Regenerative stormwater conveyance system
5. Preserving open spaces
6. Green roof
7. Stormwater swales
8. Stormwater planters
9. Pervious paving/concrete/asphalt
10. Rain garden
11. Stormwater curb extensions
12. Downspout disconnection
13. Compost and amended soil

These practices are further discussed in section 4. Section 3 focuses on those practices that do not promote infiltration.

3.3.1 Filters

Filtration help in managing stormwater quality. Amongst the different types of filtration systems are vegetative filter and media filters. Site managers can use any of these or a combination of these filters so as to achieve the desired stormwater discharge quality. Filtration can be used either to pre-treat stormwater or as a post-treatment process.

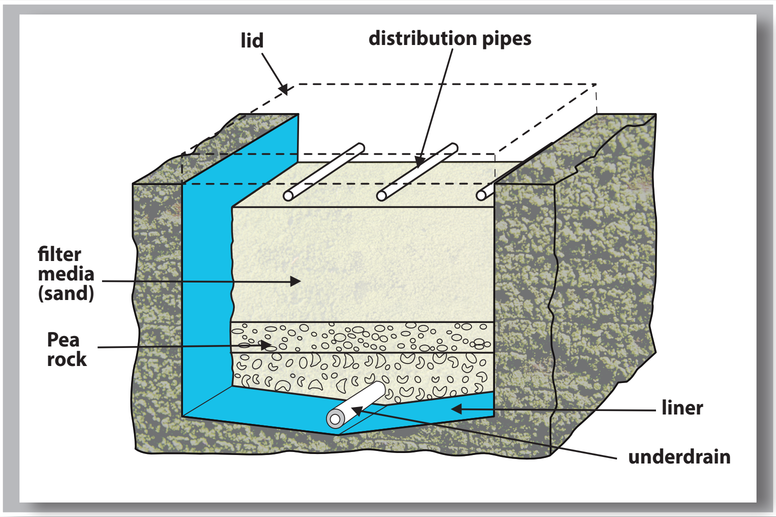


Figure 3.11: Media filter

Vegetative filter strips use plants to actively manage stormwater. Plants help in improving stormwater quality by removing suspended solids and other pollutants such as hydrocarbons, heavy metals and other nutrients. They are also effective in slowing down stormwater runoff. Filter strips are primarily a filtration method but can sometimes be used to promote infiltration.

Media filters usually consist of sand filters. Sand filters can be further classified into surface filters, underground filters and perimeter filters. On the market, proprietary media filters are also available and can be used.

Filters are very good in reducing the pollutant load in stormwater and hence can be used to pre-treat runoff from hotspot areas and highly impermeable areas. However, filters require high levels of maintenance. Poor maintenance of filters can cause odours. Moreover, they are not very aesthetic and their use tends to be limited to commercial and industrial areas.

3.3.2 Rainwater harvesting

A rainwater harvesting system involves collecting rain falling on the roof of a building and storing it for non-potable end-uses. This reduces the volume of water being delivered to downstream conveyance systems. Thus, rainwater harvesting is a cheap way of coping with stormwater run-off. Since the roof runoff does not touch the ground, rainwater harvesting also prevents contamination in hotspot areas.

Rainwater harvesting has the additional advantage of reducing a building's potable water use and hence can help to manage shortages during the dry season. Rainwater harvesting is used on new-builds as well as retrofits on flat or pitched roof. However, rainwater harvesting is not recommended on roofing systems containing tar, gravel or asbestos.

Although rainwater harvesting appears to be simple to install, the following factors have to be considered:

- Maximum rainfall intensity
- Contributing roof area

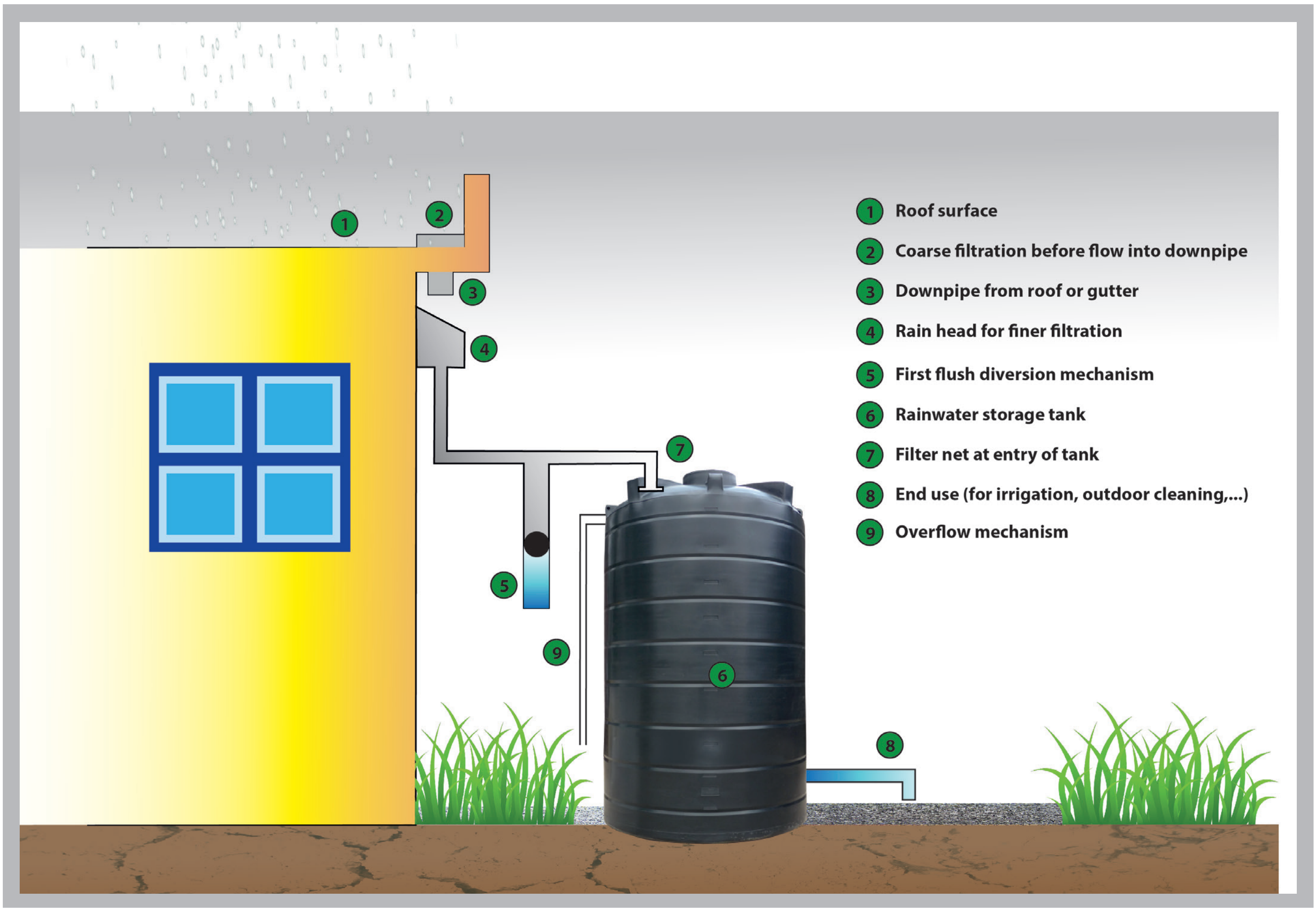


Figure 3.12: Simple rainwater harvesting system

These two factors help in determining the size of storage tank required. Filters must be installed to prevent debris from clogging the gutters. A badly designed system could also become a breeding place for mosquitoes and other vectors. For small residential projects, a suitably qualified plumber should be contracted. For larger scale projects, commercial and industrial buildings, the rainwater harvesting should be designed in accordance with BS8515:2009.

3.3.3 Stormwater ponds

Stormwater ponds are constructed basins built to capture and store runoff. The basin stores water temporarily or for an extended period of time. It is usually installed as an end-of-pipe stormwater management practice.

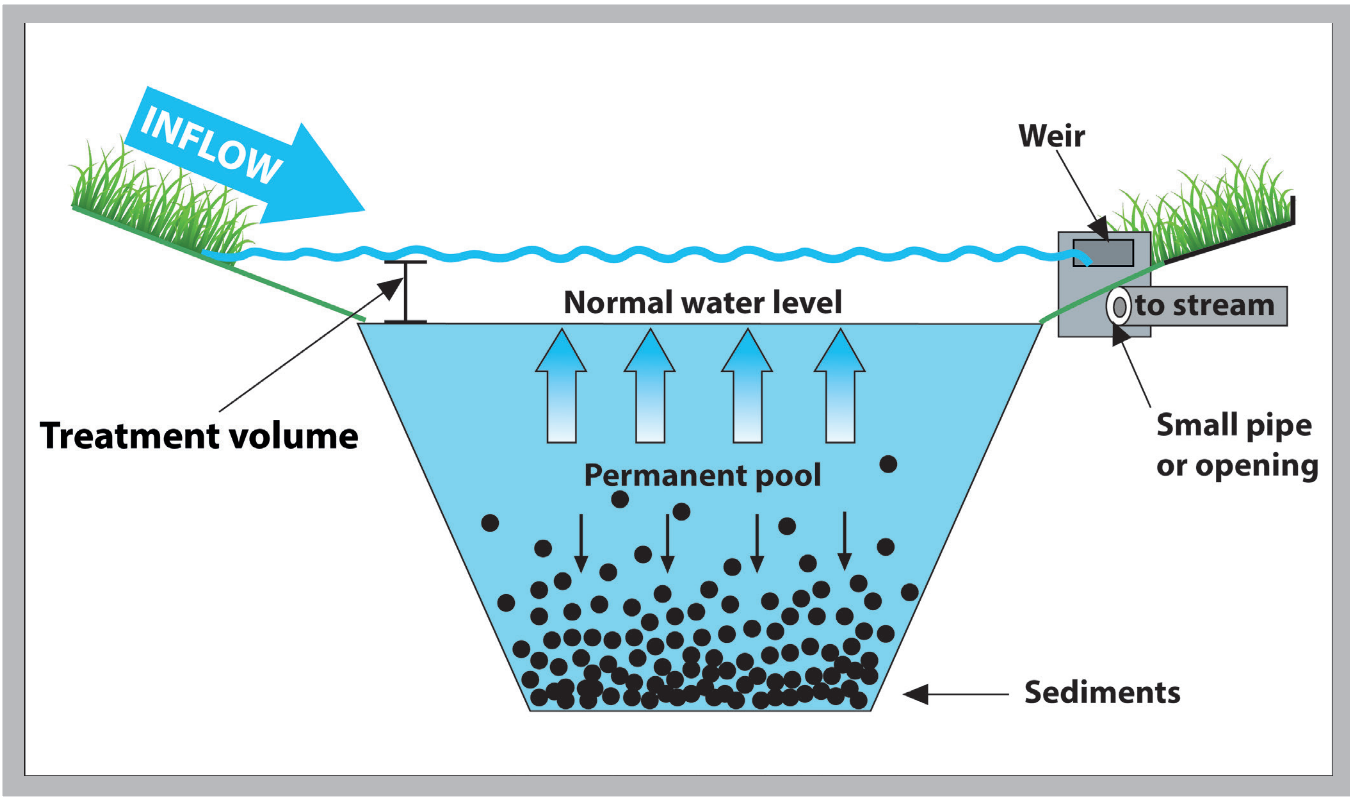


Figure 3.13: Stormwater ponds

By storing runoff, stormwater ponds give time for the sedimentation process to take place. This helps in ensuring a good stormwater quality. Stormwater ponds have the potential to act as wildlife habitat. They also have a recreational value and hence can help increase community connectivity. This practice is also often used to temporarily store rainwater during the construction stages. The disadvantage of stormwater ponds is that they require a large space. Furthermore, stagnant pools can cause odours and become the cradle for many diseases.

The different types of stormwater ponds are:

Flow-through ponds

Flow-through ponds have no extended detention and are also known as wet ponds. They are characterised by a permanent pool and has an unrestricted spillway. When it rains, new runoff displaces the water from the permanent pool.

Extended detention ponds

Extended detention ponds are similar to flow-through ponds but provide additional rate control and water quality control. This is achieved by under sizing the outflow from the pond. Thus, stormwater backs up into the pond, giving sediments more time to settle out of the water.

Micro pool extended detention pond

As the name suggests, micro pools have smaller permanent pool. They are typically used for the post-treatment of stormwater runoff and are located at the end of the main pool outlet. They help in maintaining stormwater quality by preventing sediment re-suspension.

Dry ponds

Dry ponds have no permanent pool and are mainly used to control runoff rates. They are recommended in areas with a low land relief and which suffer from severe flood risks. They also have the added advantage of not becoming a breeding place for disease vectors such as mosquitoes.

3.3.4 Stormwater wetlands

Stormwater wetlands are man-made structures and should not be confused with natural wetlands. As with stormwater ponds, wetlands are used to store, control and manage runoff quality and quantity. It has an aesthetic value and can help to restore a site's ecological diversity. Stormwater wetlands differ from ponds in terms of the depth of water stored and the vegetative complex they sustain. They also require a large surface area and are recommended for drainage areas greater than 40,000 m^2, Wetlands can be in the form of: shallow wetland, extended detention wetland, pond/wetland system

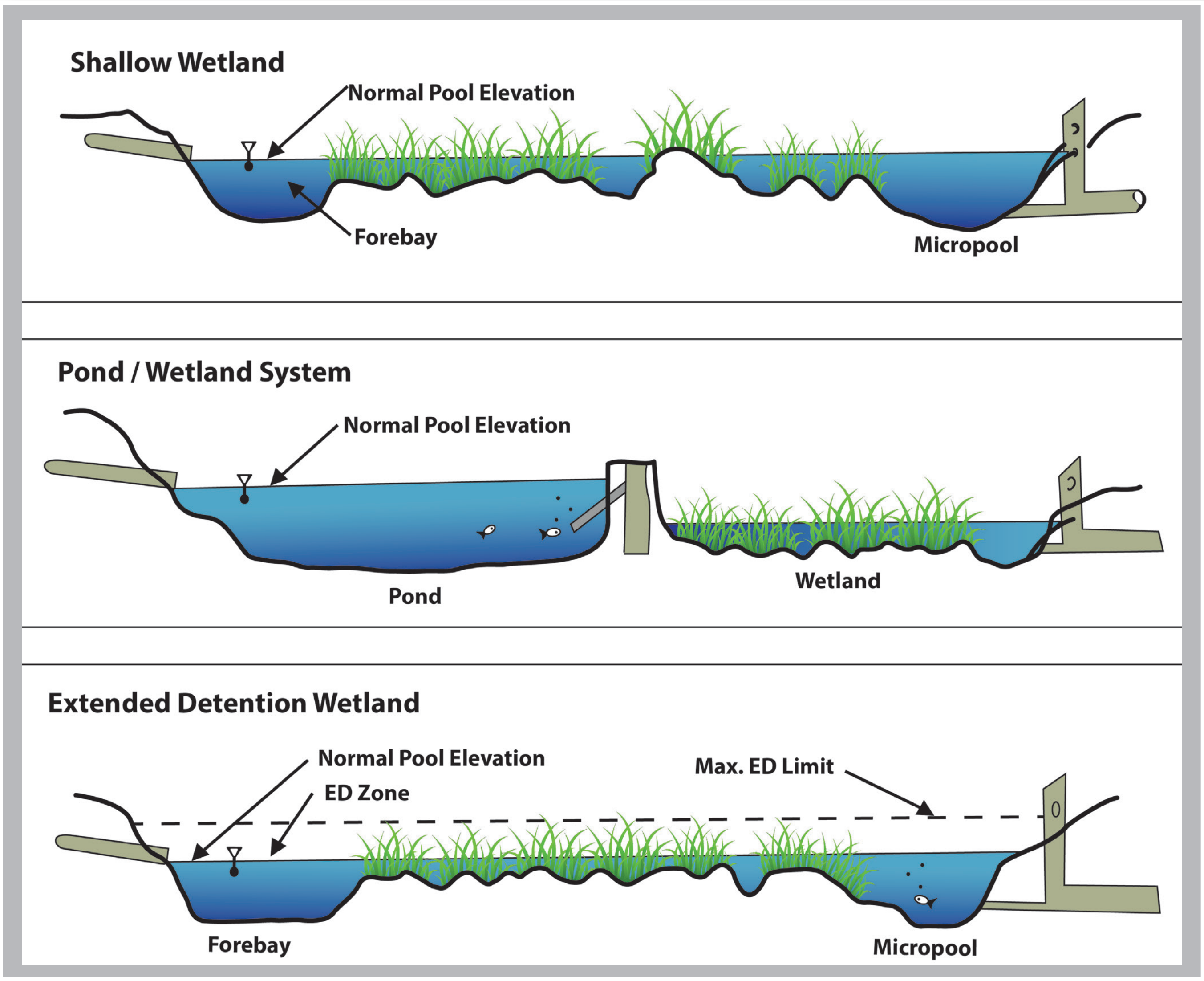


Figure 3.14: Types of stormwater wetlands

Stormwater ponds and wetlands are complex stormwater management practices and their designs and implementation should be left to suitably qualified engineers.

2.4 Summary

Table 3.2: Summary of stormwater BMP

Stormwater BMP	Permanent	Structural	Promotes infiltration
Check dam	×	✓	×
Compost and amended soil	✓	×	✓
Downspout disconnection	✓	✓	✓
Dry well / French drains	✓	✓	✓
Earth dikes and ditches	×	✓	×
Erosion control blanket/ geo textiles	×	×	×
Fibre log/rolls	×	×	×
Grade breaks	×	✓	×
Gravel bag berm	×	✓	×
Green roof	✓	✓	✓
Infiltration basins	✓	✓	✓
Media filters	✓	✓	×
Mulching	×	×	✓
Pervious paving/ concrete/asphalt	✓	✓	✓
Preserving open spaces	✓	×	✓
Rain garden	✓	✓	✓
Rain water harvesting	✓	✓	×
Regenerative stormwater conveyance	✓	✓	✓
Sediment trap/basin	×	✓	×
Silt fence	×	✓	×
Slope drain	×	✓	×
Soil binders	×	×	×
Stabilised construction exit/entrance	×	✓	✓
Storm water curb extensions	✓	✓	✓
Storm water planter	✓	✓	✓
Storm water ponds	✓	✓	×
Storm water swales	✓	✓	✓
Storm water wetlands	✓	✓	×
Straw bale barriers/ gravel bag/filter bags	×	✓	×
Street cleaning	×	×	×
Temporary pipe down drain	×	✓	×
Temporary seeding	×	×	✓
Vegetated buffers	×	×	✓
Vegetative filters	✓	✓	✓

4.0 Design of infiltration practices

4.1 Design criteria

4.1.1 General

This section provides general guidance on the design of stormwater management practices. These guidelines are applicable to both temporary and permanent best management practices. The stormwater management practice should be developed so that:

1. The stormwater systems intercept and infiltrate rainfall, control the peak runoff rate from the site, treat the runoff volume and manage and divert flow exceedance.

2. Natural drainage features are protected.

3. Public health and safety risks are minimised.

4. The BMP chosen should be economically viable in terms of its constructability and maintainability.

5. Sustainability and features enhancing the urban environment are recognised and favoured.

6. People and property onsite as well as upstream and downstream of the site are protected from flooding.

In addition to these above criteria, practices promoting infiltration have to meet some specific design criteria.

4.1.2 Infiltration

Infiltration is the movement of water through the soil surface into the soil profile. To determine the feasibility of infiltration practices, several factors are considered. The most important criterion is the permeability of the soil. Infiltration practices are used where the soil has a high permeability.

4.1.3 Infiltration coefficient

The permeability of soils is described using an infiltration coefficient. The higher the infiltration coefficient, the more permeable the soil is. Thus, coarse-grained soils have a high infiltration coefficient whilst fine-grained soils have a low infiltration rate. This is because coarse grained soils consist of large particles with a lot of void space in between the particles.

This allows water to pass freely through the soil. Fine-grained soils on the other hand have smaller particles and are more tightly packed. Hence, it is more difficult for liquids to percolate through resulting in a low infiltration rate.

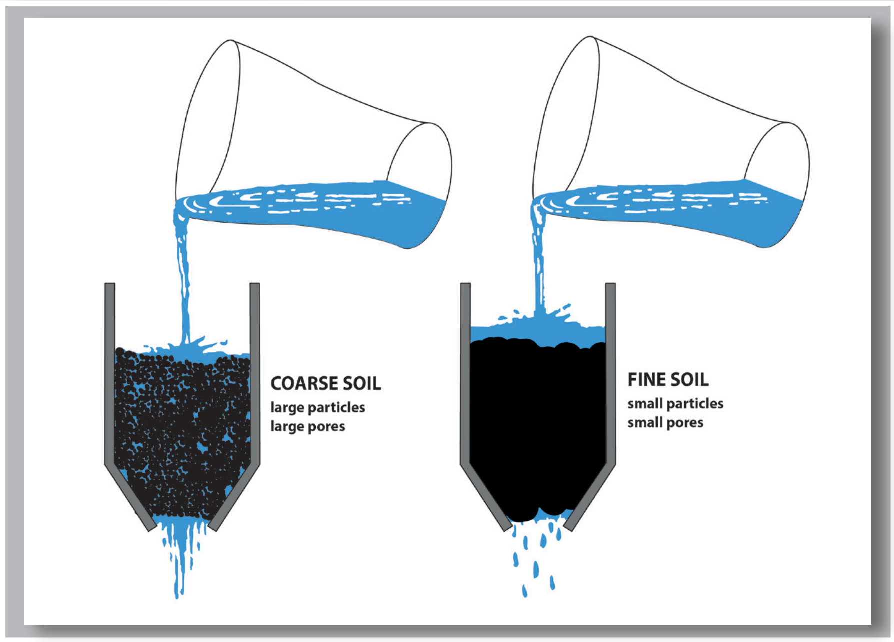


Figure 4.1: Infiltration rate for coarse and fine soils

Table 4.1 can be used to determine infiltration coefficient for different soil types. (Woods-Ballard, 2007)

Table 4.1: Typical infiltration rate of soil

Soil type	Typical infiltration rate (m/h)
Gravel	10-1000
Sand	0.1-100
Loamy sand	0.01-1
Chalk	0.001-100
Clay	<0.0001
Till	0.00001-0.01
Rock	0.00001-0.1

For detailed design, onsite investigations should be carried out. Appendix B summarises how to determine infiltration rates.

4.1.4 Contaminated soils

Infiltration practices should not be implemented on contaminated soils or on sites where the risk of contamination is very high. Such sites are known as hotspots.

Contaminated soils contain pollutants such as oils and other chemicals. When it rains, the surface runoff carries with it significant concentration of those pollutants. Implementing infiltration practices will cause these pollutants to infiltrate into the ground thus leading to ground water contamination.

Even with measures such as grease traps, infiltration measures are not recommended on contaminated soils. Instead, methods which convey surface runoff to an active treatment plant are preferred.

Hotspot: areas with polluting generating activities. Examples are:

- Petrol stations
- Vehicle maintenance areas
- Vehicle cleaning
- Auto recycling facilities
- Outdoor material storage areas
- Loading and transfer areas
- Landfills
- Construction sites
- Industrial rooftops

4.1.5 Water tables

The maximum recorded ground water level should be known. It is recommended that the infiltration surface should be at least 1 m above the maximum water level. If the water table is too close to the surface, the risk of flooding and groundwater contamination increases.

4.1.6 Geotechnical stability

A suitably qualified professional should assess the geotechnical stability of the site. This ensures that addition of water into the ground does not have any adverse impacts on surrounding man-made structures.

4.1.7 Location

Some site specific factors need to be considered before proceeding with the design stage. Implementation infiltration practices near to building foundations is not recommended as this could encourage water seepage into the building. Moreover, infiltration practices should be located at least 30 m away from the septic tanks and from drinking water sources to prevent cross-contamination.

4.1.8 Retention time

The retention time is simply defined as the time taken for a storage system to empty completely. Several infiltration facilities are characterised by a retention system in which rainwater is captured and then slowly released to the surrounding soils. The temporary storage of water in the retention facility helps in controlling runoff rate. The retention time should be carefully chosen. Too long a retention time leads to the formation of stagnant pools which become a breeding place for mosquitoes and other vectors. For a tropical country like Mauritius, a retention time of 24 hours is deemed to be reasonable.

4.1.9 Pre-treatment

Silt ingression can cause the soils surrounding the infiltration system to become clogged, hence reducing infiltration capacity. To prevent this, pre-treatment is necessary. Pre-treatment, in the form of other BMP, e.g. media filters, are implemented upstream of the infiltration practice. Typically, on a large site, infiltration practices will be towards the end of the stormwater management train.

4.1.10 Hydraulic design

To design any stormwater management system, we need to first calculate the runoff volume that needs to be treated. This volume is determined once the design storm has been selected and the runoff coefficient evaluated. Figure 4.2 gives an indication of the calculation steps required to determine the volume runoff. Appendix C gives a more detailed explanation of the calculation procedures.

As a general rule of thumb,

- Rainfall intensity for Mauritius is:

Table 4.2: Rainfall intensity in Mauritius (adapted from Proag, 2013)

Return period (years)	Storm duration (min)	Rainfall intensity (mm/h)
50	10	170
50	30	110
50	60	90

- Runoff coefficient for impermeable surfaces = 1.0

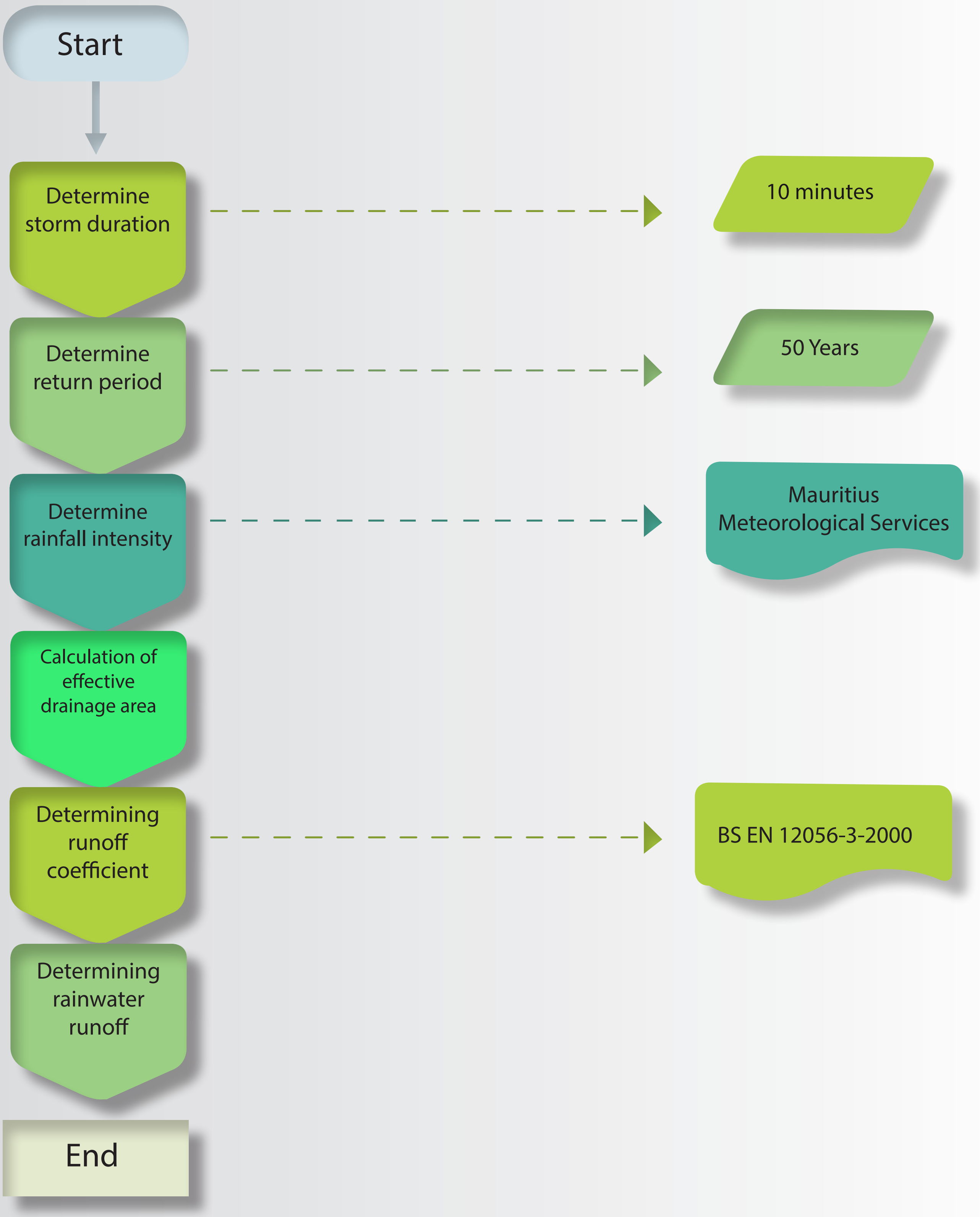


Figure 4.2: Flowchart for determining rainwater runoff

4.1.11 Cost data

The cost of implementing infiltration practices include several components such as excavation cost, the amount of materials used and the site restoration costs. Since these costs vary according to the size of the infiltration practice, it is difficult to give an overall rate for the relevant infiltration practice. Instead, a cost breakdown of the different elements involved in implementing the practice has been given. Case studies in the following sections give guidance on how to use these rates to estimate the cost of infiltration practices.

The values used to evaluate the cost of implementing infiltration practices are based on data obtained in the National Schedule of Rates and current prevailing prices. The National Schedule of Rates was published by the CIDB in 2012, and gives the average prevailing rates in the construction industry. The costs published here are for guidance only. Main contractor fees are estimated to be about 15% of the total costs of materials. Readers should always check with local suppliers for current prevailing prices when doing a budgetary estimate.

Another important aspect to bear in mind when computing the budgetary estimate is whether the stormwater management practice is being carried out for a new built or as a retrofit. Retrofits will typically cost two-three times as compared to a new project design.

Table 4.3: Cost data for Mauritius

Material/Activity	Costs
Landscaping and site restoration	
Shrubs	Rs. 50 – 200 /unit
Mature trees	Rs. 2,000 – 10,000 /unit
Grass planting	Rs. 150 /m^2
Tarmac	Rs. 1,200 /m^2
Imported (normal) soil	Rs. 250 – 300 /m^3
Imported (top) soil	Rs. 400 /m^3
Materials	
Concrete curbs	Rs. 600 - 800 /linear m
Rocksand	Rs. 1,800 /m^3
Aggregate	Rs. 900 /m^3
Mulch	Rs. 500 /m^3
Hardcore filling	Rs. 600 /m^3
Diameter 110 mm	Rs. 400 /m
Geotextile	Rs. 125 /m^2
Site preparation	
For absorption pits (up to 2 m deep)	Rs. 400/m^3
Site clearing	Rs. 20 /m^2
Wide excavation	Rs. 250 – 300 /m^3 (normal soil)
	Rs. 450 – 500 /m3 (Rocks)
Trench excavation	Rs. 1,000 – 2,000 /m
Breaking tarmac	Rs. 200 /m^2

4.2 Infiltration basins

An infiltration basin is an underground facility constructed to temporarily store stormwater. The stored water then infiltrates and percolates into the surrounding soils. Infiltration basins are used to control both the quality and quantity of stormwater. Pollutants are removed through the process of sedimentation and filtration through the sand layer. Diverting runoff away from the main stormwater drains helps in volume control.

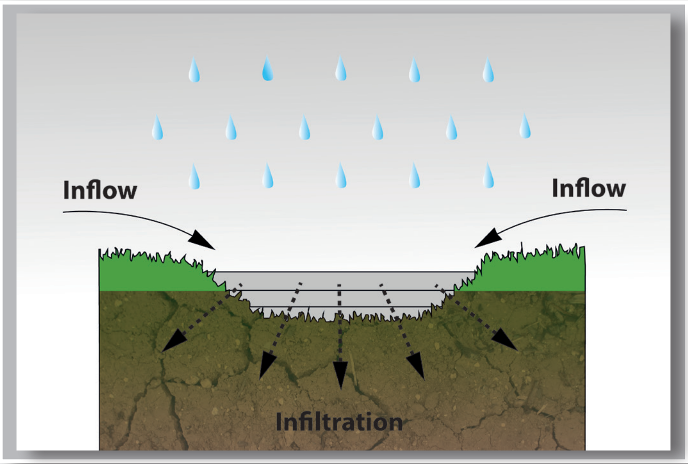


Figure 4.3: Infiltration basin

4.2.1 Pre-treatment required

- Vegetative filters
- Sediment fore bay
- Active treatment plant

4.2.2 Design

The design of an infiltration basin is an iterative process. The use of the design equations found in this section is illustrated by Case study 1.

$$f = K \times G \times A \qquad \text{Eq. 4.2.1}$$

Where f = soil infiltration rate (m^3/s)

K = hydraulic conductivity of soil (m/s)

G = hydraulic gradient[1]

A = area of infiltration (m^2)

Over the lifetime of an infiltration basin, hydraulic conductivity may decrease. Therefore, the design value of K is recommended to be half of that of the measured value.

[1]See appendix D for more details

Maximum retention time/depth is given by:

$$d = 0.5\, K \times t \qquad \text{Eq. 4.2.2}$$

Where d = maximum depth of the facility (m)
t = maximum allowable drain time (s)

Minimum Area of for infiltration is given by:

$$A = \frac{Q}{d} \qquad \text{Eq. 4.2.3}$$

Where Q = runoff volume to be treated (m^3)

Notes:

1. A suitably qualified engineer should design the infiltration basin.
2. At the base of an infiltration basin, a sand layer (≈ 150 mm) is usually installed.
3. The contractor should take the necessary precautions to prevent soil compaction during construction.
4. A suitable conveyance system should be devised to transfer overflows to a downstream drainage system in a safe and stable manner
5. Infiltration basins are not recommended in regions where the slope is greater than 10%.

Maintenance

- Removing sediment when the basin is thoroughly dry
- Inspect for clogging, excessive debris and sediment accumulation four times annually and after every storm event exceeding 25 mm
- Inspect sand layer monthly and after each storm event exceeding 25 mm.
- Regularly mow and trim vegetation
- Inspect for erosion and scour in vegetated areas
- Minimise the use of fertilisers and pesticides
- Inspect structural components for cracks, subsidence, spalling and erosion

Applications in Mauritius

- Hotels
- Flats

Case study 1

An infiltration basin is to be installed for a hotel resort to treat the runoff from its parking area. The hotel is built on a sandy soil with a hydraulic gradient of 0.75. The total parking area of the hotel is 500 m^2. The design storm is to have duration of 10 min and a return period of 50 years. The basin should be designed to drain within 24 hours.

Step 1: Determining the runoff volume

The Rational method is used to determine the runoff volume. From the rainfall intensity curve (see figure C.1 in Appendix C), for T = 50 years and D = 10 minutes, the rainfall intensity, I = 0.0028 m/min.

From table C.1 in Appendix C, the runoff coefficient, C for asphalt is 0.95. Therefore, using equation C.1 in Appendix C, the runoff volume is:

$$\dot{Q} = 0.0028 \times 500 \times 0.95 = 1.33\ m^3/min$$

For a storm duration of 10 minutes, $Q = 1.33 \times 10 = 13.3\ m^3$

Step 2: Sizing the infiltration basin

From table D.1 in Appendix D, the hydraulic conductivity for a sandy soil can be taken to 4 m/day and given that t = 1 day. Using equation 4.2.2 above, the maximum depth of the basin is,

$$d = 0.5 \times 4 \times 1 = 2.0\ m$$

Using equation 4.2.3 above, the minimum area of the basin should be:

$$A = \frac{13.3}{2.0} = 6.65\ m^2$$

Step 3: Calculating the infiltration rate of the basin

Using equation 4.2.1 above, the infiltration rate of the basin is given as:

$$f = 4 \times 0.75 \times 6.65 = 19.95\ m^3/day$$

Step 4: Checking the infiltration rate

From table 4.1 in section 4.1.3, the typical infiltration rate for sandy soil is between 0.1 to 100 m/h. This corresponds to an infiltration rate of 0.24 to 2,400 m/day. For an infiltration facility of 13.3 m^2, the effective infiltration rate is

$$f_{min} = 0.24 \times 6.65 = 15.96 \text{ m}^3/\text{day}$$

$$f_{max} = 2{,}400 \times 6.65 = 15{,}960 \text{ m}^3/\text{day}$$

Since the infiltration rate obtained in step 3 lies between the minimum and maximum infiltration rates, no further iteration is required.

Step 5: Costs evaluation

Cost elements	**Quantity**	**Unit costs (Rs./unit)**	**Total (Rs.)**
Site clearing	6.65 m^2	20	133
Excavation costs	13.3 m^3	300	3,990
Rocksand	0.998 m^3	1,800	1,796
Grass planting	6.65 m^2	150	998
Other costs (such as costs of inflow and overflow structure)			4,000
Contractor fees			1,635
Total			12,552

4.3 Dry well/French drains

This is a special type of infiltration basin. A dry well is a deep covered hole. The hole acts as an underground storage facility for stormwater until the latter seeps into the surrounding soils. Dry wells collect runoff from small drainage areas and roofs. They are also known as infiltration tubes, French drains, soak-away pits or soak holes.

The storage facility can be in the form of an excavated pit or a structural chamber. The pit or chamber is backfilled with aggregates. Topsoil and vegetation is used as the top cover, thus integrating this BMP with the landscape design.

The small size of dry wells makes them very suitable for retrofits in existing project. They are particularly useful in reducing the volume of stormwater runoff. In Mauritius, soak-away pits have been commonly used in the VRS morcellement schemes where there were no connections to the main sewer lines.

4.3.1 Pre-treatment required

- Filtration in the form of roof gutter guards and aggregates

4.3.2 Design

Designing a dry well requires the calculation of the required storage volume of the well, the size of the well and the time taken for the well to empty half its storage volume. The downpipe used to convey rainwater from the roof to the dry well also needs to be sized. The design procedures provided in this guidebook are based on the guidelines provided by the BRE (BRE, 2003). The design of a dry well is an iterative process and Case study 2 illustrates the use of the equations presented in this section.

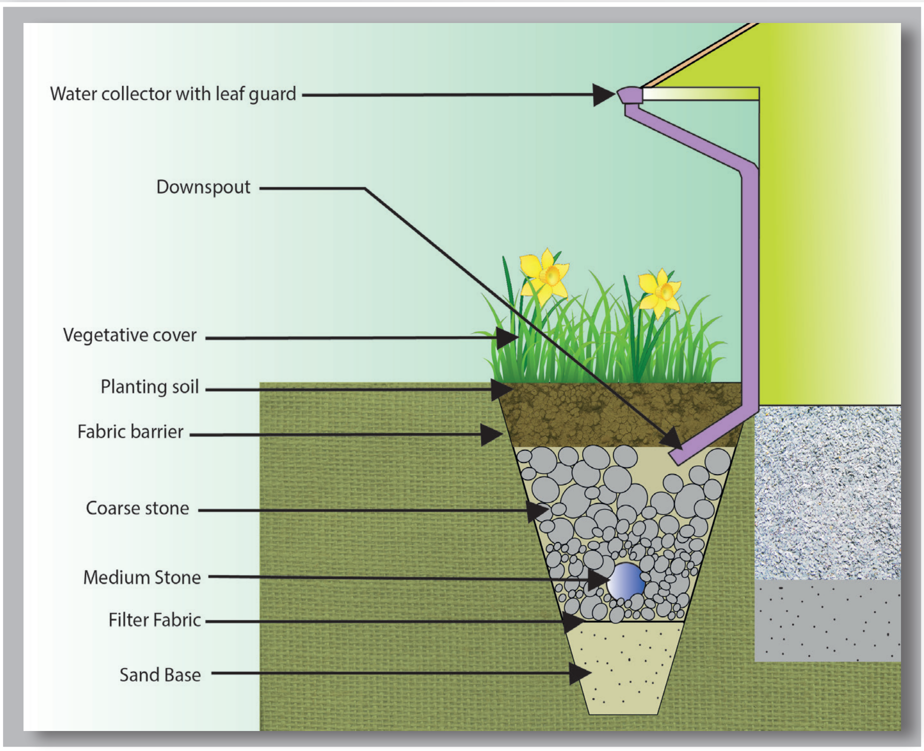


Figure 4.4: Dry well

The storage volume and size of the soakaway is evaluated using the following equations:

$$s = Q - O \qquad \text{Eq. 4.3.1}$$

Where s = dry well storage volume (m^3)
Q = Runoff volume (m^3)
O = Outflow volume (m^3)

The outflow volume is given by:

$$O = a_{s50} \times f \times D \qquad \text{Eq. 4.3.2}$$

Where a_{s50} = interfacial surface area of soakaway pit to 50% storage depth (excluding base area)(m^2)
f = infiltration rate (m/s)
D = Storm duration (s)

The interfacial surface area is calculated as follows

$$a_{s50} = P \times \frac{d}{2} \qquad \text{Eq. 4.3.3}$$

Where P = Perimeter of the soakaway (m)
d = depth of dry well (m)
To evaluate the time taken for emptying half storage volume,

$$t_{s50} = \frac{(s \times 0.5)}{a_{s50} \times f} \qquad \text{Eq. 4.3.4}$$

Where t_{s50} = time taken to empty half storage volume (s)

For residential projects, the following guidelines can be used:

Table 4.4: Downpipe diameter and dry well storage volume

Roof area (m^2)	Downpipe diameter (mm)	Dry well storage volume (m^3)
≤ 50	75	1.5
≤100	90	3.0
≤200	90 – 110	5.6
≥250[1]	110	6.8

[1]For large roof areas it might be necessary to divide the roof into different drainage zones. It is recommended that the downpipe diameter does not exceed 110 mm. Bigger downpipes might spoil the architectural beauty of the building if not well camouflaged.

Notes:

1. Overflows from dry wells must be conveyed safely to other stormwater drainage systems such as the main sewers.

2. Excavation equipment must be placed outside the limits of the dry well to prevent soil compaction.

3. Dry well construction should start only after all other areas that may drain to the dry well are stabilised. This helps prevent clogging by sediments.

4. Provisions should be made for a test well so as to allow inspections.

5. Dry wells should not be located too near to buildings as seepage could cause damage to building foundations. A minimum setback of 5 m should be kept.

6. Very large roofs should be subdivided into different catchment areas.

Maintenance

- Inspections should be carried out at least four times every year and after each storm event exceeding 25 mm.

- Infiltration rates should be checked against the design rates to detect any clogging.

- Stored runoff from an impaired or failed dry well should be pumped out.

- Debris, waste and other sediments should be disposed of in a suitable manner.

Applications in Mauritius

- Residential plots
- Small commercial projects
- Drainage areas less than 4,000 m^2

Case study 2

A dry well is to be designed for a house with a roof area of 100 m^2. From investigations carried out in the trial soakage pit, the infiltration rate of the soil was found to be 2.78 x 10^{-5} m/s. The dry well will be filled with granular material having 30% free volume. Due to the level of the water table, the effective depth of the facility is not to exceed 3.0 m.

Step 1: Determining the runoff volume

The Rational method is used to determine the runoff volume. From the rainfall intensity curve (see figure C.1 in Appendix C), for T = 50 years and D = 10 minutes, the rainfall intensity, I = 0.0028 m/min.

From table C.1 in Appendix C, the runoff coefficient, C for a concrete roof is 1.0. Therefore, using equation C.1 in Appendix C, the runoff volume is:

$$\dot{Q} = 0.0028 \times 100 \times 1.0 = 0.28 \text{ m}^3/\text{min}$$

For a storm duration of 10 minutes, $Q = 0.28 \times 1\ 0 = 2.8 \text{ m}^3$

Step 2: Determining the size and storage volume of the facility

As a first guess, assume that the dry well has a length of 2.4 m, a width of W m and an effective depth of 2.0 m. Hence, using equations 4.3.2 and 4.3.3 above,

$$a_{s50} = 2 \times (2.4 + W) \times \frac{2}{2} = 4.8 + 2\,W \text{ m}^2$$

$$O = (4.8 + 2\,W) \times 2.78 \times 10^{-5} \times 10 \text{ x } 60 = 0.08 + 0.03\,W \text{ m}^3$$

The effective volume of the well is given by:

$$s = 2.4 \times W \times 2 \times 0.3 = 1.44\,W \text{ m}^3$$

Using equation 4.3.1, we get:

$$1.44\,W = 2.8 - 0.08 - 0.03\,W$$

Solving the equation above, we get W = 1.85 m

Rounding up, we get W = 2.0 m

The new storage volume is now:

$$s = 2.4 \times 2 \times 2 \times 0.3 = 2.88 \text{ m}^3$$

$$a_{s50} = 2 \times (2.4 + 2) \times \frac{2}{2} = 8.8 \text{ m}^2$$

Step 3: Determining the time of half emptying volume
Using (eq. 4.3.4)

$$t_{s50} = \frac{2.88 \times 0.5}{8.8 \times 2.78 \times 10^{-5}} = 8{,}890 \text{ s}$$

A time of half emptying volume of 1.6 hours is clearly satisfactory and hence no further iterations is required for the design of the dry well.

Step 4: Cost evaluation

Cost elements	Quantity	Unit costs (Rs./unit)	Total (Rs.)
Site clearing	4.8 m^2	20	96
Excavation costs	2.88 m^3	300	864
Grass planting	4.8 m^2	150	720
Other costs (such as downpipe diversions)			2,000
Contractor fees			560
Total			4,240

4.4 Infiltration trench/gallery

Also known as leaky pipe, infiltration trench is a continuous perforated pipe set at a minimum slope in a stone-filled, level bottomed trench. A variant of the infiltration trench is to have an excavated trench filled with stone aggregates used to capture stormwater. Infiltration trenches act mainly as conveyance system for large storm events while during small storm events, the captured stormwater infiltrates into the surrounding soils through the bottom and sides of the trench. It is very effective in promoting ground water recharge. However, infiltration trenches are not designed to trap sediment and hence pre-treatment is required.

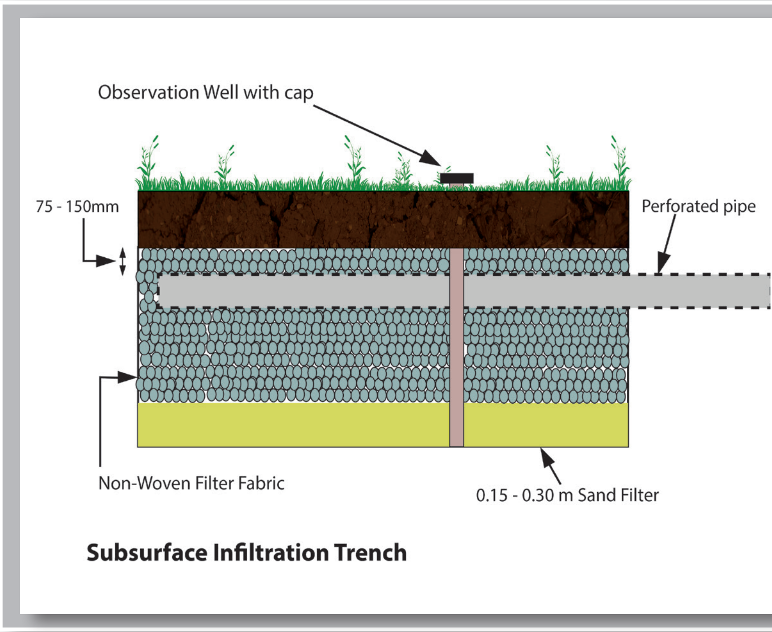


Figure 4.5: Subsurface infiltration trench

4.4.1 Pre-treatment required

- Media filters
- Vegetative filters

4.4.2 Design

To determine the area of the trench, the following equation has to be used:

$$A_t = \frac{Q}{(n \times d) + (0.5 \times f \times t)} \qquad \text{Eq. 4.4.1}$$

Where A_t = area of trench (m^2)

n = soil porosity

d = depth of trench (m)

f = infiltration rate (m/s)

t = time for trench to fill up (s)

Q = runoff volume to be treated (m^3)

Notes:

1. A suitably qualified engineer should be appointed for the design of an infiltration trench.
2. Topsoil and grass can be used to cover the top of infiltration trenches. The topsoil cover should be at least 150 mm.
3. Woody vegetation should be restricted on top of infiltration trenches.
4. Provision for an observation well should be included in the design. The observation well allows the maintenance team to perform visual checks.
5. During construction, the proposed infiltration area should be clearly identified. Heavy equipment and traffic should not be allowed to travel over this area.
6. A sand layer with a minimum depth of 150 mm should be placed at the base of the infiltration trench.
7. The trench should be wrapped in non-woven geo-textile.
8. Infiltration trenches are normally 1.0 – 3.5 m deep and not less than 7.5 m wide.

Maintenance

- Inlets to the trench should be inspected and cleaned at least twice a year
- Vegetation along surface of infiltration trench should be maintained in good condition
- Bare spots have to be re-vegetated as soon as possible
- Vehicles should not to be parked or driven on a vegetated infiltration trench
- The use of mowers should be limited to avoid excessive compaction

Applications in Mauritius

- Used for drainage areas between 4,000 and 20,000 m^2
- Ultra urban areas
- Roofs of buildings
- Adjacent to impervious surfaces such as roads, motorways and paved surfaces

4.4.3 Costs

Infiltration trenches cost between Rs 250 - 1,200/m to implement (CIDB, 2012).

4.5 Regenerative stormwater conveyance system

Regenerative stormwater conveyance system is an ecosystem restoring practice for eroded or degraded outfalls and drainage channels. It is a rather new technique and literature on this measure is quite limited. Using a series of shallow aquatic pools, riffle weir, grade controls, native vegetation, and underlying sand and woodchip beds, regenerative stormwater conveyance systems can be used to treat, infiltrate and convey stormwater. Due to the limited information available and its complex nature, details of the design of this system will not be covered here but has been added for completeness of the guide book.

4.6 Preserving open spaces

This is a non-structural measure and hence does not require any design consideration. Preserving open space aims to retain and restore the site in its native state. This is achieved by:

- Preserving and maintaining natural vegetation
- Limiting changes to the topography of the site
- Identifying and preserving the most sensitive areas
- Minimising the extent of disturbed areas

This measure could also form part of the town planning process by identifying zones where development can take place and delineating buffer ordinances.

4.6.1 Benefits

The main benefit of this practice is that it encourages compact mixed use development. Thus, it helps minimise the percentage of the plot which is to be disturbed. Undisturbed soils are important as they help promote infiltration and filter runoff. The other benefits of preserving open spaces are:

- Reduced drainage area as the area of impervious surfaces is greatly reduced
- Reduced risk of flooding and flood damage
- Reduced stream bank erosion and stream warming
- Enhanced pollutant removal
- Increased property values
- Protection of wetlands associated with the riparian corridor
- Prevention of the steep slope disturbance
- Preserved natural drainage features

4.6.2 Implementation

This stormwater management practice can be implemented at two levels:

National planning level

In Mauritius, the building permit stipulates the minimum setback required from water courses (Table 4.5). Development along mountain reserves and river reserves is subject to the approval of the Ministry responsible for issuing building and land use permits.

Table 4.5: Minimum setback requirements

Reserve	Setback
River	16 m
Rivulet	8 m
Feeder	3 m
Coastal	30 m from high water mark

Local authorities should carry out regular inspections to ensure that designated buffer zones and green belt areas are being respected and not being endangered by construction and development activities.

Project planning

This level applies more to large project development. The project team should carry out a natural resource inventory. This resource inventory will normally form part of the EIA process in Mauritius. The project developer should also ensure that fragmented development on site is avoided. Areas that are to be protected should be clearly earmarked on site plans and during construction, these areas should be fenced.

4.7 Green roof

Green roofs sometimes refer to the combination of roofing solutions which help to reduce heat gains through roofs. It can include different products such as roof pavers or the use of tiles as roofing materials. However, in this guidebook, the term is restricted to the definition of vegetated roofs.

Green roofs, eco-roofs, living roofs or vegetated roofs refer to the practice of partially or totally covering a roof's surface with vegetation or a growing media. They are a popular feature in many sustainable buildings as they:

- Help in improving stormwater quality
- Reduce the temperature of stormwater runoff
- Reduce the urban heat island effect
- Provide acoustic insulation
- Increase the effectiveness of the fabric insulation
- Increase the longevity of the roofing system
- Help in restoring wildlife habitat in an urban landscape

Although green roofs do not directly promote ground water recharge, the design of green roofs is included as it helps control stormwater quality through the process of infiltration. The role of green roofs in stormwater management is as follows:

1. Stormwater quantity control: The growing media absorbs and retains water as it rains. Once saturated, the excess water is drained from the roof into the overflow system.

2. Stormwater quality control: As the water infiltrates, the growing media acts as a filter to remove pollutants from the runoff.

Green roofs are categorised into:

Extensive roof

Extensive roofs are a lightweight vegetative system. The growing medium has a depth of 100 – 125 mm. Extensive roofs are not a high maintenance system and are usually vegetated by drought tolerant species. An extensive roof is a self-sustaining system and does not usually tolerate a high level of pedestrian traffic.

Intensive roof

Intensive roof have a greater soil depth typically between 150 mm to 1.2 m. They are designed to support a wider range of plants as well as a high volume of pedestrian traffic. Intensive roofs effectively act as an extension to the outdoor living space and can be used to carry out leisure and recreational activities.

4.7.1 Pre-treatment required

No pre-treatment is required.

4.7.2 Design

A green roof consists of the following different layers. Table 4.6 and figure 4.6 show the different layers arranged from the topmost layer to the bottommost layer.

Table 4.6: Layers constituting a green roof

Layer	Function
Plant cover	Plants which are slow-growing, shallow-rooted, and resistant to harsh weather conditions should be used.
Growing media	The growing media consists mainly (≥ 80%) of inorganic materials such as clays, pumice or scoria. The rest of the growing media consists of organic matter. The depth of the growing media depends on the nature of the green roof.
Root permeable filter fabric	This filter fabric helps prevent the clogging of the drainage system by preventing the transport of pollutants. A semi-permeable polypropylene filter fabric can be used to make the filter fabric.
Drainage system	The drainage system evacuates the excess water that the growing media has not been able to absorb
Root barrier	The root barrier protects the waterproofing layer from damage caused by root penetration. Root barriers impregnated with pesticides, metals or other chemicals could leach into excess stormwater runoff and should thus be avoided.
Insulation layer	This optional layer can be placed above or below the waterproofing layer. The insulation layer helps improve the energy efficiency of buildings and is mostly used for the metal roofs.
Waterproofing layer	Waterproofing is essential to prevent water damage to the building.
The roof/deck layer	Roofs made of concrete, wood, metal, plastic, gypsum or a composite material can be used as the foundation for the green roof. The material used for the roof deck determines the load bearing capacity of the green roof and the need for any insulation.

To estimate the volume of stormwater retained by the green roof, the following equation can be used:

$$V_S = A_R \times d \times n \qquad \text{Eq. 4.7.1}$$

Where

V_S = storage volume (m^3)

A_R = vegetated roof area (m^2)

d = depth of growing media (m)

n = media porosity (as per manufacturer's specification)

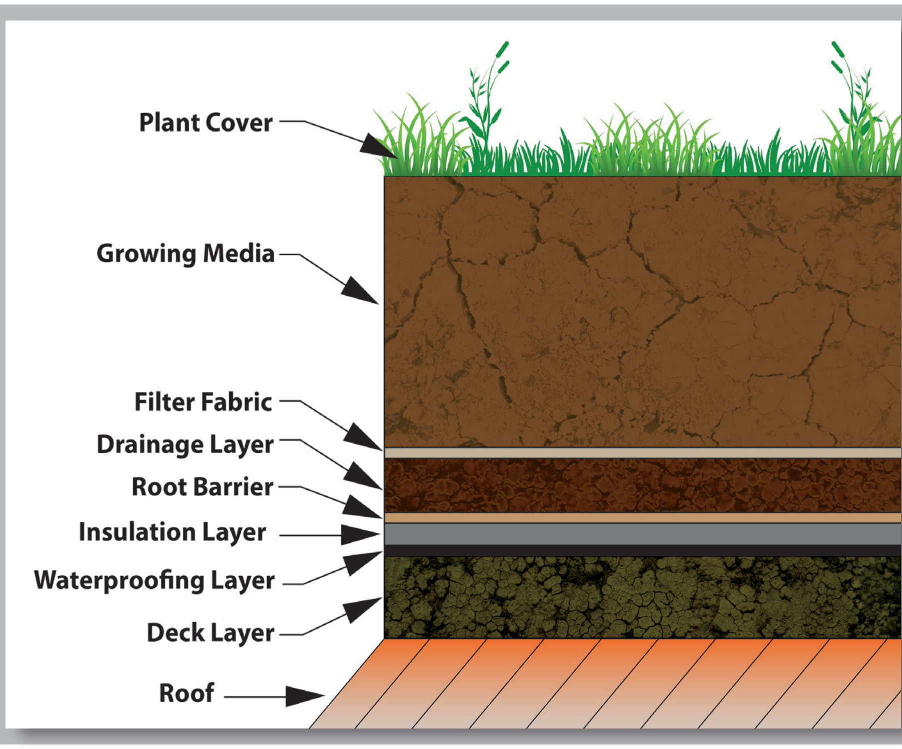


Figure 4.6: Green roof

Notes:

1. Green roofs can be implemented on both flat and pitched roofs. On flat roof, a slight slope of about 2% is required to drain excess water. For roofs with a pitch greater than 25%, baffles, grids and strips should be used to prevent the slippage of media.
2. A structural engineer should certify the load bearing capacity of the roof before the installation of an intensive roof.
3. A minimum 0.5 m wide vegetation free zone is required between green roof and electrical and HVAC systems.
4. Intensive green roofs require continuous maintenance.

Maintenance

1. Weed control is required to maintain the health of the green roof. During the first two years, weeding can occur on a monthly basis until it's frequency is reduced to once a year.
2. A slow-releasing fertiliser can be used to avoid soil acidity.
3. Intensive green roofs might require irrigation during the dry season to maintain the vegetation cover. Water collected from rainwater harvesting systems can be used for irrigation.
4. Roof gutters should be cleaned regularly to avoid formation of stagnant pools of water.
5. An electronic water leak detection system might be required to prevent water damage to the buildings.

Applications in Mauritius

- Residential projects
- Office buildings
- Schools
- Industrial buildings

4.7.3 Costs

Being a specialist design, the cost of green roofs depends on the project size and customer requirements. Typical rates for green roofs are:

Table 4.7: Costs of green roofs

Green roof	Costs (Rs./m^2)
Extensive roof	2,000 – 2,500
Intensive roof	7,000 – 10,000

4.8 Stormwater swales

Stormwater swales or water quality swales are long, narrow and gently sloping vegetated depressions. When it rains, runoff collects in these depressions. The collected runoff is stored before conveyance to other management facilities. Swales are classified either as bioretention facilities or vegetative filters. Although mainly used to control stormwater quality, swales can also be designed to encourage infiltration.

The different types of stormwater swales are:

Standard conveyance swale

Standard conveyance swales are broad, shallow vegetated channels. They are an alternative to piped or open drains. Standard swales direct and convey runoff to other management facilities.

Wet swale

Wet swales are similar to conveyance swales but allow detention of stormwater. Sometimes, an under-drain is installed so as to transfer overflows. Wet swales remain dry most of the time but during wet weather, a pool forms in the depression. Check dams retain the water in the pools and hence prevent flooding. Wet swales are a preferred option where the water table is very close to the surface.

Dry swale

Dry swales are vegetated conveyance channel, designed to encourage infiltration. As opposed to wet swales, dry swales consist of several layers which allow water to filter and infiltrate the ground. Thus, water does not stand for a long time in dry swales. Since they directly promote infiltration, the following sections focus on the design of dry swales.

4.8.1 Pre-treatment required

- Plunge pools
- Filter strips

4.8.2 Design

The different layers in a dry swale are the vegetated top cover, the prepared soil layer and the gravel layer. Swales have a trapezoidal, triangular or parabolic cross-sectional shape as shown in figure 4.7. These shapes are chosen as they are easy to construct and maintain. The sides of the swale should have a slight flow to promote sheet flow in the swale. A slope no greater than 1 in 4 is recommended.

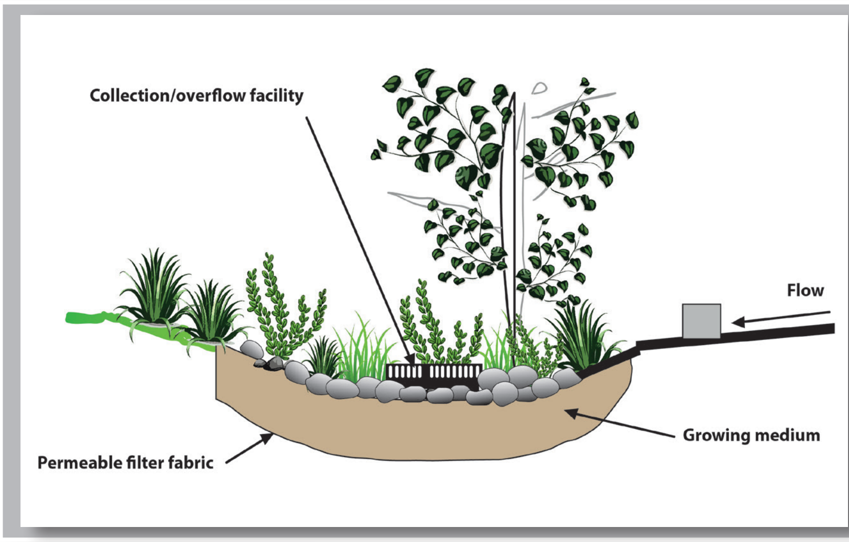


Figure 4.7: Stormwater swale

The design of a stormwater swale is an iterative process.

The most important parameter to consider is the maximum flow velocity in the swale. To determine the average velocity in the swale, the Manning's equation should be used:

$$\dot{Q} = \frac{A \times R^{2/3} \times S^{1/2}}{N} \qquad \text{Eq. 4.8.1}$$

Where $\dot{Q}$ = flow rate (m^3/s)

A = area (m^2)

R = Hydraulic radius [1] (m)

S = Overall slope of channel (m/m)

N = Manning's coefficient [2] ($m^{-1/3}s$)

Typical values for swale dimensions are:

Table 4.8: Typical dimensions of stormwater swale

Depth (mm)	400 – 600
Width (m)	0.5 – 2.0
Length (m)	≥ 30

[1] See appendix D for more details

[2] See appendix D for more details

Notes:

1. The maximum flow velocity should not exceed 0.3 m/s.
2. For above-grass flow, N can be assumed to be 0.1 $m^{-1/3}s$.
3. An under-drain below the swale is highly recommended so as to convey flow exceedance.
4. Level spreaders should be used to uniformly distribute stormwater across the swales.
5. The base of the swale should be flat.
6. A suitably qualified engineer should be appointed for the design of swales.

Maintenance

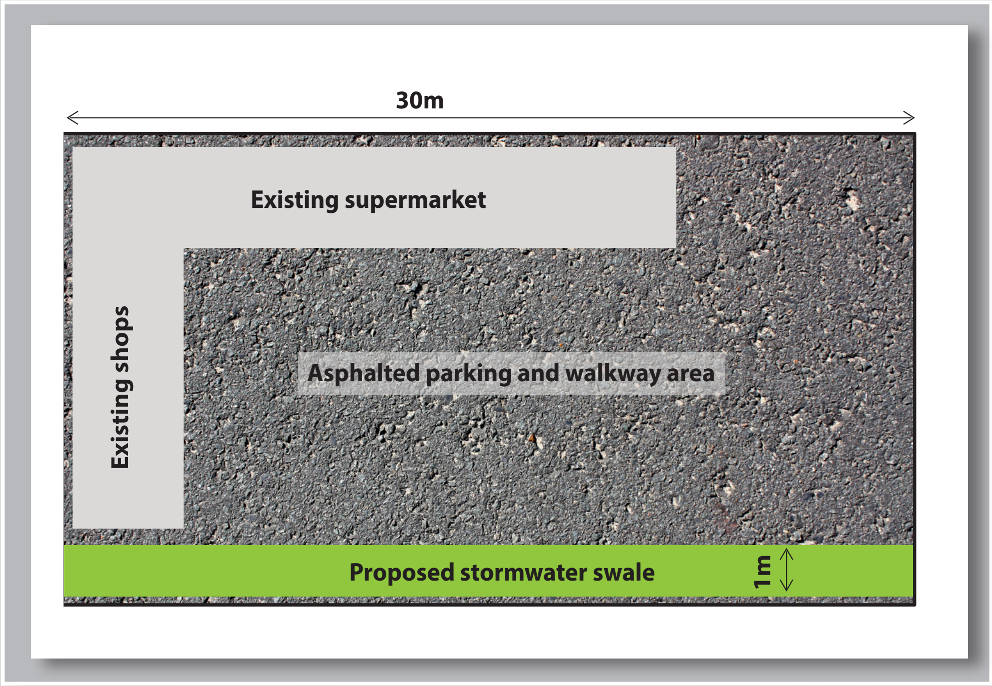
1. Regular sweeping of impervious surfaces to remove litter and debris
2. Regular cutting of grass to maintain grass height within specified design height
3. Controlling of vegetation and nuisance plants
4. Reseeding and re-turfing of bare spots resulting from erosion
5. Limiting the use of fertilisers and pesticides to avoid ground water contamination
6. Inspecting inlets, outlets and overflows to remove sediment build up
7. Verifying that infiltration surfaces are not compacted and clogged by silt accumulation

Applications in Mauritius

- Islands and medians in parking lots
- Along streets and roads
- As rain swales in residential development

Case study 3

A commercial centre has been built on a plot of land 30 m long and 20 m wide. The total built up area for this shopping centre is 125 m^2 and the rest of the site has been asphalted. In order to reduce the volume of runoff being conveyed to the storm drains, a stormwater swale 30 m long, 1m wide and 0.4 m deep has been proposed as shown.



Step 1: Area determination

$$\text{Area of stormwater swale} = 30 \times 1 = 30\ m^2$$

$$\text{Asphalted area after implementation of swale} = (30 \times 20) - (125 + 30) = 445\ m^2$$

Step 2: Determining the runoff volume after implementing the stormwater swale

The Rational method is used to determine the runoff volume from the roof and asphalted surface. From the rainfall intensity curve (see figure C.1 in Appendix C), for T = 50 years and D = 10 minutes, the rainfall intensity, I = 0.0028 m/min.

From table C.1 in Appendix C, the runoff coefficient, C for asphalt is 0.95 while that for a concrete roof is 0.85. Therefore, using equation C.1 in Appendix C, the runoff volume after implementing the stormwater swale:

$$\dot{Q}_{roof} = (0.0028 \times 125 \times 0.85) = 0.298 \text{ m}^3/\text{min}$$

$$\dot{Q}_{asphalt} = 0.0028 \times 445 \times 0.95) = 1.184 \text{ m}^3/\text{min}$$

$$\dot{Q}_{total} = 0.298 + 1.184 = 1.482 \text{ m}^3/\text{min}$$

For a storm duration of 10 minutes, $\dot{Q} = 1.482 \times 10 = 14.8 \text{ m}^3$

Step 3: Volume treated by stormwater swale

$$\text{Volume of stormwater swale} = 30 \times 0.4 = 12 \text{ m}^3$$

Therefore, retrofitting the site with a stormwater swale of 30 m^2 can reduce runoff by up to 80%.

Step 4: Costs estimation

Cost elements	Quantity	Unit costs (Rs./unit)	Total (Rs.)
Breaking of tarmac	30 m^2	200	6,000
Excavation costs	12 m^3	300	3,600
Geotextile	55 m^2	125	6,875
Excavation costs	12 m^3	300	3.600
Geotextile	30 m^2	125	3,750
Rocksand	4.5 m^3	1,800	8,100
Topsoil	4.5 m^3	400	1,800
Shrubs	15	150	2,250
Main contactor			4,300
Total			32,925

4.9 Stormwater planter

Stormwater planters are a form of vegetative filter and are a bio-retention measure. They are a self-contained long and narrow landscaped area with flat unsloped bottoms. Planters are deeper than swales and hence can store more water. There are two types of planters: infiltration planter and flow through planters. A variant of the stormwater planter is the tree pit. Stormwater planters are popular in urban developments as they do not take a lot of space and add to the aesthetic value of the development.

Infiltration planter

Infiltration planters are also known as planter box rain gardens. They are open bottomed structures which temporarily store stormwater on top of the soil. The stored stormwater then slowly infiltrates into the ground. The design section contains more details on infiltration planters.

Flow-through planter

Flow-through or filter planters are structures with an impervious bottom. These planters are filled with gravel and soil and have a waterproofed lining. They are mainly used as a filtration practice. Under-drains located below the planters help in conveying excess stormwater.

4.9.1 Pre-treatment required

- Roof gutter guards if planter receives runoff from roofs

4.9.2 Design

The infiltration planter is about 900 - 1 000 mm deep and typically consists of the following layers:

- 50 mm gravel/mulch
- 400 mm of a sand and soil mixture
- 100 mm sand
- 200 mm gravel

This leaves about 200 mm above for the storage of water. As a general rule, 1m^2 of planter area can serve up to 50m^2 of impervious drainage area.

The containing walls of the planters are made of concrete, brick or stones. Wooden or metal containers can also be recycled and used to contain the planter box rain garden.

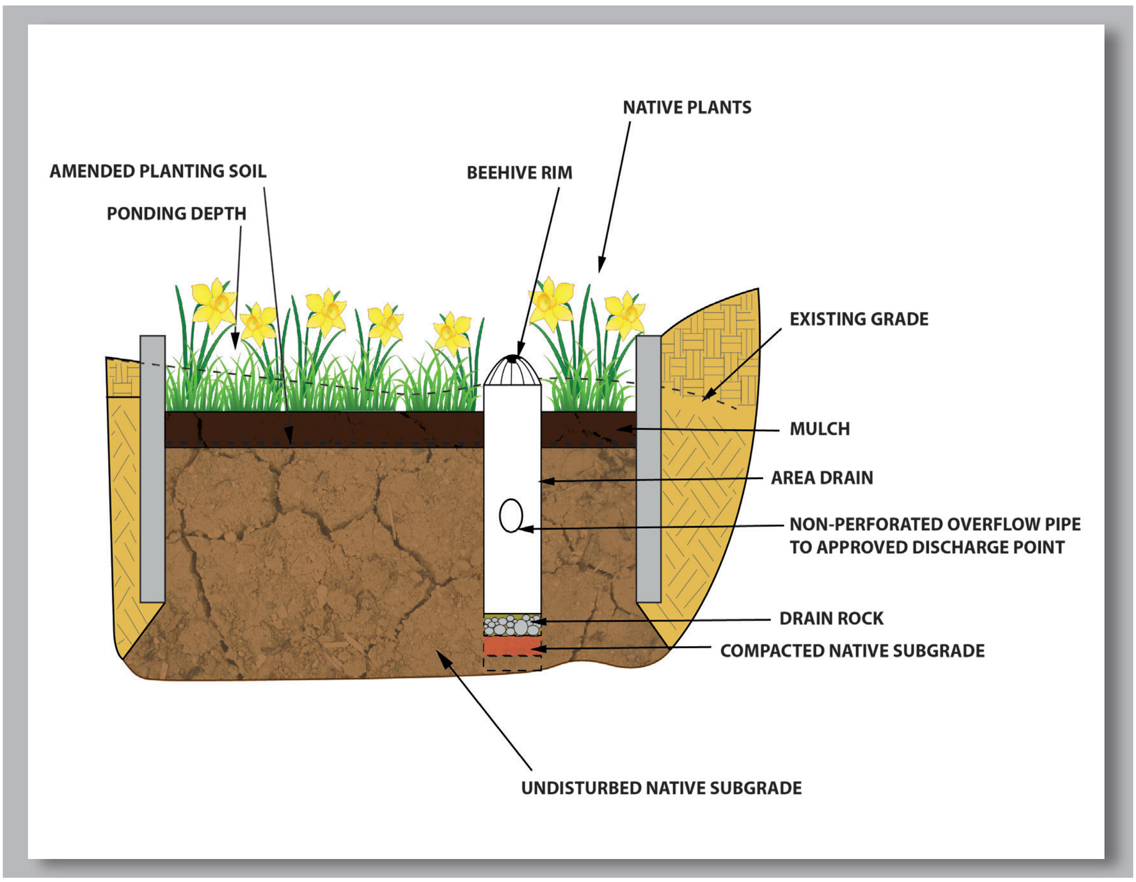


Figure 4.8: A typical stormwater planter

Notes:

1. A minimum setback of 300 mm from buildings is required.

2. Weed control helps in maintaining the health of the vegetation.

3. Native and drought tolerant plants should be selected to minimise the need for permanent vegetation.

Maintenance

1. Regular cleaning of the inlets is necessary to maintain proper drainage.

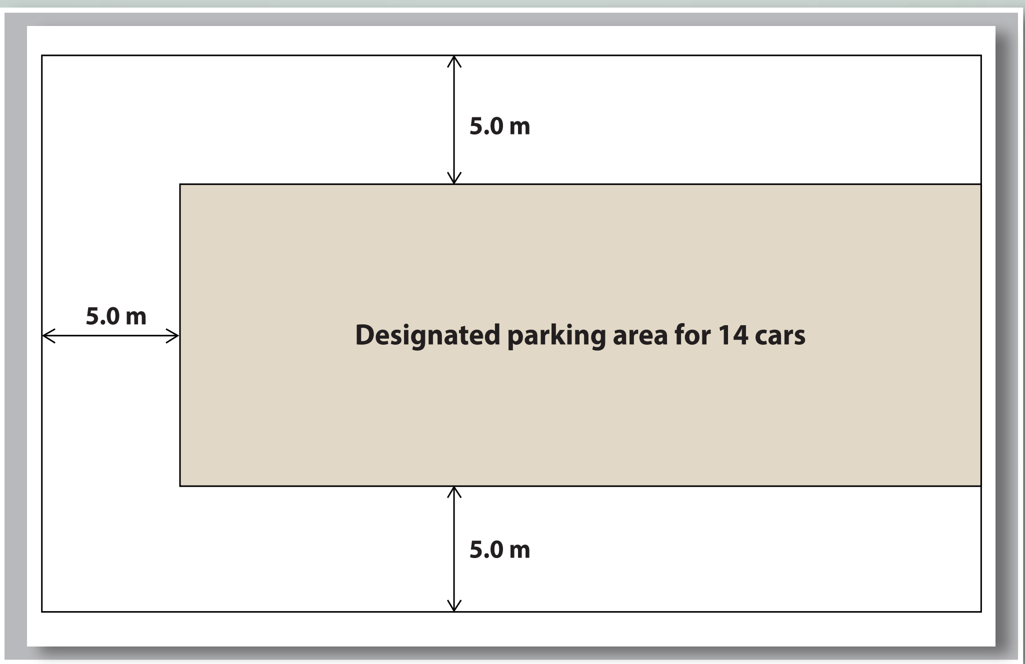
2. Regular inspection is necessary to detect any damage to the structures.

Application in Mauritius

- Street design
- Parking design
- Residential projects

Case study 4

Stormwater planters are to be designed for the parking of a small commercial building. The parking should be able to accommodate a maximum of 14 cars. Around the parking plot, a minimum of 5 m asphalted clearance is required to allow for vehicle access (as shown in the figure below). It is required to determine the minimum area for the stormwater planter.



Step 1: Determining the minimum parking area

The size of a parking slot for a car is assumed to be 2.5 m wide and 5.0 m long.

$$\text{Required area for parking slots} = 2.5 \times 5.0 \times 14 = 175 \text{ m}^2$$

Assuming that the parking will consist of 2 rows of 7 cars each,

$$\text{Length of parking lot} = 7 \times 2.5 = 17.5 \text{ m}$$

$$\text{Width of parking lot} = 2 \times 5 = 10 \text{ m}$$

Hence, the total asphalted area of the parking is:

$$\text{Length of parking plot} = 17.5 + 5 = 22.5 \text{ m}$$

$$\text{Width of parking plot} = 10 + 5 + 5 = 20 \text{ m}$$

$$\text{Total asphalted area} = 22.5 \times 20 = 450 \text{ m}^2$$

Step 2: Determining the minimum planter area required for stormwater management

Using the rule of 1 m^2 of planter for every 50 m^2 of asphalted surface,

$$\text{Planter area} = 450/50 = 9 \text{ m}^2$$

Step 3: Cost calculations

For a 9 m^2 stormwater planter, the cost of material required is:

Cost elements	**Quantity**	**Unit costs (Rs./unit)**	**Total (Rs.)**
Excavation costs	6.75 m^3	300	2,025
Aggregate	2.25 m^3	900	2,025
Soil mixture	3.60 m^3	300	1,080
Rocksand	0.9 m^3	1,800	1,620
Shrubs	2	100	200
Contingencies			2,000
Main contractor			1,300
Total			10,250

4.10 Pervious paving systems

Pervious paving systems produce less stormwater than conventional paved areas. The different types of pervious paving systems are:

1. Impervious concrete pavers with surface voids – water from impervious surfaces infiltrate the ground through these voids. To improve the infiltration process, sand, gravel or narrow grass strips are used to fill these void spaces.

2. Porous concretes or asphalts – these are special engineered materials in which the finer-grained particles are screened out. This leaves voids between the large aggregates which allow water to pass through.

Figure 4.9: Porous asphalt [1]

4.10.1 Pre-treatment

- Vegetative filters – to remove suspended solids and prevent clogging of the system.
- Runoff collected from impervious surfaces and should be conveyed directly to the paving.

4.10.2 Design

Being a highly specialist system, the design of permeable paving system is not covered in this guidebook. As a general rule, the engineer should consider the following factors before designing the permeable pavement or road system:

- Anticipated traffic intensity
- Storage capacity and retention time of the underground reservoir (if any)
- Strength of the sub-base soil

Detailed design procedures are documented in pavement design guidebooks such as Guide for design of pavement structure (ASHTO, 1993).

[1]http://t0.gstatic.com/images?q=tbn:ANd9GcRKPC5I5rurO11CHq1Fh8iWVdiqr1-reT3aGbUDi807Epr7InFfKA

Notes:

1. A suitably qualified engineer should design the pervious paving system.

2. An under-drain system should be included in the design if slow infiltration rates are expected.

3. The pavement surface and reservoir bottom should be level.

4. The ratio of contributing impervious area : permeable pavement ≤ 2:1.

Maintenance

1. Annual inspection of surface cover to detect cracks, subsidence, spalling, deterioration, erosion and growth of unwanted vegetation.

2. Remove mud or sediment tracked onto the surface as soon as possible.

3. Use high pressure hosing to dislodge sediment and other particulate matter.

4. Regularly mow and trim turf grass integrated with the permeable paving system.

Applications

- Vehicular access for residential driveways or service and access driveways
- Buggy paths and parking in golf courses
- Parking facilities
- Bicycle and pedestrian access

4.11 Rain gardens

Rain gardens are one of the simplest forms of bioretention. They are often used along with other stormwater management practices such as downspout disconnection and rainwater harvesting, where rooftop runoff and overflows from rainwater harvesting systems are diverted to irrigate the rain gardens. Rain gardens are beneficial as they have a small footprint, make use of underutilised land and add an aesthetic value to the development.

Rain gardens can be of four different types:

Infiltration garden

These are gravel filled trenches designed to receive waters directly from rooftops and other impervious surfaces.

In-ground lined gardens

These gardens are specifically designed as a filtration practice. This engineered garden consists of a layer of gravel, followed by a soil-sand mixture, and a slotted pipe in the final gravel screening layer before the PVC liner.
Filtration occurs as the rain passes through the layers of gravel, sand and soil. The slotted pipe conveys the filtered runoff to downstream management practices. The PVC liner prevents the water from infiltrating into the existing soil. In-ground lined gardens can act as a pre-treatment to other stormwater management practices.

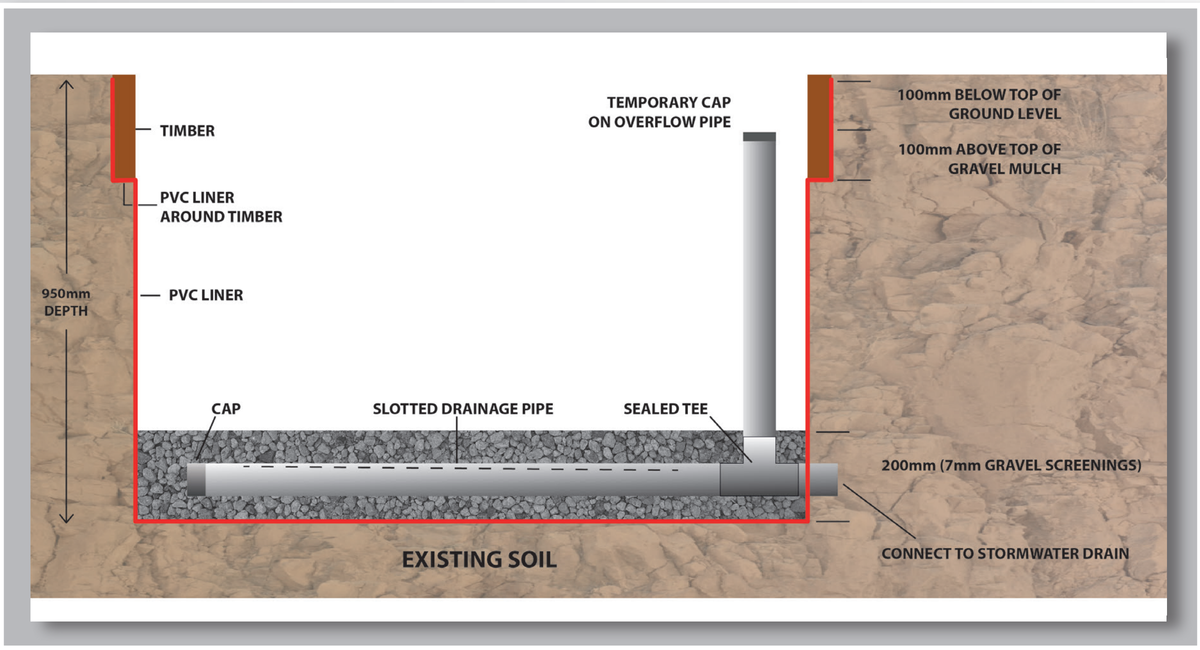


Figure 4.10: Cross - section of an in - ground lined garden

Stormwater planter

This type of rain garden is described in section 4.9.

Rain swale

Rain swales are vegetated conveyance which channel water away from the receiving point.

This section of the guidebook deals with the design of infiltration gardens.

4.11.1 Pre-treatment

- Roof gutter guards if receiving water from roofs

4.11.2 Design

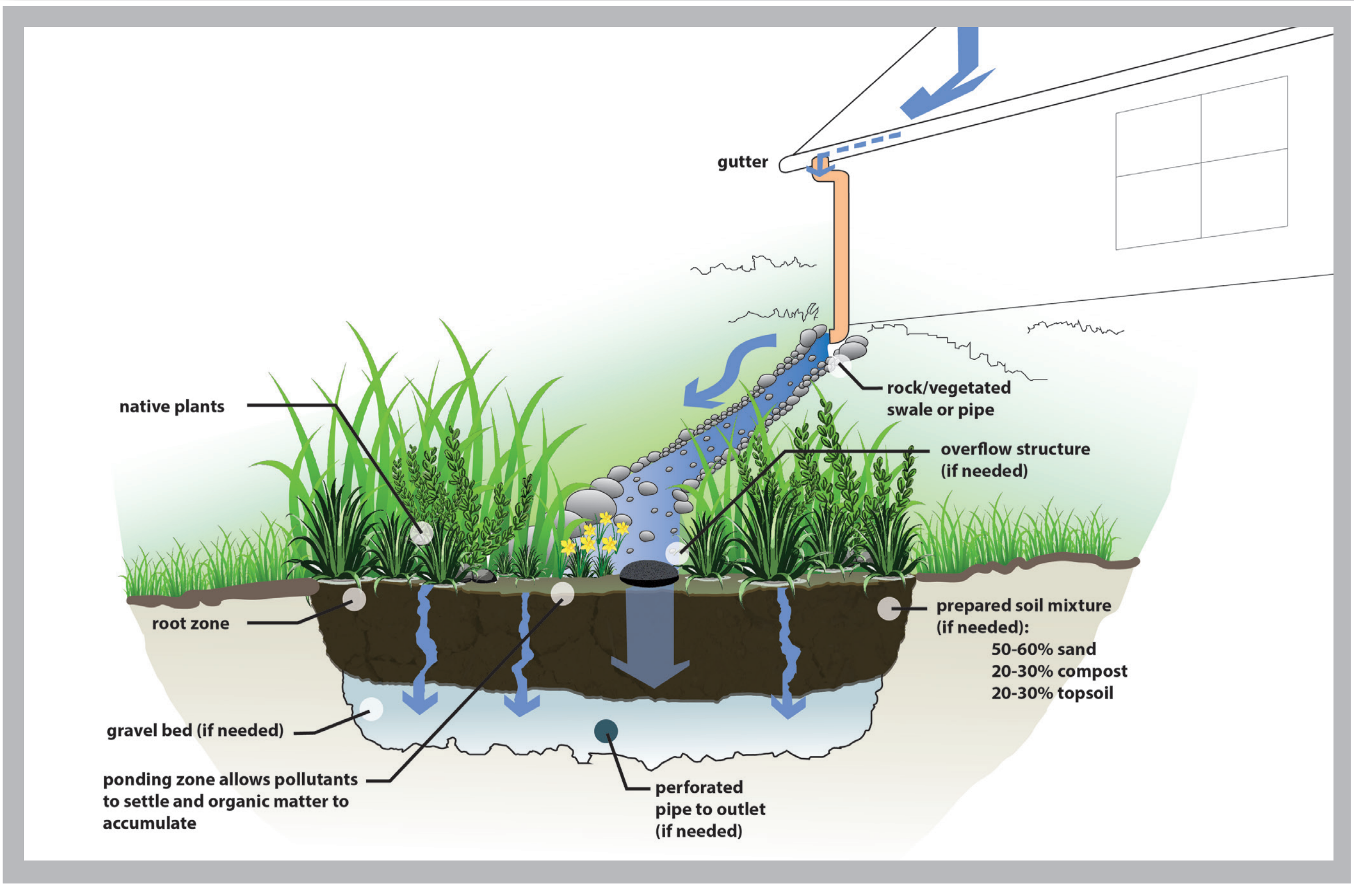


Figure 4.11: A rain garden for a house

As a general rule, the infiltration garden should be 2 – 4% of the contributing runoff area, and have a width of at least 1.0 m. The area of the infiltration garden can be determined using table 4.9:

Table 4.9: Typical areas of rain gardens

Contributing area (m^2)	Area of infiltration garden (m^2)	
Soil infiltration rate (mm/h)	**~ 100**	**≤ 3.6**
50	2	2
100	3	4
150	4	6
200	6	8
250		10
300	9	12

Building an infiltration garden requires the excavation of a trench. The trench should have a side slope (batter) to help channel runoff to the trench. The slope of the batter and the depth of the infiltration trench is shown in the diagram below.

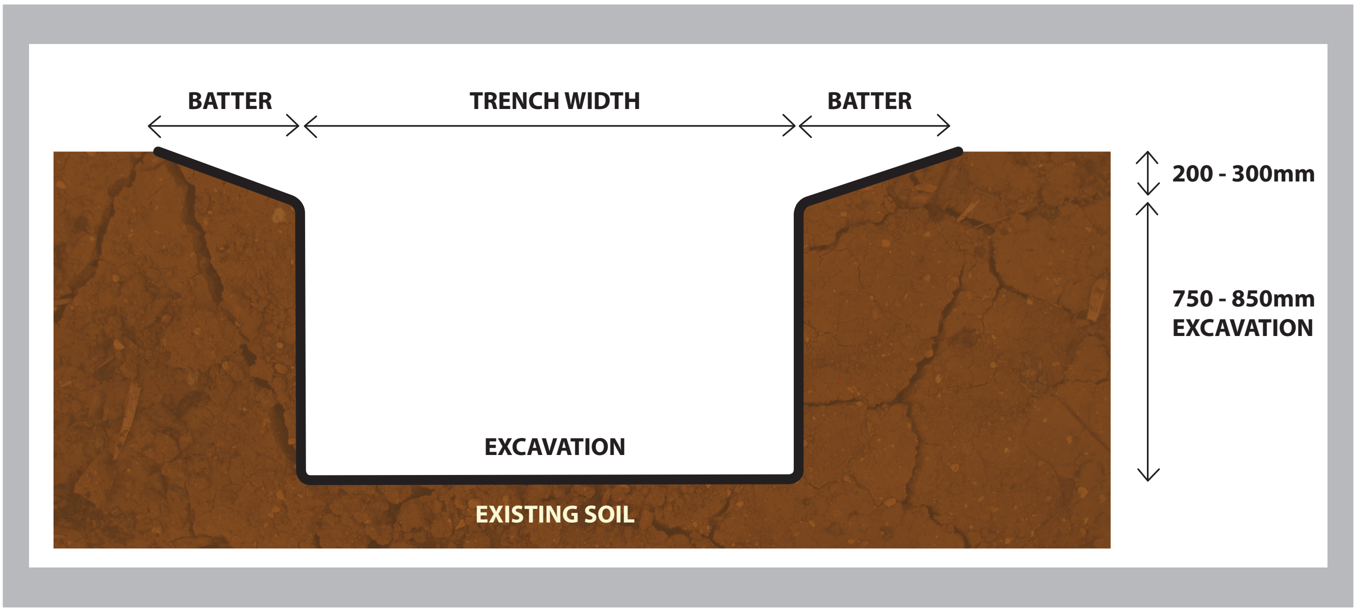


Figure 4.12: Cross - section of a rain garden

The excavated trench is filled with different layers which help filter the runoff before it infiltrates into the surrounding soils. The different layers from bottom to top are:

- 300 - 400 mm hardcore filling
- 7 mm aggregate
- 300 mm sand or soil
- 50 mm mulch
- 200 - 300 mm aggregate

Suitably adapted vegetation should be planted in the infiltration garden.

Notes:

1. A buffer of 5 m should be kept between the infiltration garden and permanent building structures. If this cannot be respected, the side of the trench nearer to the permanent structures should be PVC lined.

2. The design may include an overflow system to prevent flooding of the rain garden.

3. Strategically placing rocks prevents soil erosion and evenly distributes water in the garden.

Maintenance

1. Regularly cover the rain garden with mulch to retain moisture.

2. Ensure that the overflow system (if any) is not blocked.

3. Inspect garden regularly to replace plants and remove weeds.

4. Water the garden regularly until vegetation has been established.

Applications

- Street design
- Parking lot design
- Residential projects
- Small office development

Case study 5

An infiltration garden is to be designed for a rain garden for a single family house. The rain garden is being used to divert roof runoff from the mains sewer drains. The contributing roof area has been determined to be 250 m^2 and the surrounding soil has an infiltration rate of 2 mm/h.

Step 1: Determining the minimum area of the rain garden

Using table 4.9, for a roof area of 250 m^2 and with soil with an infiltration rate of 2 mm/h, the minimum area from the rain garden is 10 m^2.

Step 2: Cost evaluation

For a 10 m^2 rain garden, the volume of material required is:

Cost elements	Quantity	Unit costs (Rs./unit)	Total (Rs.)
Excavation costs	10 m^3	300	3,000
Hardcore filling	3 m^3	600	1,800
Aggregate	6 m^3	900	5,400
Sand/soil	3 m^3	From excavation	-
Mulch	5 m^3	500	2,500
Shrubs	5	150	750
Contingencies			1,000
Main contractor			1,500
Total			11,090

4.12 Stormwater curb extensions

Stormwater curb extensions are traditionally used to protect pedestrians from traffic. However, they also contribute to managing stormwater by conveying, slowing, filtering rainwater before it reaches the main drains. Plants grown in the curb extension help in diverting rainwater from the main drains by encouraging infiltration. Also known as curb bulb outs, chokers or chicanes, curb extensions are popular in highly residential areas or in the vicinity of schools as they help in calming the traffic.

4.12.1 Pre-treatment

- Filter strips

4.12.2 Design

Stormwater curb extensions work in a similar manner as swales or planter and hence the same principles as for the design of swales and planters can be used. As a general rule, the following design parameters can be used:

- Depth of the planted area should not be greater than 30 cm.
- The width of the curb extension should be at least 90 cm.
- To allow infiltration, the bottom of curb extensions should not be sealed.

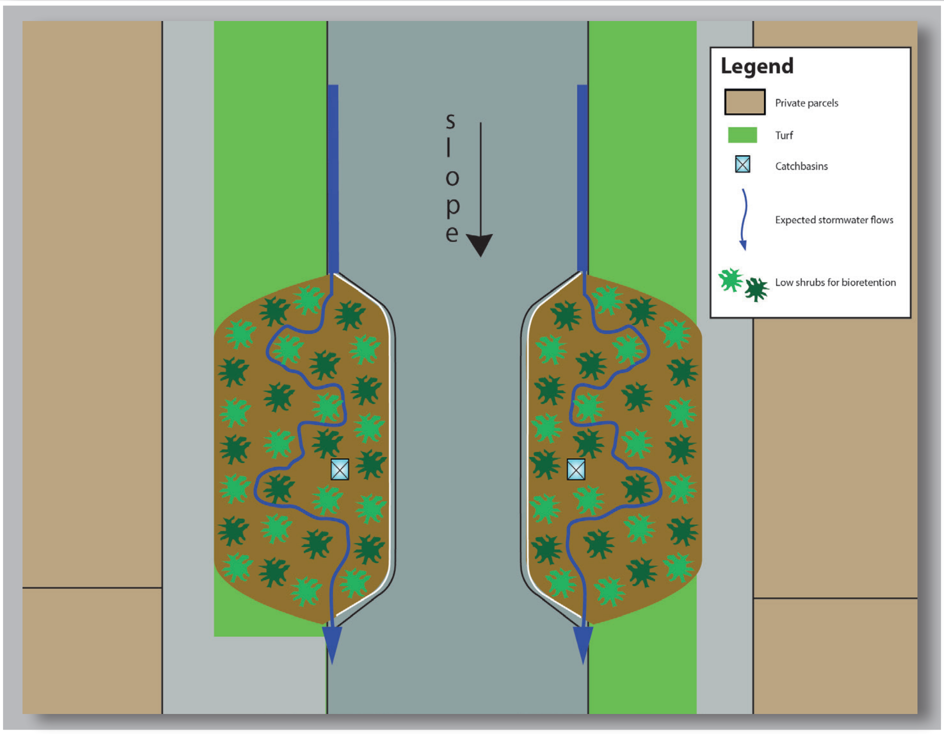


Figure 4.13: Stormwater curb extension

Maintenance

1. Remove debris regularly to prevent clogging of entry and exit ways.

2. Check regularly for signs of erosion.

3. Weed and trim plants to maintain vegetation health.

Applications

- Street design, particularly for one - way streets

4.12.3 Costs

Concrete curbs typically cost between Rs 600 - 800 / linear m.

4.13 Downspout disconnection

Downspout disconnection is mainly a retrofit measure to manage stormwater for small developments. It mostly concerns buildings whose downspouts or gutters are connected to the main drains or discharge onto the streets. Through downspout disconnection, roof runoff is diverted from the main stormwater conveyance and is instead directed onto permeable areas such as lawns. This practice can be easily integrated with other best management practices such as rain water harvesting, rain gardens, dry wells or stormwater planters.

4.13.1 Pre-treatment

- Roof gutter guard

4.13.2 Design

The simplicity of this measure implies that a lot of design is not required to implement this measure. As a general rule, for small residential projects, each downspout should serve about 45 m^2 of contributing roof area. An example of how to alter an existing gutter to be used for downpipe diversion is shown in the figure 4.14. For larger projects, the sizing of the gutters and downpipes should be in accordance with BS EN 12056:3-2000.

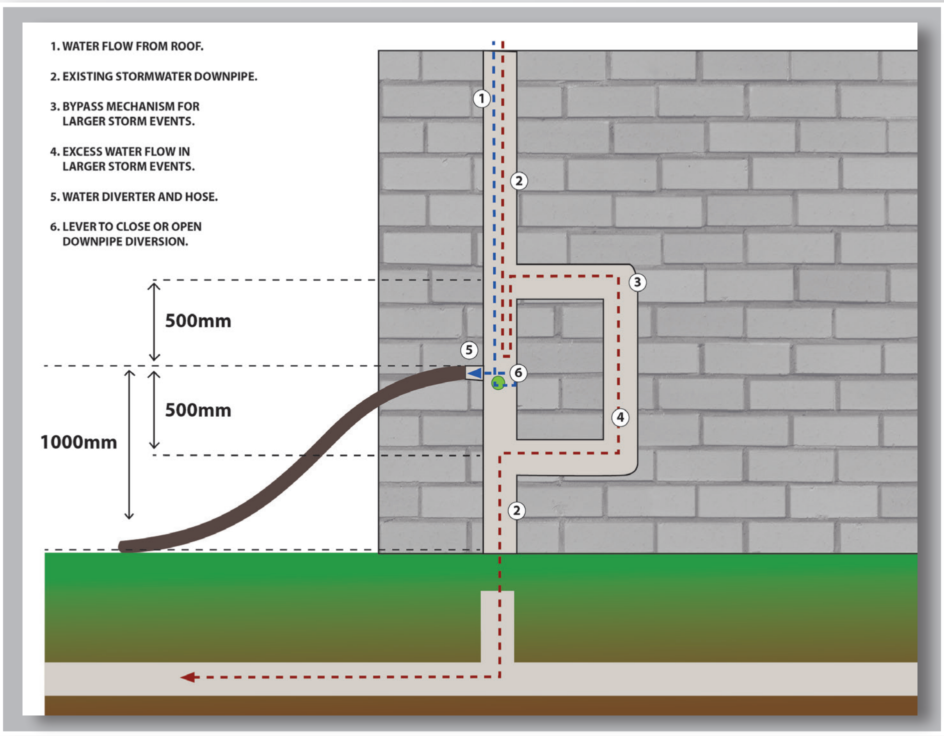


Figure 4.14: Downspout disconnection

The minimum setback for the discharge of the diverted runoff from buildings for different soil types is given in the table 4.10:

Table 4.10: Minimum setback for different soil types

Soil type	Minimum setback (m)
Sand	1
Loam	2
Medium sand	4
Clay	5

Notes:

1. All alterations to downpipes should be carried out by a suitably qualified plumber.
2. Downpipes should always be diverted onto grassed or vegetated areas so as to promote infiltration.
3. Downpipes located where the surrounding ground slopes towards the building should not be diverted.
4. Level spreaders can be used to achieve an even distribution of the runoff onto the pervious surface.

Maintenance

1. Monitor the downpipe diversion to ensure that the site and neighbouring properties are not flooded.
2. Regularly check and clean the roof gutter to prevent blockages.

Application

- Residential buildings
- Small commercial developments

Case study 6

Roof runoff for a small house is to be diverted to an existing stormwater planter built on medium sand soil. The house has two downspout connections each serving 40 m^2 of the roof area. The distances between the planter and the roof gutters are 3 m and 5 m away respectively. The stormwater planter has an overall vegetated area of 5 m^2.

Step 1: Determine the volume of runoff that can be diverted to the planter

From the rule given in 4.9, the maximum contributing roof area is $5 \times 50 = 250$ m^2

The total roof area of the house is $2 \times 40 = 80$ m^2

Since the roof area is less than the maximum contributing roof area and the two downspouts are located within the required minimum setback, both downpipes can be diverted.

4.14 Compost and amended soils

Amended soils or soil restoration is a post-construction measure used to maintain and restore soil qualities to pre-construction condition. It is a non-structural method of recovering and restoring the porosity of soils with low infiltration capacity such as heavily compacted soils. The water holding capacity of soils can be improved by adding the following compounds:

- Compost
- Topsoil
- Lime
- Gypsum
- Fibres (used for structural support)
- Sand
- Organic material other than compost

The choice of compound used to amend soils and the quantity to be used depends depend on the type of plant to be grown. It is therefore recommended that a landscape architect or experienced gardener be consulted before proceeding with soil amendments.

4.14.1 Benefits

The key benefits of soil restoration practices are:

- Increased infiltration capacity of soils due to improvements in soil porosity
- Reduced runoff as a result of increased infiltration
- Increased soil moisture holding capacity and hence reduced water demand for landscaping
- Reduced risk of soil erosion
- Reduced need for fertilisers as the compounds used for soil amendment are themselves rich in nutrients

4.14.2 Implementation

A soil management plan should be developed in order to implement this measure. To develop such a plan, the following steps should be followed:

Step 1: Determine soil conditions

The type of soil, organic and moisture content and degree of compaction should be known.

Step 2: Develop site and grading plans

These plans will help minimise soil disturbances during construction activity, help preserve open spaces and maximise preservation of good soils.

Step 3: Develop a soil management plan

The soil management plan should identify and highlight:

- Areas where native soils and vegetation will be retained
- Areas where soil will be amended
- Areas where topsoil will be stripped and stockpiled prior to grading
- Areas where imported topsoil will be applied

Step 4: Selection of soil amendment type

This involves:

- Identifying the available material sources
- Choosing the soil amendment type based on nutrient content, particle size and availability
- Calculating the application volumes

Step 5: Specifying the as-built testing procedure

Compost and amended soils can be used to increase the performance of other infiltration and bio-retention practices. However, this measure is not recommended when:

- Soils have a high infiltration rate
- The water table is within 0.5 m of the surface
- Slopes are greater than 10%
- Soils are saturated or seasonally wet
- Roots of existing trees could be harmed
- Ground slopes downhill of building foundations
- Contributing impervious surface is greater than amended soil surface area

4.15 Summary

Table 4.11: Summary of stormwater management practices

BMP	Pre-treatment required	Applications	Soil properties required for design	Other design considerations
Infiltration basin	-Vegetative filters -Sediment fore bay -Active treatment plant	-Hotels -Blocks of flats	-Hydraulic conductivity of soil -Hydraulic gradient of soil	-Avoid compaction during construction.
Dry well	-Filtration	-Houses -Small commercial projects -Drainage area < 4,000 m^2	-Infiltration rate of soil	-Avoid compaction during construction. -Make provision for test wells to allow regular inspections. -Subdivide large roofs into different catchment areas -Locate away from building foundations.
Infiltration trench	-Media filters -Vegetative filters	-Used for drainage areas between 4,000 and 20,000 m^2 -Ultra urban areas -Roofs of buildings -Adjacent to impervious surfaces such as roads, motorways and paved surfaces	-Soil porosity -Infiltration rate of soil	- No woody vegetation on top of trench -Avoid compaction during construction. -trenches to be wrapped in non-woven geo-textiles. -Depth of trench: 1.0 – 3.5 m - Width: > 7.5 m -Make provision for an observation well to allow for inspection.
Green roof	None	-Residential projects -Office buildings -Schools -Industrial buildings	-Porosity of growing media	-Flat roofs should have a slight slope of about 2%. -Use baffles or grids on sloped roofs with a slope greater than 25%.

BMP	Pre-treatment required	Applications	Soil properties required for design	Other design considerations
				-Keep a 0.5 m wide vegetation free zone between the green roof and equipment. -Confirm the load bearing capacity of the roof with a structural engineer.
Stormwater swales	-Plunge pools -Filter strips	-Islands and medians in parking lots. -Along streets and roads. -As rain swales in residential projects	-Manning's coefficient	-Depth: 400 – 600 mm -Width: 0.5 – 2 m -Length: > 30 m -Make provisions for an under-drain below the swale.
Stormwater planter	-Roof gutter guards	-Street design -Parking design -Residential projects	NA	- 1 m^2 of planter area can serve up to 50 m^2 of impervious drainage area
Pervious paving	-Vegetative filter	-Vehicular and access driveways -Cart paths in golf courses -Parking facilities -Bicycle and pedestrian access	NA	-Anticipated traffic intensity -Storage capacity and retention time of the underground reservoir (if any) -Strength of the sub-base soil -The ratio of contrib uting impervious area : permeable pavement ≤ 2:1. -Provide for an under-drain system if slow infiltration rate is expected

BMP	Pre-treatment required	Applications	Soil properties required for design	Other design considerations
Rain garden	-Roof gutter guards	-Street design -Parking lot design -Residential projects -Small office development	-Soil infiltration rate	-Locate away from building foundations.
Stormwater curb extension	-Filter strips	-Street design	-Soil infiltration rate	-Ensure that the curb extension does not impede traffice.
Downspout disconnection	-Roof gutter guards	-Residential buildings -Small commercial developments	-Type of soil -Soil infiltration rate	-Each downspout should serve about 45 m^2 of contributing roof area -Downpipes located where the surrounding ground slopes towards the building should not be diverted.

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6.0 Appendices

Appendix A – Low impact development practices

LID practices are best suited for new site developments and should be considered during the conceptual stages of the project.

General LID practices

- Scheduling: phasing of construction stages around the weather to better manage erosion during construction
- Protecting native soils and topsoil
- Preserving, protecting, creating and restoring ecologically sensitive areas
- Protecting trees and other vegetation
- Avoiding compaction of topsoil as a result of vehicle access
- Avoiding development on steep slopes
- Having a compact development footprint by reducing the building footprint
- Reducing impervious surfaces by creating opportunities for landscaping
- Minimising grading
- Avoiding alterations to the site topography, i.e., preserving natural drainage areas and building around the site topography
- Avoiding smooth conveyance – use vegetated conveyance systems instead
- Preventing pollutants from entering stormwater by ensuring that materials and other chemical products are stored in an appropriate manner
- Preventing the discharge of trash and debris to receiving waters
- Preventing and containing spills on site
- Looking at stormwater as a resource by adopting strategies such as rainwater harvesting

LID practices specific to streets and parking areas

Streets and parking bays are impervious and hence are sources of high runoff volumes. They also contribute to thermal pollution of the water courses: black asphalt absorb heat which is then transferred to stormwater. To make streets and parking areas more sustainable in terms of stormwater management, the following strategies can be implemented:

- Reducing street widths
- Slimmer sidewalks
- Adding landscaped medians
- Planted curb extensions
- Planter strips along sidewalks

- Using swales to treat road runoff
- Smaller cul-de-sac (good design would be a 30 ft radius one – to accommodate emergency vehicles)
- Incorporating landscaped areas/islands within cul-de-sac
- Shorter driveways – reducing setback and frontages
- Reducing on street parking to one lane
- Designing development sites to include smaller lots located off a few main roadways instead of site layouts that include long streets serving a relatively small number of large lots
- Using pervious asphalt and other similar pervious materials
- Changing the legal framework to allow businesses to count underused nearby on-street parking spaces
- Shared parking facilities, e.g,. religious building lending its parking facilities to a nearby office when the former is not operational.
- Providing transportation alternatives (park n ride, car-sharing, improved public transport)
- Shortening oversized parking spaces by a few feet to create landscaping areas
- Incorporate efficient parking lanes
- Reducing minimum parking demand ratios for certain land use
- Treating the parking demand ratio as a maximum limit
- Integrating landscaping opportunities in parking lots, e.g., storm water islands or traffic islands to treat runoff using bio retention, filter strips
- Design parking lots to accommodate the average parking demand instead of the highest hourly demand during the peak shopping season
- Provide multilevel parking strategies
- Using curbs to convey storm water run off from parking lots into landscaping area

Appendix B – Determining soil infiltration rate

Two methods are described in this section for the determination of soil infiltration rate. Method 1 is a simplistic approach while Method 2 takes a more detailed approach. Soil infiltration rate are affected by the moisture content of the soil at the time of the test. Hence, it may be required to wet the soil before testing.

B.1 Method 1

Method 1 has been designed to be used by non-specialists. It can be used by homeowners to determine the infiltration rate for their own projects. It is based on the guidelines provided by Melbourne Water (2010).

Materials required:

- A hoe
- PVC pipe: 90 mm diameter and at least 300 mm long
- Water
- Clock

Procedure:

1. Dig a hole 100 mm of diameter and 350 mm deep.
2. Place the PVC pipe into the hole.
3. Pour 1.3 litres of water into the pipe
4. Observe how quickly the water infiltrates the soil.
5. Repeat the test a few times until the infiltration rate is consistent.

The soil type and infiltration rate can be determined using the table B.1:

Table B.1: Infiltration rate based on infiltration time for different soil

Soil type	Approx. Permeability rate (mm/h)	Infiltration test time taken
Sand	180	< 1 hour
Loam	36	1 – 5 hours
Medium clay	3.6	5 – 50 hours
Heavy clay	0.36	> 50 hours

B.2 Method 2

Method 2 is aimed as a guide for engineers. This method should be used when developing a large-scale stormwater management plan. It is based on the method described by the BRE (2003).

Equipment:

- Back hoe loader/mini-excavator
- Dip tape
- Measuring tape
- Water bowser
- Stopwatch/clock

Procedure:

1. Excavate a trial pit to the same depth as the anticipated depth of the system. As a general rule, for drainage area of 100 m^2, the pit should be 1.5 to 3.0 m deep. The trial pit should be 0.3 to 1 m wide and 1 to 3 m long. It should have vertical sides trimmed square. If necessary, granular materials should be added to increase stability.
2. If a granular fill is used, a full height perforated, vertical observation tube should be placed in the pit. Thus, using a dip tape, water levels in the pit can be monitored.
3. Before starting the test, take careful measurements of the pit.
4. Fill the pit and allow it to drain three times to near empty. The water inflow should be quick enough to allow to pit to fill up completely in a short time. The three fillings should be done on the same or consecutive days.
5. Each time record the water level and time from filling. This should be done at sufficiently regular intervals to clearly define water level versus time.
6. Calculate the infiltration rate from the time taken for the water level to fall form 75% to 25% effective storage depth in the pit.

$$\text{Soil infiltration rate, } f = \frac{V_{P\ 75\text{-}25}}{a_{p\ 50} \times t_{p\ 75\text{-}25}} \qquad \text{Eq. B.1}$$

   Where $V_{P\ 75\text{-}25}$ is the effective storage volume of water in the trial pit between 75% and 25% effective depth
   $a_{p\ 50}$ is the internal surface area of the trial pit up to 50% effective depth and including the base area
   $t_{p\ 75\text{-}25}$ is the time for the water level to fall from 75% to 25% effective depth

7. The lowest infiltration rate value for the three tests should be taken.

Precautions

Do not enter the pit.

Appendix C – The Rational method

The Rational method is used to determine the runoff volume. This empirical method establishes a relationship between intensity of rainfall, size of catchment area, site characteristics and the runoff volume.

C.1 Determining runoff volume

1. Determination of rainfall intensity based on return period (T) and storm duration (D)

Rainfall intensity is determined from the rainfall intensity curve obtained from the Mauritius Meteorological Services. The two parameters that must be known to obtain the rainfall intensity are the storm duration and the return period.

When using the Rational Method, the storm duration is taken to the same as the time of concentration. The time of concentration is the time required for a parcel of runoff to travel from the most hydraulically distant part of a watershed to the outlet. Several empirical equations such as the Kerby method or the Kirpich method have been developed. However, these equations have been developed for watersheds found in the US.

In the absence of such an equation for Mauritius, storm duration of at least 10 minutes should be considered. This will take into account the frequency and severity of intense rains during the cyclonic period. Thus, the system is able to cope with sudden influxes of stormwater.

Mauritius is a tropical island with several storm events per year and there are high chances of exceeding the chosen rate of rainfall in a given year. Therefore, a return period of 50 years is chosen rather the typical 1 year or 2 year design storm event.

From the rainfall intensity curve obtained from the Meteorological Services and with D = 10 minutes, and T = 50 years, the rainfall intensity (I) is read.

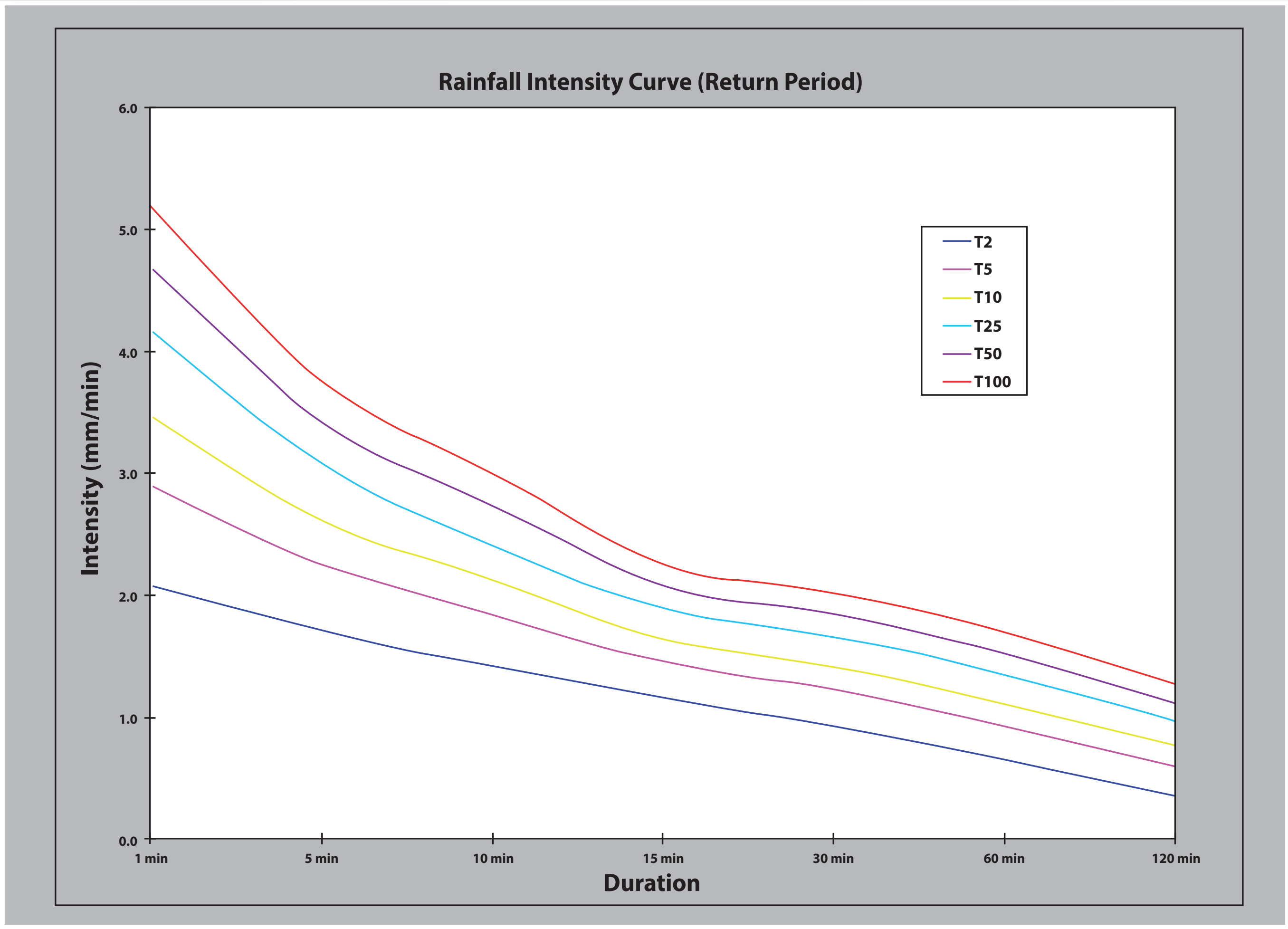

Figure C.1: Rainfall intensity curve for Mauritius

2. Calculating the effective drainage area

The effective drainage area is calculated based on the total area of the site which has been made impervious. This area can be obtained from the site plan or by making onsite measurements.

3. Determining the runoff coefficient

The runoff coefficient is the proportion of rainfall falling on a site which will contribute to surface runoff. Typical values that can be used for runoff coefficients are shown in Table C.1 (AMEC et al, 2001).

Table C.1: Runoff coefficient for different surfaces

Area type	Runoff Coefficient
Lawns	0.10 – 0.35
Unimproved areas	0.15
Downtown business areas	0.95
Neighbourhood business areas	0.70
Residential	0.50 – 0.70
Light industrial	0.70
Heavy industrial	0.80
Parks, cemeteries	0.25
Playground	0.35
Asphalt and concrete streets	0.95
Brick streets	0..85
Drives, walks and roofs	0.85
Gravel areas	0.50
Graded soils or bare soils	0.30 – 0.60

If the site has different types of impervious surfaces, an area-weighted coefficient should be used.

Example:
50% of a 100 m^2 site is covered by buildings. The remaining area consists of the following land use:

Table C.2: Schedule of areas

Area type	Area (m^2)
Lawns	30
Asphalt street and parking	15
Gravel	5

The area weighted runoff coefficient is thus given as:

Area type	Area (m^2) A	Runoff coefficient C	A × C
Roofs	50	0.85	42.5
Lawns	30	0.20	6
Asphalt street and parking	15	0.95	14.25
Gravel	5	0.50	2.5
Total	100	_	65.25

$$\text{area-weighted } C = \frac{65.25}{100} = 0.65$$

4. Calculating the rainwater runoff

The rainwater runoff is calculated using:

$$\dot{Q} = I \times A \times C \qquad \text{Eq. C.1}$$

Where $\dot{Q}$ = Runoff volume (m^3/s)

I = rainfall intensity (m/s)

A = drainage area (m^2)

C = Runoff coefficient (dimensionless)

Appendix D – Technical terms and definitions

D.1 Hydraulic conductivity

The hydraulic conductivity of soil is a measure of the ease with which water can move into the soil. It is calculated as follows:

$$K = \frac{V}{G} \qquad \text{Eq. D.1}$$

Where K = Hydraulic conductivity (m/s)

V = apparent velocity of ground water (m/s)

G = hydraulic gradient

Typical values for a hydraulic conductivity are:

Table D.1: Typical values for hydraulic conductivity

Soil type	Hydraulic conductivity (m/day)
Gravelly coarse sand	10 – 50
Medium sand	1 – 5
Sandy loam, fine sand	1 – 3
Loam	0.5 – 2
Very fine sandy loam	0.2 – 0.5
Dense clay	<0.002

D.2 Hydraulic gradient

The hydraulic gradient is a vector gradient between two or more hydraulic heads over the length of the flow path. It is a dimensionless parameter and is calculated as follows:

$$G = \frac{dh}{dl} \qquad \text{Eq. D.2}$$

Where G = Hydraulic gradient

dh = difference in the static liquid pressure between 2 or more points (m)

dl = flow path between the points where the static pressure has been recorded (m)

The static liquid pressure can be determined by the use of piezometers.

D.3 Hydraulic radius

The hydraulic radius is the equivalent circular radius for a flow channel which has a rectangular or square shape. In channel flow, the hydraulic radius is a measure of the flow efficiency: the larger the radius, the higher the volume of fluid conveyed.

The hydraulic radius is obtained as follows:

$$R = \frac{A}{P} \qquad \text{Eq. D.3}$$

Where R = hydraulic radius (m)
A = cross sectional area of the duct (m^2)
P = Wetted perimeter (m)

D.4 Manning's coefficient

The Manning coefficient or Gauckler-Manning coefficient is a measure of the roughness of a surface. It is a dimensionless unit used to determine flow parameters in open flow channels. The Manning coefficient is an empirical constant. Typical values for the Manning coefficient are:

Table D.2: Manning's coefficient of loughness for different materials

Surface material	Manning's Roughness coefficient
Asphalt	0.011
Brick	0.015
Concrete	0.011 – 0.015
Earth (smooth)	0.018
Earth channel (clean)	0.022
Earth channel (gravelly)	0.025
Earth channel (weedy)	0.030
Gravel	0.023