Runoff Reduction Guidelines in an Urban Set-Up

October 2021

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BACKGROUND / RATIONALE FOR THE RUNOFF REDUCTION GUIDELINES

1.1 Purpose of this document

This document presents a proposal of runoff reduction guidelines that are to be applied within the context of urban areas of Rwanda. The purpose is to identify effective planning and management strategies for surface water management, within view of reducing actual runoff generated in urban areas. The goal is to embed flood resilience, cost-effectiveness and general sustainability of runoff management systems in the planning process for urbanization.

The guidelines are therefore a resource to developers, engineers, technicians, planners and construction inspectors to ensure delivery of infrastructure projects with sustainable water management systems.

1.2 The importance of runoff reduction for urban water management

Water management is a key aspect of good urban planning. Planning for water provides opportunities to design urban spaces to be greener, safe, more attractive and biodiverse, and resilient to climate change. The current approach to urban development delivery in Rwanda has demonstrably shown that it leads to generation of high volumes of runoff, which have had significant contribution to increased flood risk downstream. It is now more critical that runoff reduction principles should be embedded in the urban planning process.

Continuing the current approach to resolve the challenge of downstream flooding through increasing the size of drainage channels is perpetuating unsustainable solutions that are not adaptable to a changing future. There are many opportunities for taking a different approach to managing runoff, which fit into the urban landscape, while also addressing the issues of water quality.

Runoff reduction measures will help to solve flooding and water quality issues whose occurrence are increasing in frequency in urban areas of Rwanda. Such measures provide an integrated approach to managing surface water across wider areas and different urban settings, supporting the water cycle as a whole and helping to create green spaces within the urban environment.

Runoff reduction measures elaborated in these guidelines can be cheaper than traditional drainage solutions, and generally provide more benefits as summarized in the table below:

Table 1 – Benefits of runoff reduction measures

Issue addressed	Benefit
Flooding	Management of the rate and volume of runoff, thereby reducing flood risks
Water quality	Runoff reduction measures can treat and improve the quality of water before discharge to streams and rivers
Amenity and aesthetics	Implementation of runoff reduction measures can enhance and improve the amenity value of urban spaces
Biodiversity and ecology	Runoff reduction measures can lead to an increase in biodiversity and ecology, creating new habitats in urban environments
Climate change	Runoff reduction measures are more adaptable and flexible to climate change than traditional drainage solutions.

2

NATIONAL POLICY CONTEXT

The Rwanda's vision 2050 stipulates that urbanization will follow an integrated approach considering spatial, economic, social and environmental considerations (smart and green cities for sustainable growth).

The National Land Use Master Plan adopted in 2020 acknowledges that the built-up areas will increase from 10.96% to 15.1 % by 2050 and recommends that all the proposed investments in urban areas should have integrated, resilient, reliable and sustainable infrastructure (p.131).

According to the National Urbanization Policy of Rwanda, disaster risk management, resiliency and urban safety are among the key elements of Pillar 3 – Conviviality, whereby physical planning and development should aim at improving the quality of life and mitigation of disaster. Flood risk is projected to increase due to climate change, and reduction of the risk is proposed through water retention, upstream land-use planning and adaptations, control of building activities and permissible technologies .

The Rwanda National Sanitation Policy, in Objective 4 of Policy Directions, recommends enhancement of storm water management in urban areas to mitigate impacts on properties, infrastructure, human health and the environment . The key objectives of the policy is to achieve sector and stakeholder cooperation in storm water management in urban areas through integration of measures which aim at managing runoff close to its source and treating it as a resource rather than a waste product.

The National Sanitation Policy Implementation Strategy recommends 'water sensitive urban design' or 'low impact development' as approaches to urban planning and design that integrate management of the total water cycle into urban development . Sustainable urban drainage techniques such as porous pavements, infiltration and rain harvesting systems, swales and wetlands are recommended for incorporation into new developments, or retrofitting in upgrades of existing infrastructure.

The National transport policy and strategy adopted in 2021 provides that all new roads to be constructed will be designed more resilient, to suffer less from climate events (p.2).

The different policy statements are in agreement that surface water should be managed to achieve maximum benefit and urban resilience to climate change. The key message is cooperation between different institutions and stakeholders towards integrating surface water management into the development of Rwanda's urbanization plans, and for the City of Kigali and District authorities to ensure that sustainable runoff management is a key condition for building permits.

3

BASIC PRINCIPLES OF THE GUIDELINES

A Runoff reduction is to be delivered through the planning process for urbanization. It is at the planning stage that the benefits of water sensitive design can be fully maximized. Subsequent stages of urbanization delivery will follow from plans in which the need for space for surface water has been duly considered.

B Construction permit applications and public infrastructure development proposals should be accompanied by site-specific stormwater management designs that demonstrate full compliance with national policies and technical standards for the reduction and maximization of on-site management of runoff. Policies relate to government and local directives on the provision and maintenance of sustainable drainage for flood risk reduction, whereas technical standards relate to the requirements for design, construction, operation and maintenance for sustainable run of management, as issued by relevant government institutions and/or municipal authorities.

C These guidelines support existing technical standards for sustainable surface water management like the building code, drainage manual, guidelines for harvesting of rainwater from buildings, among others, and they provide clarification on the requirements and process for reducing the urban water runoff in Rwanda. The guidelines are to be reviewed regularly to reflect best practice.

D Stormwater management should be considered as an integral part of the due-diligence process for land acquisition, that is early in the development planning and design processes, along with other key considerations such as:

- Layout
- Density of buildings and infrastructure
- Site access
- Topography
- Ground conditions
- Final discharge points of excess surface water runoff (local streams, rivers)
- Characteristics of downstream areas en-route to the final discharge points (built-up area, agricultural areas, etc.). This is an important consideration given that most flood hotspots in urban areas of Rwanda tend to be downstream in the catchment area, predominantly in transition zones between hill slopes and wetlands.

E It is easier and more cost-effective to incorporate water sensitive design, runoff reduction and sustainable drainage systems along with landscape design from earliest stages of planning a new development or new infrastructure. Cost effective drainage solutions are best achieved by integrating components into overall site design.

F This guideline document provides general orientations to reduce run off in different urban landscapes and is not intended to define the full technical details. The user should consult other official government, local municipal or acknowledged best-practice documents which give relevant technical details.

G This document is presented as a practice document and therefore will be reviewed regularly based upon feedback received from users at the City of Kigali and District authorities, as well as other government institutions and stakeholders.

4

KEY PRINCIPLES IN RUNOFF REDUCTION

The run off volume reduction can be done mainly through:

- √ Canopy interception;
- √ Soil infiltration;
- √ Evaporation;
- √ Transpiration;
- √ Rainwater harvesting and reuse; and
- √ Engineered infiltration

4.1 Three principles of runoff reduction

The reduction of runoff is characterized by three principles:

Principle 1: Minimization and avoidance

This principle seeks to achieve generation of less runoff through site design strategies that preserve hydrologically functional areas of the site and thereby maintain the pre-developed hydrologic response characteristics.

Minimization and avoidance of runoff seeks to preserve open space and working areas, protect natural systems, and incorporate existing site features to manage stormwater at or close to its source. To achieve this, solutions such as Low Impact Developments or Conservation Developments are proposed, with the aim of clustering and concentrating development, minimizing disturbed areas, and reducing the size of impervious areas.

Low Impact Developments are environmentally sensitive approaches to site development and stormwater management, which minimize the effect of urbanization on water, land and air. These developmental concepts integrate site design and planning techniques that preserve natural systems and hydrological functions of a site.

Principle 2: Runoff reduction

This principle aims at reducing the generated runoff through the application of runoff management practices that effectively control runoff volume through infiltration, interception and evapotranspiration, rainwater harvesting and reuse, extended filtration, soil amendments, etc.

The aim is to preserve as much as possible the hydrological response characteristics of sites using source controls.

The deployment of source controls for runoff reduction in the development of urbanization plans is not a singular prescriptive design standard, but a combination of practices that can result in a variety of environmental benefits. Implementation of source controls encourages runoff reduction by managing it close to where it falls, while enabling a more natural and functional landscape.

Principle 3: Additional controls as needed

When principles 1 and 2 have been fully maximized, additional structural controls can be implemented to reduce the peak rate and volume of runoff, and/or reduce the pollutant load concentrations in the runoff volume.

When the principle of minimization and avoidance of runoff has been optimized in site design, and source controls for runoff reduction are maximized, the excess runoff will need to be adequately managed.A combination of Structural Solutions and Nature-Based Solutions will need to be applied and these can include well designed drainage systems or ideally grass swales where the slope allows (<6%), detention basins, artificial lakes, constructed wetlands, etc.

4.2 Site planning and design procedure for runoff reduction

The figure below sets out a chart depicting site planning and design procedure for effective runoff reduction. The procedure starts with an analysis of the site and its natural water cycle systems, and proceeds to integrate non-structural and structural controls in the development of an effective runoff reduction plan.

The procedure involves total site design process whereby stormwater management is placed in the initial stages of the site planning process, such that comprehensive runoff reduction is integrated into the site design process. This is in contrast to the traditional practice in which stormwater drainage is relegated to the final stages of site design and overall land development process, after most building and land use determinations have been made.

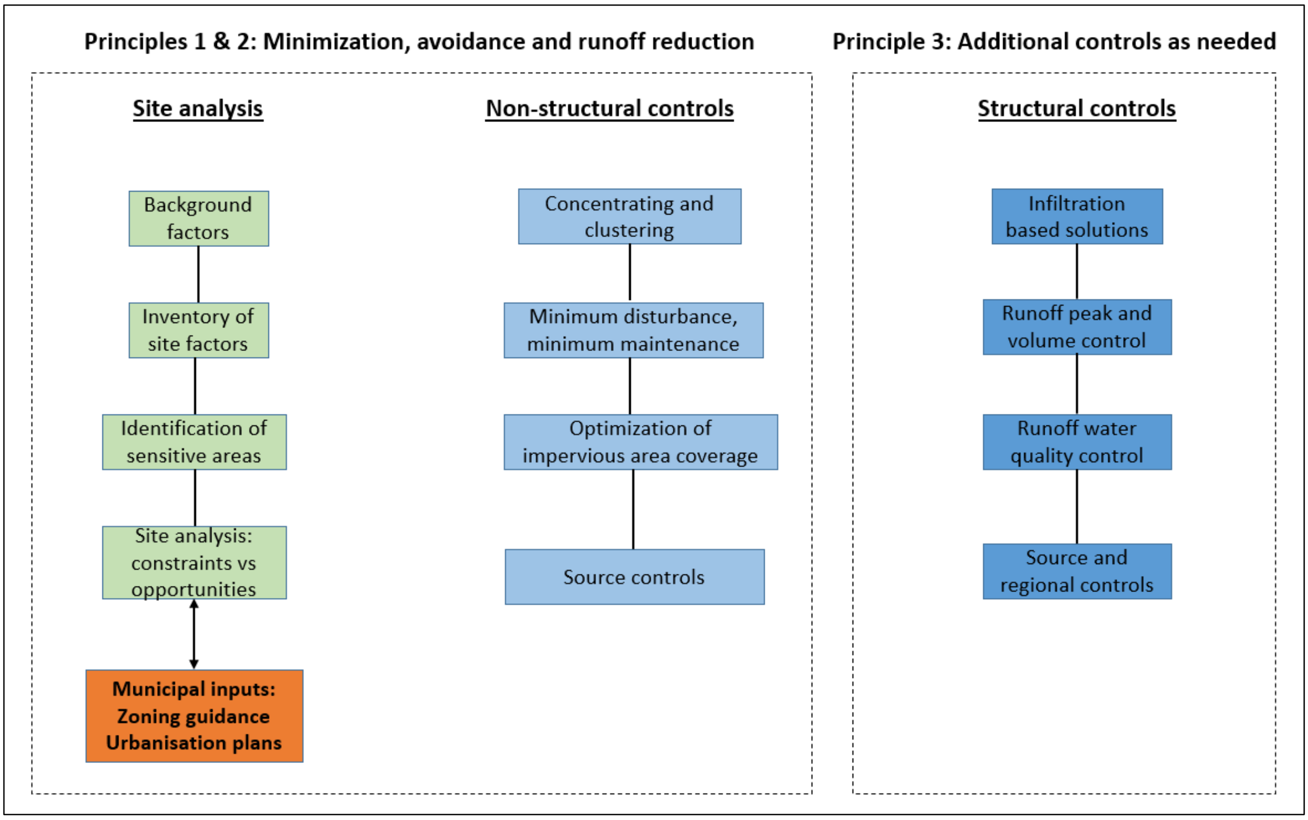


Figure 1 *– Site planning and design procedure for effective runoff reduction*

4.2.1 Site analysis and assessment of background conditions

The following elements should be assessed as part of site analysis:

- A review of the site's hydrological context and other natural elements. The review should include an assessment of water sensitivities downstream, location of any known downstream flooding and sensitive areas;
- Site factors inventory will include a description of the size and shape of the site to establish constraints and opportunities, and a description of any existing developed features (existing structures downstream, existing impervious areas, existing drainage systems at/adjacent to site, etc.). This should also include a review of important features of the site such as existing topography, areas of vegetation, steep slopes, high groundwater table areas, etc.
- Optimize site design by avoiding development on or near sensitive natural features (constraints zones) and identifying opportunity zones for development.

4.2.2 Non-structural controls

Non-structural controls for runoff reduction will include the following:

- Reduction of impervious area coverage: Optimize the road widths and maximize the widths of natural buffer zones, reduce parking sizes and examine potential for shared parking. Utilize permeable surfaces for parking features, design sidewalks for single-side movement, etc.
- Optimize tree coverage across the site to provide rainfall interception and evapotranspiration.

4.2.3 Structural controls

Structural controls will include the following:

- Volume/peak rate reduction by means of green roofs and rainwater harvesting / reuse;
- Volume/peak rate control through infiltration can be achieved using permeable pavements, swales, filter strips, infiltration / detention basins, and rain gardens. It should be noted that the risk of soil saturation and gully formation should be thoroughly assessed especially in steep areas, before implementation of any structural measures with infiltration;
- Volume and peak rate control through regional controls such as detention basins, retention ponds, artificial lakes, constructed wetlands, modular attenuation storage tanks; etc.

5

LOW IMPACT DEVELOPMENT FOR RUNOFF REDUCTION

5.1 Description

Low Impact development (LID) is a site design approach, which integrates hydrologically functional design with pollution prevention measures to compensate for land development impacts on hydrology and water quality.

The goal of low impact development is to mimic natural hydrology and process by using small-scale, decentralized practices that infiltrate, evaporate, detain and transpire storm water. LID stormwater controls are uniformly and strategically located throughout the site.

LID is achieved by:

- Minimizing stormwater runoff impacts to the extent practicable through preservation of existing landscape features and their hydrological functions;
- Maintaining predevelopment time of concentration through strategic routing of flows using a variety of site design techniques;
- Dispersing runoff storage measures throughout the site's landscape.

The aim of low impact development is to manage stormwater at or close to its source. LID promotes measures that reduce impervious cover,minimize disturbance, preserve and recreate natural landscape features, and facilitate infiltration (where no soil water saturation and gully formation risks are identified) and detention opportunities. LID leads to the formation of a multifunctional landscape that relies on natural features, emphasizing simple, non-structural, low-tech methods.

5.2 Application of LID

Low Impact development can be applied to a broad range of land use situations., LID should be strongly encouraged in communal residential schemes, as well as institutional, commercial, industrial and government developments. Experience has shown that LID work in new developments, as well as constrained sites involving urban infill in an otherwise vacant or undeveloped site within an existing community.

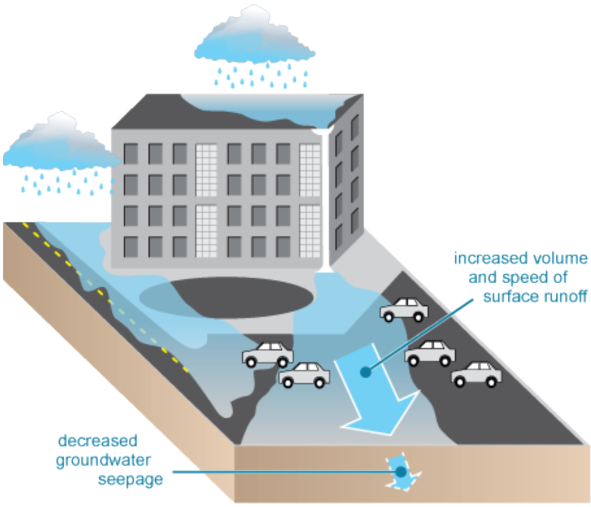
5.3 Planning considerations

Low Impact development is a design approach and represents a collection of stormwater practices that may be utilized together to manage stormwater. LID measures should preferably be used in replacement or in supplement where necessary, of conventional stormwater management practices.

It is recommended to adopt the following steps in the LID site planning process:

- Determine the applicable zoning, land use and subdivision regulations;
- Define the total area of the development that affects hydrology on site (total development envelope);
- Use drainage / hydrology as a design element;
- Reduce total site impervious areas;
- Minimize directly connected impervious areas;
- Compare pre & post development hydrology and identify optimization potential;
- Complete LID site plan.

Maximum Impact development



Low Impact development

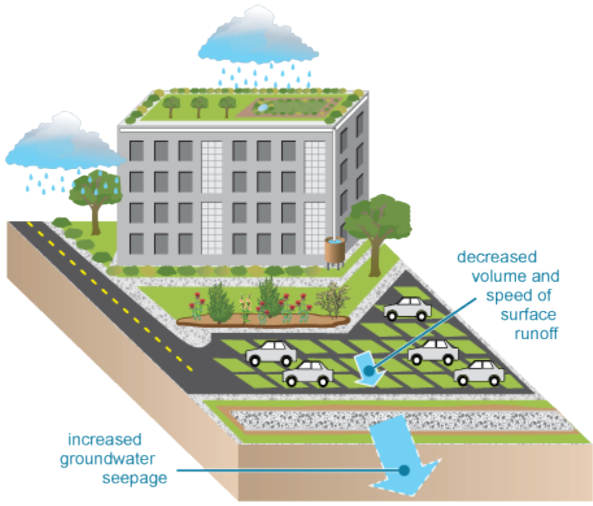


Figure 2 – Low and Maximum impact developments

Source:http://managingstormwater.blogspot.com/2014/09/rain-garden-build-your-own-in-3-hours.html)

To insert also two comparative images for roads showing a high impact development road (maximized road width with no buffer zone) and low impact development road (optimized road width with a natural buffer zone)

LID should be designed to minimize disturbance and manage runoff at or close to its source, as is far as is practicable. Specific LID controls fall into the category of Nature Based Solutions (NBS) and these are discussed under Section 6.

The following planning considerations are recommended for low impact developments:

- Clay soils: Higher proportions of clay particles (greater than 27%) will reduce the effectiveness of infiltration-based measures;
- Steep slopes: site topography should be carefully assessed to determine the impact of infiltration to soil water saturation and potential land sliding or gully formations downstream;
- High water table, even when seasonal, may restrict the use of some LID controls. It is recommended to provide at least 1.0 m to 1.5 m depth of separation between the bottom of an LID control and the highest level of the water table. On-site investigations by a qualified hydrogeologist are recommended;
- Public health concerns about mosquito borne diseases (malaria, etc.) should be taken into account when designing any water retention system as these may serve as breeding ground for mosquitos.
- Building formation and structures: LID controls with infiltration should not be located near the foundations of buildings and other structures;
- Design costs: Up-front design cost for LID might be higher than that of conventional stormwater drainage approach due to the microscale design nature of LID. However, construction costs are often less;
- Maintenance access: easements and other measures should be provided to give access for maintenance;
- Public awareness: public education materials should be provided throughout the site to inform the public on the importance of long-term management of the LID controls.

6

NATURE-BASED LOW IMPACT DEVELOPMENT CONTROLS

6.1 Introduction

Nature Based Solutions (NBS) build on the concept that surface water is valuable resource when used sustainably within the built environment. NBS not only seek to control the volume and rate of runoff to mitigate the risk of downstream flooding, but they also promote integrated and sustainable surface water management by enhancing landscapes and biodiversity, and promoting the amenity value of the built environment.

The NBS approach involves slowing down and reducing the volume of surface water runoff from developed areas as means to manage the downstream flood risk, as well as reducing the risk of pollution in downstream watercourses caused by the runoff. To achieve this, Nature Based Solutions provide systems that enable infiltration, slowing down, storage and effective conveyance as well as treatment of runoff on site.

Besides the mitigation of downstream flood risk, Nature Based Solutions play a pivotal role in the provision of spaces that promote natural habitats and biodiversity, as well as providing benefits to the local community in terms of improved well-being, quality of life for individuals (liveability).

It is important to note that if the full benefits of Nature Based Solutions are to be achieved, the control of the rate and volume of runoff should be at the core of drainage design. This requires a multi-disciplinary and multi-stakeholder collaborative approach from the outset. In many cases, NBS will be required to be retrofitted into existing urban areas, therefore opportunities for delivering sustainable solutions that offer multiple benefits will need be sought.

Benefits of Nature Based Solutions

i. Control and reduction of volume of runoff
ii. Protection of people and property from flood risk otherwise resulting from uncontrolled runoff
iii. Protection of local surface water (rivers, lakes and streams) from pollution
iv. Promotion of local natural habitats, ecosystems and general biodiversity
v. Improving the amenity value by creating attractive places to live, work and invest through the integration of water and green spaces within the built environment
vi. Delivery of cost-effective infrastructure, which uses less resources and is more resilient to climate change than traditional drainage systems

Effects of climate change include changes in weather patterns. Such changes are becoming more and more apparent in Rwanda where rainfall events are now more intense for longer durations. This will increase the risk of flooding, soil erosion and landslides.

Rapid urbanization, poor drainage systems and urban topography are the main drivers for flooding, given the increase in impermeable areas and the resulting rise in rates and volumes of runoff.

The approach to achieving a reduction in runoff in urban areas through Nature Based Solutions should therefore include:

- Understanding surface water-related opportunities and challenges in urban environments;
- Determining appropriate Nature Based Solutions components
- Early engagement with stakeholders

Nature Based Solutions should be designed to support the following:

- The management of flood risks through the control of both flow rates and volumes of runoff;
- The creation of sustainable habitats through the use of NBS;
- Sustainable use of water through the implementation of rainwater harvesting systems;
- Provision of sustainable living and working built environments, resilient to impacts of climate change.

6.2 Designing Nature Based Solutions

6.2.1 Principles and objectives

The objective in the design of Nature Based Solutions should be to provide systems that control and manage surface water runoff to mitigate flood risks. The benefits achieved by NBS design will depend on local conditions, but broadly speaking, should fall into four categories, namely: water quantity, water quality, amenity and biodiversity.

NBS design principles are summarized in the following diagram:

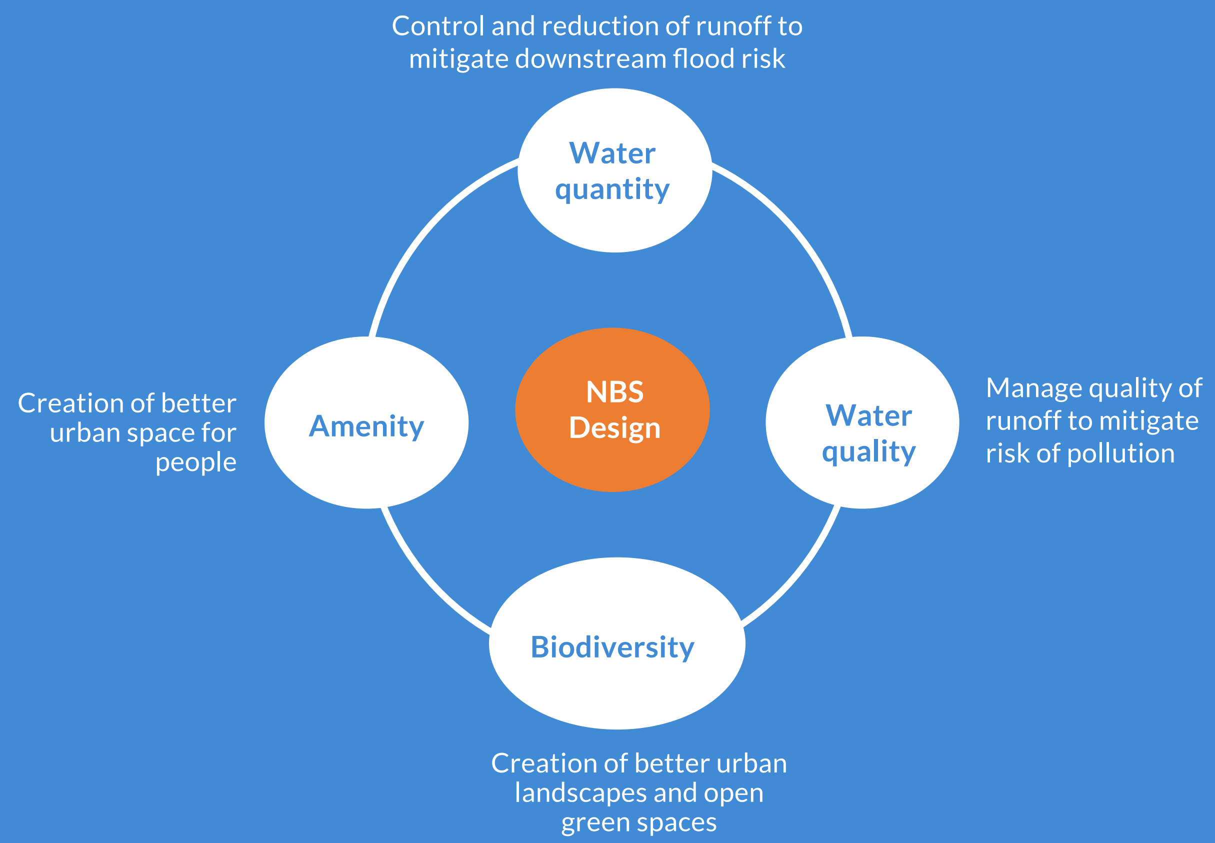


Figure 3 – Principles of NBS design

6.2.2 NBS design criteria

The table below summarizes the NBS design criteria that should be applied.

	Design criteria
Water quantity	• Utilisation of surface water asa resource • Drain the area effectively • Manage on-site and downstream flood risks by reducing the rate and volume of runoff • Protect downstream river morphology • Maintain as much as possible the natural water cycle on site
Water quality	• Protect the quality of downstream rivers and streams
Biodiversity	• Preserve local landscapes and protect natural local habitats and species • Maintain local biodiversity
Amenity	• Promote the greening aspect of the urban environment • Enhance liveability and visual character • Deliver safe surface water management systems • Deliver incentives for local development

Table 2 *– NBS design criteria*

The extent to which each criterion can be delivered will depend on local urban characteristics, constraints, opportunities, as well as local objectives and context of urbanisation.

Water quantity and water quality criteria should be the main drivers in developing NBS design philosophy, and the designs to be chosen should depend on best practice. The delivery of amenity and biodiversity criteria will depend on other required local planning objectives.

6.2.3 Designing for runoff reduction

NBS systems should be designed for flood risks mitigation by controlling how fast the runoff is discharged from sites (i.e. peak runoff rate control), and how much runoff is discharged (i.e. runoff volume). Design proposals should target the management of water quantity as near the source as possible where possible.

The selected NBS components should be those that are most effective at reducing flood risks in the local urban context (topography, space availability and type of developments). NBS designs should target the control of peak runoff rate, ensuring, where possible, that it is limited to the rate of runoff that would have occurred before the sites were developed (greenfield runoff rate).

Runoff reduction can be achieved by designing for flow attenuation, which is the slowing and storing of runoff on or near the source, and then discharging it downstream at a specified flow rate.

Below are examples of design criteria for managing runoff to effectively mitigate the risk of downstream flooding.

Water quantity design criterion	Indicator
Use surface water runoff as a resource	A proportion of runoff from rainfall events is harvested for use
Support the effective management of flood risk in the receiving sub-catchment	The rates and volumes of runoff for high return period events are controlled
Protect morphology and ecology in receiving surface waters	The rates and volumes of runoff for high return period events are controlled
Preserve and protect natural landscapes and hydrological systems	Natural hydrological drainage systems are preserved or enhanced as part of the landscape and / or surface water management system
Drain the sites effectively	Runoff from design rainfall events infiltrates (where there are no landslides risks) or drains through the NBS systems within a suitable time so that the performance of the system for managing runoff from subsequent rainfall events is not reduced
Manage on-site flood risk	Runoff from rainfall events that exceed the NBS systems' capacity is managed in identified exceedance routes and storage areas
Design in-system flexibility / adaptability to cope with future change	The NBS system is designed with the flexibility to be suitably adapted during its design life

***Table 3** – Water quantity design criteria*

6.2.4 Designing for challenging urban site conditions

Urban areas in Rwanda pose different challenges in relation to the selection and integration of effective NBS components. The main challenges expected in the urban context include local topography (steep slopes), slope instability and high groundwater levels.

Steep slopes

The following considerations should be taken into account when designing NBS components for steep slopes:

- Effective utilisation of storage capacity in the NBS component: given that available storage capacity can be reduced where NBS systems are implemented on a slope, designs should involve splitting the runoff catchment into small, manageable sub-catchments, and looking for all potential opportunities for runoff conveyance and storage;
- High velocity of runoff through the NBS components due to steep slope, causing scour and erosion: application of check dams in the NBS conveyance components should be considered;
- The risks of infiltrated water reappearing as spring lines further down the slope, which could cause flooding, or slope instability. As a general principle, infiltration on steep slopes (above 50 %) should be avoided.

High groundwater levels

The use of infiltration will not be suitable in areas where there is not an adequate depth of unsaturated soils between the infiltration surface and groundwater (<1 m). Depending on the depth of groundwater below the site, the possibility of using shallow infiltration basins or permeable pavements should be considered, with horizontal discharges from below the previous surface. Other options may include use of ground-raising techniques with suitable fill material. Storage and conveyance systems should be kept above maximum likely groundwater levels where possible. This will avoid difficulties during construction caused by water flows into excavations.

Slope instability

For urban sites which are prone to sub-surface soil instability, NBS design proposals should take into account issues such as the potential for water infiltration causing further instability in poorly consolidated soils, causing slope failure, potentially affecting nearby structures. For these sites, NBS systems that use infiltration should be avoided. However, lined systems can be proposed to ensure full prevention of infiltration.

6.3 NBS catalogue

There are numerous Nature Based Solutions components that can be applied for the reduction of runoff. The NBS catalogue of components presented hereafter has been developed with view of applicability and relevancy in the Rwandan urban context. The list of NBS components presented in the catalogue is not exhaustive and can be subject to modification.

The following literature has been referred to in the development of the catalogue:

- European Union, New Strategy for Re-Naturing Cities through Nature-Based Solutions – URBAN GreenUP (European Union, May 2018);

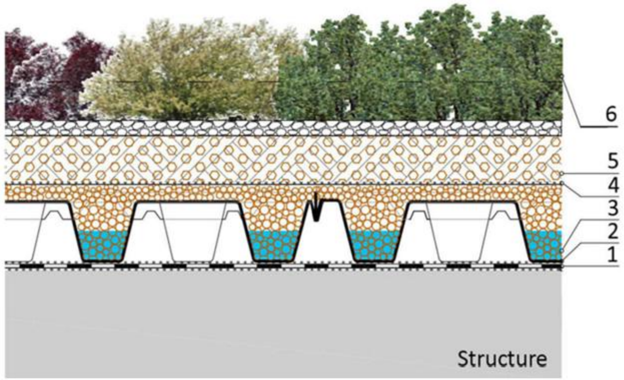
- UNEP, Smart, sustainable and resilient cities: the power of nature-based solutions (2021);
- The South African Guidelines for Sustainable Drainage Systems (2013);
- Global Standards for Nature-based Solutions (International Union for Conservation of Nature, IUCN 2020);

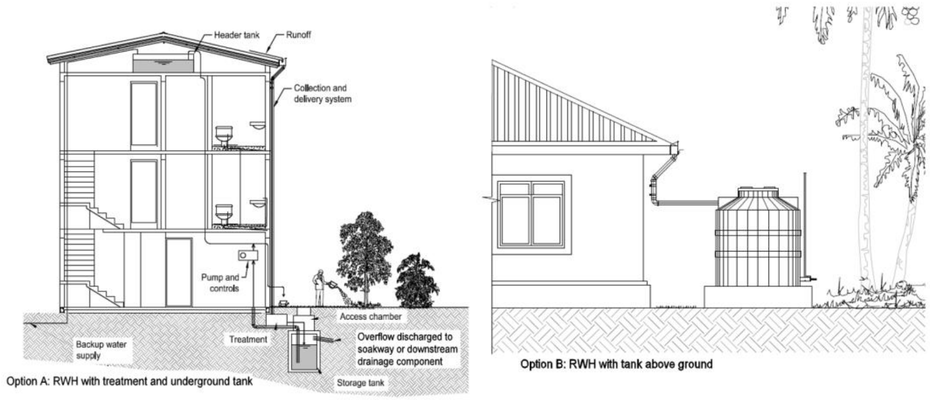
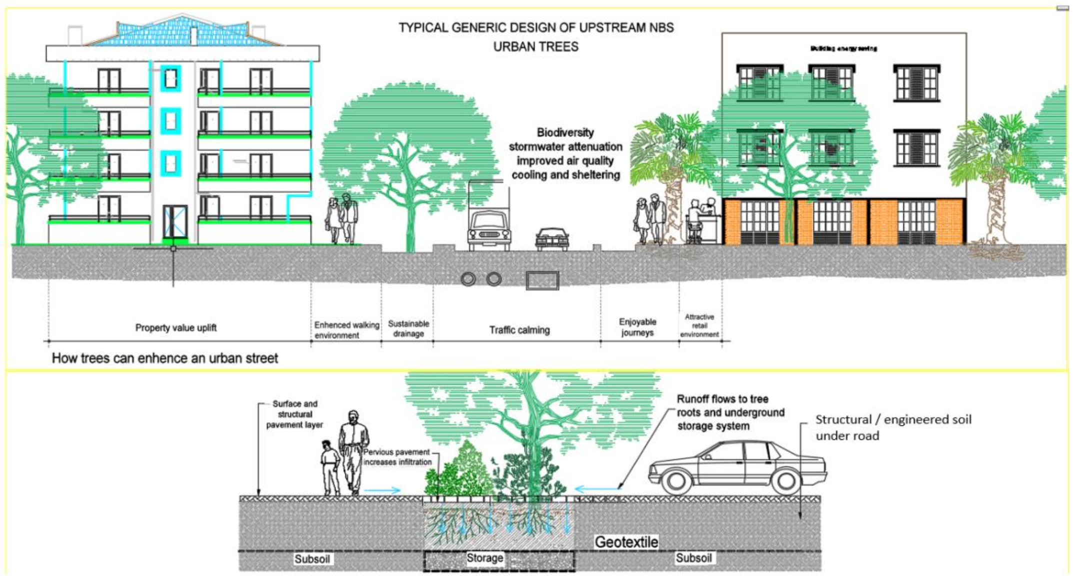
The selection and layout of NBS components for runoff reduction should be carried out in consideration of the urban area conditions and site characteristics, as well as runoff reduction objectives and flood risk. This should be subject to assessment of site constraints and space availability. Where the site allows, the layout of NBS components should follow the management train principle. The NBS components to be considered are summarised in the table below.Descriptions and graphic details are provided thereafter.

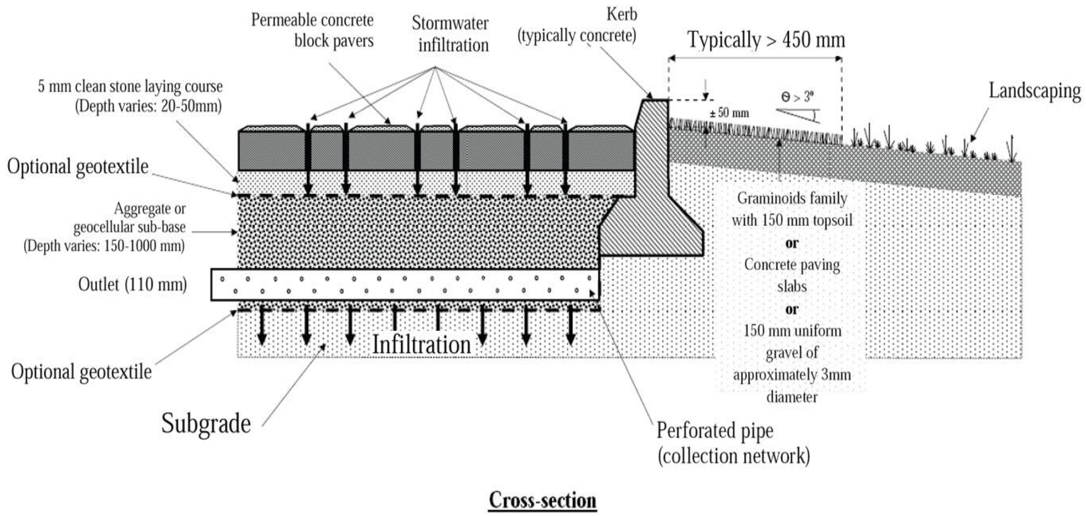
NBS component Type	Design criteria						Private funding potential	Community contribution (maintenance) Y/N
	Runoff reduction			Water quality	Amenity	Biodiversity		
		Volume						
	Peak runoff rate	Small events	Large events					
Green roofs	●	√		√	√	√	√	N
Rainwater harvesting systems		√	√		√		√	Y
Urban trees	√	√	√	●	√	√	√	Y
Permeable paving	√	√	√	√			√	Y
Filter strips		√		√	●	●	√	Y
Grassed swales	√	√	√	√	√	√	√	Y
Green resting areas	√	√	√	●	√	√	√	Y
Green walls / facades	√	√	√	●	√	●	√	Y
Stepped drains	√	√	√					N
Detention basin	√	√		√	√	√		Y
Ponds and wetlands	√	√		√	√	√	N	Y

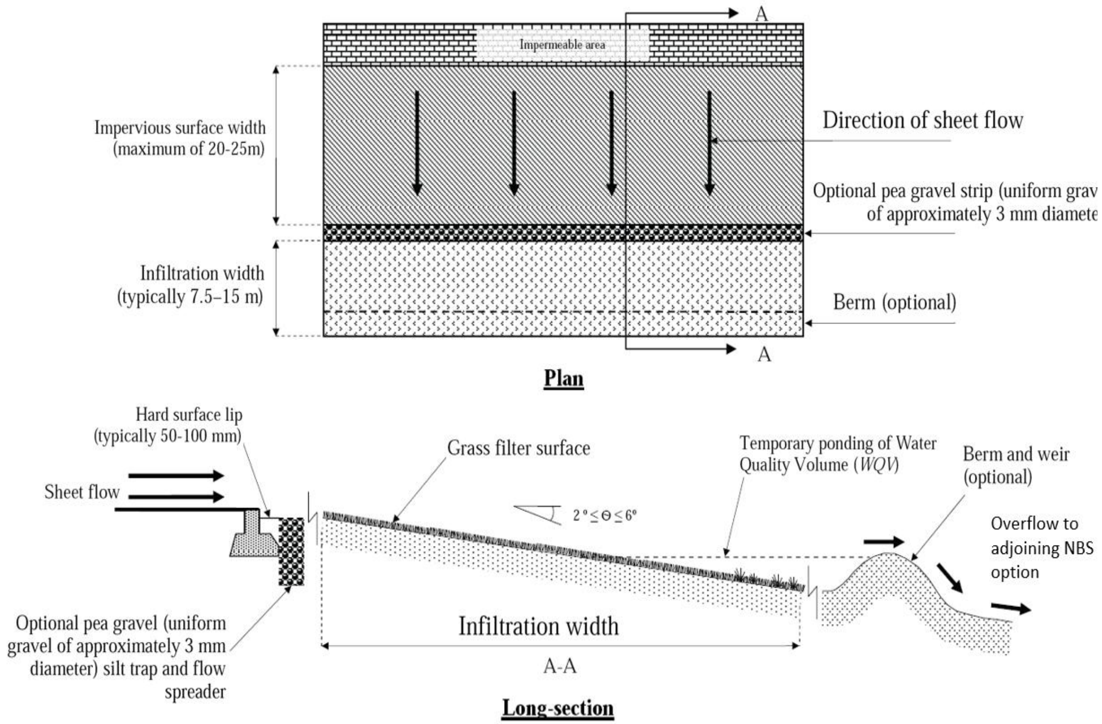
√ Significant contribution to design criterion

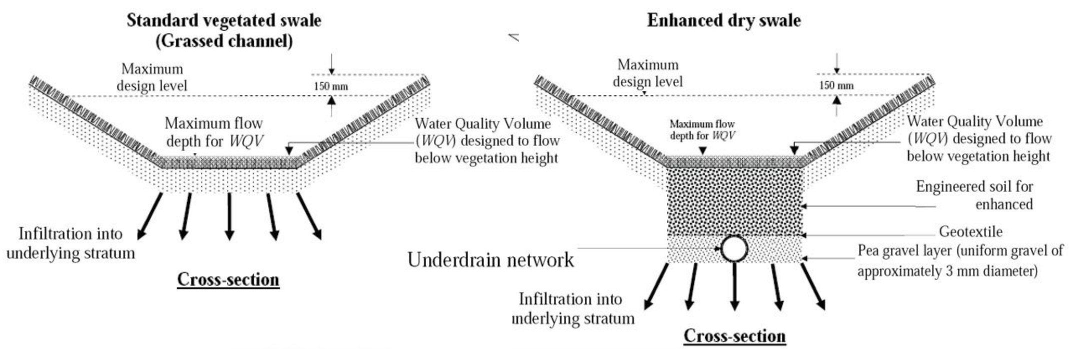
● Some contribution to design criterion

NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Green roof	Green roofs are areas of living vegetation installed on top of buildings for a range of reasons including the reduction of surface water runoff, visual amenity and enhanced building performance. Green roofs consist of a system in which several materials are layered to achieve the desired vegetative cover and drainage characteristics.	Canopy interception Evapo-transpiration Substrate infiltration Storage	- Individual household - Communal residential buildings, e.g. apartments - Estates - Public and commercial buildings	 1. Waterproof membrane 2. Separating layer (geotextile sheets) 3. Draining and water retention layer 4. Filtering layer to prevent loss of fine substrate particles 5. Substrate (supports vegetation where work of roots takes place 6. Vegetation *Image credit: European Union (URBAN GreenUP)*  *Image credit: University of Greenwich (UK)*

NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Rainwater harvesting (RWH)	Rainwater harvesting (RWH) is the collection of rainwater runoff for use. Runoff can be collected from roofs and other impervious areas, treated and reused.	Storage Reuse in certain cases depending on design	- Individual household - Communal residential buildings - Estates - Public and commercial buildings	
Urban trees	Trees enhance the urban environment in many ways: • Interception of rainwater as an effective contribution to the reduction of runoff from urban areas; • Addition of beauty and character to the urban landscape.	Canopy interception Evapo-transpiration	- Individual household - Communal residential buildings, e.g. apartments - Estates - Public and commercial buildings - Roads - Public space	

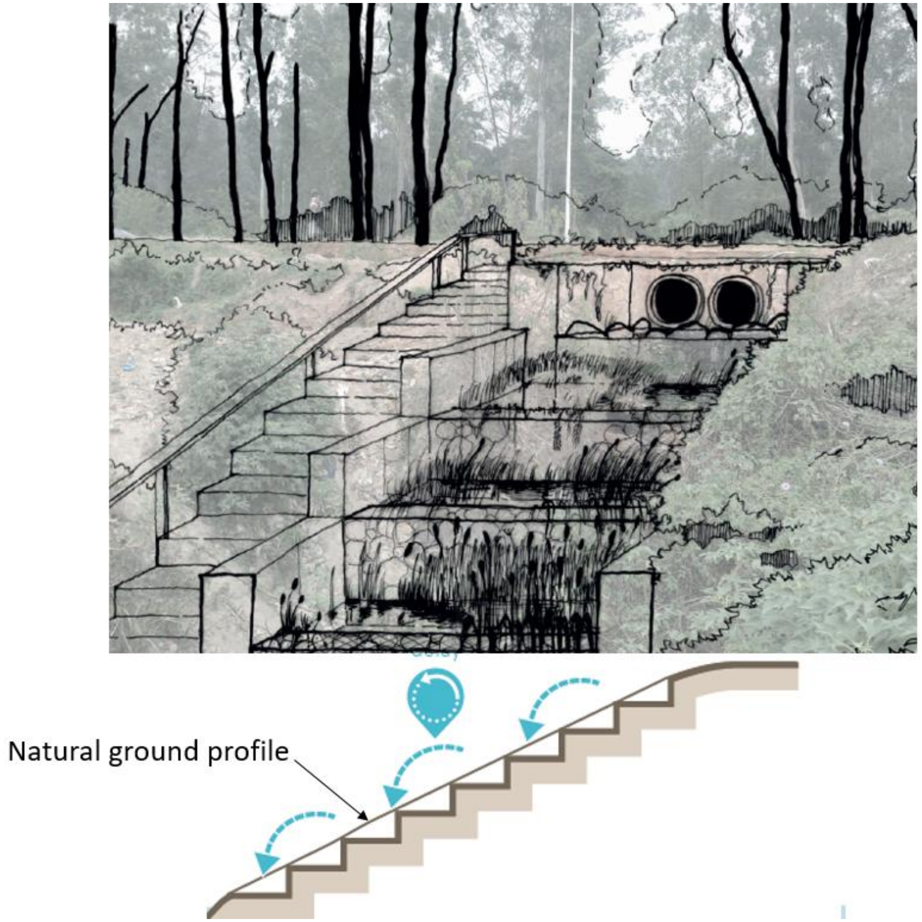
NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Permeable pavements	Permeable pavements provide an area suitable for pedestrian and/or vehicular traffic, while allowing rainwater to infiltrate. It is an efficient means of managing runoff close to its source, whereby water is temporarily stored beneath the surface, before infiltration to the ground, or discharged downstream via underlying pipes where soil infiltration is not suitable.	Soil infiltration (where acceptable) Storage	- Individual household - Communal residential buildings, e.g. apartments - Estates - Public and commercial buildings - Small streets - Public spaces and parks	 *Image credit: South African Guidelines for Sustainable Drainage Systems (2013)*

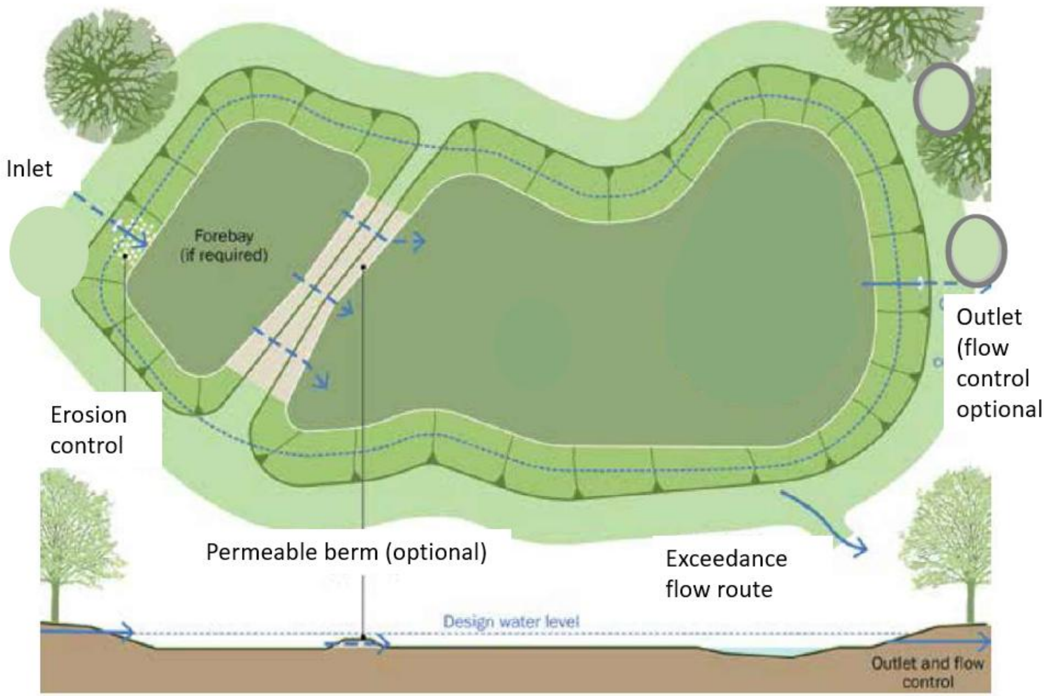
NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Filter strips	Filter strips are uniformly graded and gently sloping strips of grass or other dense vegetation that are designed to treat runoff from adjacent impermeable areas by promoting sedimentation, filtration and infiltration. Runoff flows across the strip before discharge to other NBS components such as swales.	Soil infiltration (where acceptable) Evapo-transpiration Reduction of runoff velocity	- Communal residential buildings, e.g., apartments - Estates - Public and commercial buildings / zones - Public spaces and parks	 *Image credit: South African Guidelines for Sustainable Drainage Systems (2013)*

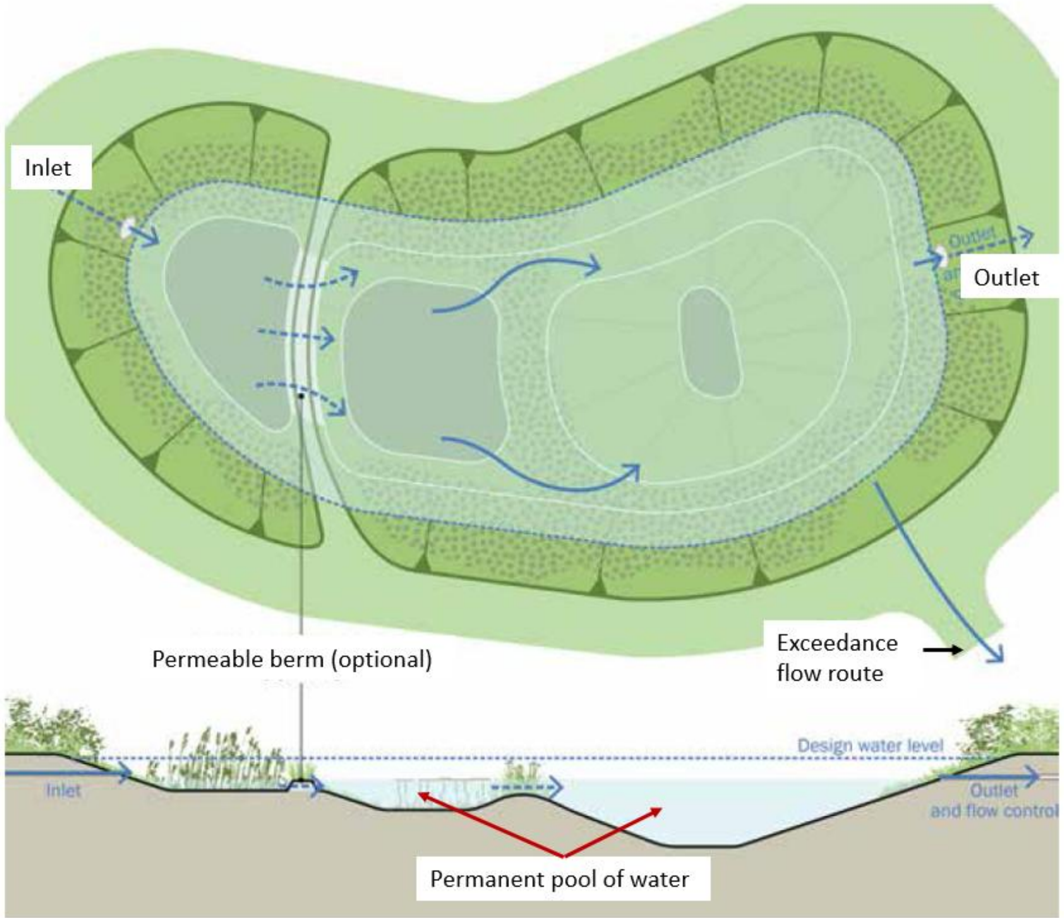
NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Grassed swales	Swales are flat-bottomed, vegetated open channels designed to convey, treat and often attenuate surface water runoff. They can be used to enhance the natural landscape and provide of aesthetic and biodiversity benefits. They are used to drain roads (specifically those laid along contour lines in steep areas), paths and car parks.	Soil infiltration (where acceptable) Evapo-transpiration Reduction of runoff velocity	- Estates' roads and parking zones - Public and commercial buildings roads and parking zones - Roads - Public spaces and parks	  *Image credit: South African Guidelines for Sustainable Drainage Systems (2013)* **Design standards** - Shape: Trapezoidal - Bottom width: 0.5 m to 2.0 m - Longitudinal slope: 0.5% to 6% - Check dams: to be installed every 20 m to 30 m on slopes greater than 3% up to 6% - Depth: 0.4 m to 1.0 m (normal application). Depth can be increased where deemed application, taking into account health and safety considerations - Velocity: Maximum flow velocity should be 0.4 m/s at normal flow. For extreme events, maximum velocity of 1.0 m/s is allowed

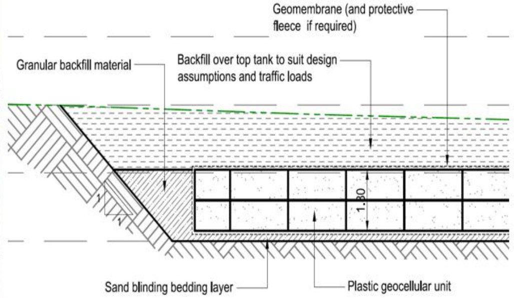
NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Green resting areas	Green resting areas are green spaces projected for social passive recreation (resting, relaxation, observing nature, social contact). They decrease impervious areas and provide water retention possibilities on site, reducing peak runoff.	Water retention Evapo-transpiration Reduction of peak runoff Soil infiltration (where acceptable)	- Communal residential buildings, e.g., apartments - Estates - Public and commercial buildings - Public spaces and parks	 1. Native soil 2. Compacted soil mixture (sand, compost and topsoil) 3. Draining gravel layer 4. Vegetation (trees) 5. Vegetation (shrubs) 6. Lighting equipment to ensure comfort and safety 7. Bench attached to firm foundation 8. Pavement (preferably permeable paving) *Image credit: European Union (URBAN GreenUP)*

NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Green walls/facades with climbing plants	A green façade is a wall completely or partially covered with greenery. A green façade uses a trellis system to hold vines of plants that are rooted in the ground or containers.	Water retention Evapo-transpiration Reduction of peak runoff Soil infiltration (where acceptable)	- Individual household - Communal residential buildings - Public and commercial buildings	 1. Soil container 2. Soil mixture (sand, compost and topsoil) 3. Trellis system 4. Climbing plants 5. Air gap between the building an the trellis system *Image credit: European Union (URBAN GreenUP)*

NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Stepped drains	Stepped drains are drains built with cascades to reduce the slope angle of the drain profile. This helps reduce the velocity of flow along the drain. Given the steep topography of urban areas of Rwanda, stepped drains offer a solution to peak runoff velocity, slope stability and erosion protection.	Reduction of runoff velocity	Drainage channels built down the slope, which drain runoff from: - Estates & other residential areas - Commercial and industrial zones - Roads	 *Image credit: Defacto / SHER*

NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Detention basins	Detention basins are vegetated depressions that are normally dry except during and immediately following storm events. They are designed to control flow rates and decrease flow peaks by storing excess runoff and releasing It slowly.	Temporarily storage Reduction of peak runoff Soil infiltration (where acceptable)	- Estates - Public and commercial buildings - Roads, e.g. roundabouts - Public spaces and parks	 *Image credit: European Union (URBAN GreenUP)* **Design standards** - Retention time: 24 hours to 48 hours - Slope at bottom: 1% to 3% - Design return period: detention basins are to be designed to provide flood attenuation for a 1:30 year event, but this level of service can be increased or reduced depending on the risk of flooding downstream, and space availability - Depth of water: maximum depth of water should be in the range of 2.5 m to 3.0. Adequate safety measures, such as fencing, should be provided.

NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Retention ponds / Constructed wetlands	Retention ponds and wetlands are features with a permanent pool of water that provide both volume attenuation and treatment of runoff. They can support emergent and submerged aquatic vegetation along their shoreline and in shallow, marshy zones. Attenuation is provided above the permanent pool of water, and the outlet controls the rates of discharge.	Storage Reduction of peak runoff	- Wetland zones - If a retention pond is to be applied in an estate, or in public /commercial / industrial areas for amenity and biodiversity purposes, special considerations need to be made to ensure the provision of aquatic vegetation that is mosquito-repellent	

NBS Component	Description	Mechanism for runoff reduction	Application in urban landscapes	Graphic detail
Underground modular / geo-cellular attenuation storage tanks	Attenuation storage tanks are used to create below-ground void spaces for the temporary storage of runoff before infiltration, controlled release or use. The structure is usually made of modular geo-cellular units with 90% to 95% void space	Storage Soil infiltration (where acceptable) Reduction of peak runoff if infiltration is applicable	- Communal residential buildings, e.g. apartments - Estates - Public and commercial buildings - Public spaces and parks	  *Image credit: Geoplast / SHER*

7

PLANNING PROCESS FOR DELIVERING SUSTAINABLE RUNOFF REDUCTION

7.1 General considerations

As a general principle, consideration of sustainable stormwater management should take place at the project inception phase, and this should be a key component of the design process. Drainage information should then be used as important input to the development of urbanization plans, public infrastructure or private development proposals.

Best practice is to adopt the principle of ‘working from the whole to part’, considering all aspects of the site proposed for development. This will enable delivery of the most cost-effective solution that achieves sustainable surface water drainage whilst ensuring that project viability is not compromised.

7.2 Consultations with municipal authorities

Delivering sustainable runoff reduction will require discussions between private developers or public infrastructure development institutions and local municipal authorities (City of Kigali or Districts) as well as other relevant agencies responsible for stormwater management. It is recommended that such discussions take place shortly after the area for development has been confirmed, and discussions should continue throughout the design and application process.

The aim of the pre-application discussions is to resolve as many issues as can be identified early in the process to achieve maximum benefits for water sensitive design. Private developers or public infrastructure development institutions should take a pro-active approach in their discussions with municipal authorities, and the latter should provide advice in a timely manner. The goal will be to enable informed decision-making early in the process.

City of Kigali or District planning authorities may need to engage with other national agencies or professional bodies with technical expertise in stormwater management to ensure a well-informed decision making.

Private developers or public infrastructure development institutions should gather all site relevant information, which could have an impact on water sensitive design. This information can be used during the pre-application discussions with municipal authorities and could include:

- Flood risk assessment reports
- Flood risk management strategies
- Draft surface water management plans

7.2.1 Matters to be discussed

Each development should be considered individually, and the pre-application discussions should focus on the site in question and its surroundings with the aim of identify issues and constraints, and to enable submission of relevant information for the construction permit.

An exhaustive list of matters to be discussed cannot be here produced, however the following key matters will need to be considered during the pre-application discussions:

- Existing site topography, that is natural drainage route if the site is a greenfield, or existing drainage infrastructure if the site is built;
- Hydrogeology, that is consideration is to be given to levels of groundwater on site;
- Earthworks and land regrading to be implemented on site, and how this will affect natural or existing drainage routes;
- Constraints on site and off site;
- Phasing in the delivery of the development (multiples phases of construction, or one phase only);
- Proposed discharge point(s) of surface water from the developed site;
- Flood risk on site and downstream of the developed site, and proposed mitigation measures;
- Temporary drainage works during the construction phase;
- Existing and proposed roads / highways;
- Maintenance plans for drainage systems on the developed site;
- Considerations for environmental and ecological factors;
- Identification of all permits required

To meet technical requirements to achieve runoff reduction, the following additional issues will need to be discussed:

- Volumes and locations on site for surface water storage;
- Peak flow runoff rates from the developed site, and how this compares to pre-development runoff rates;
- Sub-catchment areas;
- Drainage management train components;
- Proposed landscaping plans and vegetation cover;
- Design calculations for:
  - ✓ Peak flow rates post development
  - ✓ Existing runoff rates before development
  - ✓ Infiltration rates where necessary
  - ✓ Requirements for storage / volume attenuation
- Exceedance routes
- Climate change allowances

7.3 General technical considerations

a. Developments proposed within the general context of urbanization should have drainage systems designed to mimic natural drainage flow routes. The flow routes should be designed to utilize existing natural low-lying zones within the site;

b. Where developments will cause changes to the natural flow routes and discharge points, designs of the new drainage system will need to demonstrate how runoff is to be managed and how any downstream flood risk is to be mitigated;

c. Where design flows are considerably high, exceedance flows that cannot be managed via the drainage system will need to be routed via flood exceedance routes. Where the new drainage system is to connect to an existing public drain, designs should consider the capacity of the existing drain to ensure that the proposals do not result in increased flood risk on site or downstream of the site;

d. The following design principles are recommended:

  i) Drainage designs should follow standards for nature-based solutions;

  ii) Proposed drainage systems should be designed with the capacity to accommodate all runoff from the site as a whole, including all impermeable areas and any overland runoff from permeable areas so that flood risk is not increased;

  iii) Drainage proposals for a new development should be designed in such a way as to control the volume of runoff with the aim of reducing the risk posed by high runoff volumes to the morphology and water quality of downstream watercourses;

  iv) Drainage systems should be designed in such a way that runoff is managed within the sub-catchment, within the site close to source;

  v) Drainage proposals should include detailed description of system maintenance requirements such that the drainage system can be effectively operated throughout its design life;

  vi) Provision of open space should be a key consideration in the design of drainage systems;

  vii) New drainage system design should take into account climate change and potential future changes in impermeable areas on site;

  viii) Requirements for urban design, including landscaping, biodiversity, amenity and aesthetics, should be considered in the design of drainage systems.

  e. The design of drainage systems should assess the impact of failure of all important components of the system, and the associated consequences and flood risks. The proposals should recommend flood risk mitigation measures were such a failure to occur.

7.4 Specific technical considerations

7.4.1 Discharge points

Best practice recommends the following hierarchy of discharge points for surface water runoff. The aim is to discharge runoff as high up the hierarchy as technically feasible:

Hierarchy of discharge points for runoff

1. Into the ground (infiltration)
2. To a surface water body
3. To a public drainage system

To reduce runoff from the development, it is recommended to manage surface water as close to source as possible, that is as close to where the rain falls as possible. Application of the above hierarchy will enable effective control and management of runoff. Drainage designs should include a drainage strategy describing how the hierarchy has been applied in the determination of the runoff discharge point.

It is important to consider that each site will have a set of unique characteristics, and these should be carefully assessed in the selection of appropriate sustainable drainage systems to use and runoff discharge point(s). For example, given the topography of urban areas of Rwanda, not all sites will be suitable for drainage via infiltration, especially sites located on hill slopes due the risk of landslides or gully formation as a result of water saturation in soils. High ground water levels or local soil and geological characteristics may also preclude the use of infiltration as a discharge point for runoff.

It is recommended that opportunities and constraints are identified early in the design process. Drainage design and system component selection will be an important aspect of the planning and overall design of the new development and selection of discharge points will be a key parameter in the determination of which drainage system to use.

It will not always be feasible to discharge all runoff from the developed site to one point. In such a case, it is recommended to divide the site into different sub-catchments which may discharge to different points. As much as is feasible, existing drainage routes should be used a guide in the division of the site into different sub-catchments.

Where a water body exists near the proposed development, direct discharge of runoff to the water body should be carefully assessed and ensure that the run off is well treated so that it does not affect the quality of the receiving water bod. The status of the waterbody in terms of water quality and morphology should be assessed to determine the appropriate quantity and quality control to apply to the runoff from the new development.

If the proposed discharge point of runoff is to a public drainage system, it is recommended that the developer has discussion with authorities at the City of Kigali or Districts (owners of public drains). The aim is to assess the potential impacts the new connection may have on the system, and to confirm if the public drain has the capacity for additional flows.

The discharge rate of runoff, either to a water body or to public drainage system, should be agreed with the relevant responsible authorities (or municipality or agencies in charge of water resources and environment) to mitigate the flood risk in the event of uncontrolled discharge rates.

7.4.2 Peak flow control

To reduce runoff, peak flow control will be an important design aspect of the drainage system. The following peak flows controls are recommended in line with guidance from best practice:

Recommendations for peak flow control

i. For developments proposed on greenfield sites (previously undeveloped site), the peak runoff rate from the new development either to a surface water body or to a public drainage system for the 1 in 1 year rainfall event and the 1 in 100-year event should ideally not exceed the peak runoff rate under greenfield conditions for the same events.

ii. For developments on previously developed sites, the peak runoff rate from the new development to a public drain or water body for the 1 in 1 year rainfall event and the 1 in 100-year event should ideally be similar to the greenfield rates for the same events. It should also not exceed the peak runoff rate of the same events from the site before re-development.

The designer should use the most appropriate method for calculating peak runoff for the greenfield state and developed state of the site, and this should be thoroughly checked and reviewed by officers in charge of drainage at municipal authorities. Best practice would normally assign the responsibility of determining the method for calculating peak runoff rate to the municipal authorities and for this to be used as standard in drainage design. Examples of peak runoff rate calculation methods include the Rational Method and the SCS Curve Number method (see Annexe 1).

Consultations with municipal authorities (CoK and Districts) and the agency in charge of stormwater or water resources management should be undertaken in order to establish the allowable peak flows from major developments early on in the design stage.

Attenuation storage systems and flow controls should be provided as part of the drainage system where the calculated peak runoff rates from the new development are greater than greenfield rates for the aforementioned rainfall events, and where they exceed allowable peak flow rates. It is recommended that flow control systems are simple to operate and to maintain.

Flow control systems should de designed to include mitigation measures for the risk of blockage from sediments or other debris. These can include bypass or overflows.

If a new development is to be undertaken on a previously developed site and existing drainage systems are still operational and details of drainage components are available (diameter, lengths, etc.), these can be assessed for fitness for use in the drainage system of the new development. Peak flow controls should be applied to these as well.

In the event that a new development is not able to meet the requirement for peak flow control on site with justifiable reasons, consultations with municipal authorities should be undertaken to assess if there are existing drainage systems and flood alleviation infrastructure downstream, with sufficient capacity to accommodate uncontrolled runoff flows from the development.

7.4.3 Volume control

Volume control is as equally important as peak runoff rate. Even with peak flow rate control at greenfield values, the risk of flood may be increased by additional volume of runoff coming from the new development, especially during rainfall events of long duration.

Recommendations for volume control

i. For developments proposed on greenfield sites (previously undeveloped site), the peak runoff volume from the new development either to a surface water body or to a public drainage system for a6-hour rainfall event of a 1 in 100-year event, should ideally not exceed greenfield runoff volume of the same event.

ii. For developments on previously developed sites, the peak runoff volume from the new development to a public drain or water body for a 6-hour rainfall event in a 1 in 100-year event should ideally be similar to the greenfield runoff volume for the same event. It should also not exceed the runoff volume from the site before re-development for the same event.

In the event that a new development is not able to meet the requirement for volume control on site with justifiable reasons, consultations with municipal authorities should be undertaken to assess if there are existing drainage systems and flood alleviation infrastructure downstream, with sufficient capacity to accommodate uncontrolled runoff flows from the new development.

If the design of drainage in the new development is unable to accommodate volume control due to space constraints on site, consultations with municipal authorities and other relevant stakeholders should be undertaken to identify any off-site locations that can be used for volume control. This should be given serious consideration especially if the risk of downstream flooding is determined to be significant.

7.4.4 Overcoming perceived challenges

The biggest barrier to the implementation of sustainable drainage systems which deliver runoff reduction are the perceived challenges in their installation on site. Challenges that will most commonly be encountered in urban areas of Rwanda are space constraints, ground conditions, topography, existing utility services and willingness of developers and local communities to adopt sustainable drainage systems (nature-based solutions).

Space constraints: to overcome this challenge, opportunities should be maximized in the design of new developments to develop multifunctional areas such as green roofs on buildings, car parks with geo-cellular/underground water storage, and green landscape areas that also double as detention basins. Innovative design, early consultations with municipal authorities and other stakeholders should be undertaken.

Ground conditions: each site will have its own unique ground conditions. Drainage design should be undertaken with good understanding of local ground conditions, and should be suitable for the site. A 'one size fits all' approach cannot not be applied for different sites.

Topography: the aim is for runoff to be managed above ground, and understanding existing above ground flow routes will be key. Steep topography common in Rwanda should also be carefully assessed to inform the selection of appropriate sustainable drainage systems for application.

Existing utility services: if existing services such as water, electricity and fibre optics on site cannot be moved or changed, drainage design should be innovative to provide measures to work within the constraints set by the existing utility services. It is important that utility owners are consulted early in the design process to establish what is and is not feasible with view of minimising constraints.

Willingness of developers and local communities: Sustainable drainage systems / nature-based solutions promote the use of surface features which are not familiar in the Rwandan context, and their operation may not be readily welcomed. It will therefore be important for municipal authorities together with other government institutions to explain the benefits of the systems and adopt programmes early public engagement in any project.

7.4.5 Structural integrity of drainage systems

The following key technical aspects should be taken into consideration:

Recommendations for structural integrity

i. Components should be designed to ensure structural integrity of the drainage system and any nearby infrastructure under the peak flow conditions.

ii. Materials used for construction of the drainage system, including components and fittings, should be of acceptable quality and fit for purpose with regards to the intended use

The designer should ensure that any components that will require replacement and/or maintenance are designed to be accessible, and the access should not adversely impact the function of the drainage system.

The designer should select materials that do not react and/or degrade over time leading to eventual degradation of the function of the drainage system. Construction techniques should be such that the structural stability of the components is guaranteed even during extreme rainfall events.

7.4.6 Designing for maintenance

Operational maintenance requirements of the drainage system should be considered throughout all phases of design, and suitable access provided to enable access for inspection, maintenance and repair.

The location of access and service points should be taken into consideration during the design phase such that access causes minimal disruption to the function of the drainage components.

Capital expenditures and operating expenditures of the proposed drainage system should be taken into account as this will be a decision factor into the design choices for the drainage components.

Components of the proposed sustainable drainage system should be designed to ensure management and control of sediments. If the components provide means for managing sediments, the design should provide for appropriate maintenance activities for sediments removal.

7.4.7 Designing for health and safety

Sustainable drainage systems should be implemented taking into account and complying with relevant Rwandan health and safety regulations. Proposals should ensure that the design, construction, operation and maintenance of the system meet the requirements for health and safety.

It should be noted that health and safety risks may be different during the construction phase and during the operation phase of the system, and all these should be fully considered. An example can be here given for a detention basin which is normally dry, but fills up with water during a storm – the level and type of risks change.

Public interface with the drainage system component will be vital, therefore public engagement should be undertaken early in the planning and design phase.

7.4.8 Amenity and urban design

Drainage design should ensure that the proposals complement existing urban and natural environment such that the components fit into the general urban layout, context and objectives. Future urban plans should also be taken into account.

7.4.9 Designing for exceedance

It should be noted that the occurrence of a rainfall event which causes flow exceedance is possible and measures should be included in the design for managing the exceedance. In some cases of design, playgrounds and car parks have been used to provide exceedance flow routes during such storms.

8

ANNEXE

8.1 Calculation of peak runoff rate

8.1.1 Rational Method

The Rational Method is an empirical method for estimating peak runoff rates based on the equation below. The formula is generally recommended for rough estimations of runoff from small catchments by field technicians / engineers in a broad and high-level sense.

$$Q_p = 0.00278 \times C.I.A$$

Where:

Qp = peak discharge (m^3/s)

C = runoff coefficient (no units)

I = rainfall intensity (mm/h)

A = catchment area (ha)

8.1.2 SCS Curve Number method

The SCS Curve Number Method is an empirical method for estimating peak runoff rates based on the equation below. This method is more refined as it is based on time of concentration, hydrographs, etc. and the majority of hydrological modelling software are based on it.

$$Q_p = 0.21 \times \frac{A \times Q}{Tp}$$

Where:

A = catchment area (km^2)

Q = runoff depth (mm)

Tp = time to peak (h) with $T_p = 0.7\ T_c$

The time of concentration of the catchment is computed based the watershed lag method[4] and considering that the lag time equation is 0.6 times the time of concentration. The runoff depth defined with the SCS CN method depends on two parameters: the Curve Number and the rainfall.

The Curve Number is based on reference tables (NRCS, 2014)[5] , whereas rainfall is derived from applicable IDF curvesfor a duration corresponding to the time of concentration of the catchment.

8.2 Climate change factors

In the context of climate change, it is important to take into account the potential changes in rainfall patterns over the coming years. To do this, percentages of change should be applied according to the return periods and scenarios set up by the IPCC.At the global scale, extreme daily precipitation events are projectedto intensify by about 7% for each 1°C of global warming (IPCC 6, 2021).

The Rwanda's Third National Communication Report to UNFCCC (2018) indicates that there could be a 5 to 10 % increase in rainfall intensity by 2050. The climate change scenarios identified under the 6thIPCC Report for the horizon 2041-2060 are presented in the table below and a 7 % increase of rainfall intensity is applied to each 1°C of global warming.

Table 5: ***Potential increase in extreme daily precipitation events at global scale according to the 6th IPCC Report***

Climate change scenario	*Return period (years)*
	2041-2060
SSP1-1.9- Very low emission	*11.2 %*
SSP1-2.6- Low emissions	*11.9 %*
SSP2-4.5- Intermediate emissions	*14.0 %*
SSP3-7.0- High emissions	*14.7 %*
SSP5-8.5-Very high emissions	*16.8 %*

8.3 Designing for attenuation storage

Attenuation storage should be provided to temporarily store water during periods when runoff rates from the developed site exceed allowable discharge rates from the site, say greenfield runoff rate. Attenuation storage systems should be designed to drain at a rate controlled by the outlet flow control device or structure. Storage should be provided on site using structural elements installed either above or below ground surface, or non-structural features such as landscape features include detention basins (normally dry) or retention ponds (a permanent water body).

Attenuation storage can be implemented either on-line or off-line. On-line storage uses a storage component through which flows all runoff from upstream catchment. Off-line storage is a storage component that is separate from the main drainage conveyance path, to which runoff is diverted when flow rates or levels exceed the set threshold.

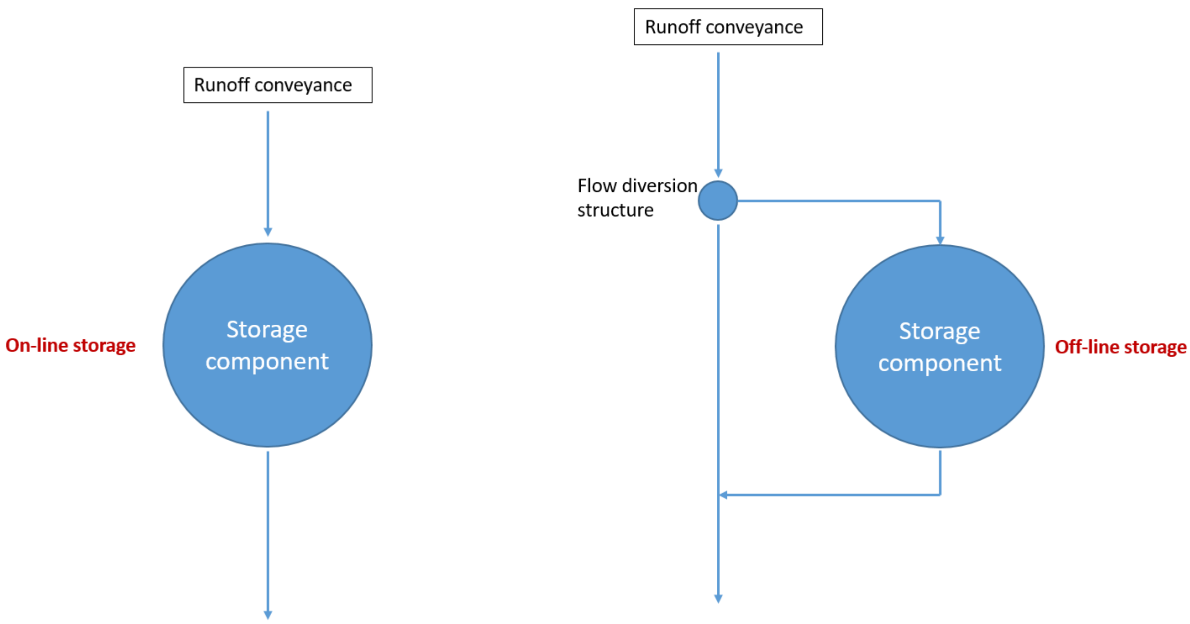


Figure 4 *– On-line and off-line attenuation storage*

8.4 Conveyance design

The layout of the development site, particularly roads and the drainage system, should be designed so that natural overland conveyance routes are used to manage runoff.

Surface conveyance systems, such a swales, channels and ditches, should be designed to convey the peak design flow rate. It is recommended to design the conveyance systems for peak flows of a return period of 1:20 year event, but this level of service might be either increased or decreased depending on the flood risk on site or downstream.

Manning's formula can be used to check on the capacity of individual conveyance components.

$$Q = \frac{AR^{2/3} S^{1/2}}{n}$$

Where:

Q = flow rate (m^3/s)

n = Manning's coefficient, a roughness coefficient dependent upon the channel characteristics. Values of Manning's coefficient can be obtained from many standard textbooks.

S = overall slope of the channel (m/m)

R = Hydraulic radius = A/P, where A is the cross-sectional area (m^2) and P is the wetted perimeter (m)

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