Design of Nature Based Solutions (NBS)for Flood Risks Reduction in four urban sub-catchments in Rwanda

October 2021

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INTRODUCTION

1.1 Reference to design standards

This report presents design outputs for Nature Based Solutions (NBS) in the context of flood and landslide risk assessment and mitigation study for the sub-catchments of RwandexMagerwa in Kigali City, Bishenyi in Kamonyi District.

Seeing there are no existing design standards for NBS in Rwanda, the design proposals given in this report have been developed with reference to the following standards, taking into consideration the local conditions and NBS applicability.

- Smart, sustainable and resilient cities: the power of nature-based solutions (UNEP, 2021);
- Global standards for nature-based solutions (International Union for Conservation of Nature, IUCN 2020);
- NBS catalogue (European Union, URBAN GreenUP - 2018);
- The South African guidelines for sustainable drainage systems (2013).

Given the multiple resources referred to, no absolute compliance to any of the aforementioned standards was sought, but these were used to inform best-practice as can be applied to the Rwandan situation in general, and local site conditions in particular.

1.2 What are Nature Based Solutions?

Nature Based Solutions are surface water management elements designed to replicate, as closely as possible, the routes of the natural water cycle to ensure that flood risk in the downstream areas does not increase as a result of urbanisation or construction of new developments upstream. Nature Based Solutions can also increase the quality of water in the runoff from urbanised areas, and can enhance the amenity and biodiversity value of places.

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, NBS provide systems that enable infiltration, slowing down, storage and effective conveyance of runoff.

1.3 Selected NBS components

There is a range of NBS components available to provide effective surface water management that intercept and store excess runoff. Given the terrain and topography of the study areas, and considering local conditions and applicability, the NBS components in Table 1are recommended for the upstream and downstream sections of the sub-catchments. The selection of NBS components applicable in each sub-catchment is based on a general knowledge of the areas and engineering judgment. It may be that there are other NBS components not listed which can be applied, therefore the list given below is not exhaustive and can be subject to modification at the detailed design phase when more information is available.

Given that topographic surveys were carried out for the downstream sections of the sub-catchments, this report presents preliminary designs (including drawings) of NBS components in these areas only. General design information and specifications are given for the NBS components that can be applied in the upstream areas of the sub-catchments, and an estimation of impact they may have in terms of reduction of runoff.

Table 1: **Types of NBS components considered in the study**

Component	Description	Applicability in study areas	Applicability in upstream and/or downstream areas of sub-catchments
Rainwater harvesting (RWH)	RWH is the collection of rainwater runoff for use. Runoff can be collected from roofs and other impermeable areas, and stored in tanks for use	All	Upstream (all)
Green roofs	Green roofs are areas of living vegetation installed on top of buildings to provide visual benefits, ecological value, enhanced building performance and reduction of runoff	All	Upstream (all) Downstream (Rwandex - Magerwa)
Trees	This includes trees planted along urban streets, as well as in areas of woodland in the urban fringes. They increase the amenity value of urban landscapes, and the canopies intercept rainwater to reduce runoff	All	Upstream (all)
Permeable pavements	These provide a pavement suitable for pedestrian and/or vehicular traffic while allowing rainwater to infiltrate through the surface and into underlying structural layers to the ground below	All	Upstream (all) Downstream (Rwandex - Magerwa)
Swales	Flat bottomed vegetated open channels used to convey, treat and often attenuate surface water runoff	All	Upstream and downstream (all)
Detention basins	These are landscaped depressions, which are normally dry except during and immediately following storm events. They provide storage of peak runoff, slowly releasing it downstream	All	Downstream (all)
Attenuation storage tanks	These tanks are used to create below - ground void space for the temporary storage of surface water before infiltration, controlled release or use. The storage structure is commonly formed using geocellular storage systems.	All	Upstream (all) Downstream (Rwandex - Magerwa)

2

DESCRIPTION OF FLOOD MECHANISMS IN THE STUDY AREAS

The study area comprises of four sub-catchments, namely: Rwandex-Magerwa in Kigali City, in Kamonyi District, Rwabayanga in Huye District and Kamembe-Gihundwe in Rusizi District in Kigali City. These are shown on the location map below.

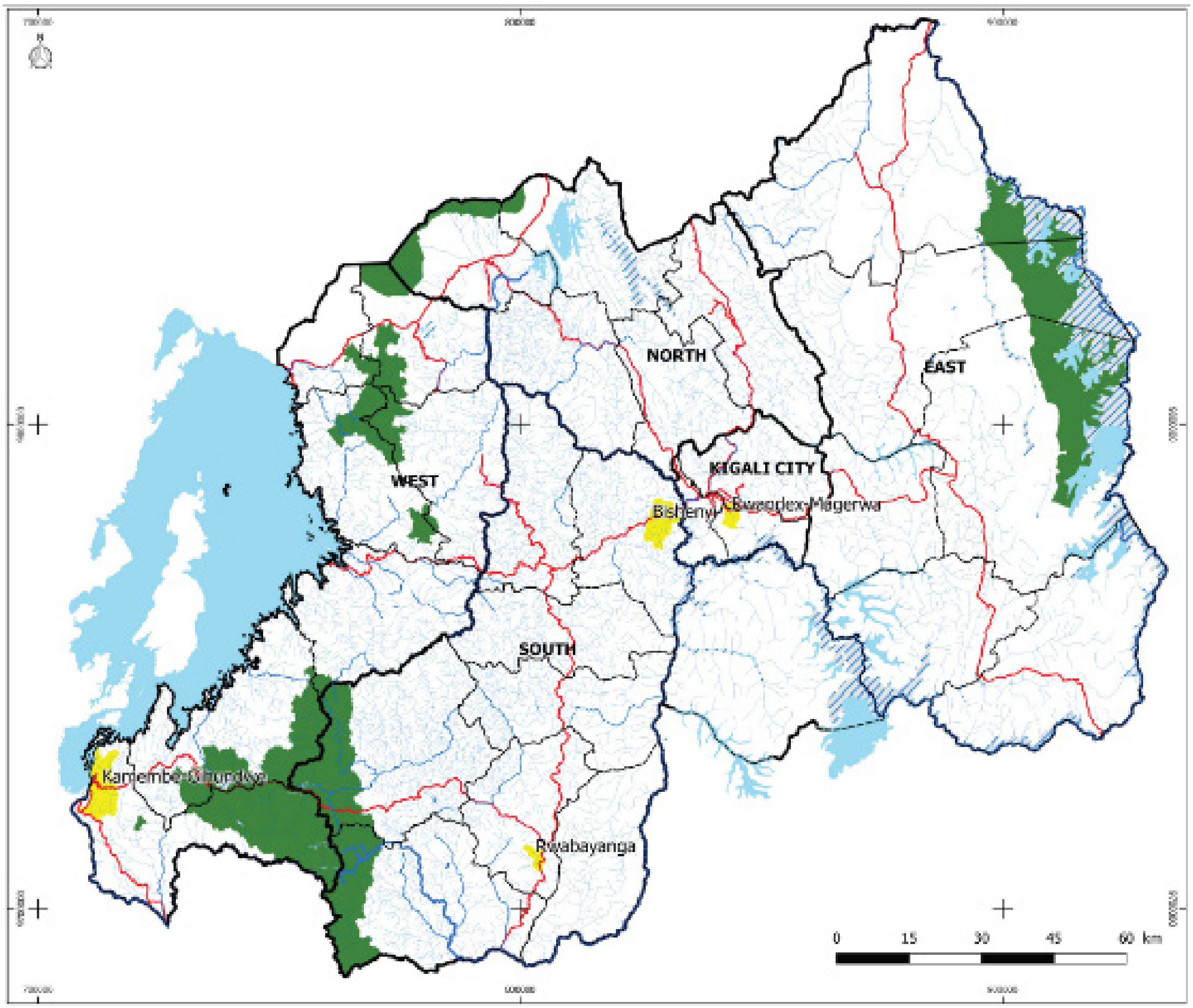


Figure 1 – Location map of study areas

2.1 Rwandex-Magerwa

Rwandex-Magerwa sub-catchment is located to the centre-south of Kigali City and it forms part of the larger Kinamba sub-catchment, which drains to Nyabugogo River. Upstream areas of the sub-catchment are predominantly residential, including planned settlements in Gikondo and Kicukiro and unplanned settlements in Gatenga and Karambo.

The downstream area of the sub-catchment comprises business and commercial complexes as well as other public buildings, many of which sit in area that is can be categorised as a flood plain. There is a wetland at the lower sections of the downstream area, to which runoff is channelled and discharged onwards to the Gikondo wetland.

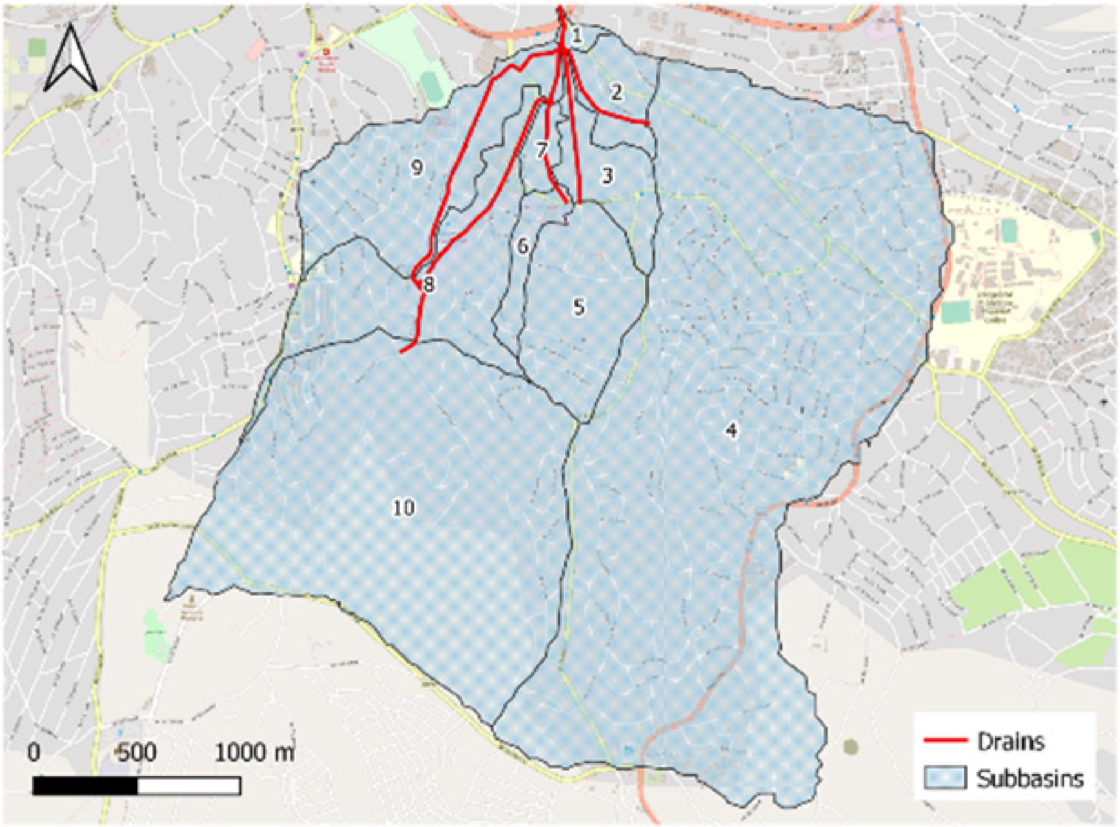


Figure 2 *– Rwandex-Magerwa sub-catchment location map (Background: OpenStreetMap)*

Flood hotspots have developed in recent years around the Magerwa complex. This has been mostly due increased surface water runoff from the urbanising areas upstream, where new residential neighbourhoods have developed in Gikondo (Rujugiro area), and public infrastructure such as the new tarmac road linking Nyanza and Gikondo, as well as the Kigali Cultural Village at Rebero, which have been recently built. All the runoff drains down the slopes of Gikondo and Gatenga via drainage channels, which converge at Magerwa on-route to the nearby Gikondo wetland. The channels are undersized for peak runoff conveyance and as a result, the site is flooded during heavy storms.

Previous studies have also reported that the Magerwa complex is built on top of the drainage channels, creating obstacles to the flow of runoff .

Magerwa authorities has attempted to mitigate the flooding risk by widening the channels located immediately upstream of the southern side of the fence wall to protect it from collapse. However this did not solve the problem entirely as the flood hotspot only shifted farther downstream to the main ring road.

Findings indicate an issue of lack of space of managing storm water in the downstream areas of the sub-catchment (around Magerwa), but also lack of flow attenuation upstream, resulting in flash floods due to rapid transfer of flows. Other issues identified include channels built with sharp bends, with potential to create hydraulic jumps as flow energy is dissipated, resulting in road surface floods (typical case at the main gate entrance to NAEB), as well as inconsistent drainage channel widths, with potential to cause back flow effects and floods during heavy storms.

The reader is referred to the hydraulic modelling report for more details on flood hazard mapping of the area.

2.2 Bishenyi

Bishenyi sub-catchment is located in Kamonyi District, to the west of Kigali City. It drains the areas of Bishenyi, Runda, Ruyenzi, Sheli and Rugalika. Land use in the sub-catchment is predominantly agricultural, but there has been large-scale construction of residential homes on hilltops and slope sections during the last 10 years, especially in the Ruyenzi area. The area is projected to become predominantly urban / peri-urban as per the 2050 land use master plan.

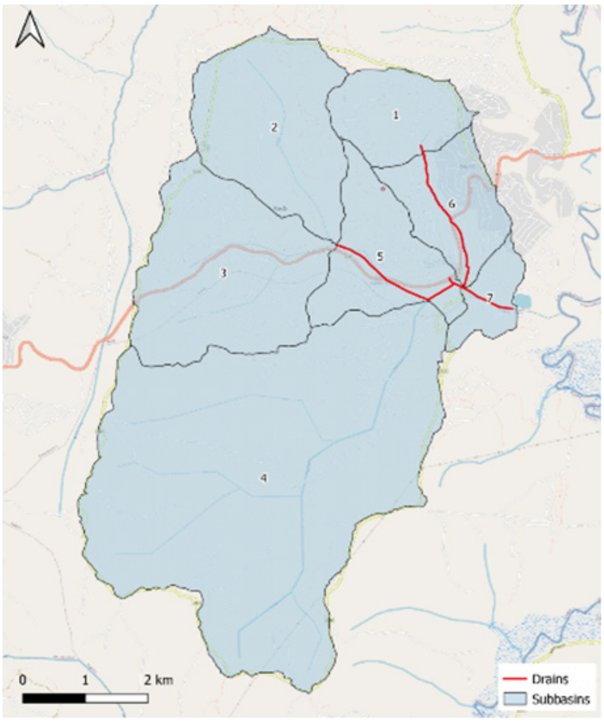


***Figure 3** – Bishenyi sub-catchment location map (Background: OpenStreetMap)*

As the upstream areas of the catchment have seen rapid urbanisation, the wetland downstream used for agriculture has correspondingly experienced an increase in flood risk. Flooding has caused loss of lives and destroyed crops in the wetland , and affected motor vehicle movements along the main Kigali-Muhanga national road. The flood hotspot is located on the road near Hashi petrol station.

Whilst the increased urbanisation in the Ruyenzi hilltop and slope areas (Sub-basin 6) has contributed to the problem of flooding by generating high volumes of runoff drained to Bishenyi wetland, it should also be noted that irrigation channels in the wetland are undersized for the high flows, causing overflows and floods. Hydraulic modelling has also shown that existing structures at passage points (culverts, bridge sections) are undersized for peak flows. It was also observed that little to no flow attenuation nor rainwater harvesting exist in the urbanising areas of Ruyenzi, resulting in rapid transfer of storm flows downhill to the wetland.

Flood hazard mapping of the area is included in the hydraulic modelling report.

2.3 Rwabayanga

Rwabayanga sub-catchment is located in Huye District in the Southern Province. The eastern and northern sides of the sub-catchment are urbanised, part of Huye City, whilst the western and southern ends are semi-urban/rural agricultural areas. The area is projected to become predominantly urban / peri-urban as per the 2050 land use master plan.

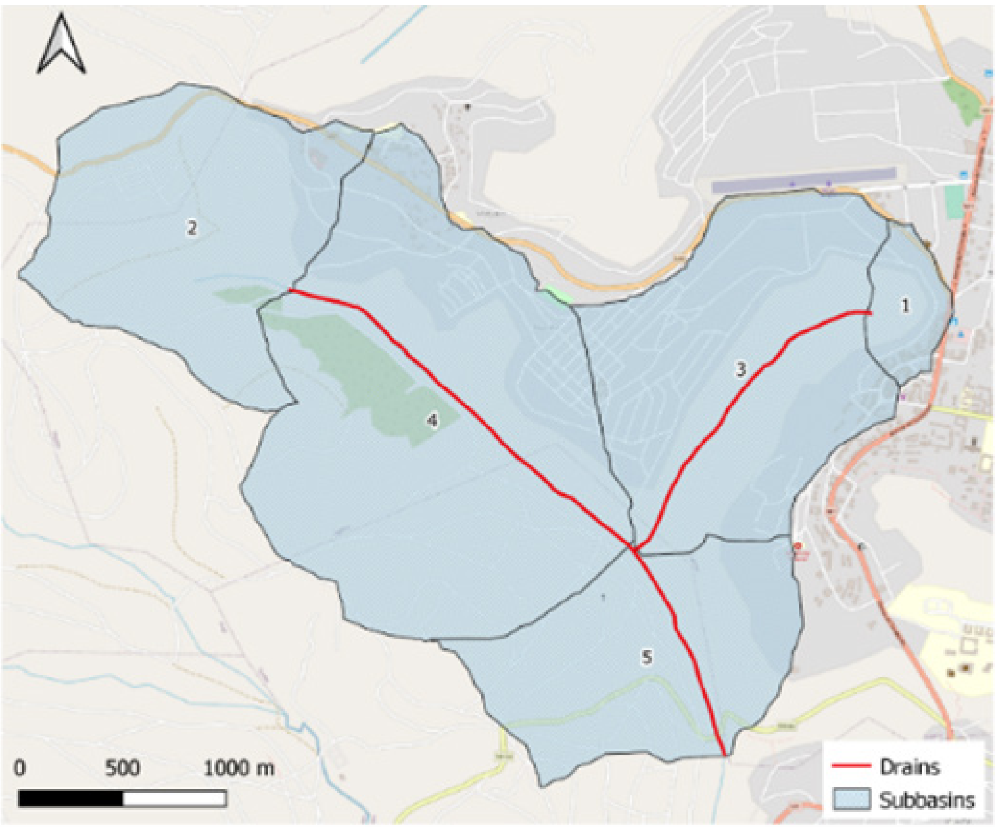


***Figure 4** – Rwabayanga sub-catchment location map (Background: OpenStreetMap)*

The busy commercial area of Huye City, also known as 'Mu Cyarabu', sits on the hilltop of sub basins 1 and 3 from where runoff is drained directly to Rwabayanga wetland downstream. This area has experienced rapid urbanisation including construction of new buildings in the city, including new paved roads constructed under the World Bank's RUDP programme. This has led to the generation of high volumes of runoff that are not attenuated.

Runoff has historically drained downhill along natural flow channels. Two main problems have resulted from this: flooding in the Rwabayanga wetland, and a creation of a large ravine (between 5 and 10 m deep) below Huye market on the southern end of Sub-basin 3.

New stone-masonry drainage channels have recently been constructed on slopes of sub-basins 1 and 3 to drain runoff from new RUDP paved roads. Other drainage channels have also been constructed on the slopes of sub-basins 2 and 4 to drain the new paved road to Nyaruguru District. Information collected from farmers in the wetland is that flooding has significantly increased in the wetland since the construction of the Nyaruguru road. Flood hazard mapping of the area is included in the hydraulic modelling report.

2.4 Kamembe-Gihundwe

The Kamembe-Gihundwe sub-catchment is located in Rusizi District in the Western Province. This site is not a 'sub-catchment' per se, but it is composed of small sub-catchments distributed across three cells as shown in the table below:

Table 2 – **Sub-catchments in Kamembe-Gihundwe site**

Sector	Cell	Village (mini-sub-catchment)
Kamembe	Cyangugu	Mont Cyangugu
	Ruganda	Kadashya
Gihundwe	Burunga	Burunga
		Karushiririza
		Karangiro

Observations made on site show that there are no large scale flooding issues in the area, but a general lack of drainage infrastructure, which causes localised flood hotspots at low points in the new neighbourhoods particularly in the Gihundwe area (Sub-basin 1). The City of Rusizi is currently experiencing a boom in the construction of new residential homes and adjoining roads, but no formal drainage systems are in place to provide safe passage of generated runoff. The current situation in some new neighbourhoods is that stormwater from the hilltop areas creates informal channels on its downstream route, and this puts settlements within its path at risk, especially in Sub-basin 6 (Mont Cyangugu) and Sub-basin 1 (Gihundwe). The solution to this problem is the provision of formal drainage channels, design of which is provided in the hydraulic structures design report.

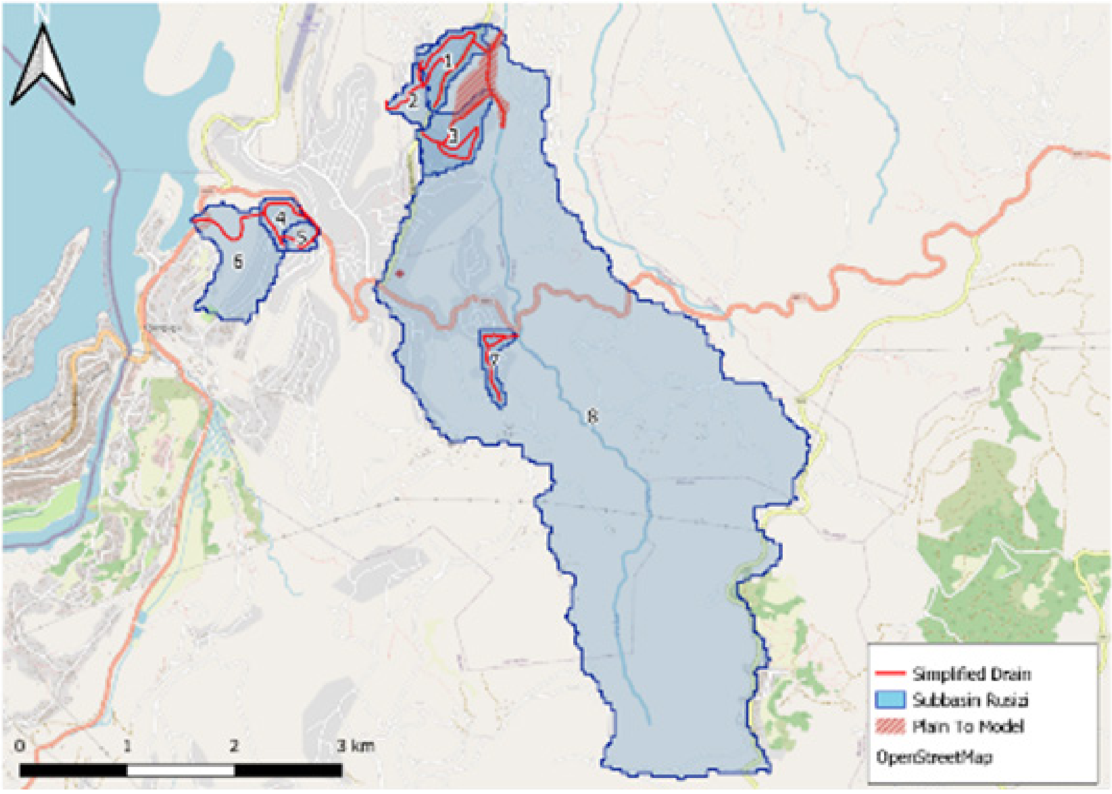


***Figure 5** –Kamembe-Gihundwe sub-catchment location map (simplified drains in red refer to proposed drains)*

3

CONCEPTUAL DESIGN CONSIDERATIONS FOR UPSTREAM NATURE-BASED SOLUTIONS

This section presents generic design considerations for Nature-Based Solutions (NBS) applicable in upstream zones of the study areas. These NBS can be applied to all the four sub-catchments given that the upstream sections are generally similar in terms of land use as per existing and projected urbanisation plans, which include residential housing, public buildings, commercial centres, roads, etc.

Rainwater harvesting systems (RWH), green roofs, trees, and permeable paving are discussed in this section. Design details of swales and attenuation storage tanks, which can also be applied in upstream areas (see Table 1), are presented in Section 5.

3.1 Rainwater harvesting (RWH)

Rainwater harvesting (RWH) is the collection of rainwater runoff for use. Runoff can be collected from roofs and other impermeable areas, treated (where required) and then used for different purposes in domestic, commercial and/or industrial environments. RHW provide the following benefits:

- RWH can meet some of the building's water demand, which in turn leads to water conservation and climate resilience benefits;
- RWH help reduce the volume of runoff from a site;
- RWH can help reduce the volume of attenuation storage required on site.

The collected water can generally be used for a range of non-potable purposes, such as flushing toilets, washing, and other external uses. Care should be taken when RWH systems are used to provide potable water for consumption to ensure that water is filtered, boiled or chlorinated depending on the scale of application (domestic, commercial or industrial). Provisions of the National Rainwater Harvesting Strategy (Rwanda Natural Resources Authority, 2016) should be followed.

3.1.1 Gravity RWH systems

Gravity systems should be designed so that rainwater is collected by gravity and stored at elevation so it can be supplied by gravity. In such cases, the key design constraints include the structural capacity of the building to store water at an elevated location.

In low elevation buildings, above-ground storage tanks should be used to serve ground floor water use points and other external uses.

In both applications, water from rooftops and other impermeable surfaces should pass through a coarse filter before discharge to the collection tank.

3.1.2 Pumped RWH systems

Pumped RWH should be designed to include either an above-ground or below-ground water storage tank from where which water is pumped for to different usage points. Pumping can either be directly to a header tank or directly to the usage units.

3.1.3 Selection and siting of RWH systems

Selection and siting of RWH systems will depend on the size and access requirements of the tank and the physical constraints of the site. In all cases, easy but safe access is needed to all components of the system to ensure that there is no impediment to maintenance.

RWH tanks should be placed in a safe, secure location either above ground or below ground adjacent to buildings. Structural considerations such as depth of foundations and the water-tightness of the tank are important design considerations.

3.1.4 Water quality protection

The gutters that contribute to the RWH system should be partially covered to reduce the risk of entry of debris, animal and other contaminants. A trap filter should also be installed at the inlet of the storage tank.

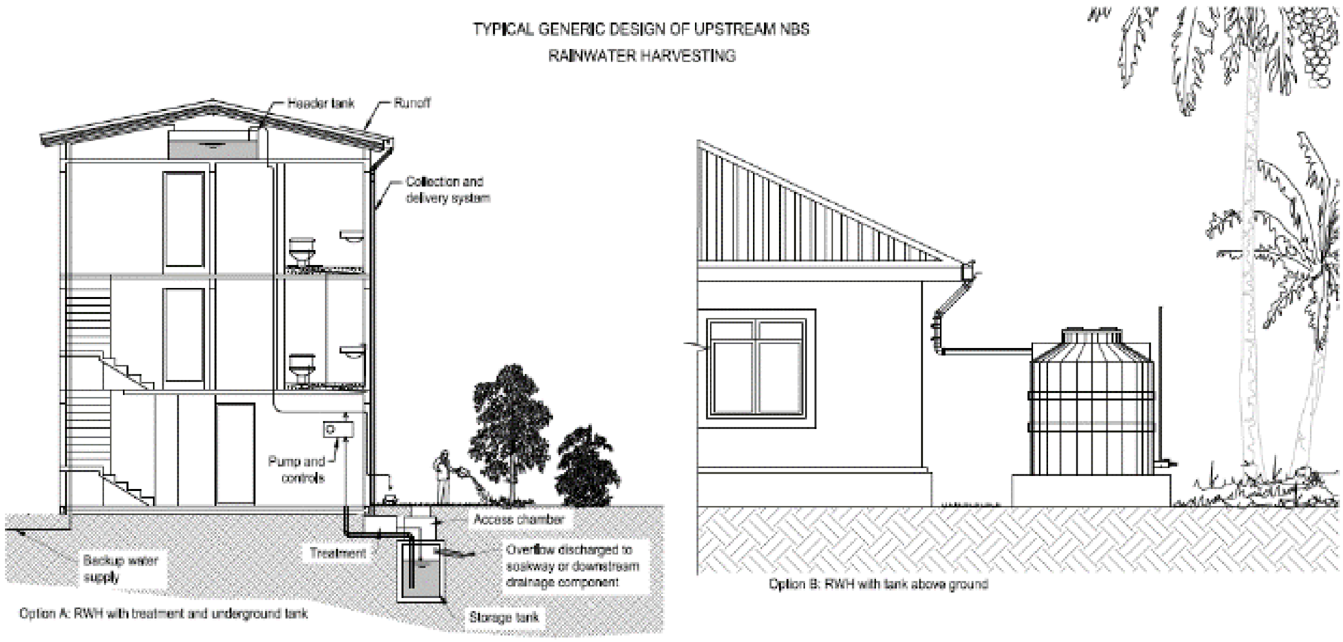


Figure 6 *– Schematic representation of RWH system option (Refer to drawing No.: RW114-IR3-NBS-US-001)*

3.1.5 Hydraulic design

The sizing of a RWH storage tank should consider the following:

- Area contributing runoff to the tank;
- Water demand from RWH system;
- Regularity of the demand;
- Local rainfall characteristics.

The following equation can be used to calculate the volume of usable rainfall collected from roofs to RWH storage tank, i.e. annual collectable rainfall:

$$V = R \times A \times C^3$$

Where :

V = Volume of usable water (l)

R = Average rainfall over period (mm)

A = Area contributing to runoff (m2)

C = Runoff coefficient (0 – 1)

Table 3 – Typical runoff coefficients for rainwater harvesting off roofs

Roof classification	Runoff coefficient, C
Pitched roof, tiled	0.85
Flat roof, tiled	0.6
Green roof	0.2

3.1.6 Construction and maintenance considerations of RWH systems

Most RWH storage tanks in Rwanda are manufactured in plastics or concrete. When selecting a material and product type, consideration should be given to:

- Tank service life;
- Structural design and installation complexity;
- Ease of maintenance.

RWH systems should be installed using safe construction methods and in accordance with manufacturers' guidelines. Any buried tank should be constructed in accordance with the structural engineer's specifications to ensure that it is suitable for the ground conditions in which it is installed. Careful consideration of the structural impact of the tank on the building due to excavation and subsequent operation of the system needs to be taken.The operation of the tank overflow when the system is full needs to be considered and designed to avoid damage or nuisance. Households that utilise RWH system for potable purposes should be aware of the potential health risks and take the necessary operation and maintenance precautions, including filtering, boiling or chlorination. The following table summarises maintenance requirements of RWH systems:

Table 4 – Maintenance requirements of RWH systems

Schedule	Action	Frequency
Regular maintenance	Inspection of the tank for debris and sediment build-up, inlet/outlet devices, overflow areas and pumps/filters where applicable	Annually or following poor performance
	Cleaning of tank, inlets, outlets, gutters, downpipes, and filters of silts and other debris	Annually or following poor performance
Occasional maintenance	Cleaning and/or replacement of any filters	Three monthly or as required
Remedial actions	Repair of overflow erosion damage or damage to tank	As required
	Pump repairs (where applicable)	As required

3.1.7 Estimation of impact of RWH on runoff reduction in the study areas

A study[5] carried out in Brazil to assess the impact of rainwater harvesting on the drainage system showed that there was a decrease in peak runoff ranging from 4.4% to 4.9% when measured at the catchment outfall. Using a conservative approach, a reduction of 4.0% in peak flow is assumed for the four study areas. Using results from the study quoted above, an assessment was carried out to estimate the impact of RWH on the reduction of runoff from upstream area, assuming that a 50% coverage of RWH systems in Buildings and Settlement zones, which translates to an estimated 50% of the runoff being affected by the RWH systems in the study areas. The estimation of peak runoff reduction is summarised in the tables below for current and projected (2050) land use plans:

Table 5 – Estimation of peak runoff reduction from RWH for current land use plan (2018)

Site	Total Surface area (ha)	Surface area of the buildings and settlements zone (ha)	Calculated peak flow T100 (from hydrological study report) (m3/s)	Estimated peak flow with application of permeable paving at 50% coverage (m3/s)
Bishenyi	4,686.8	175.9	62.1	60.8
Rwabayanga	809.0	114.6	13.2	12.9
Rusizi	1,321.0	412.47	18.7	18.3
Magerwa (sub-basin 10)	233.4	107.4	50.3	49.3

Table 6 – Estimation of peak runoff reduction from RWH for projected land use plan (2050)

Site	Total Surface area (ha)	Surface area of the buildings and settlements zone (ha)	Calculated peak flow T100 (from hydrological study report) (m3/s)	Estimated peak flow with application of permeable paving at 50% coverage (m3/s)
Bishenyi	4,686.8	1167.9	97.6	95.6
Rwabayanga	809.0	429.4	27.8	27.2
Rusizi	1,321.0	730.4	34.8	34.1
Magerwa (sub-basin 10)	233.4	184.4	83.4	81.7

[5] Impact of rainwater harvesting on the drainage system: case study of a condominium of houses in Curitiba, Brazil (Teston et al., 2018)

3.2 Green roofs

Green roofs are areas of living vegetation installed on top of buildings for a range of reasons including visual amenity, enhanced building performance and the reduction of surface water runoff. There two types of green roofs:

- Extensive roofs: these have low substrate depths, and therefore low loadings on the building structure. They are characterised by simple planting and low maintenance requirements. They cover the entire roof area with slow growing, drought tolerant low maintenance plants (herbs, grasses, mosses, etc.). Extensive green roofs should typically comprise of a 20 mm to 150 mm thick growing medium, and should only be accessed for maintenance. They can be installed flat or sloping (0˚ to 20˚) However steeper pitches will reduce the storage capacity of the system as water drains away faster.
- Intensive roofs: these have deeper substrates and therefore higher loadings on the building structure. The deep substrate can support a wide variety of planting by which tend to require maintenance that is more intensive. They are planted with a range of plants including grasses and shrubs. They should be designed for easy access as they require a fairly high level of regular maintenance. The depths of the substrate should > 150 mm.

Green roofs consist of a system in which several materials are layered to achieve the desired vegetative cover and drainage characteristics. Design components vary depending on the green roof type and site constraints, but typically include the elements shown in the figure below:

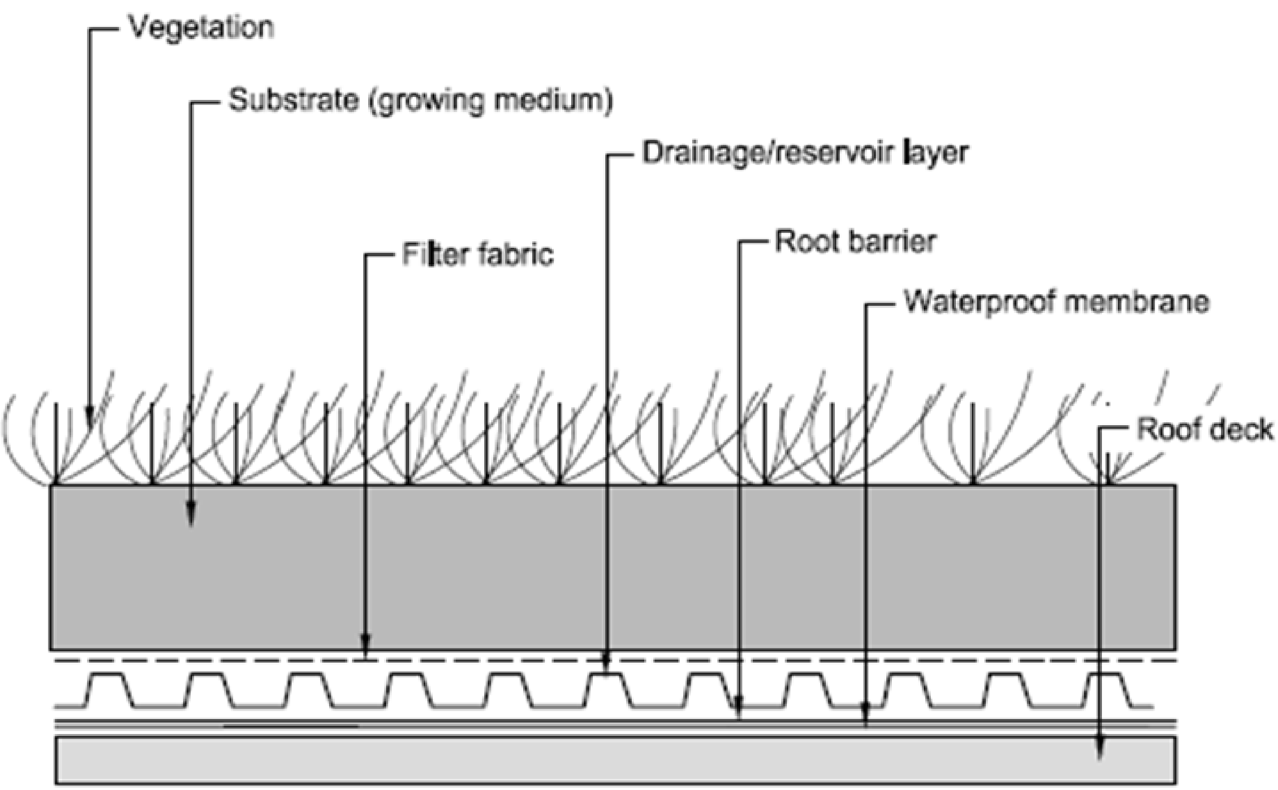


Figure 7 *– Section showing typical green roof components (Refer to drawing No.: RW114-IR3-NBS-US-002)*

3.2.1 Hydraulic performance

Greens roofs can be assumed to provide interception, whereby the amount of rainfall that can be absorbed before runoff takes place is dependent on antecedent conditions (relative soil moisture of substrate before the storm). However, the proportion of runoff from a green roof will increase as the duration and depth of the storm increases. The type of plants used and soil depths will influence evapotranspiration rates and available storage in the substrate. Given the relative complexity in the design of green roofs, their hydraulic performance should be determined using modelling.

3.2.2 Amenity and biodiversity considerations

A green roof should be designed to provide valuable amenity if the roof is to be accessible, creating more colourful aesthetically pleasing and natural environment. Green roofs should also be designed to provide high ecological value, enhancing biodiversity, and creating valuable habitats for birds, bees and other insects and invertebrates.

3.2.3 Construction and maintenance requirements

Construction materials of a green roof should include the following:

- waterproof membrane;
- a root barrier;
- a drainage layer located on top of the waterproof membrane;
- a geotextile filter layer to prevent clogging of the drainage layer; and
- a soil and growing medium;
- landscaping and vegetation.

The following table summarises maintenance requirements of green roofs:

Table 7 – Maintenance requirements of green roofs

Schedule	Action	Frequency
Inspection	Inspect all components including soil substrate, vegetation and drains, membrane and the ro of structure for integrity of waterproofing.	Annually and after severe storm
	Inspect soil substrate for any evidence of erosion channels and identify any sediment sources	Annually and after severe storm
Maintenance	Remove debris and litter to prevent cl ogging of inlet drains and interference with plant growth. Replace dead plants as required. Remove weeds. Mow grasses and prune shrubs	Six monthly or as required
Remedial actions	If erosion channels are present, these should be stabilized with extra soil substrate similar to the original material. Control sources of erosion	As required
	Repair drain inlets that have settled, cracked or moved	As required

3.2.4 Estimation of the impact of green roofs on runoff reduction in the study areas

Different studies have undertaken to evaluate the impact of green roofs on runoff reduction. A study assessing the effect of green roofs in Canada and China showed a roof top runoff reduction of 29%, 55% and 100% in the cities studied, which represents an average reduction of 61%. Another study in Canada showed that green roofs discharged 63% less runoff than conventional roofs.

For the purpose of estimating runoff reduction effect of green roofs in the study areas, a conservative value of 45% is used. Given that green roofs are not a common technology used in Rwanda, it is assumed that only 5% of buildings and settlements in the study areas would be willing to take up and use the technology. This would translate to an estimated 5% of the runoff being affected by the green roofs in the study areas. The estimation of peak runoff reduction is summarised in the tables below for current and future (2050) land use plans:

Table 8 – Estimation of peak runoff reduction from green roofs for current land use plan (2018)

Site	Total Surface area (ha)	Surface area of the buildings and settlements zone (ha)	Calculated peak flow T100 (from hydrological study report) (m3/s)	Estimated peak flow with application of permeable paving at 50% coverage (m3/s)
Bishenyi	4,686.8	175.9	62.1	60.7
Rwabayanga	809.0	114.6	13.2	12.9
Rusizi	1,321.0	412.47	18.7	18.3
Magerwa (sub-basin 10)	233.4	107.4	50.3	49.2

Table 9 – Estimation of peak runoff reduction from green roofs for projected land use plan (2050)

Site	Total Surface area (ha)	Surface area of the buildings and settlements zone (ha)	Calculated peak flow T100 (from hydrological study report) (m3/s)	Estimated peak flow with application of permeable paving at 50% coverage (m3/s)
Bishenyi	4,686.8	1167.9	97.6	95.4
Rwabayanga	809.0	429.4	27.8	27.2
Rusizi	1,321.0	730.4	34.8	34.0
Magerwa (sub-basin 10)	233.4	184.4	83.4	81.5

3.3 Urban trees

Trees enhance the urban environment in many ways including:

- Interception of rainwater as an effective contribution to the reduction of runoff from urban areas;
- Addition of beauty and character to the urban landscape, which in turn helps to improve the health and wellbeing of local communities;
- Filtering harmful pollutants from the air; and
- Creating vital wildlife habitats.

3.3.1 General design considerations

Besides rainwater interception, tree (pits and roots) can also be used to manage surface water runoff. However, they should only be intended to manage water from the local area, and should not be used to manage large volumes of runoff that have been collected from large areas. Trees require space, appropriate soil, and a supply of water. It should therefore be ensured that the runoff area draining to the tree will provide it with enough water. Designing tree planting zones to accommodate the largest size tree possible will increase the tree zone's capacity to manage runoff. Mature, large species trees with their large dense canopies provide the most interception and can manage the most runoff. The likely rooting characteristics of the proposed trees should be considered to ensure tree viability and stability in the urban environment, as well as ensuring protection from damage of underground urban utility services.

Suitable trees should be chosen on an area-by-area basis, based on the constraints and opportunities afforded by a particular location, and to achieve optimum delivery of runoff management, amenity and biodiversity objectives. Selection and siting of trees should be determined with support from urban and landscape architects, in consideration of the following:

- Runoff characteristics (flow rates and volumes);
- The nature of soils into which trees are to be planted;
- The location and characteristics of the planting site (e.g. narrow canopy trees may be required for narrow streets)

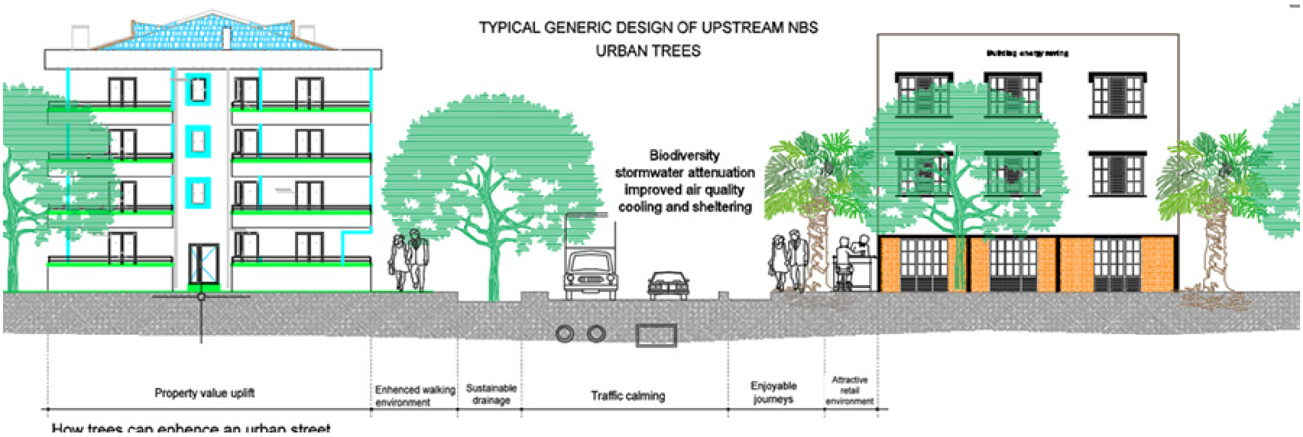


Figure 8 *– Typical urban landscape with trees (Refer to drawing No.: RW114-IR3-NBS-US-003)*

3.3.2 Maintenance requirements

Table 10 – Maintenance requirements of urban trees

Schedule	Action	Frequency
Regular maintenance	Remove litter and debris	As required
	Manage other vegetation and remove nuisance plants	As required
Occasional maintenance	Check and manage tree health	Semi-annually
	Remove silt build-up from around tree	As required
	Water	As required

3.3.2 Maintenance requirements

Gravity systems should be designed so that rainwater is collected by gravity and stored at elevation so it can be supplied by gravity. In such cases, the key design constraints include the structural capacity of the building to store water at an elevated location.

In low elevation buildings, above-ground storage tanks should be used to serve ground floor water use points and other external uses.

In both applications, water from rooftops and other impermeable surfaces should pass through a coarse filter before discharge to the collection tank.

3.3.3 Estimation of the impact of urban trees on runoff reduction in the study areas

According to the NBS Catalogue produced by the European Union, urban surface water runoff can be reduced by as much as 62% where trees and tree pits are present, in comparison with areas continuous asphalt roads without trees. The same document also notes that one young tree, planted in a small pit over an impermeable asphalt surface, can reduce urban surface water runoff by about 60%.

For the purpose of estimating runoff reduction effect of trees in the study areas, a conservative value of 50 % is used. It is assumed that coverage of trees in the building and settlement zone of each study area will be 50%. The estimation of peak runoff reduction is summarised in the tables below for current and project land use plans:

Table 11 – Estimation of peak runoff reduction from urban trees for current land use plan (2018)

Site	Total Surface area (ha)	Surface area of the buildings and settlements zone (ha)	Calculated peak flow T100 (from hydrological study report) (m3/s)	Estimated peak flow with application of permeable paving at 50% coverage (m3/s)
Bishenyi	4,686.8	175.9	62.1	46.6
Rwabayanga	809.0	114.6	13.2	9.9
Rusizi	1,321.0	412.47	18.7	14.0
Magerwa (sub-basin 10)	233.4	107.4	50.3	37.7

Table 12– Estimation of peak runoff reduction from urban trees for projected land use plan (2050)

Site	Total Surface area (ha)	Surface area of the buildings and settlements zone (ha)	Calculated peak flow T100 (from hydrological study report) (m3/s)	Estimated peak flow with application of permeable paving at 50% coverage (m3/s)
Bishenyi	4,686.8	1167.9	97.6	73.2
Rwabayanga	809.0	429.4	27.8	20.8
Rusizi	1,321.0	730.4	34.8	26.1
Magerwa (sub-basin 10)	233.4	184.4	83.4	62.5

3.4 Permeable paving

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 in the coarse gravel sub-base, before infiltration to the ground, or discharged downstream via underlying pipes where soil infiltration is not suitable.

3.4.1 General design considerations

Permeable pavements can be designed to suit many applications including residential drive-ways, public and commercial buildings' parking areas, and private roads. There are three principal systems of water management that should be considered for permeable paving:

- Total infiltration: this is the system where all the runoff passes into the substructure from where it infiltrates through the soil. This system should be provided subject to soil infiltration tests;
- Partial infiltration: In this system, the proportion of runoff that exceeds the infiltration capacity of the subsoils is directed to a receiving drainage system. This is generally achieved by installing perforated pipes below the permeable paving structure;
- No infiltration: where soil infiltration tests indicate poor infiltration capacity, or where the permeable paving is to be constructed over fill materials (risk of failure when saturated with water), no infiltration to the soil should be allowed. To achieve no infiltration, the system should be wrapped in an impermeable, flexible membrane placed above the formation level.

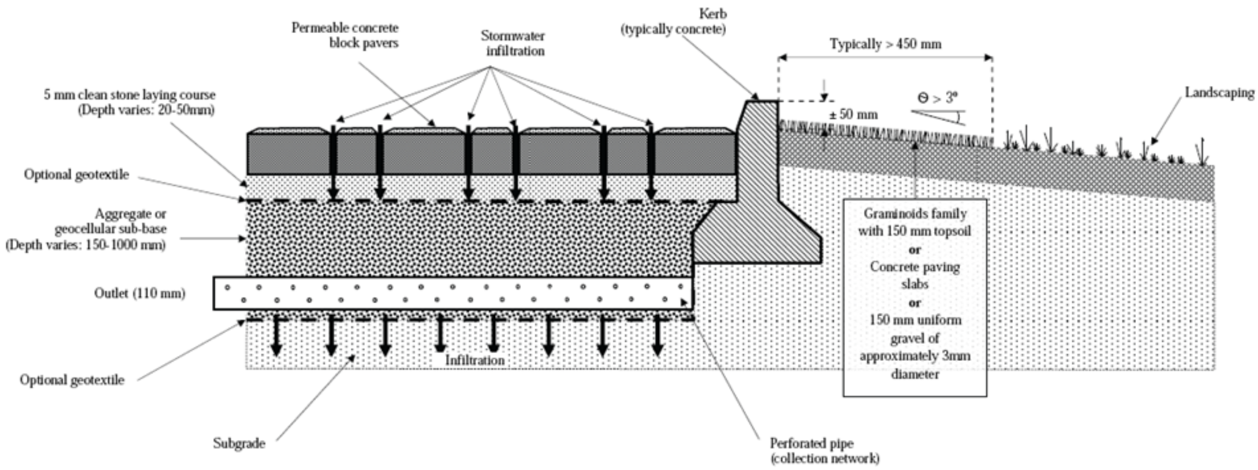


Figure 9 *– Typical design of permeable paving systems (Source: The South African Guidelines for Sustainable Drainage Systems (2013)*

3.4.2 Hydraulic design considerations

The following considerations should be taken into account for hydraulic design:

- The surface infiltration rate through permeable pavement joints should be greater than the design intensity to avoid surface water;
- The required capacity of the sub-base depends on rainfall characteristics, return period, and the infiltration potential into the subgrade. The thickness of the sub-base required should be obtained by simple calculation or by detailed hydrological and hydraulic modelling;
- On sloping sites, the volume of available storage within the sub-base is reduced compared to a flat surface. Studies have shown that where slopes are 3% or greater, terracing should be considered, or internal check dams build within the sub-base;
- The attenuation storage within the sub-base provides means to reduce peak flow rates. The attenuation storage volume available can be calculated using the following formula:

Attenuation storage in sub-base = volume of sub-base x porosity in the sub-base aggregates

3.4.3 Operation and maintenance requirements of permeable paving systems

Table 13 – Maintenance requirement of permeable pavement

Schedule	Action	Frequency
Regular maintenance	Sweeping, brushing and high pressure jet washing of the surface.	Quarterly or as required
	Removal of weeds and grass grow th though the structure joints	Six monthly or as required
Remedial actions	Remedial work to any depressions, rutting and cracked or broken blocks.	As required
Monitoring	Inspect for evidence of poor operation and/or weed growth	Quarterly
	Inspect sediment accumulation rates and establish appropriate brushing frequencies	Annually

3.4.4 Estimation of the impact of permeable paving on runoff reduction in the study areas

According to the NBS Catalogue , urban surface water runoff can be reduced by up to 30% at the catchment level where permeable paving is extensively used. A lower value of value of 20 % is used for the purpose of estimating runoff reduction effect of permeable pavements in the study areas. It is assumed that coverage of permeable pavements in the building and settlement zone of each study area will be 50%.

The estimation of peak runoff reduction is summarised in the tables below for current and projected (2050) land use plans:

Table 14 – *Estimation of peak runoff reduction from permeable pavements for current land use plan (2018)*

Site	Total Surface area (ha)	Surface area of the buildings and settlements zone (ha)	Calculated peak flow T100 (from hydrological study report) (m3/s)	Estimated peak flow with application of permeable paving at 50% coverage (m3/s)
Bishenyi	4,686.8	175.9	62.1	55.9
Rwabayanga	809.0	114.6	13.2	11.9
Rusizi (Cyunyu)	1,321.0	412.47	18.7	16.8
Magerwa (sub-basin 10)	233.4	107.4	50.3	45.3

Table 15 – *Estimation of peak runoff reduction from permeable pavements for projected land use plan (2050)*

Site	Total Surface area (ha)	Surface area of the buildings and settlements zone (ha)	Calculated peak flow T100 (from hydrological study report) (m3/s)	Estimated peak flow with application of permeable paving at 50% coverage (m3/s)
Bishenyi	4,686.8	1167.9	97.6	87.8
Rwabayanga	809.0	429.4	27.8	25.0
Rusizi	1,321.0	730.4	34.8	31.3
Magerwa (sub-basin 10)	233.4	184.4	83.4	75.1

3.5 Impact of upstream NBS on peak runoff flow - summary

The NBS components discussed in sections 4.1 to 4.5, when applied in the upstream areas of the sub-catchments, will have a combined impact towards the reduction of peak surface water runoff from these areas. The table below summarises the runoff reduction effect (in percentage) for the each NBS component as discussed in the preceding sections, as well as the cumulative reduction effect as a weighted average.

It should be noted that the upstream NBS components discussed in this section all have potential for private funding and ownership.

Table 16 – Estimation of cumulative runoff reduction effect of upstream NBS components

Upstream NBS component	Potential for private funding and ownership (Y/N)	Estimated runoff reduction of each component (A)	Assumed percentage coverage in upstream areas (B)	Weighted runoff reduction (A*B)
Rainwater harvesting	Y	4%	50%	2%
Green roofs	Y	45%	5%	5%
Urban trees	Y	50%	50%	25%
Permeable paving	Y	20%	50%	25%
Cumulative weighted runoff reduction effect = sum of (A*B) / sum of (A)				**36%**

3.6 Estimation of costs of upstream NBS

The table below provides unit cost estimates of upstream NBS components discussed in the preceding sections. The unit costs were arrived at using information from the local and regional market.

The estimation of peak runoff reduction is summarised in the tables below for current and projected (2050) land use plans:

Table 17 – Unit costs of upstream NBS components

NBS Component	Estimated unit cost / m^2 (USD)
Green roofs	40.0
Urban trees	5.0
Permeable paving	10.0

Rainwater harvesting systems are estimated at an average of USD 500 per building plot.

It is assumed that these NBS components are applicable to the buildings and settlements zone of the existing land use plan. Each NBS component is assigned the following surface area coverage at a single building plot, based on Rwanda building standards:

Table 18 – Coverage of NBS-affected building elements at individual building level

Building element	Coverage
Roof (RWH or green roof)	50 %
Pavement (permeable paving)	20 %
Landscaping (garden with trees)	30 %

Roads within the Building and Settlements zone are also assumed to include elements of Nature Based Solutions, These roads, referred, also be referred to as 'green roads', are to include a swale and trees planted at each 7 m interval along the road. The figure below presents a cross section of an urban green road. The unit cost of swale/trees to create an urban green road is estimated at 200,000 USD / km.

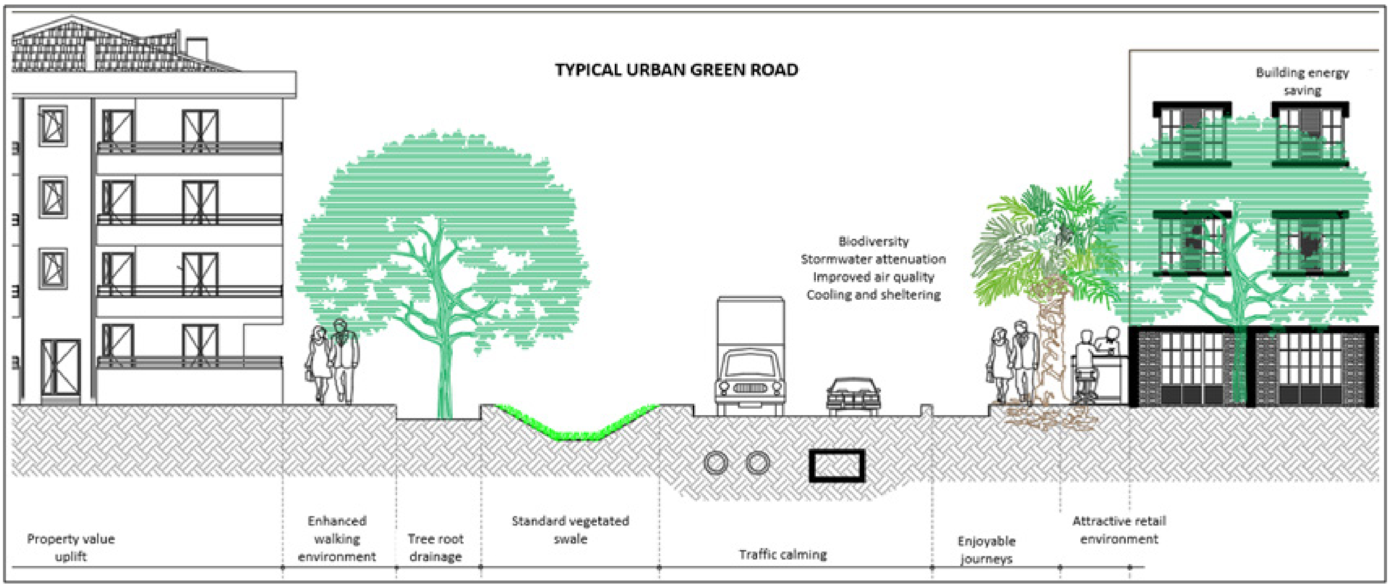


Figure 10 – *Typical urban green road (not to scale)*

The tables below present the cost estimates of the upstream NBS components as applied to the Buildings and Settlements zone in each sub-catchment.

Note: These NBS components are proposed for application at individual building level (domestic and public/private institution); therefore, the costs of their installation would normally be expected to be met by the owners. The role of the government and its partners would be to provide a framework that incentivises their installation.

Table 19 – Estimated cost of upstream NBS in Bishenyi sub-catchment

	Percentage coverage in the buildings and settlement zone	**Coverage (ha)**	**Coverage (m²) *[A]***	**Number of building plots (assuming an average of 500 m² per plot** [B] [=A/500] *(Applicable to RWH only)*	**Estimated average unit cost of RWH / building plot (USD)** *[C]*	**Estimated unit cost / m² (USD)** *[D]*	**Estimated cost (USD)** *= [B*C] for RWH or = [A*D] for others*
Roof (RWH)	47.5%	83.6	835,857.5	1,671.7	500.0	-	835,857.50
Roof (Green roof - 5% of 50% total roof coverage)	2.5%	4.4	43,992.5	-	-	40.0	1,759,700.00
Permeable paving	20%	35.2	351,940.0	-	-	10.0	3,519,400.00
Urban trees	30%	52.8	527,910.0	-	-	5.0	2,639,550.00
						TOTAL (BISHENYI)	**8,754,507.50**

Table 20 – Estimated cost of upstream NBS in Rwabayanga sub-catchment

	Percentage coverage in the buildings and settlement zone	**Coverage (ha)**	**Coverage (m²) *[A]***	**Number of building plots (assuming an average of 500 m² per plot** *[B] [=A/500] (Applicable to RWH only)*	**Estimated average unit cost of RWH / building plot (USD)** *[C]*	**Estimated unit cost / m² (USD)** *[D]*	**Estimated cost (USD)** *= [B*C] for RWH or = [A*D] for others*
Roof (RWH)	47.50%	54.42	544,207.50	1,088.42	500	-	544,207.50
Roof (Green roof - 5% of 50% total roof coverage)	2.50%	2.86	28,642.50	-	-	40	1,145,700.00
Permeable paving	20%	22.91	229,140.00	-	-	10	2,291,400.00
Urban trees	30%	34.37	343,710.00	-	-	5	1,718,550.00
						TOTAL (RWABAYANGA)	**5,699,857.50**

Table 21– Estimated cost of upstream NBS in Rwandex-Magerwa sub-catchment (sub-basin 10 only)

	Percentage coverage in the buildings and settlement zone	Coverage (ha)	Coverage (m^2) *[A]*	Number of building plots (assuming an average of 500 m^2 per plot *[B]* *[=A/500]* *(Applicable to RWH only)*	Estimated average unit cost of RWH / building plot (USD) *[C]*	Estimated unit cost / m^2 (USD) *[D]*	Estimated cost (USD) *= [B*C] for RWH* *or* *= [A*D] for others*
Roof (RWH)	47.50%	51.00	509,979.00	1,019.96	500	-	509,979.00
Roof (Green roof - 5% of 50% total roof coverage)	2.50%	2.68	26,841.00	-	-	40	1,073,640.00
Permeable paving	20%	21.47	214,728.00	-	-	10	2,147,280.00
Urban trees	30%	32.21	322,092.00	-	-	5	1,610,460.00
						TOTAL (RWANDEX-MAGERWA)	5,341,359.00

Table 22– Estimated cost of upstream NBS in Kamembe-Gihundwe sub-catchment

	Percentage coverage in the buildings and settlement zone	Coverage (ha)	Coverage (m^2) *[A]*	Number of building plots (assuming an average of 500 m^2 per plot *[B]* *[=A/500]* *(Applicable to RWH only)*	Estimated average unit cost of RWH / building plot (USD) *[C]*	Estimated unit cost / m^2 (USD) *[D]*	Estimated cost (USD) *= [B*C] for RWH* *or* *= [A*D] for others*
Roof (RWH)	47.50%	195.92	1,959,232.50	3,918.47	500	-	1,959,232.50
Roof (Green roof - 5% of 50% total roof coverage)	2.50%	10.31	103,117.50	-	-	40	4,124,700.00
Permeable paving	20%	82.49	824,940.00	-	-	10	8,249,400.00
Urban trees	30%	123.74	1,237,410.00	-	-	5	6,187,050.00
						TOTAL (RUSIZI)	20,520,382.50

4

PRELIMINARY DESIGN OF DOWNSTREAM NATURE-BASED SOLUTIONS

This section presents preliminary designs for Nature-Based Solutions (NBS) that have been selected for application in downstream zones of the study areas (Refer to Table 1). Design of the following NBS components are discussed:

Table 23–NBS component designed for downstream zone of the study areas

NBS component	Application in study area
Swale	Rwandex-Magerwa Bishenyi Kamembe-Gihundwe
Detention basin	Rwandex-Magerwa Bishenyi Rwabayanga Kamembe-Gihundwe
Modular attenuation storage tank	Rwandex-Magerwa

4.1 Swales

4.1.1 General description

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. In the upstream zones of a catchment, they can be used to drain roads (specifically those laid along contour lines in steep areas), paths and car parks. In the downstream zones, they can be used to collect runoff coming from upstream zones and convey it to other downstream NBS components with storage function, such as detention basins.The standard swale channel us broad and covered by vegetation, usually grass, to slow the water, thereby facilitating sedimentation, filtration through the root zone and soil matrix, evapotranspiration and infiltration into the soil. A swale can have check dams installed across the flow path to reduce flow velocity, particularly in areas with steeper gradients.

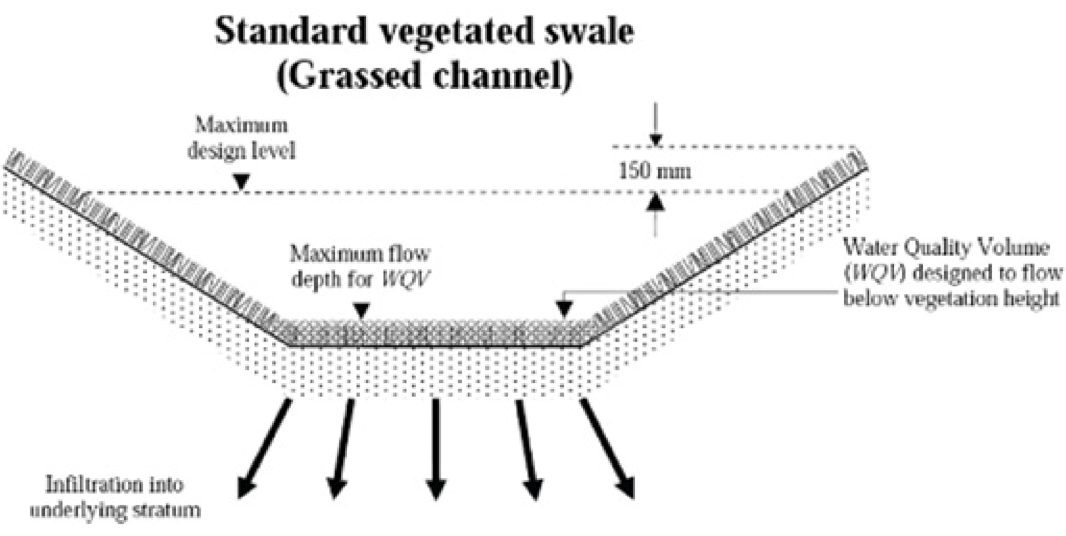


Figure 11 *– Typical cross section of a swale (Source: The South African Guidelines for Sustainable Drainage Systems (2013)*

4.1.2 Design parameters and standards for swales

The swales designed for application in the study areas are all located in the downstream zones of the sub-catchments, which are gentle sloping to relatively flat. Locations of the swales in each catchment are shown in location maps included in subsequent sections of the report. Detailed maps are also included in the drawings submitted together with this report.

The table below summarizes the design criteria and standards for swales:

Table 24 – Design parameters and standards for swales

Parameter	Design standard	Design comment
Shape	Trapezoidal	A trapezoidal shape is easy to construct and maintain. This shape has been selected for all sites.
Bottom width	0.5 m to 2.0 m	Rwandex-Magerwa = 1.5 m Bishenyi = 1.0 m Rusizi = 0.6 m
Longitudinal slope	0.5 % to 6%	2% to 5% for all sites
Check dams	Check dams should be incorporated on slopes greater than 3%	Checks dams have been provided at every 30 m for all sites.
Depth	In normal applications, the swale depth should be in the range of 0.4 m to 1.0 m. However, depth can be increased where deemed applicable, taking into account health and safety considerations	Rwandex-Magerwa = 1.5 m Bishenyi = 1.0 m Rusizi = 0.6 m

Vegetation	It should typically be maintained at a height of 75 mm to 200 mm.	Height of grass should be maintained in the standard range at all sites
Flow velocity	Maximum flow velocity should be 0.4 m/s at normal flow Flow velocity for extreme events (T100) should be kept below 1.0 m/s	Flow velocity in the swales ranges from 0.1 m/s to 0.4 m/s at lower return periods and has been kept below 1.0 m/s at T25 and T100
Roughness coefficient	Coefficient values vary with type of vegetative cover, ranging from 0.04 to 0.4	A value of 0.15 was applied
Design return period	Swales should be designed to convey the peak design flow rate for a return period of 1:30 year event, but this level of service can be either increased or reduced depending on the consequence of flooding at a location	T25 for Bishenyi and Rusizi T100 for Rwandex-Magerwa due to the sensitivity of the site

4.1.3 Preliminary design of swales

4.1.3.1 Rwandex – Magerwa

It is proposed to replace the existing open drainage channel, from the rear wall of Magerwa's parking lot to the entrance to NAEB, with a swale. This channel conveys a significant volume of runoff from upstream zones (sub basin 10 in Figure 2) directly to the wetland at high velocity, causing floods along the way, particularly at the entrance of NAEB.

Figure 12– Photo of existing drainage channel which is proposed to be transformed into a swale

The swale, with check dams every 30 m, is proposed to mitigate the flooding through reduction of the flow velocity, as well as enabling some infiltration of runoff along its path. The total length of the proposed swale is 1.04 km, with a bottom width of 1.5 m, depth of 1.5 m and longitudinal slope ranging from 2% to 5% depending on existing ground levels, which averages at 3%. It is proposed to construct detention basins upstream of the swale.

Details of the detention basins are given in Section 5.2.

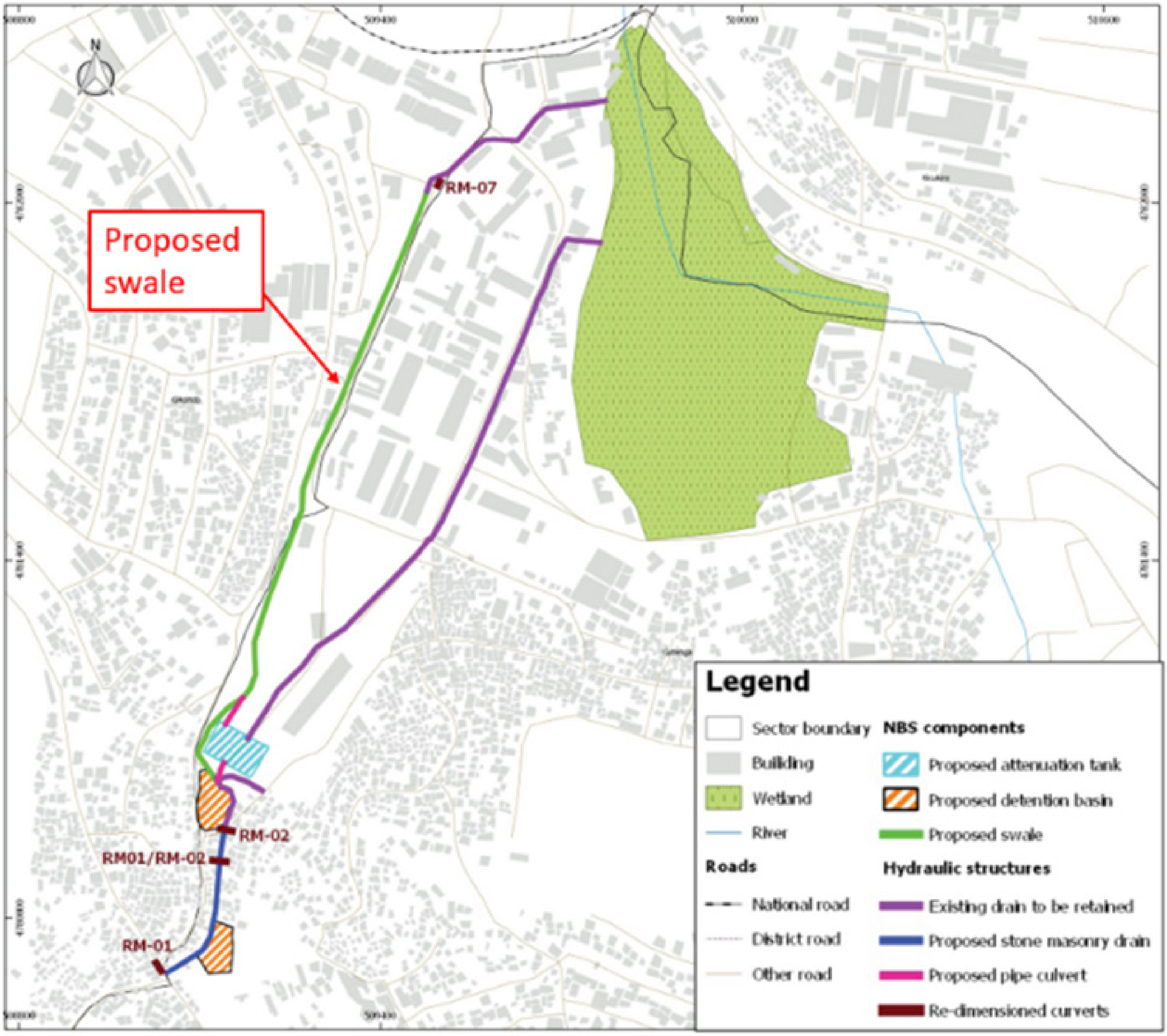


***Figure 13** – Proposed swale in Rwandex-Magerwa sub-catchment*

Manning's formula has been used to determine the flow capacity of the swale.

$$Q = \frac{A\ R^{/3} S^{\ /2}}{n}$$

Where:

Q = flow rate (m^3/s)

n = Manning's coefficient

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

R = Hydraulic radius = A/P, where A is the cross-sectional area (m2) and P is the wetted perimeter (m)

The table below presents hydraulic parameters for the swale. Reference is made to Appendix 1 for calculations using Manning's formula.

Table 25 – Design hydraulic parameters of Rwandex-Magerwa swale (designed for T100)

Parameter	Value
Total length	1.04 km
Width at bottom	1.5 m
Depth	1.5 m
Average hydraulic gradient	3 %
Design flow capacity	4.4 m^3/s
T100 peak flow from upstream catchments after installation of detention basins (see Section 5.2 below)	4.1 m^3/s
Flow velocity at design flow capacity	0.98 m/s
T2 peak flow after installation of detention basins	0.78 m^3/s
Flow velocity at T2 peak flow	0.17 m/s
Check dam interval	30 m

Preliminary design drawings of the swale are submitted together with this report.

4.1.3.2 Bishenyi

Two swales are proposed in the Bishenyi sub-catchment to convey runoff from the upstream Ruyenzi urbanized area (sub basins 1 and 6 in Figure 2) to the proposed detention basis downstream (see Section 5.2). The proposed swales are shown in the location map below. Each swale, with check dams every 30 m, will comprise a bottom width of 1.0 m, depth of 1.0 m and longitudinal slope ranging from 2% to 5% depending on existing ground levels, which averages at 3%. It is proposed to construct detention basins downstream of the swales.

Design details of the detention basin are given in Section 5.2. The table below presents hydraulic parameters for swale No.1. Reference is made to Appendix 1 for calculations using Manning's formula.

Table 26–Design parameters of Bishenyi swale No.1 (designed for T25)

Parameter	Value
Total length	0.7 km
Width at bottom	1.0 m
Depth	1.0 m
Average hydraulic gradient	3 %
Design flow capacity	2.3 m^3/s
T25 peak flow from upstream catchment (Sub basin 1, assuming reduction of 36% by upstream NBS)	2.2 m^3/s
Flow velocity at design flow capacity	0.77 m/s
T5 peak flow (assuming reduction of 36% from upstream NBS)	0.84 m^3/s
Flow velocity at T5 peak flow	0.28 m/s
Check dam interval	30 m

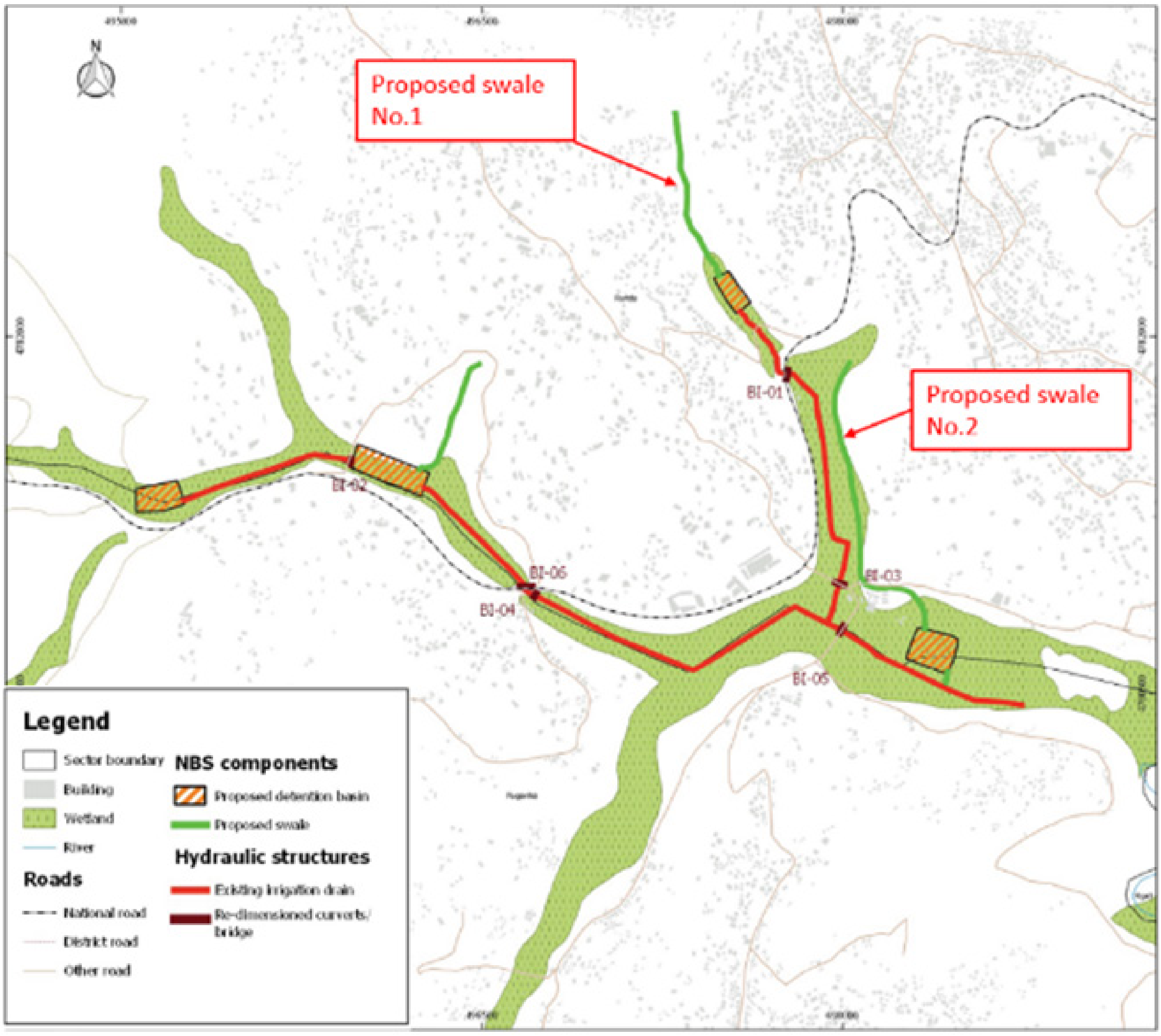


***Figure 14** – Proposed swales in Bishenyi sub- catchment (Refer to submitted drawings for details)*

The table below presents hydraulic parameters for swale No.2. Reference is made to Appendix 1 for calculations using Manning's formula.

Table 27 – Design parameters of Bishenyi swale No.2 (designed for T25)

Parameter	Value
Total length	1.4 km
Width at bottom	1.0 m
Depth	1.0 m
Average hydraulic gradient	3 %
Design flow capacity	2.3 m^3/s
T25 peak flow from upstream catchment (Sub basin 6, assuming reduction of 36% by upstre am NBS)	1.9 m^3/s
Flow velocity at design flow capacity	0.77 m/s
T5 peak flow (assuming reduction of 36% from upstream NBS)	0.77 m^3/s
Flow velocity at T5 peak flow	0.26 m/s
Check dam interval	30 m

Preliminary design drawings of the two swales are submitted together with this report.

4.1.3.3 Gihundwe-Kamembe

Two swales are proposed in the Gihundwe sub-catchment to convey runoff from the area proposed to be local playground within the new neighbourhood located to the north of the catchment. Roads adjacent to this area have low spots that are prone to flooding due to lack of runoff conveyance structures, whereby adjacent homes get flooded after high intensity rainfall.

Figure 15 – *Photos of site proposed for construction of swales in Gihundwe*

One swale is proposed to be laid along the eastern side of the playground, discharging to the second swale on the western side, which will discharge to the stone masonry drain proposed for installation to the north of the playground. This is shown in the location map below:

The proposed swales will comprise a bottom width of 0.6 m, depth of 0.6 m and longitudinal slope ranging from 2% to 5% depending on existing ground levels, which averages at 3%.The tables below presents hydraulic parameters for swales. Reference is made to Appendix 1 for calculations using Manning's formula.

Table 28 – Design parameters of Gihundwe swale east (designed for T25)

Parameter	Value
Total length	0.16 km
Width at bottom	0.6 m
Depth	0.6 m
Average hydraulic gradient	3 %
Design flow capacity	0.6 m^3/s
T25 peak flow	0.1 m^3/s
Flow velocity at design flow capacity	0.55 m/s
Check dam interval	30 m

Table 29 – Design parameters of Gihundwe swale west (designed for T25)

Parameter	Value
Total length	0.85 km
Width at bottom	0.6 m
Depth	0.6 m
Average hydraulic gradient	3 %
Design flow capacity	0.6 m^3/s
T25 peak flow	0.2 m^3/s
Flow velocity at design flow capacity	0.55 m/s
Check dam interval	30 m

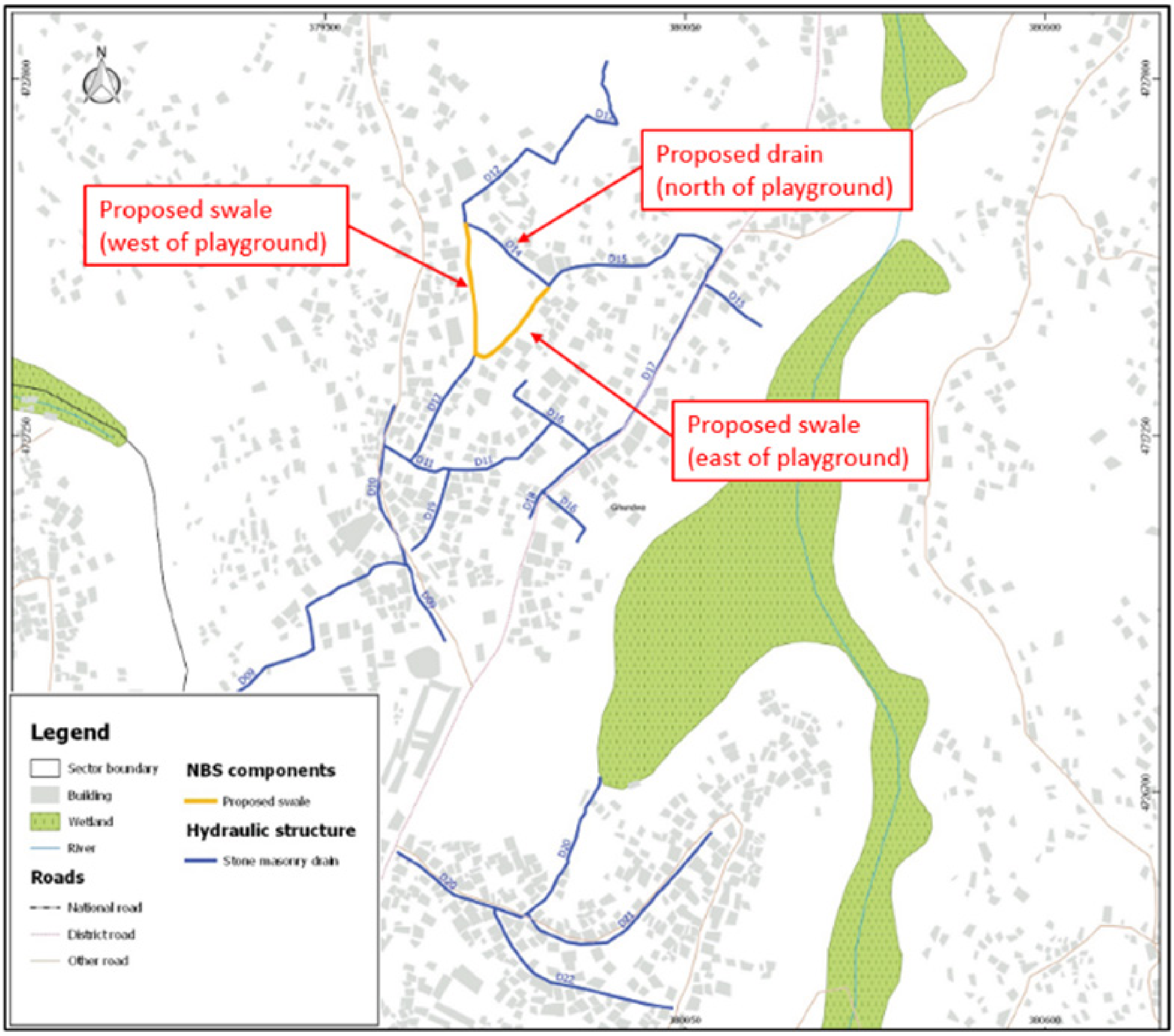


***Figure 16** – Proposed swales in Gihundwe sub- catchment (Refer to submitted drawings for details)*

4.1.4 Amenity and biodiversity considerations for swales

- Swales in Bishenyi will be installed in green spaces, and should therefore have a natural feel with soft edges and flowing forms;
- Swales in Rwandex-Magerwa and Gihundwe, being urban areas, may have hard edges and straight lines as appropriate to the local urban environment;
- Plant species should be selected to suit the existing landscape characteristics of the sites;
- Use planting of known wildlife value, appropriate to each location, ensuring no introduction of invasive species;
- The use of plants that are native and of local provenance should be maximised, ensuring that they are suited to local soils and hydrology;
- Trees and other appropriate woodland features should be planted on the edges of the swales;

- Small information boards can be provided adjacent to the swale, particularly in Rwandex-Magerwa and Gihundwe, to give information on the function of the swale;
- In Rwandex-Magerwa and Gihundwe, some form of barriers such as road kerbs or structural planting, should be installed to prevent vehicles parking on the swale edges.

4.1.5 Construction, operation and maintenance requirements of swales

- Swales locations should be clearly marked before site work begins and protected by signage to avoid disturbance during construction;
- Sufficient space should be provided between vehicular traffic and swale construction area, particularly in Rwandex-Magerwa and Gihundwe sub-catchments;
- Excavating equipment should operate from the side of the swale and not from the swale;
- Where compaction of soils is to occur, a minimum of 300mm depth of soil should be removed and replaced with a blend of top soil and sand to promote infiltration and biological growth;
- Care should be taken that design levels and slopes for swale base and sides are constructed accurately to avoid ponding in the swale base and flow channelling.
- Swales should not receive any runoff until the vegetation is fully established. Particularly for Rwandex-Magerwa and Gihundwe sub-catchments, this will be achieved by diverting the flows until the vegetation is well rooted;
- The major maintenance requirement for swales is mowing/grass cutting. Mowing should ideally retain grass heights of 75 mm to 200 mm to assist in filtering pollutants and retaining sediments. However, taller grass, where appropriate, would not pose significant risk to swale functionality. Grass clippings should be disposed of either off site or outside the area of the swale;
- Litter and debris removal should be undertaken regularly as part of general landscape maintenance;

Table 30– Operation and maintenance requirements for swales

Schedule	Action	Frequency
Regular maintenance	Remove litter and debris	Monthly or as required
	Cut grass to retain height to within the specified design range	Monthly or as required
	Manage other vegetation and remove nuisance plants	Monthly or as required
	Inspect vegetation coverage	Quarterly
	Inspect base of swale for ponding and silt accumulation, and record areas where water is ponding for more than 24 hours	Monthly or as required
Occasional maintenance	Reseed areas of poor vegetation growth, alter plant types to better suit conditions if required	As required or if bare soil is exposed over 10% or more of the swale areas
Remedial actions	Repair erosion or other damage	As required
	Relevel uneven surfaces and reinstate design levels, especially at location where water is ponding for more than 24 hours	As required
	Remove build-up of sediment	As required

4.2 Detention basins

4.2.1 General description

Detention basins are vegetated depressions that are normally dry except during and immediately following storm events. They can be on-line components where surface water runoff is routed through the basin, or off-line components into which runoff is diverted once flows reach a specified threshold. The proposed basins in Bishenyi, Rwabayanga and Kamembe-Gihundwe sub-catchments are inline, whereas those proposed for Rwandex-Magerwa are offline.Detention basins provide water quality benefits in terms of removal of sediments and buoyant materials. Levels of nutrients, heavy metals and other compounds in the runoff can also be significantly reduced.

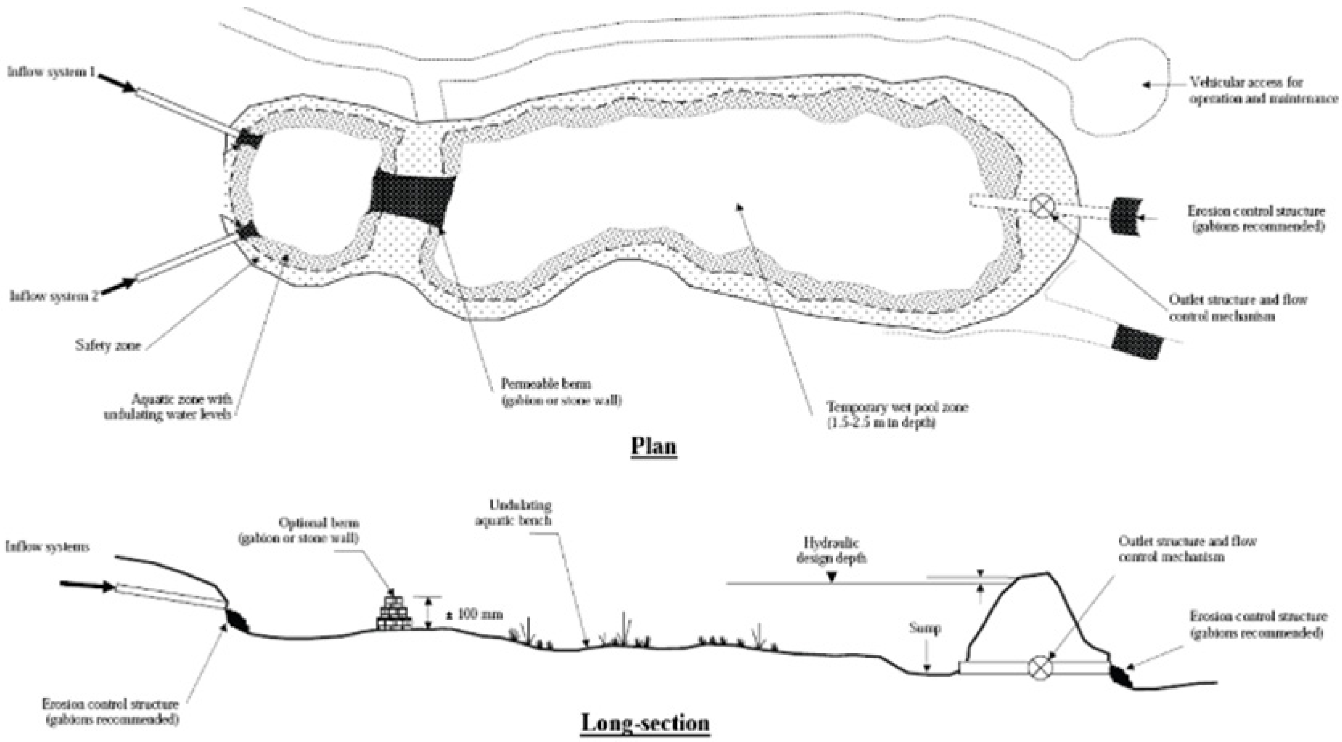


Figure 17 *– Typical cross section of a detention basin (Source: The South African Guidelines for Sustainable Drainage Systems (2013)*

4.2.2 Design parameters and standards for detention basins

The detention basins designed for application in the study areas are all located in the downstream zones of the sub-catchments, which are gentle sloping to relatively flat. Locations of the detentions in each sub-catchment are shown in location maps included in subsequent sections of the report. Detailed maps are also included in the drawings submitted together with this report.It should be noted that where there are existing flowing streams of water that pass though the areas of the proposed basin, these should be diverted towards a bypass, and an overflow weir installed to allow flow to continue towards the detention basin during high storms. Details of the weir and stream bypass will be considered at the detailed design phase.The table below summarizes the design criteria and standards for detention basins:

Table 31 – Design parameters and standards for detention basin

Parameter	Design standard	Design comment
Retention time	Detention basins should temporarily store water for 24 hours to 48 hours	The retention times in all basins are less than 24 hours
Slope at bottom	The bottom of the vegetated basin should be fairly flat with a gentle slope towards the outlet, the slope ranging from 1% to 3%	Bottom slope in all basins is within the standard range
Design return period	Detention basins should be designed to provide flood attenuation for return period of 1:30 year event, but this level of service can be either increased or reduced depending on the consequence of flooding at a location	T25 for Bishenyi, Rwabayanga and Rusizi. T100 for Rwandex - Magerwa A comparative assessment has also been carried out to establish the volumes of detention basins required for Bishenyi and Rwabayanga at T100
Depth of water	Detention basins should have a maximum depth of water not exceeding 3.0 m	Maximum depth in all basins are within standard

4.2.3 Preliminary design of detention basins

4.2.3.1 Hydraulic modelling methodology

Storage elements, representing detention basin were applied to the hydraulic models produced as part of Interim Report No.2. The basins were located in the model upstream of sub-basin showing flooding issues. They consist of four key elements:

- The basin itself, defined by a volume [m^3];
- An upstream channel connected to the basin where the input hydrograph is inserted.
- A downstream channel where the output hydrograph is collected;
- An outlet structure modelled in HEC-RAS to link the basin with the downstream channel/drain. Modelled outlet structures were sized to 1000 mm of internal diameter.3

Table 32 – Sub-basins for which detention basins have been modelled

Sub-catchment	Sub-basin for which a detention basin is modelled
Rwandex-Magerwa	10
Bishenyi	1, 2, 3 & 6
Rwabayanga	1, 2 & 4

Hydraulic modelling for the proposed detention basin for sub-basin 4 in Rusizi (Mont Cyangugu) was not carried out due to the small area (channels only) for which the topographic survey was carried out. Simple volume calculation was used for this basin.

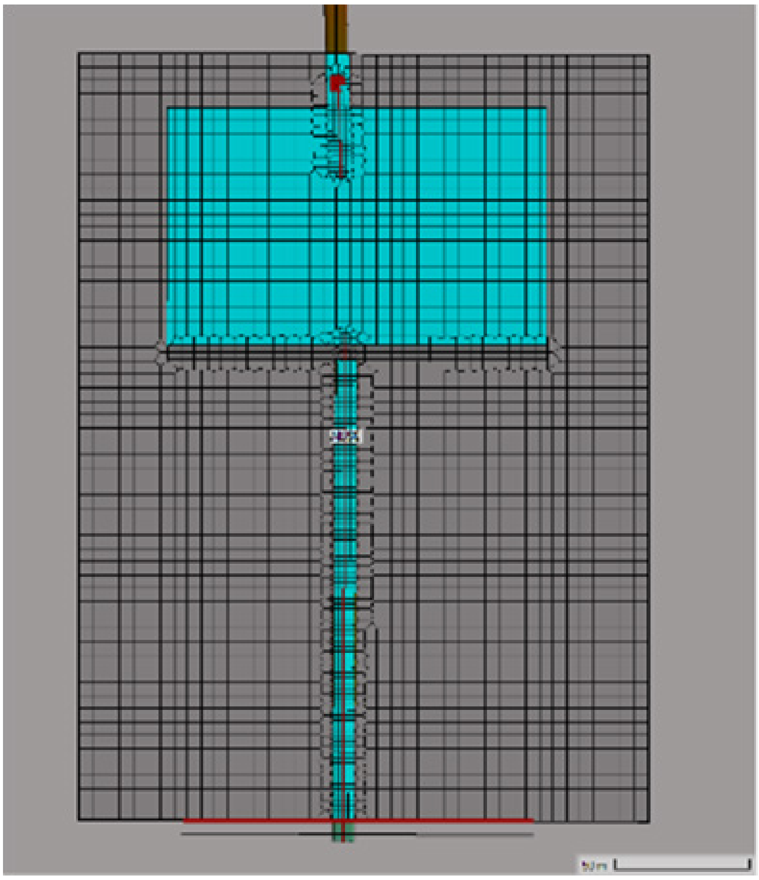


__Figure 18__ – Example of a detention basin created in the HEC-RAS model

The following steps were followed in modelling the detention basins in HEC-RAS:

- Estimation of basin volume based on the runoff volume;
- Multiple iterations of model runs to establish the volume of the detention basin at which it does not overflow for a rainfall with a return period of 25 years;
- Iterations of model runs were also carried for a return period of 100 years, and the required size of the basin was confirmed if the peak outflow from the basin for a T100 rainfall is less or equal to the peak runoff rate for a 5-year return period rainfall. T5 was selected arbitrarily as a measure of reduction of T100 runoff. As there is no T5 in the Deltares model for Magerwa, the reference peak runoff rate was taken as the average of T2 and T10.

4.2.3.2 Rwandex – Magerwa

It is proposed to construct two detention basins and a modular geocellular attenuation storage tank in the Rwandex-Magerwa sub-catchment to provide volume attenuation for runoff coming from sub-basin 10.Detention basin 1 is located on a piece of land south of Magerwa, adjacent to the existing informal channel. The land is currently unoccupied and no agricultural activities take place therein.Detention basin 2 is located just behind the rear wall of Magerwa, on the southern end of the complex. The area of the basin could technically be defined as a wetland, although a number of homes have been constructed within its perimeter. Compensation for land expropriation will be required for this site.

The attenuation underground storage tank is proposed to be constructed in the parking lot of Magerwa, near the rear southern wall. An example of attenuation storage tank installation details, specifications and other relevant information is included in appendices.

***Figure 19** – Photos of sites proposed for detention basins*

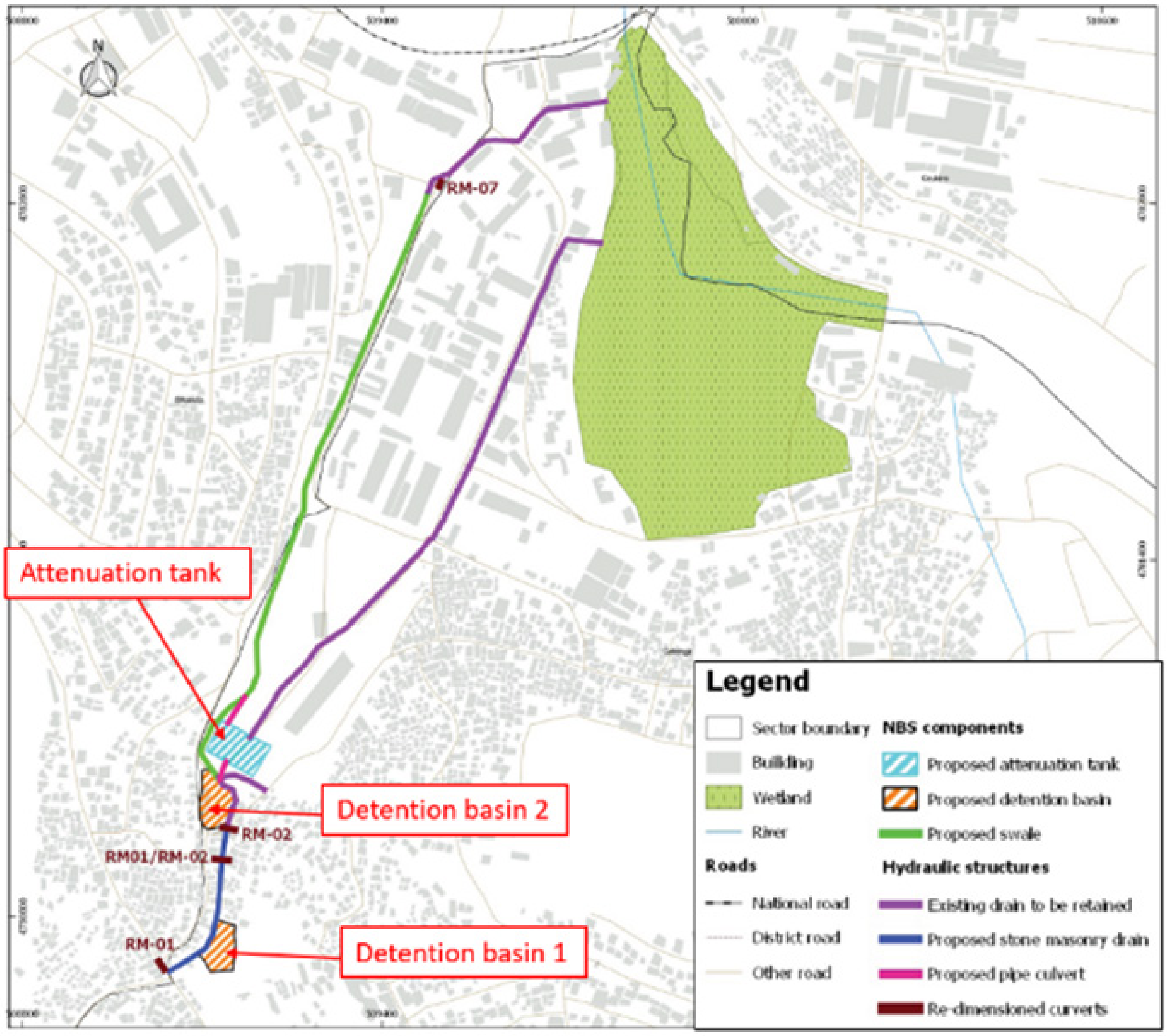


***Figure 20** – Proposed detention basins and attenuation storage tank in Rwandex-Magerwa sub-catchment*

Table 33 – Design hydraulic parameters of detention basin 1 RwandexMagerwa (designed for T100)

Parameter	Value
Mean surface area	3,000 m^2
Maximum depth of water	2.0 m
Total volume of storage	6,000 m^3
Diameter of inlet pipe	1,000 mm
Diameter of outlet pipe	1,000 mm

Table 34 – Design hydraulic parameters of detention basin 2 RwandexMagerwa (designed for T100)

Parameter	Value
Mean surface area	3,500 m^2
Maximum depth of water	1.5 m
Total volume of storage	5,250 m^3
Diameter of inlet pipe	1,000 mm
Diameter of outlet pipe	1,000 mm

Table 35 – Design hydraulic parameters of the attenuation storage tank RwandexMagerwa (designed for T100)

Parameter	Value
Mean surface area	5,000 m^2
Maximum depth of water	1.8 m
Total volume of retention	9,000 m^3
Diameter of inlet pipe	1,000 mm
Diameter of ou tlet pipe (x2)	1,000 mm

The HEC-RAS model was run for using the unit hydrograph of 1 in 100 years return period for sub-basin 10, with application of an assumed 36% reduction from upstream NBS. The objective was to assess the total volume of storage required to achieve a peak flow from the storage area which is less or equal to the average of peak flows of T2 and T10 (Deltares model does not have T5).

Model results are summarized below:

Table 36 – Table 36 – Model results for storage basins in Rwandex-Magerwa

Parameter	Value
Volume required for flood attenuation as modelled by HEC -RAS	18,150 m^3
Volume provided (detention basin 1 + detention basin 2 + attenuation storage tank)	20,250 m^3
Surplus storage capacity	2,100 m^3
T100 peak flow	12.6 m^3/s
Estimated T100 peak flow with application of upstream NBS (reduction of 36%)	8.1 m^3/s
Modelled peak flow downstream of the three storage areas	4.1 m^3/s
Retention time in the storage basins	14 hours

The graphs below show the combined effect of the detention basins and the attenuation storage tank on the T100 unit hydrograph for sub-basin 10, as well as the combined retention time in the basins.

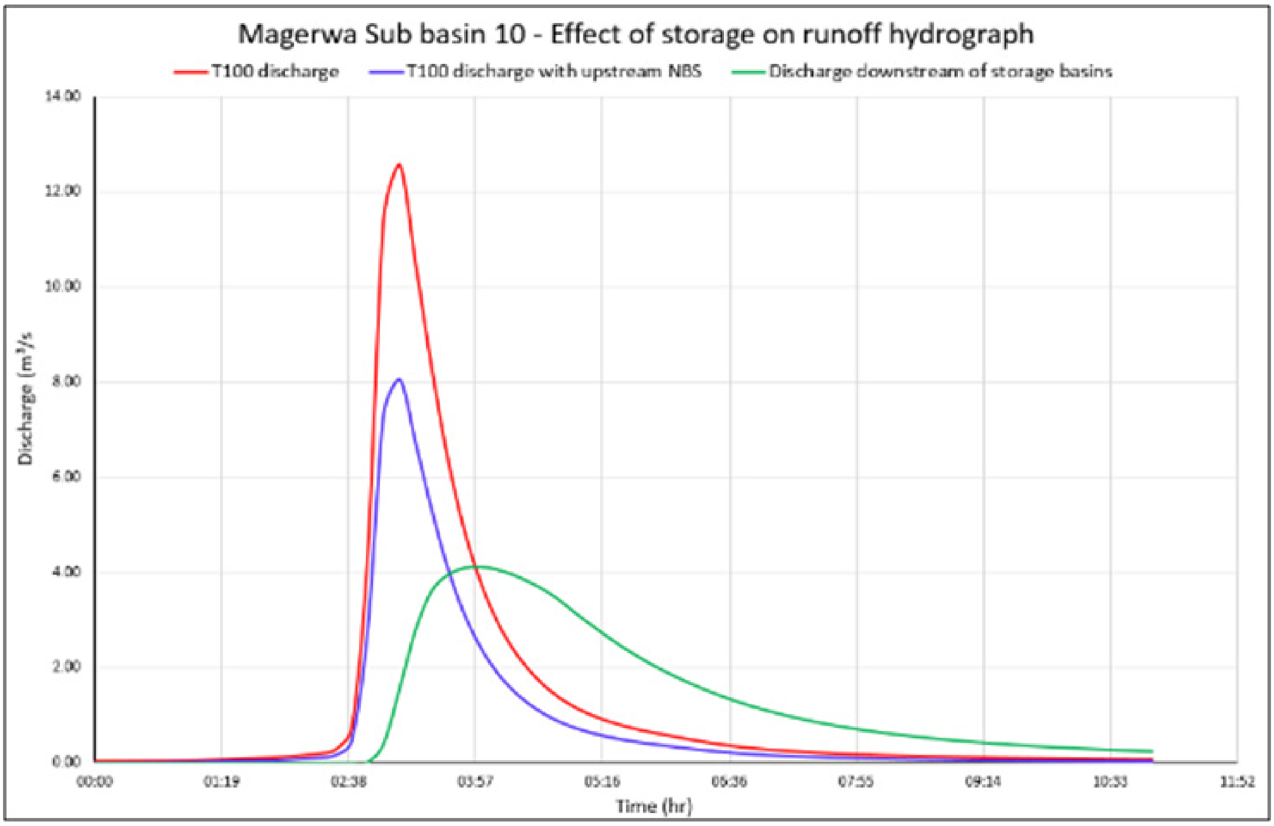


Figure 21 *– Effect of storage on T100 runoff hydrograph for Sub-basin 10 Magerwa*

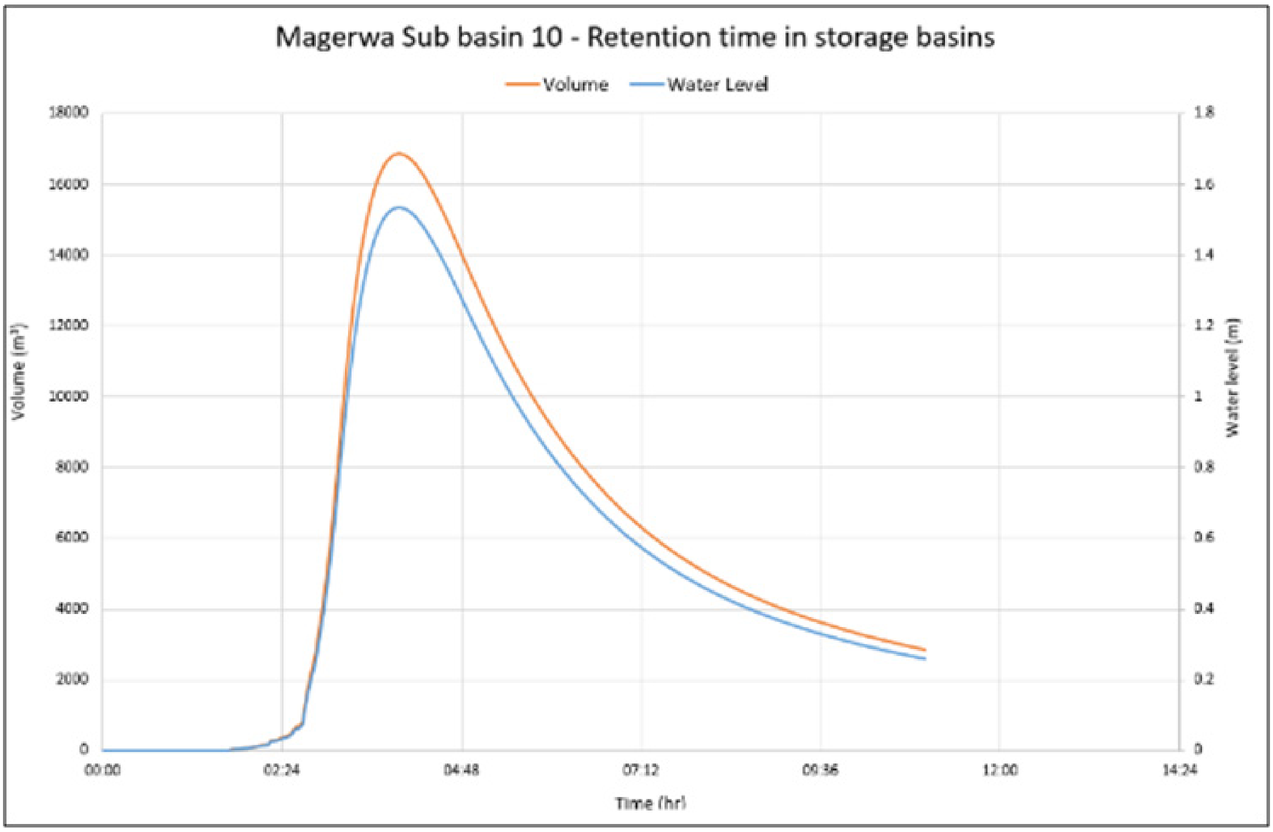


Figure 22 *– Retention time in storage basins for Sub-basin 10 Magerwa for T100*

Preliminary design drawings of the detention basins and attenuation storage tank are submitted together with this report. Flood hazard maps indicating the impact of storage are also included in the submission.

4.2.3.3 Bishenyi

It is proposed to construct three detention basins in the Bishenyi sub-catchment to provide volume attenuation for runoff coming from sub-basins 1, 2, 3 and 6. The areas in which the basins are proposed for construction are all used for agriculture, and compensation for crops and land expropriation will be required.

Detention basins 1 is proposed to be constructed in the valley located to the west of the sub-catchment, and will receive runoff from sub-basins 2 and 3 of Bishenyi sub-catchment.

Detention basin 2 will be located on the eastern side of the sub-catchment, adjacent to the main channel that drains towards Nyabarongo River. The basin will receive runoff conveyed by swale No.2 (see Section 5.1.3.2) from sub-basin 6.

Detention basin 3 is proposed to be constructed in the valley below Ruyenzi residential neighbourhood, just downstream of the proposed swale No.1 (see Section 5.1.3.2). This basin will receive runoff from Sub-basin 1.

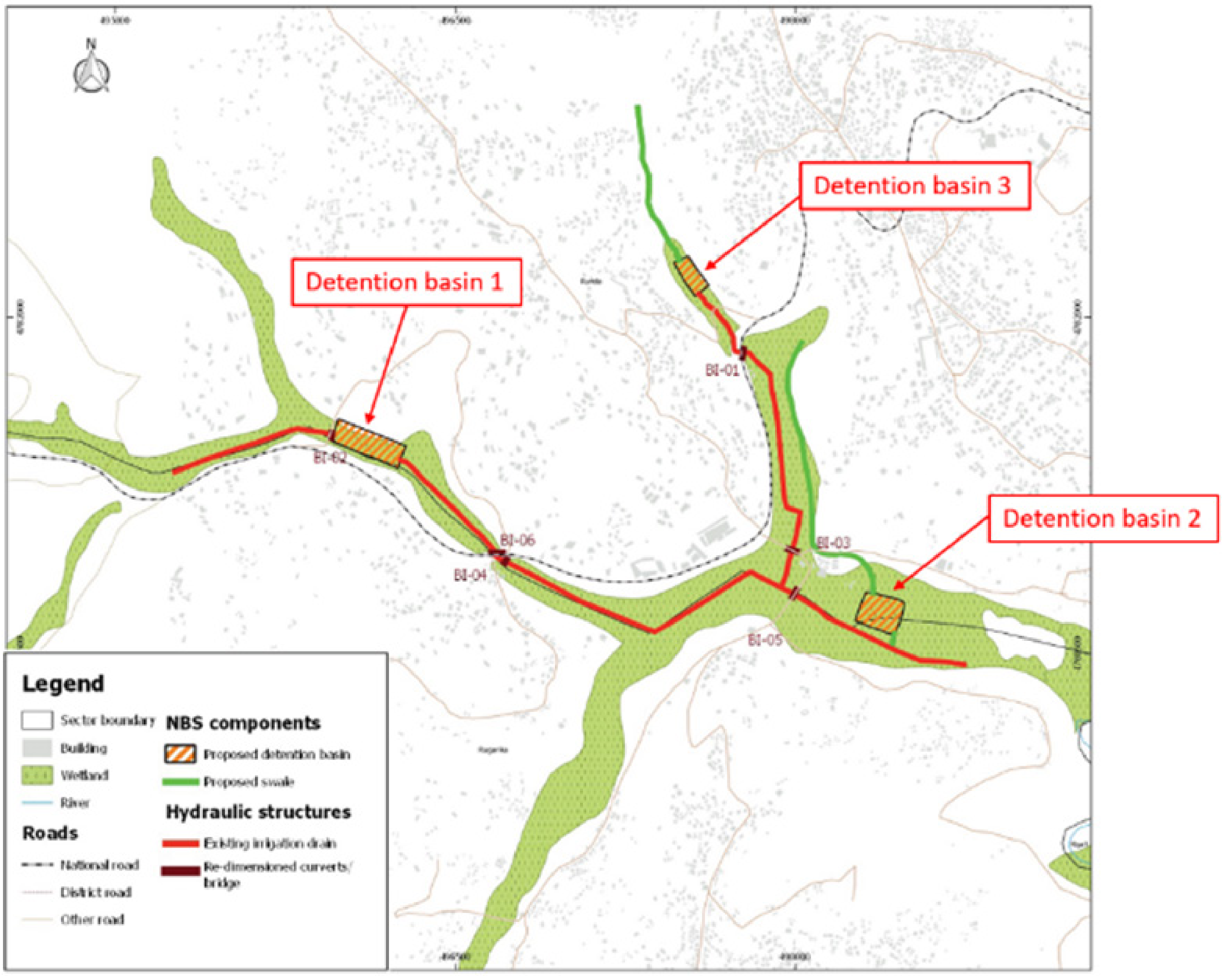


Figure 23 – Proposed detention basins and attenuation storage tank in Bishenyi sub-catchment

Table 37 – Design hydraulic parameters of detention basin 1 Bishenyi (designed for T25)

Parameter	Value
Mean surface area	35,000 m^2
Maximum depth of water	2.5 m
Average depth	1.4 m
Total volume of storage	49,000 m^3
Diameter of inlet pipe	1,000 mm
Diameter of outlet pipe	1,000 mm

Table 38 – Design hydraulic parameters of detention basin 2 Bishenyi (designed for T25)

Parameter	Value
Mean surface area	10,800 m^2
Maximum depth of water	2.5 m
Average depth	1.5 m
Total volume of storage	16,200 m^3
Diameter of inlet pipe	1,000 mm
Diameter of outlet pipe	1,000 mm

Table 39 – Design hydraulic parameters of the detention basin 3 Bishenyi (designed for T25)

Parameter	Value
Mean surface area	6,000 m^2
Maximum depth of water	2.5 m
Average depth	1.5 m
Total volume of retention	9,000 m^3
Diameter of inlet pipe	1,000 mm
Diameter of outlet pipe (x2)	1,000 mm

Table 40 – Model results for detention basin 1 (sub-basins 3 and 4 Bishenyi)

Parameter	Value
Volume required for flood attenuation as modelled by HEC -RAS	41,760 m^3
Volume provided (detention basin 1)	49,000 m^3
Surplus storage capacity	7,240 m^3
T25 peak flow (sub basins 2 and 3)	16.4 m^3/s
Estimated T25 peak flow with application of upstream NBS (reduction of 36%)	10.5 m^3/s
Modelled peak flow downstream of the three storage areas	6.3 m^3/s
Retention time in the storage basin	13 hours

The graphs below show the combined effect of detention basin 1 on the T25 unit hydrograph for sub-basins 2 and 3, as well as the retention time in detention basin 1.

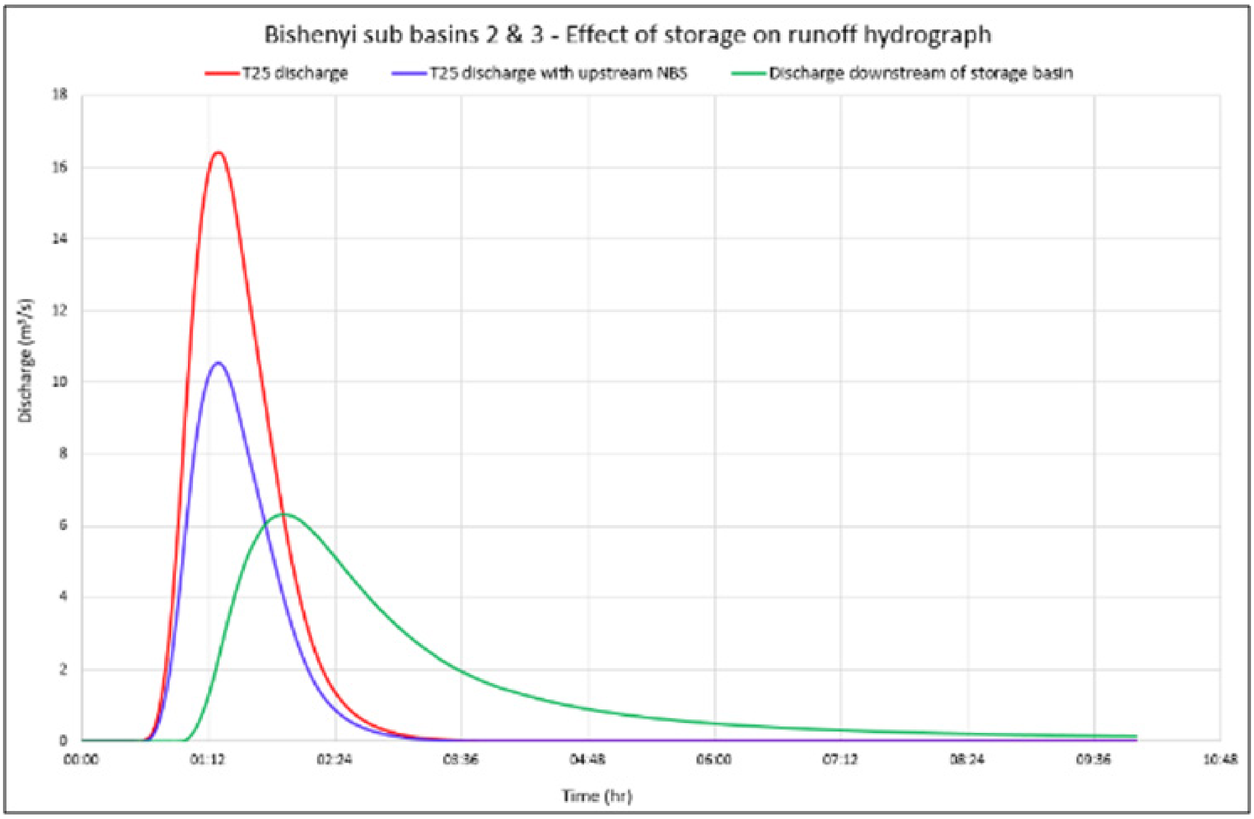


Figure 24 – Effect of storage on T25 runoff hydrograph for sub-basins 2 & 3 Bishenyi

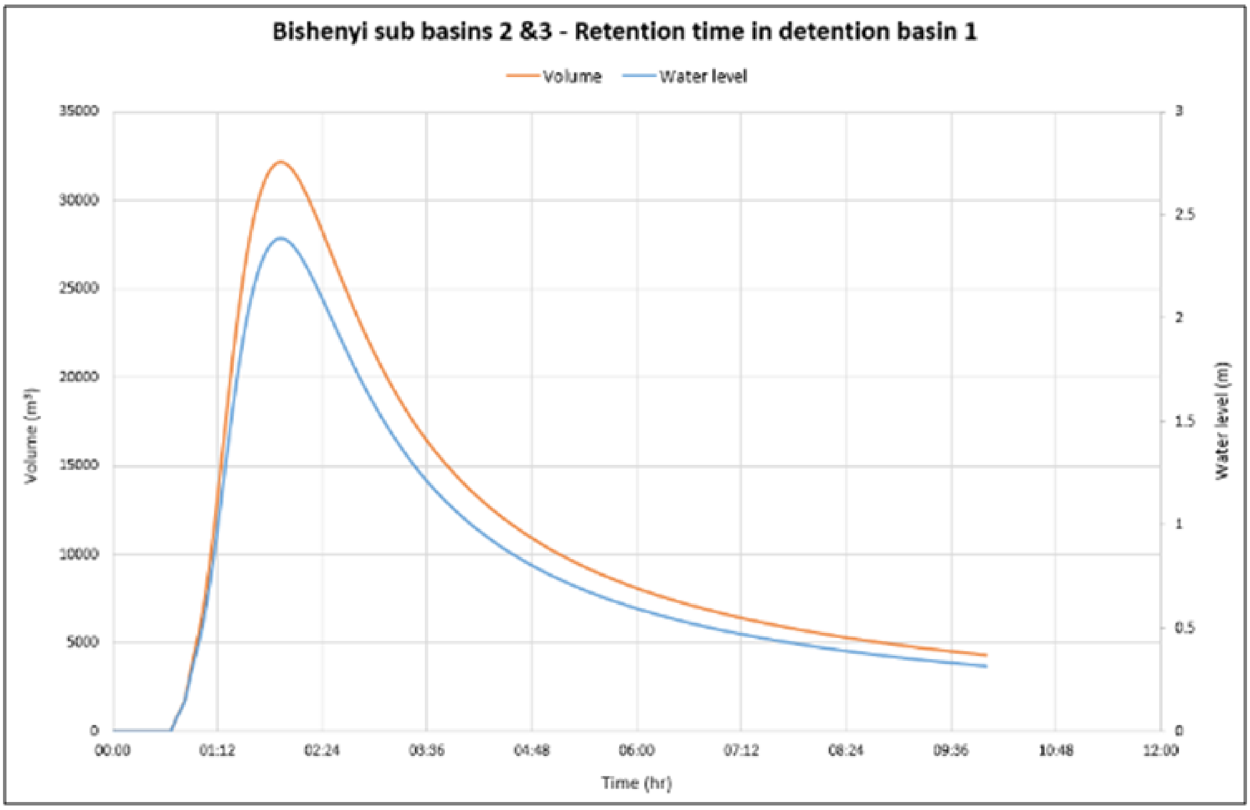


Figure 25 – Retention time in detention basin 1 for sub-basins 2 & 3 Bishenyi for T25

Table 41 – Model results for detention basin 2 (sub-basin 6 Bishenyi)

Parameter	Value
Volume required for flood attenuation as modelled by HEC -RAS	4,125 m^3
Volume provided (detention basin 2)	16,200 m^3
Surplus storage capacity	12,075 m^3
T25 peak flow (sub basin 6)	3.1 m^3/s
Estimated T25 peak flow with application of upstream NBS (reduction of 36%)	1.9 m^3/s
Modelled peak flow downstream of the three storage areas	1.8 m^3/s
Retention time in the storage basin	12 hours

The graphs below show the combined effect of detention basin 2 on the T25 unit hydrograph for sub-basin 6, as well as the retention time in detention basin 2.

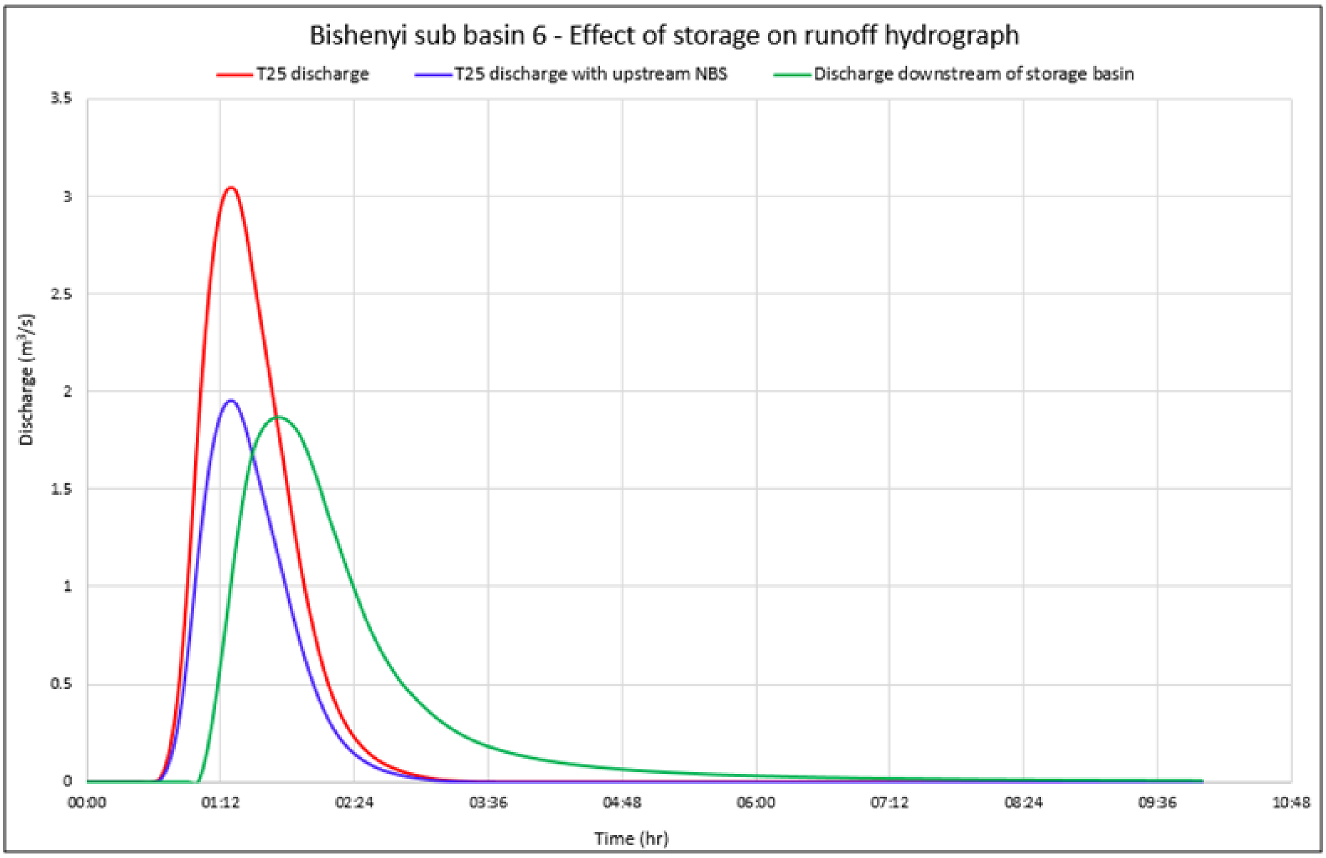


Figure 26 – *Effect of storage on T25 runoff hydrograph for sub-basin 6 Bishenyi*

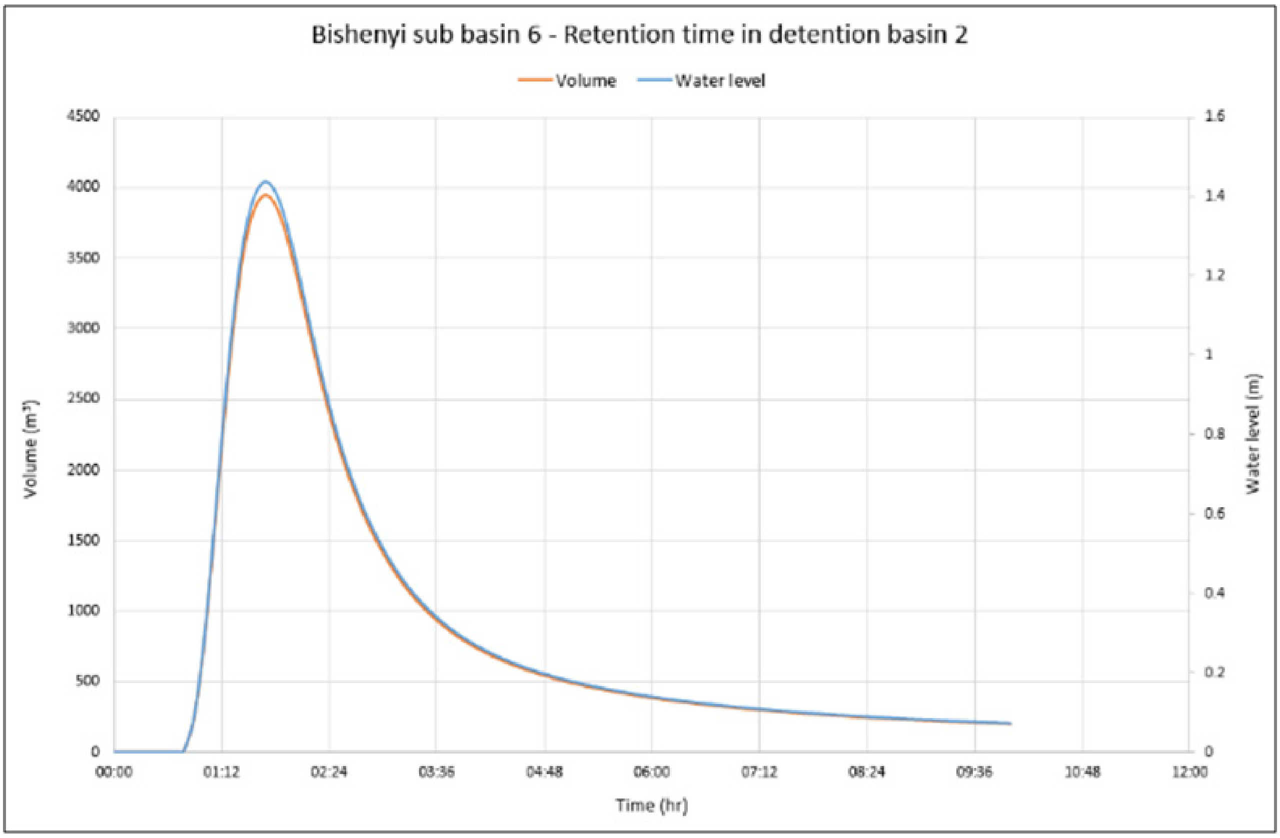


***Figure 27** – Retention time in detention basin 2 for sub-basin 6 Bishenyi for T25*

Table 42 – Model results for detention basin 3 (sub-basin 1 Bishenyi)

Parameter	Value
Volume required for flood attenuation as modelled by HEC-RAS	8,400 m3
Volume provided (detention basin 3)	9,000 m3
Surplus storage capacity	600 m3
T25 peak flow (sub basin 1)	3.5 m3/s
Estimated T25 peak flow with application of upstream NBS (reduction of 36%)	2.3 m3/s
Modelled peak flow downstream of the three storage areas	1.2 m3/s
Retention time in the storage basin	12 hours

The graphs below show the combined effect of detention basin 3 on the T25 unit hydrograph for sub-basin 1, as well as the retention time in detention basin 3.

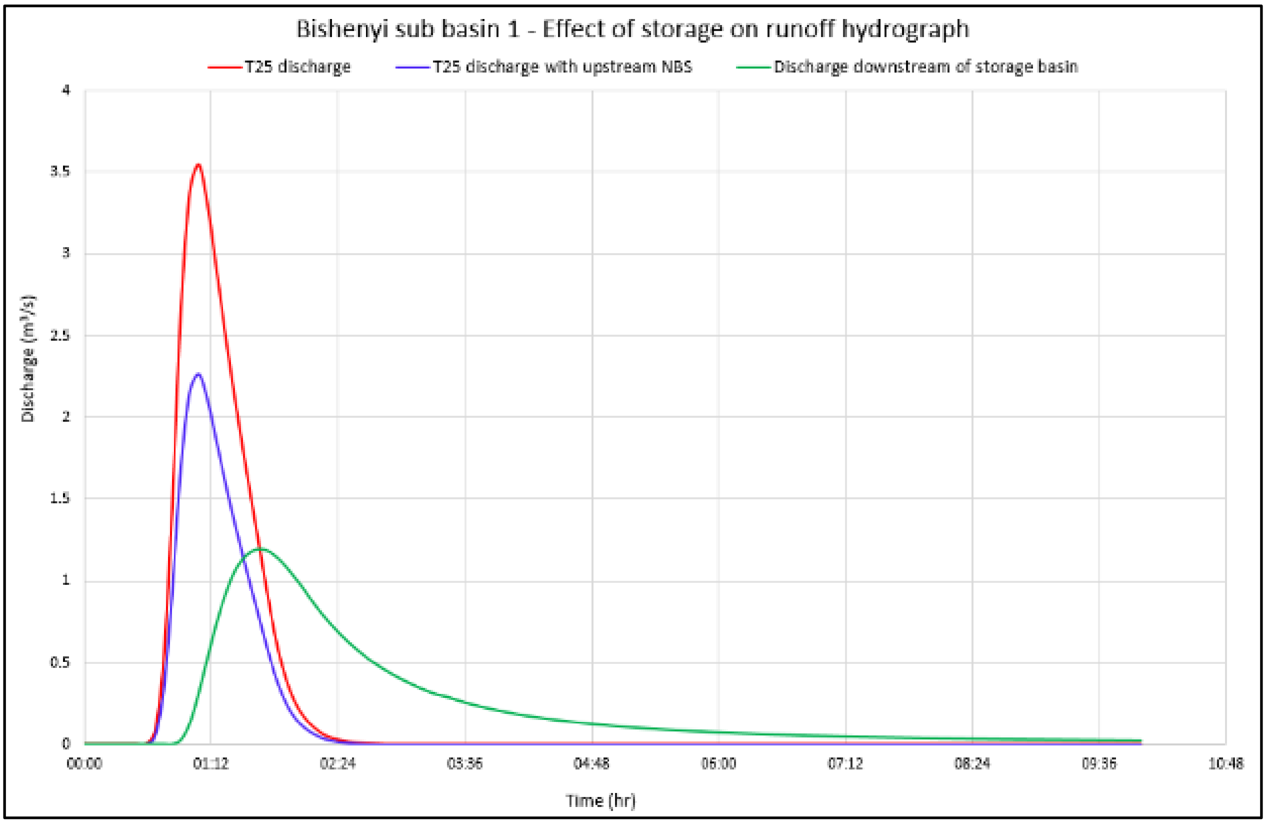


***Figure 28** – Effect of storage on T25 runoff hydrograph for sub-basin 1 Bishenyi*

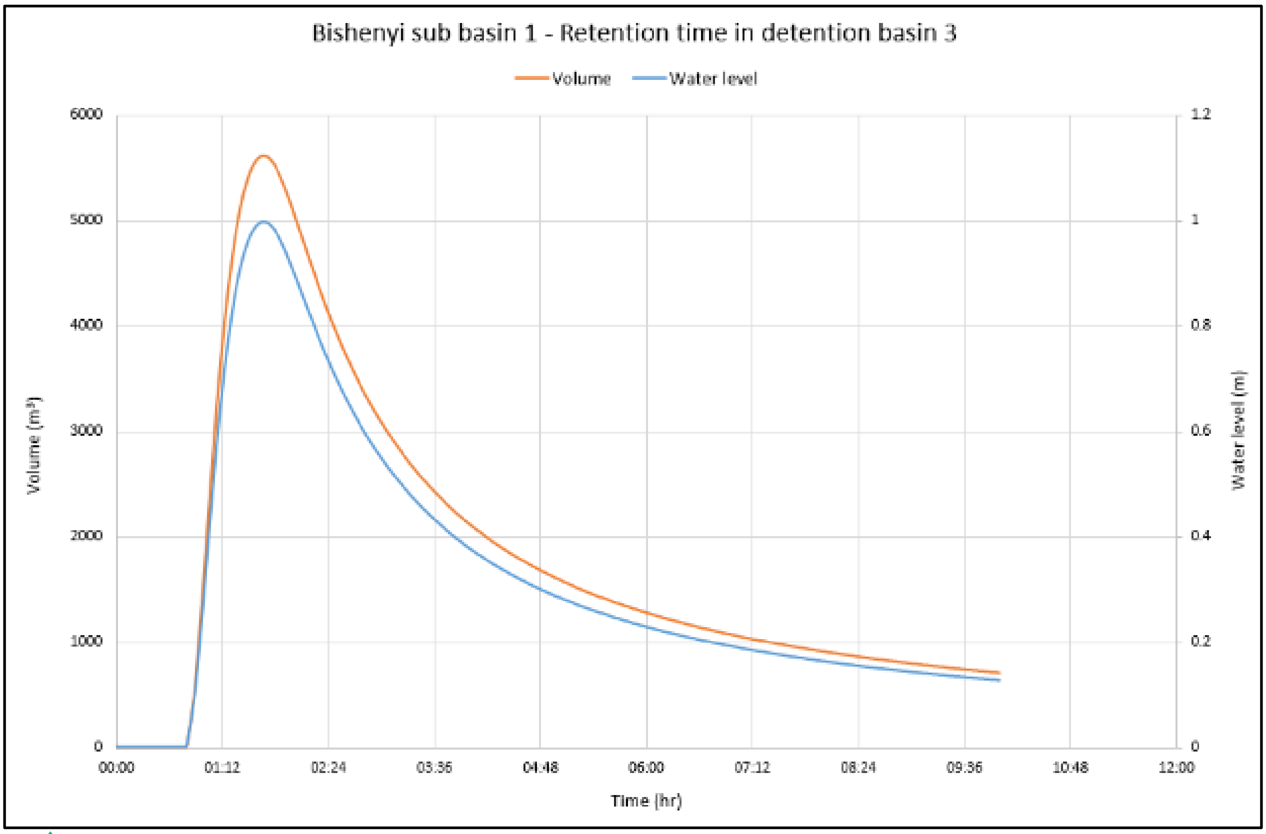


***Figure 29** – Retention time in detention basin 3 for sub-basin 1 Bishenyi for T25*

Determination of required volumes for Bishenyi detention basins at T100 flows

Iterations of model runs were carried for a return period of 100 years. The required sizes of the basins were confirmed if the peak outflow from the basin for a T100 rainfall is less or equal to the peak runoff rate for a 5-year return period rainfall. Results are presented in the table below:

Table 43 – Detention basin size requirements for T100 Bishenyi

	Modelled volume T25 [m^3]	Volume provided by design T25 [m^3]	Surface area of basin for T25 design, assuming average depth of 1.5 m [m^2	Required volume for T100 [m^3]	Surface area of basin for T100, assuming average depth of 1.5 m [m^2]
Detention basin 1	41,760	49,000	**32,666**	101,690	**67,793**
Detention basin 2	4,125	16,200	**10,800**	25,200	**16,800**
Detention basin 3	8,400	9,000	**6,000**	18,700	**12,466**

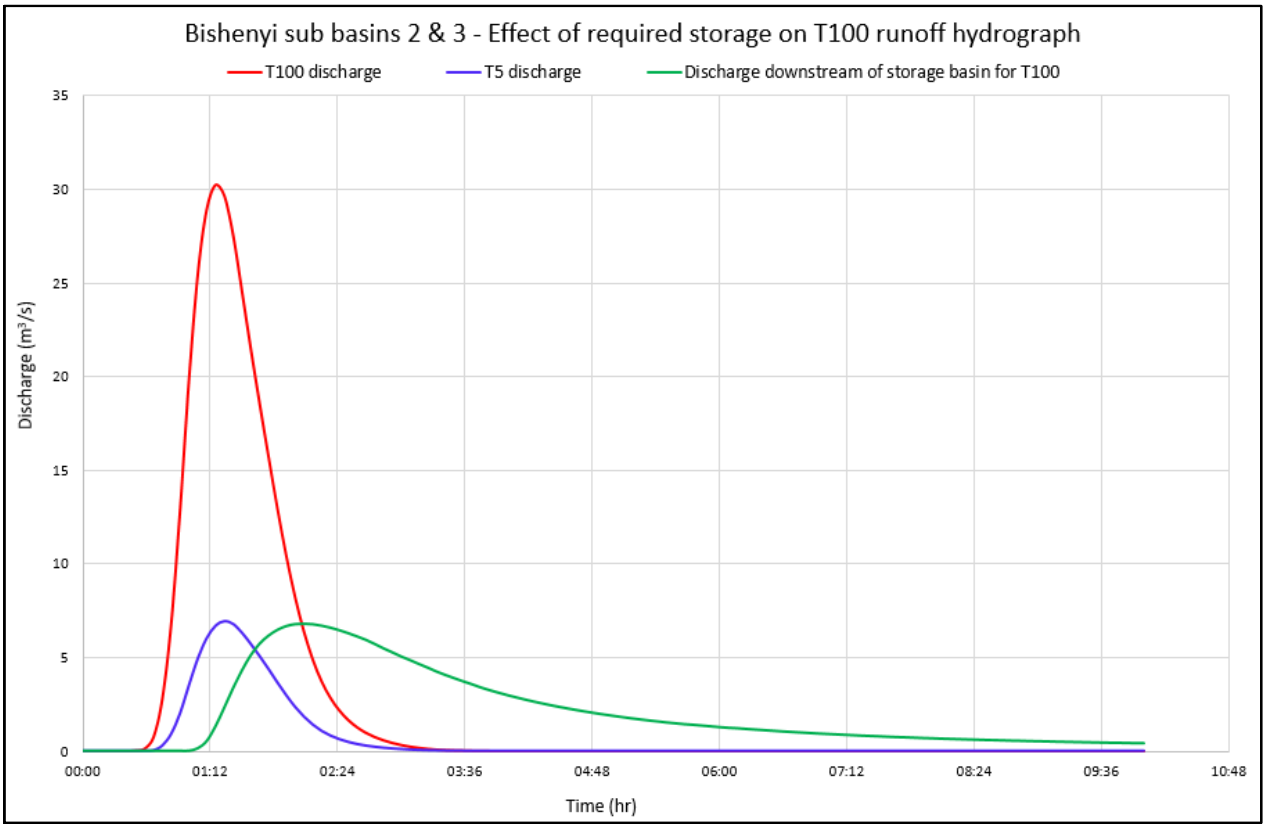


***Figure 30** – Effect of required storage in detention basin 1 on T100 runoff hydrograph for sub-basins 2 and 3 Bishenyi*

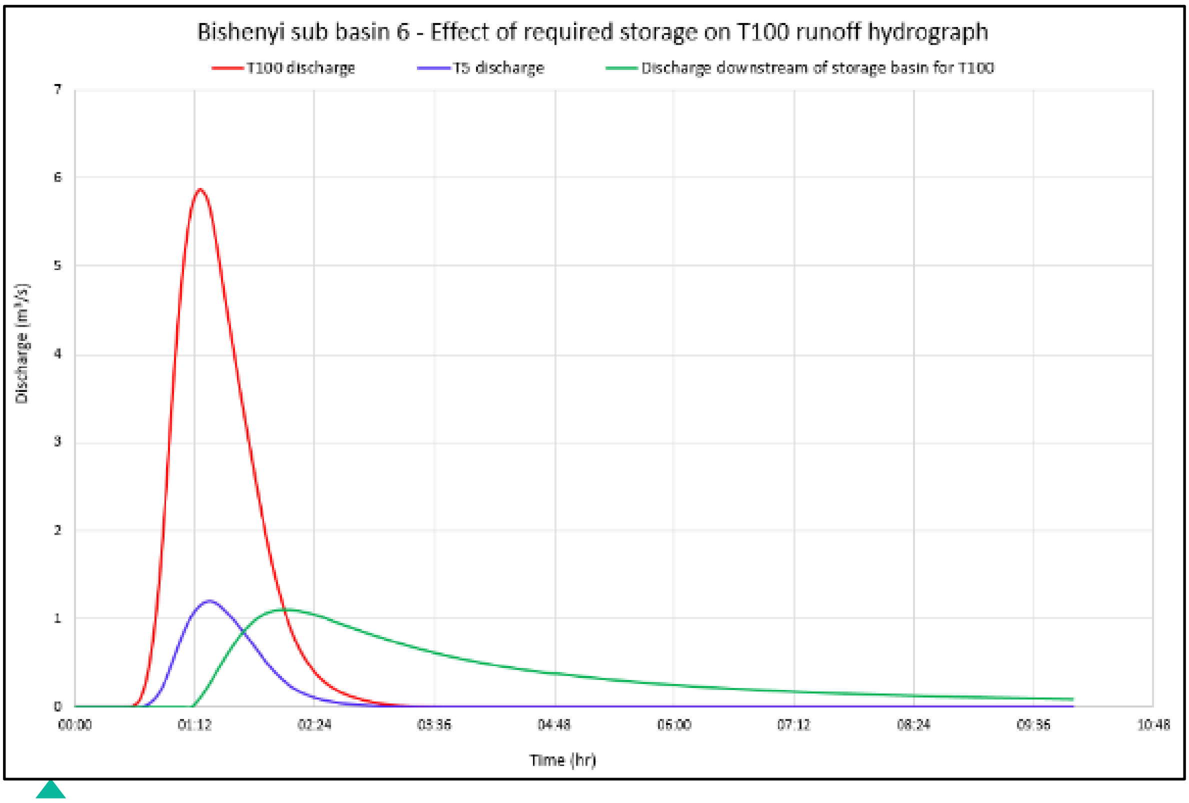


***Figure 31** – Effect of required storage in detention basin 2 on T100 runoff hydrograph for sub-basin 6 Bishenyi*

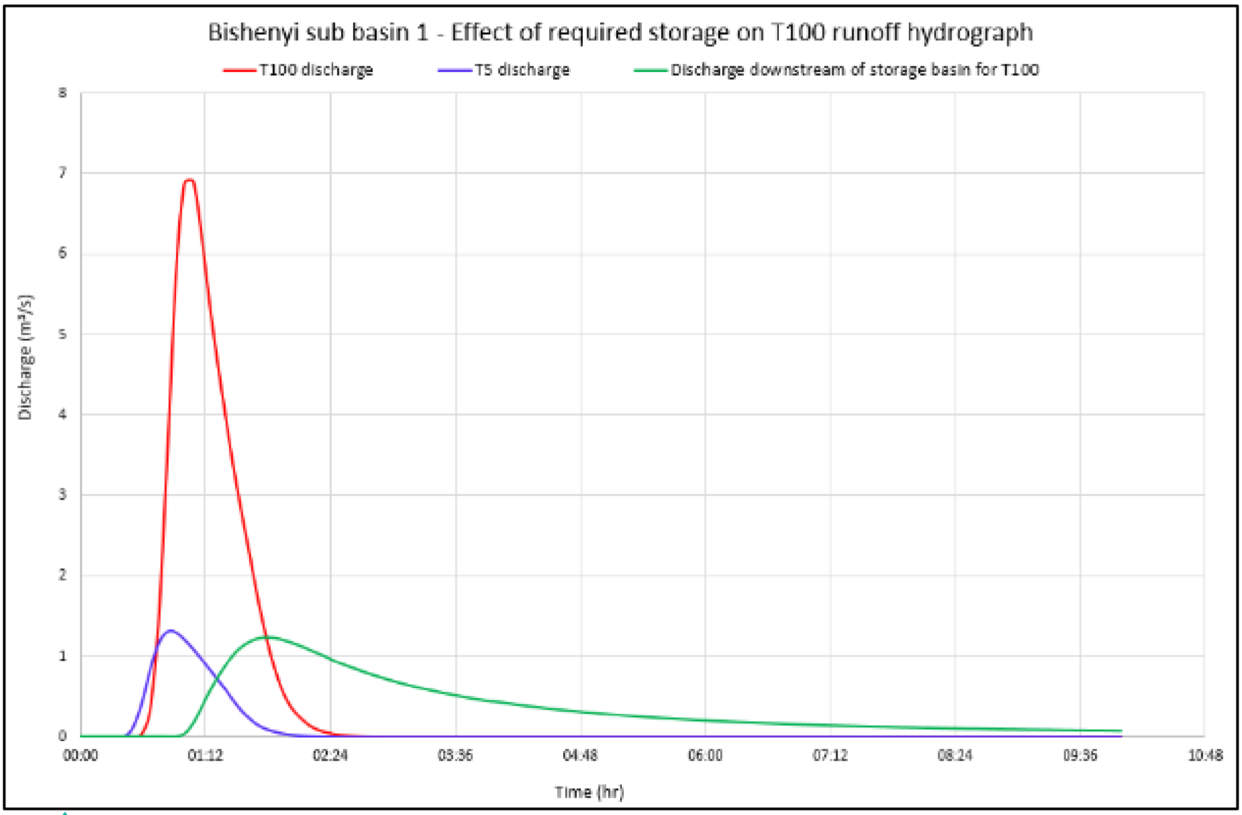


***Figure 32** – Effect of required storage in detention basin 3 on T100 runoff hydrograph for sub-basin 1 Bishenyi*

4.2.3.4 Rwabayanga

It is proposed to construct two detention basins in the Rwabayanga sub-catchment to provide volume attenuation for runoff coming from sub-basins 1, 2, 3 and 4. The areas in which the basins are proposed for construction are all used for agriculture, and compensation for crops and land expropriation will be required.

Detention basins 1 is proposed to be constructed in the valley located to the north east of the sub-catchment, and will receive runoff from sub-basins 1 and 3 of Rwabayanga sub-catchment.

Detention basin 2 will be located on the north western side of the sub-catchment, and will receive runoff from sub-basins 2 and 4.

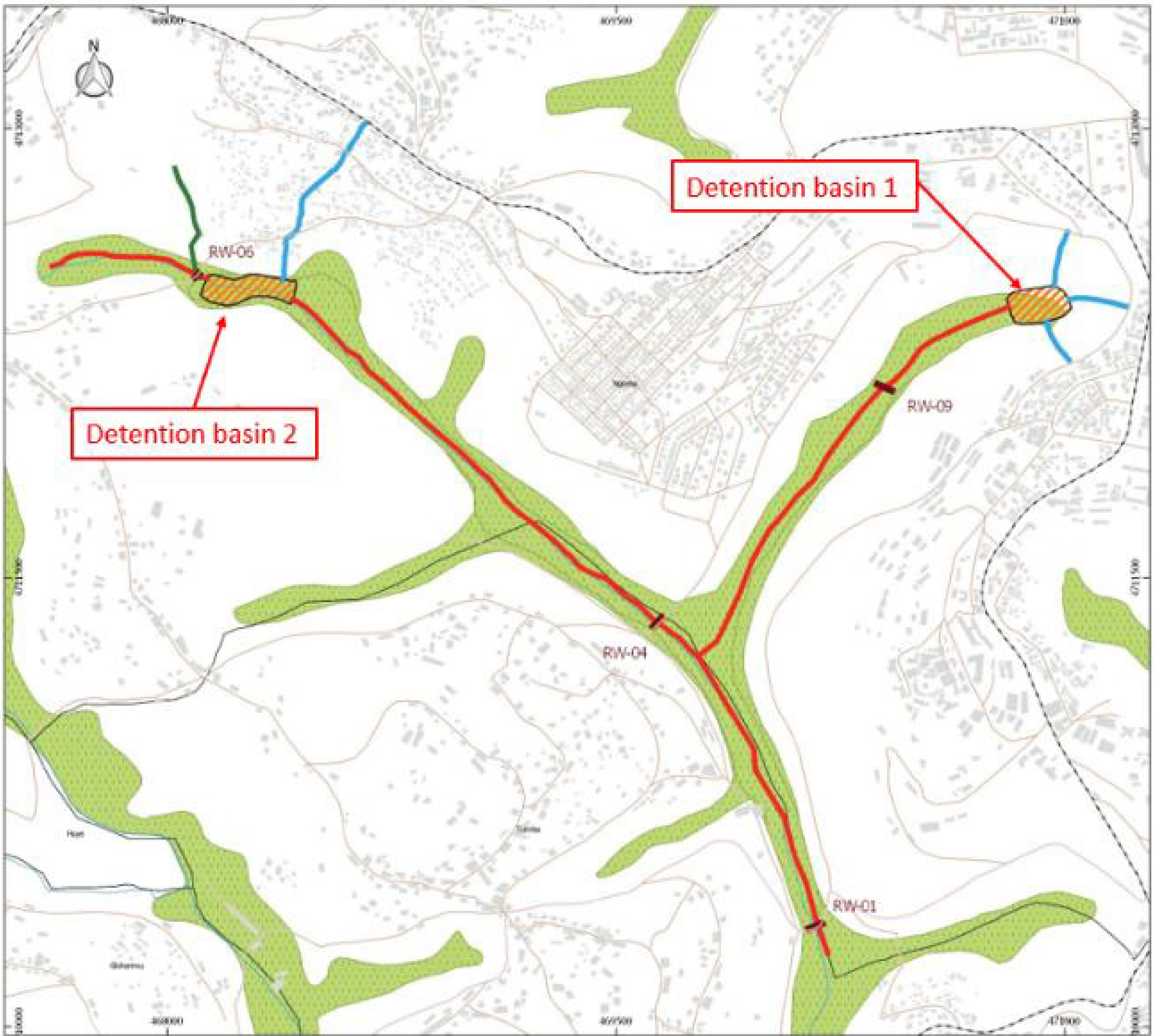


Figure 33 *– Proposed detention basins in Rwabayanga sub-catchment*

Table 44 - Design hydraulic parameters of detention basin 1 Rwabayanga (design ed for T25)

Parameter	Value
Mean surface area	9,000 m^2
Maximum depth of water	2.0 m
Average depth	1.5 m
Total volume of storage	13,500 m^3
Diameter of inlet pipe	1,000 mm
Diameter of outlet pipe	1,000 mm

Table 45 - Design hydraulic parameters of detention basin 2 Rwabayanga (designed for T25)

Parameter	Value
Mean surface area	14,000 m^2
Maximum depth of water	1.8 m
Average depth	1.4 m
Total volume of storage	19,600 m^3
Diameter of inlet pipe	1,000 mm
Diameter of outlet pipe	1,000 mm

The HEC-RAS model was run for using the unit hydrographs of 1 in 25 years return period rainfall for sub-basin 1, 2, 3 and 4, with application of an assumed 36% reduction from upstream NBS. The objective was to assess the total volume of storage at which the basin does not overflow. Model results for all basins are summarized below:

Table 46 - Model results for detention basin 1 (sub -basins 1 and 3 Rwabayanga)

Parameter	Value
Volume required for flood attenuation as modelled by HEC -RAS	8,550 m^3
Volume provided (detention basin 1)	13,500 m^3
Surplus storage capacity	4,950 m^3
T25 peak flow (sub basins 1 and 3)	3.2 m^3/s
Estimated T25 peak flow with application of upstream NBS (reduction of 36%)	2.0 m^3/s
Modelled peak flow downstream of the three storage areas	1.6 m^3/s
Retention time in the storage basin	12 hours

The graphs below show the combined effect of detention basin 1 on the T25 unit hydrograph for sub-basins 1 and 3, as well as the retention time in detention basin 1.

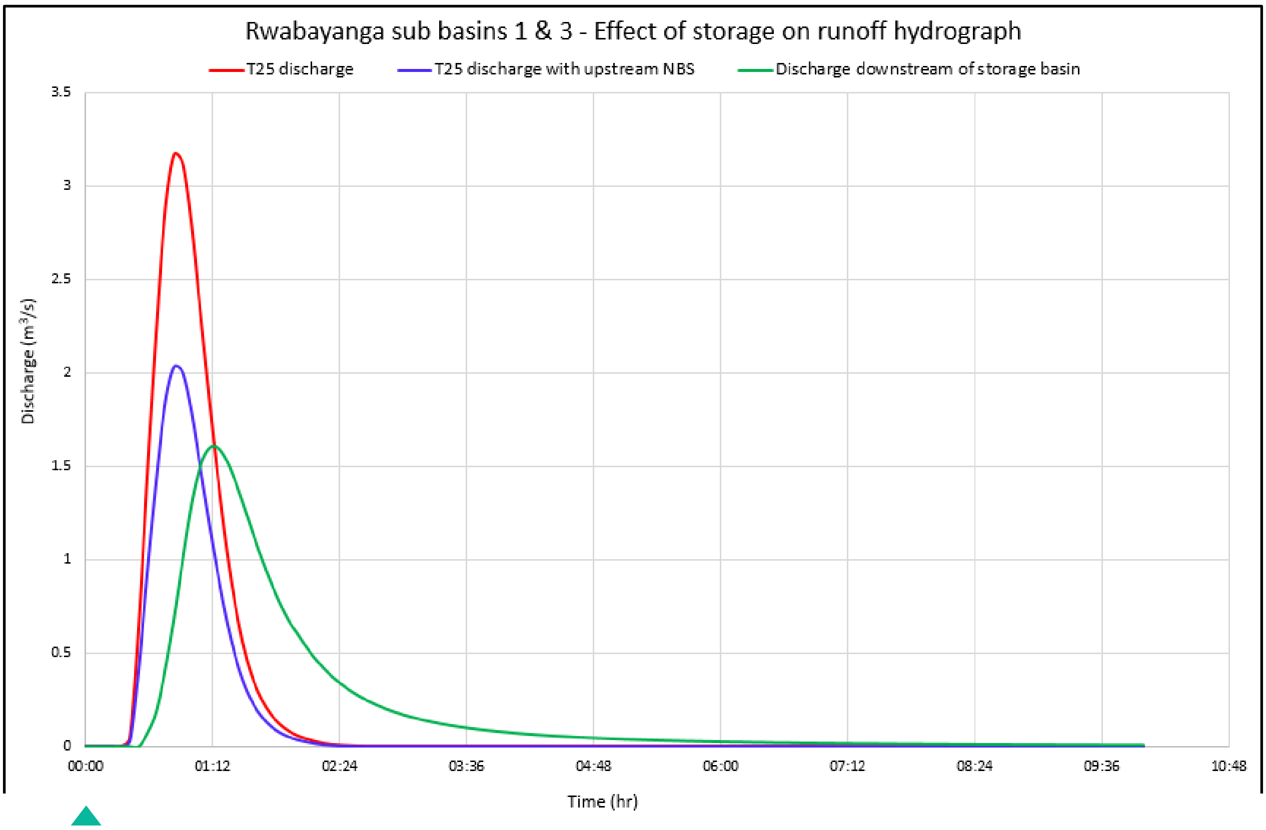


***Figure 34** – Effect of storage on T25 runoff hydrograph for sub-basins 1 & 3 Rwabayanga*

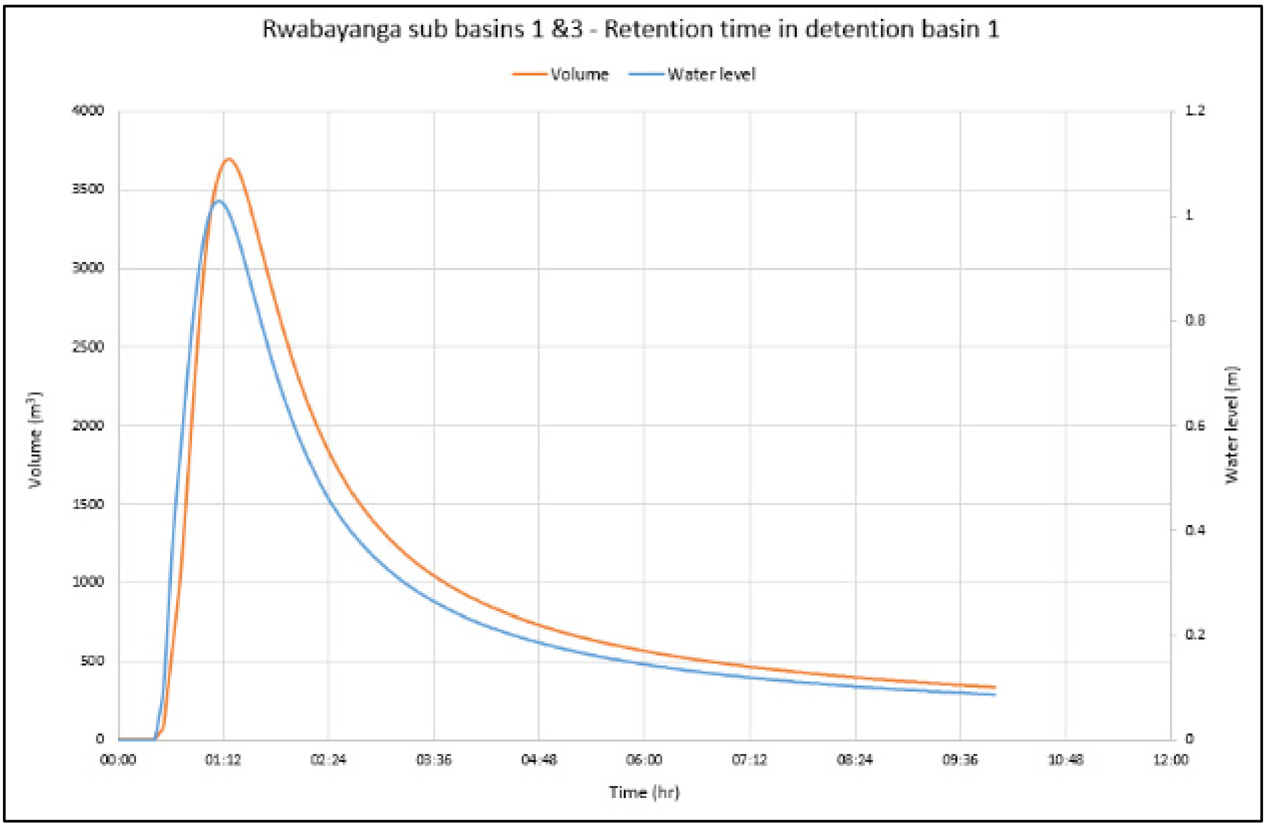


***Figure 35** – Retention time in detention basin 1 for sub-basins 1 & 3 Rwabayanga for T25*

Table 47 - Model results for detention basin 2 (sub -basins 2 and 4 Rwabayanga)

Parameter	Value
Volume required for flood attenuation as modelled by HEC -RAS	13,350 m^3
Volume provided (detention basin 2)	19,600 m^3
Surplus storage capacity	6,250 m^3
T25 peak flow (sub basins 2 and 4)	7.6 m^3/s
Estimated T25 peak flow with application of upstream NBS (reduction of 36%)	4.9 m^3/s
Modelled peak flow downstream of the three storage areas	3.8 m^3/s
Retention time in the storage basin	12 hours

The graphs below show the combined effect of detention basin 1 on the T25 unit hydrograph for sub-basins 1 and 3, as well as the retention time in detention basin 1.

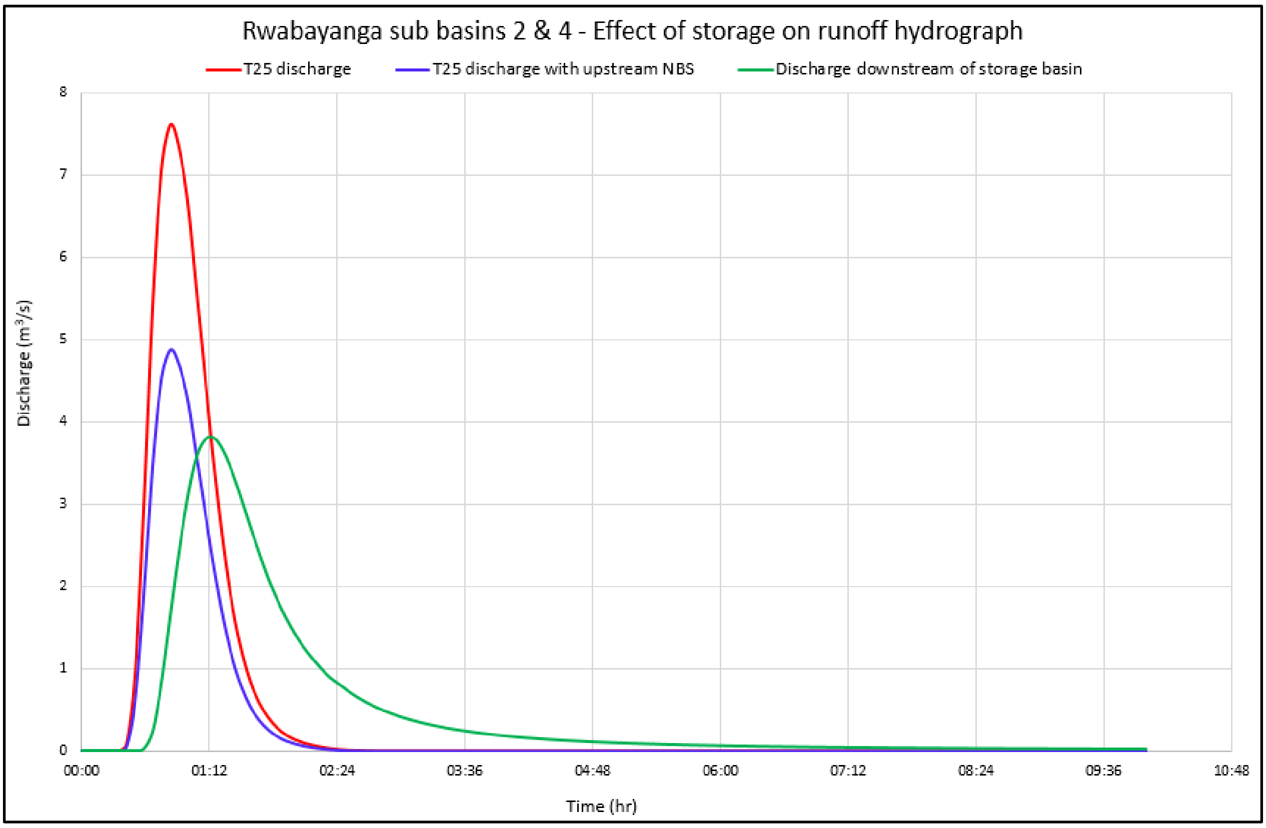


***Figure 36** – Effect of storage on T25 runoff hydrograph for sub-basins 2 & 4 Rwabayanga*

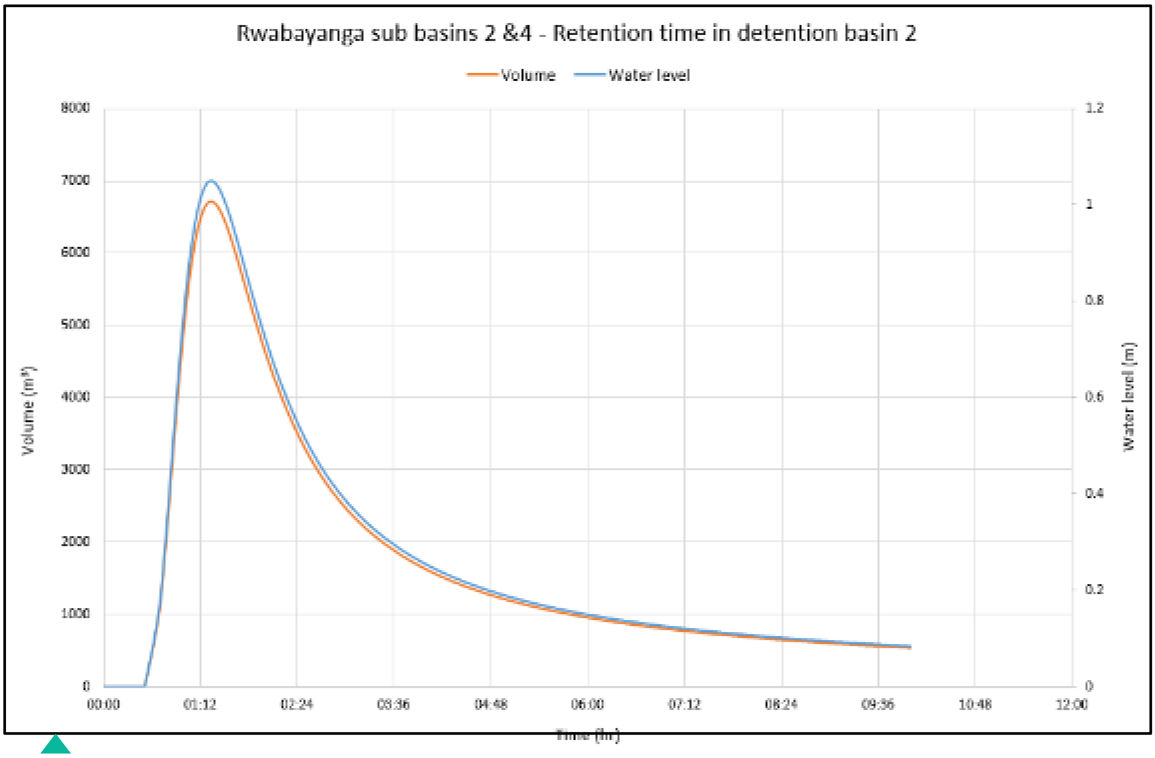


***Figure 37** – Retention time in detention basin 2 for sub-basins 2 & 4 Rwabayanga for T25*

Determination of required volumes for Rwabayanga detention basi ns at T100 flows

Iterations of model runs were carried for a return period of 100 years. The required sizes of the basins were confirmed if the peak outflow from the basin for a T100 rainfall is less or equal to the peak runoff rate for a 5-year return period rainfall. Results are presented in the table below:

Table 48 - Detention basin size requirements for T100 Rwabayanga

	Modelled volume T25 [m^3]	Volume provided by design T25 [m^3]	Surface area of basin for T25 design, assuming average depth of 1.5 m [m^2]	Required volume for T100 [m^3]	Surface area of basin for T100, assuming average depth of 1.5 m [m^2]
Detention basin 1	8,550	13,500	**9,000**	16,100	**10,733**
Detention basin 2	13,350	19,600	**13,066**	20,100	**13,400**

It is noted that the differences between the surface areas of the basins as designed and the surface areas for T100 is not large. It is therefore recommended to consider the surface areas for T100 at the detailed design phase.

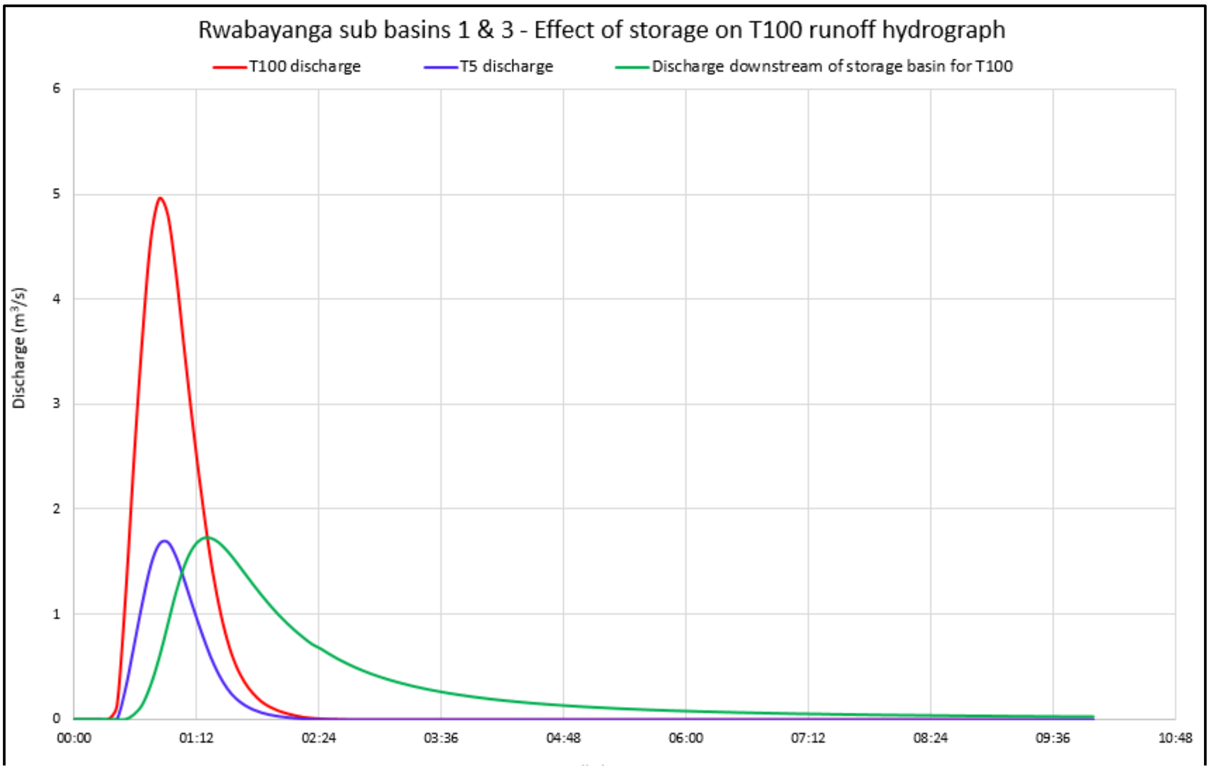


***Figure 38** – Effect of required storage in detention basin 1 on T100 runoff hydrograph for sub-basins 1 and 3 Rwabayanga*

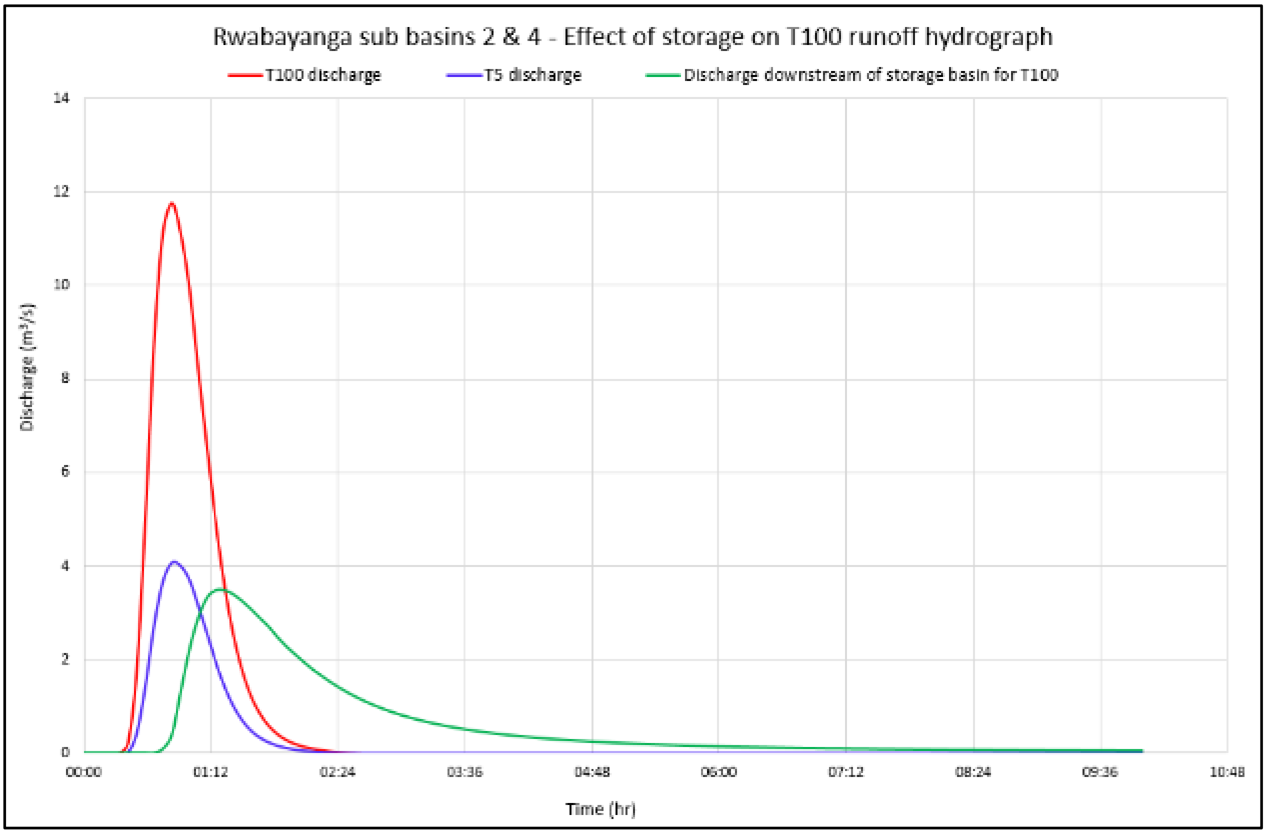


***Figure 39** – Effect of required storage in detention basin 2 on T100 runoff hydrograph for sub-basins 2 & 4 Rwabayanga*

4.2.3.5 Rusizi

It is proposed to construct a detention basins on the hill 'Mont Cyangugu' to intercept and store runoff running down from the residential zone on the hill. As part of this project, a drainage channel has been proposed to convey the runoff down the hill along the main neighborhood road, and will discharge it to the proposed detention basin, from which another channel will convey the basin outflow to Lake Kivu.

An important design feature of this basin is that it should be built with an impermeable geotextile lining to prevent all infiltration. This is important given that the basin will be located a hill and infiltration could cause water saturation in the soil, potentially leading to gullies or landslides.

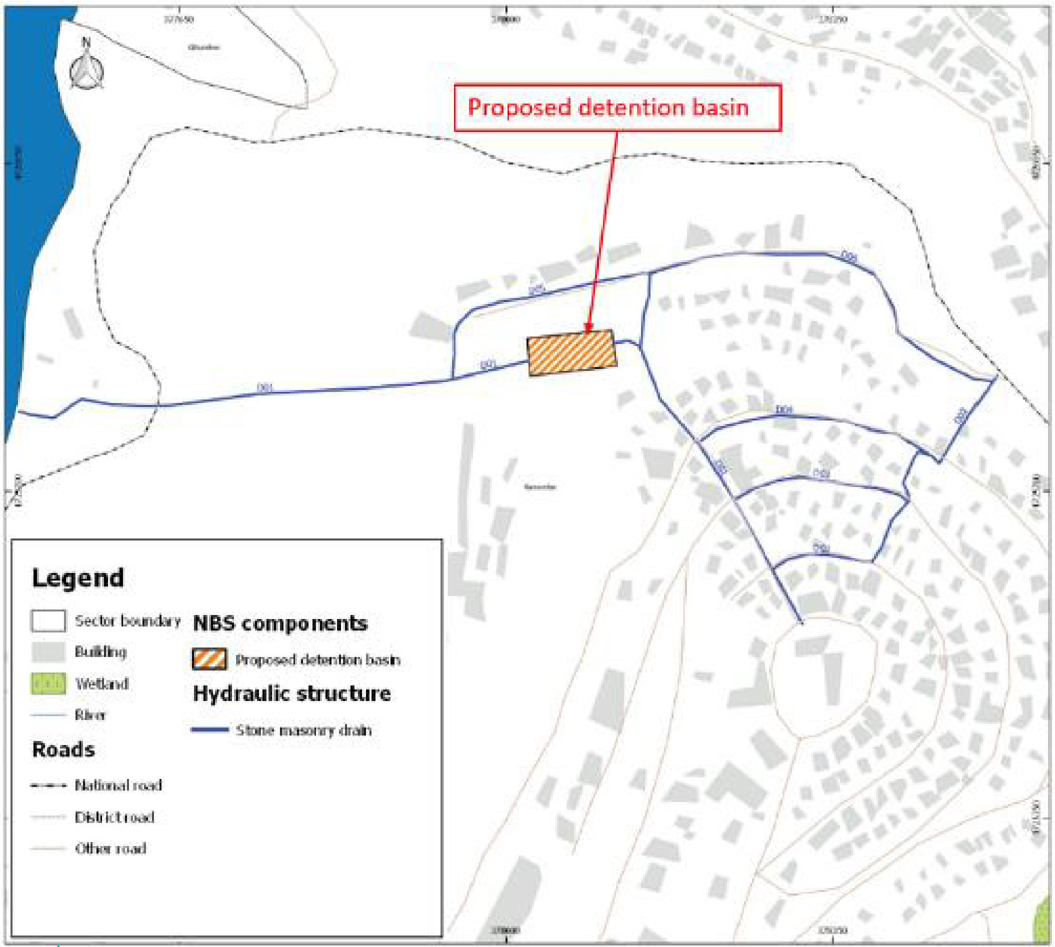


Figure 40 – Proposed detention basin in Mont Cyangugu, Rusizi

Table 49 - Design hydraulic parameters of the detention basin in Mont Cyangugu

Parameter	Value
Mean surface area	600 m^2
Maximum depth of water	2.0 m
Average depth	1.5 m
Total volume of storage	900 m^3
Diameter of inlet pipe	1,000 mm
Diameter of outlet pipe	1,000 mm

The topographic survey in Rusizi only covered a small strip of Mont Cyangugu hill where the proposed drainage channel is to be constructed (linear survey). Therefore HEC -RAS modelling was not carried out for the design of this basin. The extent of hydraulic modelling in Rusizi was discussed in Interim Report No.2.

Simple volume c alculations were done to determine the required volume of the basin; results are presented in the table below. It should be noted that the recommended storage volume of 900 m³ is sufficient for return periods up to and including T100.

Table 50 - Calculation results of the detention basin in Mont Cyangugu

Catchment details		
Total catchment area (m^2)	124,000.00	
Runoff coefficient	0.35	
Design storm intensity (mm/hr)	78.20	T25
Design storm duration (mins)	30.00	

Estimated outflow (l/s)	600.00

Results	
Storage volume required (m^3)	**616.94**

Storage design	
Length	30.00
Width	20.00
Average depth	1.50

		Check
Storage volume provided (m^3)	900.00	OK
Time for emptying 50% (hr)	0.14	OK

Verification for other return periods

	Intensity (mm/hr)	Storage volume required (m^3)	Check
T5	56.70	150.39	OK
T10	63.80	304.46	OK
T50	80.40	664.68	OK
T100	90.00	873.00	OK

4.2.4 Amenity and biodiversity considerations for detention basins

- Detention basins should be constructed in such a manner to have a natural feel with soft edges and flowing forms;
- Inlet and outlet pipes and culverts should have minimal access, preferably with additional fencing;
- Inlets and outlets should be installed with grilles to prevent entry or exit of large solids to/from the basin;
- It is recommended to install a pollutant/solids capture net at the inlet of the basins, This will provide some treatment to the incoming water to improve its quality. An example of the solids capture net with specifications is included in the appendices of this report;

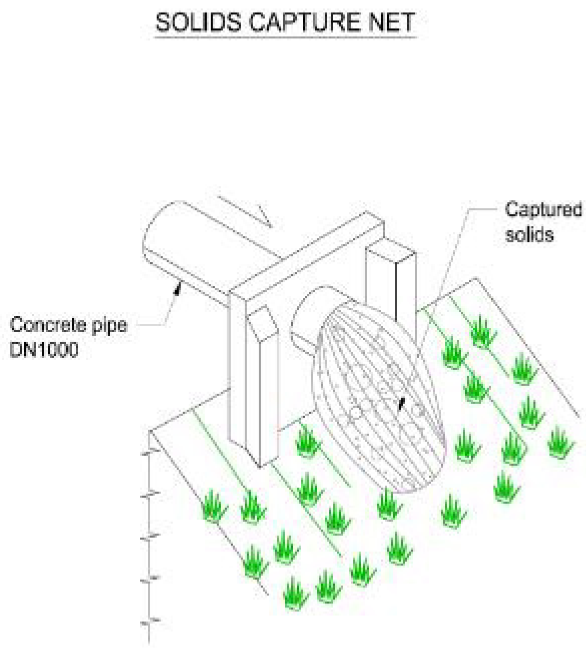


***Figure 41** – Proposed pollutants/solids capture net at inlet of detention basins*

- Plant species should be selected to suit the existing landscape characteristics of the sites;
- Use planting of known wildlife value, appropriate to each location, ensuring no introduction of invasive species;
- The use of plants that are native and of local provenance should be maximised, ensuring that they are suited to local soils and hydrology;
- Trees and other appropriate woodland features should be planted on the edges of the detention basin;
- Small information boards can be provided adjacent to the basins to give information on the function of the swale;
- It is recommended to install a fence along the full perimeter of the basins to prevent access and potential accidents especially during the rainy season. Shrubs and trees should be planted along the fence to improve the aesthetics and nature blending of the fence.

4.2.5 Construction, operation and maintenance requirements of swales

- The bottom and side slopes of the basin should be carefully prepared to ensure that they are structurally sound. The grading should be uniform and smooth to the design slope so that water does not pond in depressions and to minimise the risk of channelling and erosion through preferential flow paths;
- Backfilling against inlet and outlet structures needs to be controlled so as to minimise settlement and erosion;
- The soils used to finish the side slopes need to be suitably fertile, porous and of sufficient depth to ensure health vegetation growth;
- Where an impermeable liner is to be used, such as the detention basin in Mont Cyangugu (Rusizi), care should be taken to ensure that it is not damaged during construction;
- Construction of the basins should be timed to avoid the rainy seasons when high runoff rates are to be expected;
- During the construction phase, the runoff from bare soils should be minimised. To this end, vegetation on slopes should be rapidly established, base-of-slope trenches should be constructed as part of temporary works to retain inevitable runoff sediments;
- Maintenance responsibility for the basins should be placed with an appropriate organisation with direct supervision of the local authority;
- Litter and debris removal should be undertaken as part of the general landscape maintenance of the site, and/or can be included in the monthly 'Umuganda' activity (when it resumes) for locals to engage in. All litter should be removed from the site;
- The major maintenance requirement for detentions basins is mowing / grass cutting. Regular mowing is only required along maintenance access routes, across embankments and the main storage area. - Mowing / grass cutting should retain grass heights of 75 – 150 mm across the main storage surface to assist in filtering pollutants and retaining sediments;
- Grass clippings should be disposed of offsite or outside the detention basin area;
- All vegetation management activities should take into account of the need to prevent the spread of invasive species;
- Sediments will need to be removed once deposits exceed a height of 50 mm preferably.

Table 51 - Operation and maintenance requirements for detention basins

Schedule	Action	Frequency
Regular maintenance	Remove litter and debris	Monthly or as required
	Cut grass to retain height to within the specified design range	Monthly or as required
	Manage other vegetation and remove nuisance plants	Monthly or as required
	Inspect inlets and outlets for blockages, and clear if require	Monthly
	Inspect banksides, structures, pipework, etc. for evidence of physical damage	Monthly
	Inspect basin, inlets and outlets for silt /	Monthly

Schedule	Action	Frequency
	sediment accumulation. Establish appropriate removal frequencies	
Occasional maintenance	Reseed areas of poor vegetation growth, alter plant types to better suit conditions if required	As required or if bare soil is exposed over 10% or more of the swale areas
	Prune and trim any trees and remove cuttings	Every two years, or as required
	Remove sediments from inlets, outlets and main basin	Every year or as required
Remedial actions	Repair erosion or other damage	As required
	Relevel uneven surfaces and reinstate design levels, especially at location where water is ponding for more than 48 hours	As required
	Repair inlets and outlets	As required

4.3 Estimation of impact of NBS on flood levels

The following tables present the comparison between current flood levels and those after installation of NBS with resized hydraulic structures.

Table 52 – Comparison of flood levels for Rwandex -Magerwa sub-catchment

Structure	Estimated overflow level for T25 [cm]	Modelled water level T100 [cm]	
		Current	NBS
Slab Bridge RM-01	-	80	10-30
Wooden bridge RM-02	40	80-100	5-15

	T100
Current flooded area [ha]	3.37*
Flooded area with NBS + resized hydraulic structures [ha]	1.07*

***Note**: the flooded area excludes the main flood plain / wetland in Rwandex -Magerwa sub-catchment.

Table 53 – Comparison of flood levels for Bishenyi sub-catchment

Structure	Estimated overflow level for T25 [cm]	Modelled water level T25 [cm]	
		Current	NBS
Pipe culvert BI-01	-	-	Not resized
Wooden bridge BI-02	0 - 60	10-15	0
Wooden Bridge BI-03	-	-	0
Flow control structure BI-04	10 - 60	10-20	0
Wooden Bridge BI-05	10 - 70	-	0
Double pipe culvert BI-06	No information	10-60	0

	T25	T100
Current flooded area [ha]	20.39	38.63
Flooded area with NBS + resized hydraulic structures [ha]	17.46	30.26

Table 54 – Comparison of flood levels for Rwabayanga sub -catchment

Structure	Estimated overflow level for T25 [cm]	Modelled water level T25 [cm]	
		Current	NBS
Wooden bridge RW-04	0 - 90	20-40	20-30

	T25	T100
Current flooded area [ha]	22.86	26.36
Flooded area with NBS + resized hydraulic structures [ha]	22.58	26.08

Interpretation of results

Rwandex-Magerwa

Implementation of NBS and resizing hydraulic structures in Rwandex-Magerwa sub-catchment leads to a noteworthy reduction of flooding in terms of flood depth and flooded area. Taking the example of Slab Bridge RM-01, the flood depth at this structure reduces from the current 80 cm to a range depth ranging from 10 cm to 30 cm (average 20 cm) when NBS and resizing of structure are implemented. This represents an average reduction of 75 % on flood depth.

The flooded area in the critical zone of Rwandex-Magerwa (excluding the wetland) also sees a significant reduction from 3.37 ha to 1.07 ha at T100, which represents a 68% reduction to absolute zero flooding.

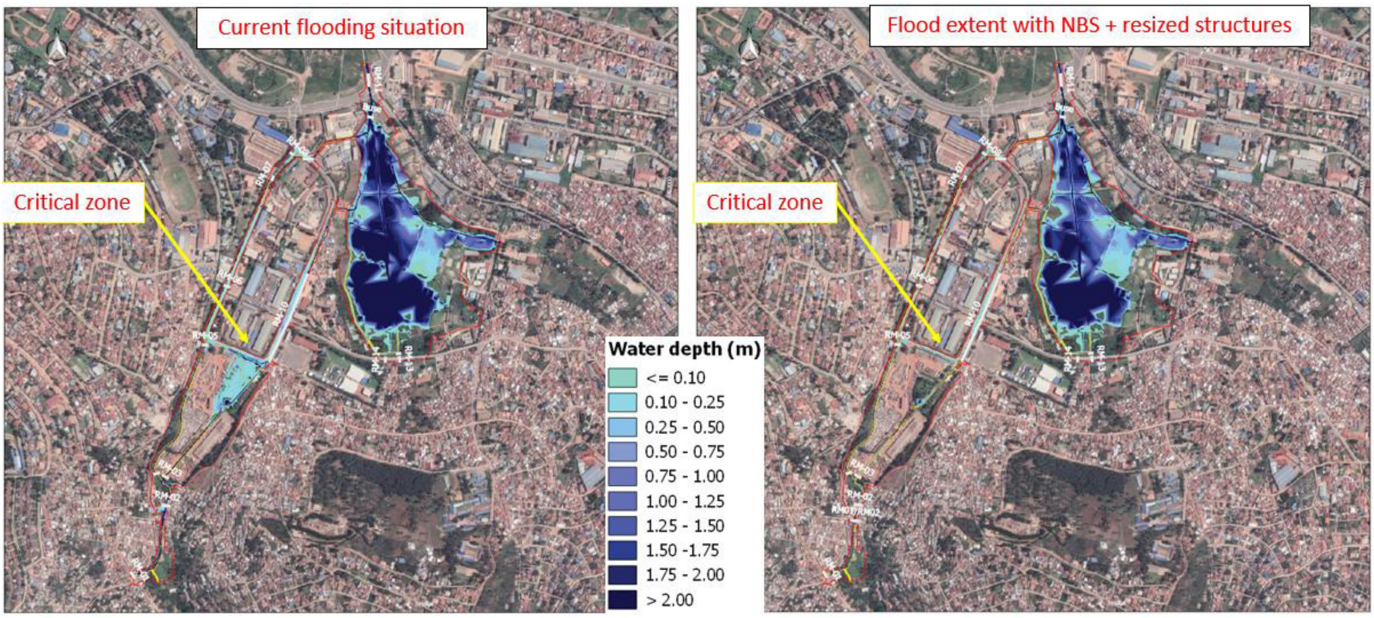


***Figure 42** – Comparison of flood extents between the current situation and after application of NBS + resized structures (T100) in Rwandex-Magerwa*

Bishenyi

For Bishenyi sub-catchment, we note that implementation of NBS and resizing of hydraulic structures has an important reduction effect on flood depth. Table 52 shows that there is no flooding at the structures (100 % reduction measured at the structures). However, the flooded area is reduced by 22 % at T100. Whilst the reported 22 % may not seem not as significant, it is emphasized that this refers to absolute reduction to zero flooding, and a big portion of the remaining 78 % is small depths of water, which the model nonetheless identifies as flooding given its binary nature of assessment. To achieve a higher value of absolute reduction to zero flooding would require a complete redesign of existing irrigation channels.

It should also be noted that critical hotspots are resolved, such the reduction of flooding at the existing double pipe culvert on the national road near Hashi petrol station, as well as the wetland immediately upstream and downstream of it. The impact of NBS and resizing of structures on flooding can be visually seen in the figure below.

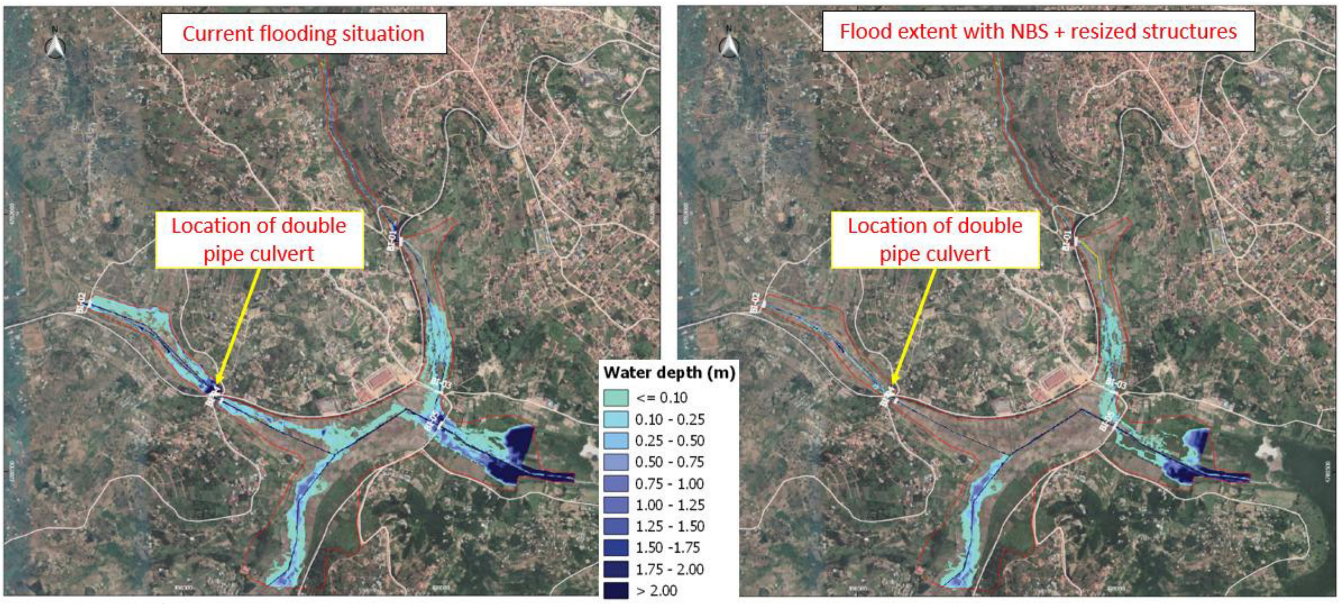


***Figure 43**– Comparison of flood extents between the current situation and after application of NBS + resized structures (T100) in Bishenyi*

Rwabayanga

Rwabayanga follows a pattern similar to that of Bishenyi whereby reduction to absolute zero flooding in depends on the redesign of the irrigation channels. The net reduction of the flooded area is an insignificant 1 % whereas the reduction of flood depth is 16 %. Results present a strong case to review the existing irrigation system in Rwabayanga. The channels need to be redesigned to convey flow downstream of the proposed detention basins without overflowing.

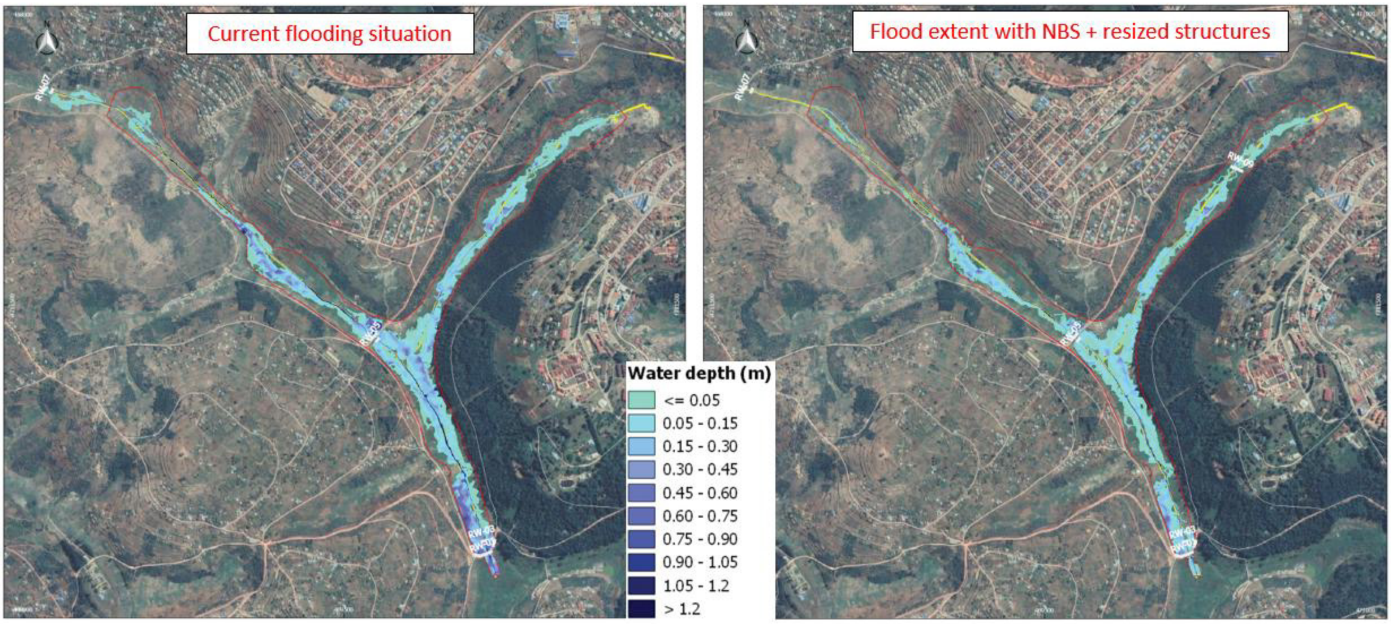


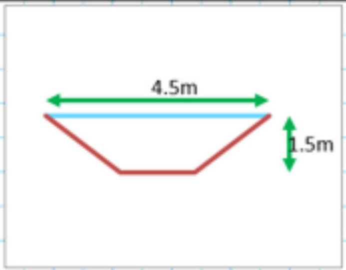
***Figure 44** – Comparison of flood extents between the current situation and after application of NBS + resized structures (T100) in Rwabayanga*

APPENDICES

Appendix 1 - Manning formula calculation for swales

Project:	Design of Rwandex Magerwa swale **T100**		
Calculation:	Manning Formula - Flow in Open Channel		
Sheet Number:	1	**Date:**	18/08/2021

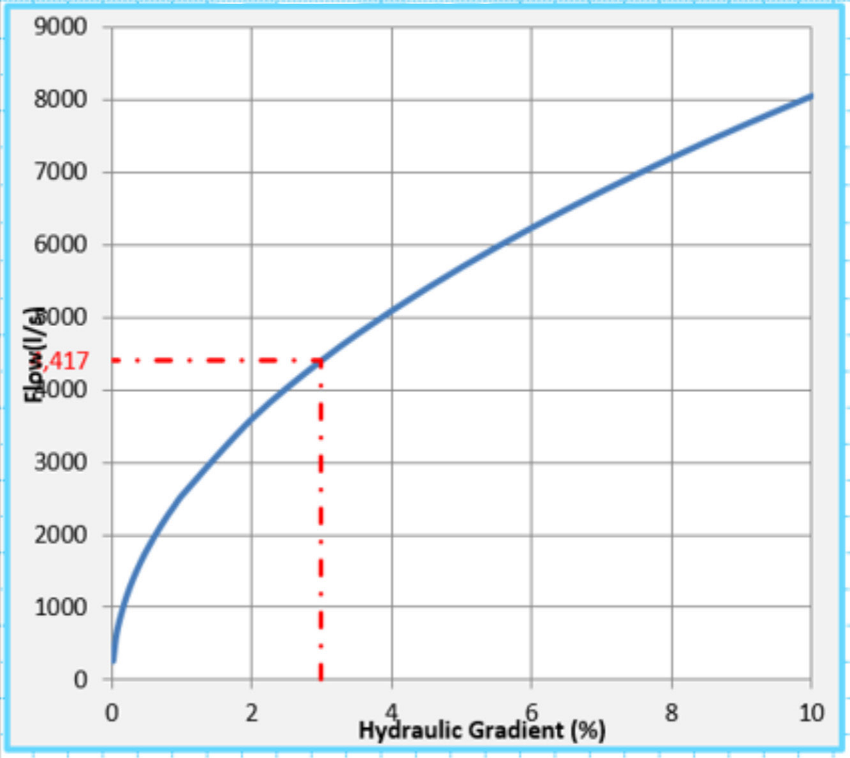
Shape of Channel	Trapezoidal		
Dimensions			
Width *(W)*	1.5	m	
Depth *(D)*	1.5	m	
Side Slopes (G)	100	%	= 1.00 m/m or 1 in 1
Hydraulic Gradient (*S*)	3	%	= 0.03 m/m or 1 in 33
Roughness Coefficient (*n*)	0.15		



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

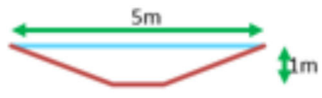
Results

Velocity *(v)*	**0.98**	m/s	
Flow *(Q)*	**4,417**	l/s	= 4.4 m³/s



Project:	Bishenyi swale No.1 T25		
Calculation:	Manning Formula - Flow in Open Channel		
Sheet Number:	1	**Date:**	18/08/2021

Shape of Channel	Trapezoidal



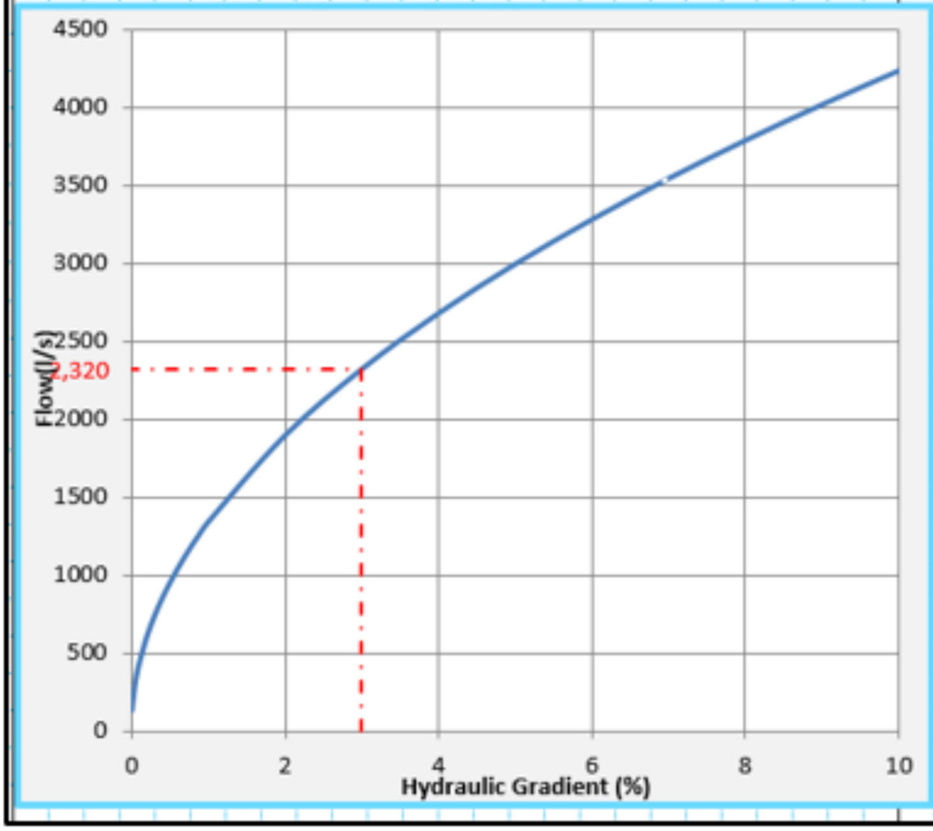
Dimensions			
Width *(W)*	1	m	
Depth *(D)*	1	m	
Side Slopes (G)	50	%	= 0.50 m/m or 1 in 2

Hydraulic Gradient (*S*)	3	%	= 0.03 m/m or 1 in 33
Roughness Coefficient (*n*)	0.15		

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

Results

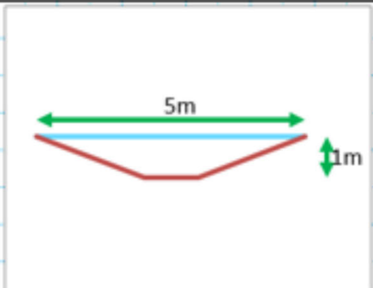
Velocity *(v)*	**0.77**	m/s	
Flow *(Q)*	**2,320**	l/s	= 2.3 m³/s



Project:	Bishenyi swale No.2 T25		
Calculation:	Manning Formula - Flow in Open Channel		
Sheet Number:	1	**Date:**	18/08/2021

Shape of Channel	Trapezoidal

Dimensions		
Width *(W)*	1	m
Depth *(D)*	1	m
Side Slopes (G)	50	%



= 0.50 m/m
or 1 in 2

Hydraulic Gradient (*S*)	3	%
Roughness Coefficient (*n*)	0.15	

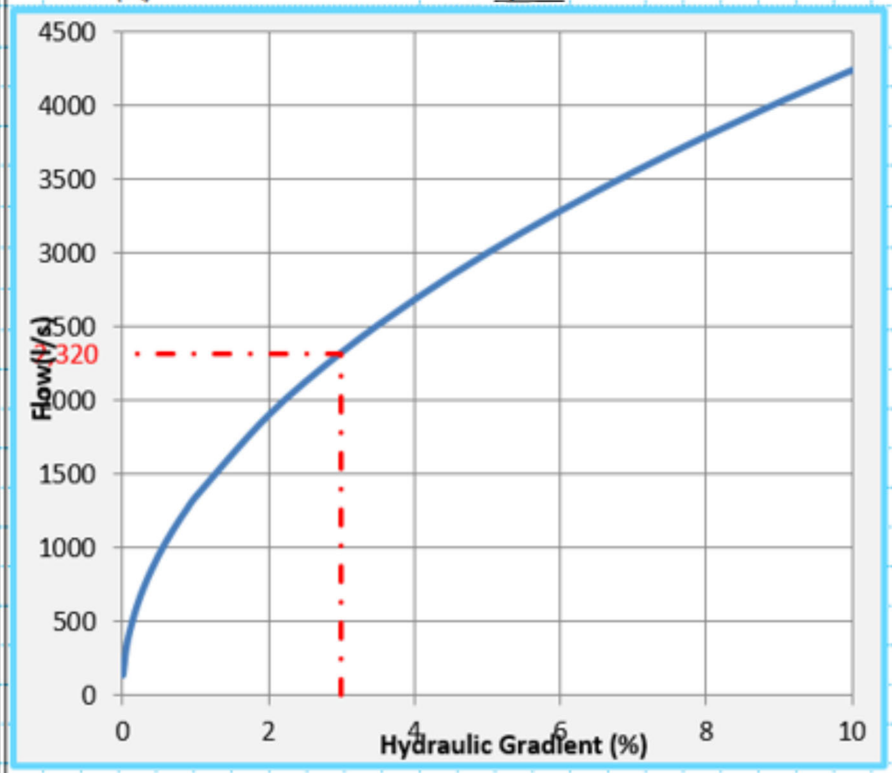
= 0.03 m/m
or 1 in 33

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

Results

Velocity *(v)*	**0.77**	m/s
Flow *(Q)*	**2,320**	l/s

= 2.3 m³/s



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Project:	Gihundwe swale east T25		
Calculation:	Manning Formula - Flow in Open Channel		
Sheet Number:	1	**Date:**	18/08/2021

Shape of Channel	Trapezoidal

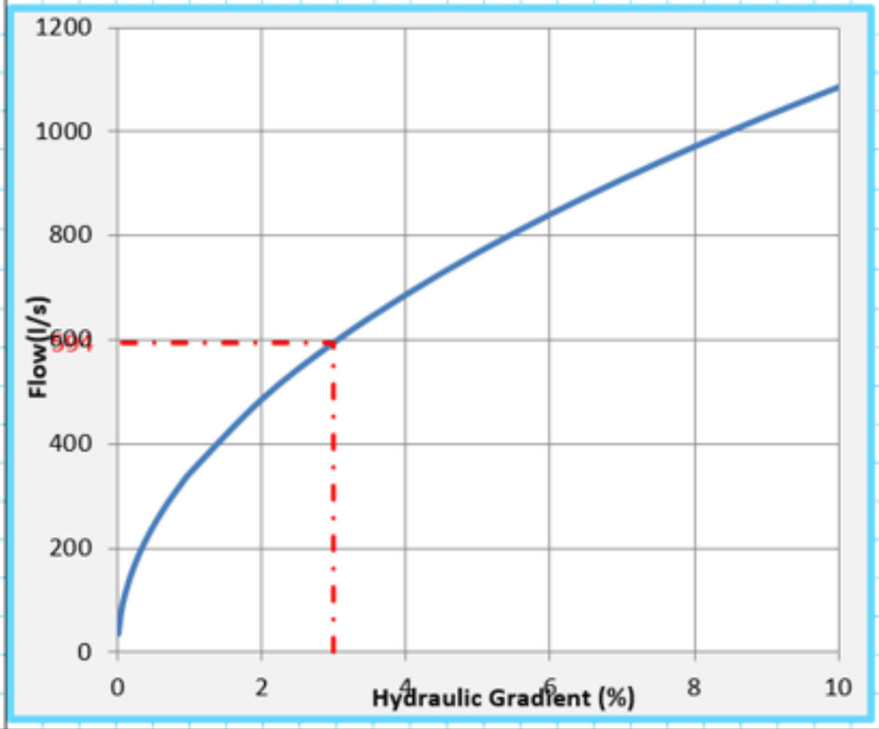
Dimensions			
Width *(W)*	0.6	m	
Depth *(D)*	0.6	m	
Side Slopes (G)	50	%	= 0.50 m/m or 1 in 2

Hydraulic Gradient (*S*)	3	%	= 0.03 m/m or 1 in 33
Roughness Coefficient (*n*)	0.15		

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

Results

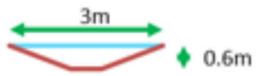
Velocity *(v)*	0.55	m/s	
Flow *(Q)*	594	l/s	= 0.6 m³/s



Project:	Gihundwe swale west T25		
Calculation:	Manning Formula - Flow in Open Channel		
Sheet Number:	1	**Date:**	18/08/2021

Shape of Channel	Trapezoidal

Dimensions		
Width *(W)*	0.6	m
Depth *(D)*	0.6	m
Side Slopes (G)	50	%



= 0.50 m/m
or 1 in 2

Hydraulic Gradient (*S*)	3	%
Roughness Coefficient (*n*)	0.15	

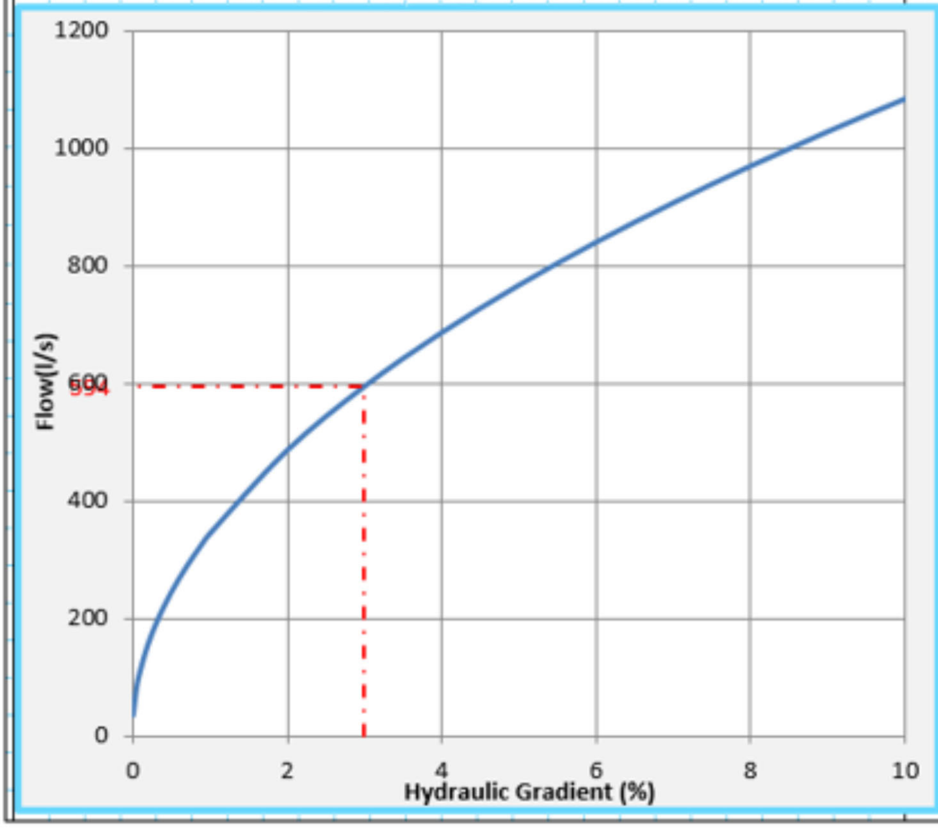
= 0.03 m/m
or 1 in 33

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

Results

Velocity *(v)*	**0.55**	m/s
Flow *(Q)*	**594**	l/s

= 0.6 m³/s



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