# SCOPING STUDY ON GREEN ROADS FOR WATER OPPORTUNITIES IN SEBEYA CATCHMENT

## Integrating climate change adaptation and water management in the design, construction and rehabilitation of roads

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# Executive Summary

The Green Roads for Water Initiative started in 2014 in Ethiopia and spread to more than 15 countries to promote the beneficial use of roads as instruments for better water management and climate change adaptation. Learning from international experiences and seeing the potential to benefit from this concept, the International Union for Conservation of Nature (IUCN) and the Rwanda Water Resources Board (RWB) assigned MetaMeta - a social enterprise (https://metameta.nl/) - to undertake a scoping study on the opportunities for Green Roads for Water in Sebeya catchment in Rwanda. Accordingly, the scoping study was undertaken by MetaMeta between February and June 2022. The scoping study consisted of desk review, in-country fieldwork for data collection through road assessments and meetings with key stakeholders, data analysis and report writing.

Sebeya's catchment topographical characteristics, in combination with deforestation, mining exploitation, unsustainable agricultural practices, and some of the heaviest rainfall in Rwanda has resulted in extreme soil erosion and downstream flooding. Population growth in the area and higher need for agricultural use of the land put more pressure on the ongoing challenges. A lot of effort has been made to address the current challenges and reduce landscape degradation in Sebeya catchment. Varius studies have been conducted and natural resource management practices have been tested and implemented at scale. However, what has not been studied is the contribution of roads to landscape degradation and the potential for using roads as instruments for better water management and regreening. Therefore, the objective of this study is to is to assess the current issues on roads and the surrounding of the roads landscape in Sebeya catchment, explore the potential for Green Roads for Water in Sebeya, provide recommendations for Green Roads for Water interventions in Sebeya and prepare a plan for implementing Green Roads for Water on a pilot feeder road.

A wide variety of recommended Green Roads for Water interventions for Sebeya catchment are presented in this study. The recommended interventions are based on three main purposes: (1) maintaining hydrological connectivity across the landscape, (2) reducing land degradation around roads, and (3) ensuring roads' sustainability by reducing reducing/avoiding water related road damage. Since the biophysical conditions limit implementable options, it is suggested to follow a landscape approach and select suitable interventions based on slope, type of rocks, soil and land use & landcover conditions. Factors like permeability, erodibility, saturation limits, soil thickness, slope and road safety need to be considered. Recommended interventions also need to be in harmony with existing policies, strategies and regulatory framework of the country.

Three different feeder roads have been identified for piloting GR4W interventions during road rehabilitation, but this study focuses on one of the proposed pilot roads. The selected pilot road is located in north part of Sebeya, and its length is 12.6 km. The capacity of the drainage system of the selected pilot road has been assessed and recommendations has been made on two sets of measures: (1) measures to protect the road infrastructure by improving the condition of road drainage and (2) Green Roads for Water measures to mainly reduce erosion and flood risk upstream and downstream of the roads and some additional measures to increase water availability for consumptive and productive use. For the implementation of the recommended measures, a multisectoral approach is needed. For this reason, a list of roles and responsibilities of key actors towards the implementation of the recommended measures is presented in this study.

# 1. Introduction

The Green Roads for Water (GR4W) Initiative was started in 2014 in Ethiopia to promote the beneficial use of roads as instruments for better water management, landscape restoration and climate change adaptation. The aim of this initiative is to improve livelihoods and resilience of communities living around roads and reduce negative impacts such as erosion, flooding, sedimentation, and dust while improving the climate resilience of road infrastructure and reduce water-related road damage. GR4W interventions have been successfully taken place in more than 15 countries across the world including Ethiopia, Kenya, Uganda, Malawi, Nepal, Bangladesh, Tajikistan, and Bolivia. Based on experience and learning through pilots, a global guideline Green Roads for Water: Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience" has been drafted and officially published by The World Bank in 2021. Green Roads for Water services include:

- Road water assessments – identifying the best options along selected roads
- Working with engineers and implementers to design better practice
- Developing guidelines appropriate to specific countries and situations
- Training and coaching towards a change in culture and governance for green roads for water
- Developing strategies to optimize the wider socio-economic benefits of road development and road construction

Learning from international experiences and seeing potential to benefit from this initiative, the International Union for Conservation of Nature (IUCN) and the Rwanda Water Resources Board (RWB) assigned MetaMeta Research to undertake a scoping study on the opportunities for Green Roads for Water in Sebeya catchment in Rwanda under the "Embedding Integrated Water Resource Management in Rwanda" (EWMR) Project. The overall objective of this study is to identify techniques that can be applied to create a safe and proper passage, storage and usage of water resources from road-runoff, protect & restore the natural landscape around roads, while improving communities' connectivity and access to markets and services through road rehabilitation in Sebeya catchment.

Accordingly, MetaMeta Research undertook a preparatory desk study and field assessment in Sebeya. The field assessment was carried-out between 8 April and 15 April 2022. Experts from the MetaMeta team, participated in the field assessment alongside experts from IUCN and Rubavu district. In addition to field visits, discussions were held with heads of key institutions both at national and regional level including RWB, Rwanda Transport Development Agency (RTDA) and officials from the district of Rubavu. Discussions were also held with potential beneficiary communities and those affected by water-related hazards.

This report documents the current water-related issues on roads and the surrounding of the roads lansdcape and presents opportunities for greening roads in Sebeya or in otherwords decreasing the negative impact of roads on local hydrology and environment. This report also provides a guideline with various suitable GR4W measures for Sebeya's biopsysical and social charactheristics as well as an implementation plan for GR4W interventions on a pilot road in Sebeya catchment.

### a. Objectives and Scope of the Study

The EWMR Project is implementing Integrated Water Resource Management (IWRM) packages in landscape restoration and human livelihoods improvement activities in Sebeya catchment. The project is funded by the Government of the Netherlands (EKN) and implemented by a consortium led by the RWB with technical support from the IUCN and SNV. Packages under this program include support to rainwater harvesting for domestic use and runoff reduction, landscape restoration initiatives to reduce the negative effects of flooding, livelihoods improvement activities, as well as other supporting measures that contribute to the livelihoods improvements.

This study is part of the EWMR Project and aims at providing an additional support measure to Integrated Water Resources Management and reduce landscape degradation in Sebeya catchment. In Rwanda, as in other parts of the world, roads are a major source of land degradation, local flooding and sedimentation while from another perspective; water is a major cause of damage to roads. In some cases, road construction has limited consideration of management of run-off and the beneficial use of such water. With high rainfall and often-unstable slopes, these challenges are pronounced in Rwanda. Therefore, the scope of this study is to assess the contribution of roads to landscape degradation and the potential of using the roads as instruments for beneficial water management, landscape restoration and water management in Sebeya catchment. One important component of this study is the identification of suitable GR4W measures and recommendations for minimizing the negative impact of roads on the landscape and safeguarding the road infrastructure as well as the development of an implementation plan for applying GR4W measures on a selected pilot road within the Sebeya catchment. In addition to this, this study is aimed to trigger incorporation of the GR4W approach into the Sebeya Catchment Management Plan 2018-2024.

### b. Study Area

Sebeya -Nile divide. Sebeya is a Level 2 catchment and part of the larger Level 1 Lake Kivu catchment. Sebeya catchment has a total surface area of 336.4 km², approximately 1.4 % of the total surface area of Rwanda (26,338 km²) and includes four Districts: Rubavu, Rutsiro, Ngororero and Nyabihu. The main river in the catchment is the Sebeya River, which flows for 48 km, running in a north-westerly direction from its origin in the mountains (2,660 masl) to its outflow into Lake Kivu at the town of Rubavu (1,470 masl) (MoE, 2018).

Sebeya's catchment topographical characteristics (steep, mountainous terrain), in combination with deforestation, mining exploitation, unsustainable agricultural practices, poorly designed road network and some of the heaviest rainfall in Rwanda has resulted in extreme soil erosion and downstream flooding. Population density in the catchment, especially the northern part, which is far in excess of Rwandan national average puts another pressure on the ongoing challenges. Because of the limited economic opportunities in the Sebeya, the majority of the people depend on subsistence farming on steep and eroded soils. Climate exchange is expected to compound the above challenges.

In the context of this study, the contribution of roads to landscape degradation and extensive erosion in Sebeya catchment is being studied. For the assessment of the current condition of road network and its effect on the surrounding of the roads' landscape, road transect surveys were undertaken along all accessible roads within Sebeya catchment.

# 2. Methods of the Study

The methodology followed during the study is based on the scope of the work. The work includes desk review, data collection, data integration and field survey. This chapter also presents the methodology used for assessing the current capacity of road drainage of the pilot road.

## a. Methodology for desk review, data collection, data integration and field survey

Prior to the field visits in the study area, desk review on background information documents, notes, reports and preliminary studies on past and current research and developments in Sebeya Catchment was carried out. A crucial part of the desk review was the collection of secondary data on the road network and the biophysical conditions of the study area from various sources. Relevant secondary data on Rwanda and Sebeya catchment, was collected from online sources and sector offices. High resolution and multispectral images and digital elevation models (DEM) were collected from USGS, ESA and World Imagery. Remotely sensed data were geocoded, corrected, enhanced and interpreted using ERDAS IMAGINE. On-screen digitization was used to extract features from the high-resolution images to minimize possible interpretation errors when using software algorithms. Integration and analysis of generated image information and secondary spatial data were done in a GIS using QGIS and ArcGIS, as required. The high temporal and spatial resolution images were used to update previous thematic information and generate base maps for the field survey.

The field survey was done within and around Sebeya catchment along road stretches selected based on the existence of road-related problems, the potential for GR4W, land use, accessibility, coverage and natural conditions such as geology, soil, hydrological features, and landforms. The southern part of the catchment was not properly covered due to access problem and time shortages. The field survey took place between the 15th and the 19th of April 2020. During the field survey, road assessments along all accessible roads within the Sebeya catchment, interviews with community members along the roads that were assessed as well as meetings with key stakeholders at national and district level were carried out. Further information on each aspect is presented below:

- Road assessments

  The objective of the road assessments was to understand the catchment, validate generated thematic maps, explore the potential for GR4W at the catchment level and identify a pilot road for piloting GR4W interventions. More than 400 ground points were collected during this phase to be used to validate and refine the thematic layers generated above. Observations were also taken on the current condition of roads and their drainage system and the occurrence of water-related road damages, road induced erosion on the surrounding of the roads environment and existing practices/experiences related to GR4W. Two types of road assessments were carried out (Figure 1):

  - Rapid road assessment: Transect drive along 120 kms of tarred highway and 185 kms of district and feeder road within and around Sebeya catchment (Duration: 3 days). The rapid road assessment conducted helped to evaluate hydrological factors, assess road conditions, existing road and land management practices and water-related road problems at catchment level, and identifying a road for piloting GR4W. The approach followed was a landscape approach (both up and downstream of a road) to see the whole natural and anthropogenic processes affecting a given watershed, particularly, in relation to GR4W.

- Detailed road assessment: Transect walk along the feeder road identified for piloting GR4W interventions (Duration: 1 day). The detailed road assessment helped to collect data on the size and current condition of the road drainage structures.

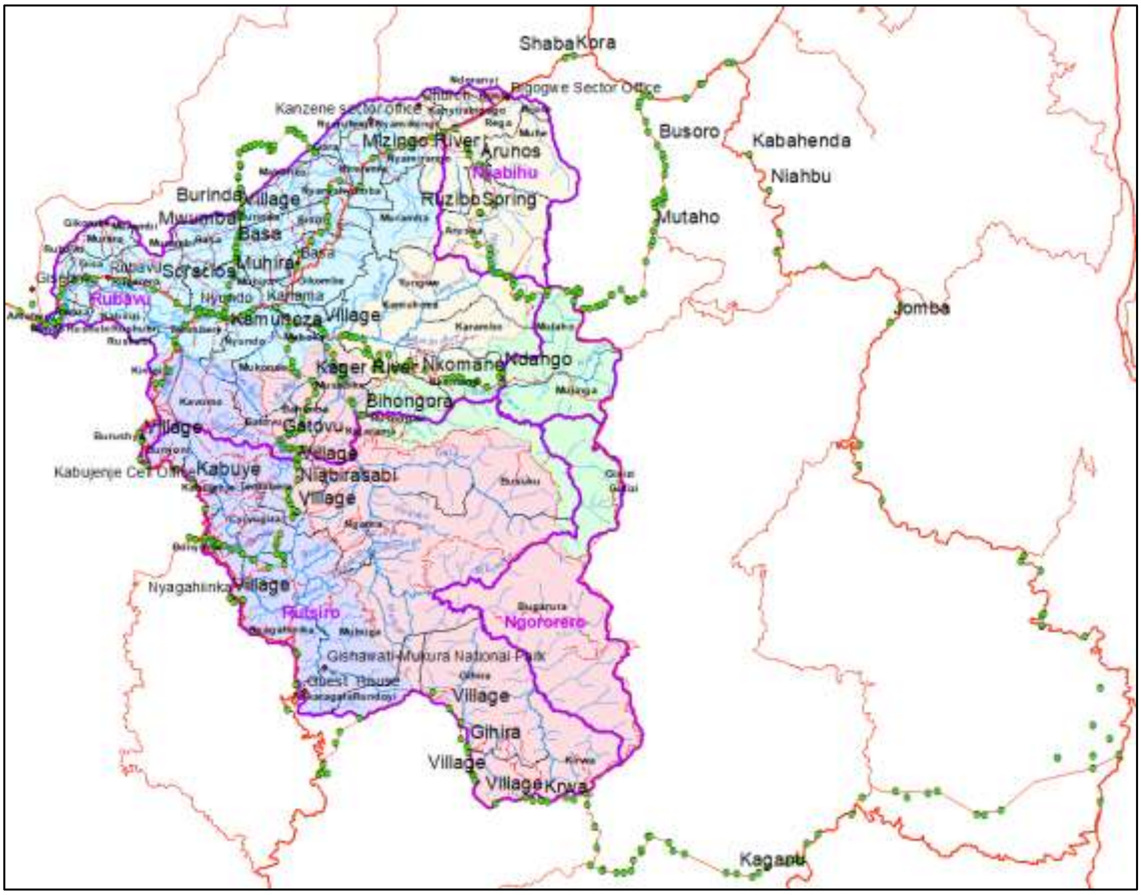



*Figure 1: Transect drive and walk routes within and outside of Sebeya catchment. Green dots on the road indicate the observation points collected during the fieldwork (427 control points were collected).*

- <u>Interviewing community member along the visited roads</u>
  Discussions were made with community members at selected points, on the existing and potential road problems related to water, the potential for GR4W and the types of measures to be recommended. Observations and measurements were taken.

- <u>Meetings with key stakeholders</u>
  Meetings were held at national and district level with key representatives from water, agriculture, environment, and road sectors. The objectives of these meetings were to introduce the scope of this study to key stakeholders, present preliminary findings, request their feedback and inputs, explore opportunities for GR4W as part of their current activities and make linkages with ongoing programs and jointly discuss the next steps and deliverables of the study.

## b. Methodology for assessing the capacity of drainage structures

### i. Introduction

The identification of existing drainage structures and their locations, size was done from the site (Figure 2). From DEM 10x10m resolution, and with help of ArcGIS with arc hydro tools integrated, the drainage lines and their corresponding catchments were generated. The catchment characteristics like catchment area, mean slope, longest flow path were calculated. The runoff discharge for different return periods were calculated by rational method for the area below 5km$^2$ and Soil Conservation System-Curve Number (SCS-CN) method for the catchments area greater than 5km$^2$. The obtained discharges were compared with the hydraulic capacity of existing structure. In addition, some locations were recommended to add drainage structures.

*Figure 2: Taking the dimensions of existing structures on the pilot road*

### ii. Design Standards and References

In line of complying with the specifications provided in the Terms of Reference, the following documents were used:

- Draft Drainage Manual, RTDA (2017)
- Urban Drainage Manual, U.S. Department of Transport (2009)

### iii. Criteria and Guidelines for Hydrological and Hydraulic Studies

The hydrological study was performed within the project area for which the catchment drains its water towards the pilot road. For the hydrological assessment, the topography and land use were used while determining the relationship of rainfall-runoff within the catchment. The runoff estimation method was based on the size of the catchment area. Then the estimated peak runoff was used for the hydraulic assessment. The criteria followed are the catchment size which helped in selecting the method of discharge estimation; land use and land cover, soil texture and slope which helped in runoff coefficient estimation; the longest flow path which helped in computing the time of concentration. The proposed management plans were based on obtained discharges, the conditions of existing structures, the land use and land cover.

The hydraulic study serves to determine the location and capacity of the hydraulic structure to convey or drain the runoff estimated from the hydrological assessment with the aim of avoiding the overtopping of the road or the stagnation of water close to the road embankment and protect the road from erosion and flooding.

### iv. Hydrological study for the pilot road

**I. Catchment area and its parameters**

The catchments for this project were delineated based on the digital elevation model (DEM) of 10x10m resolution by using the Arc Hydro tools integrated into Arc GIS software. Then, the characteristics of the delineated catchments (area, length, slope, longest flow path, max and min elevation) were determined in order to be used in runoff estimation (Table 1). Figure 3 shows the delineated catchments.

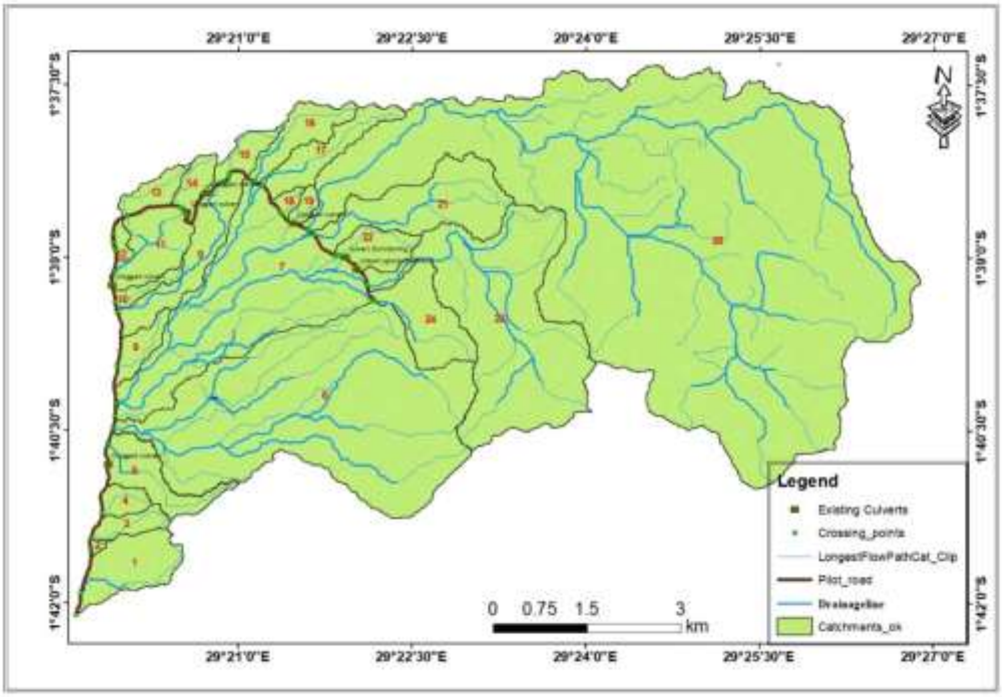



*Figure 3: Delineated catchments, drainage points and existing culverts.*

*Table 1: Geometrical characteristics of delineated catchments*

| Cat. No. | Area km$^2$ | Longest flow path (m) | Max (m) | Min (m) | Cat. avrg slope (%) | Stream-Slope m/m |
|---|---|---|---|---|---|---|
| 1 | 1.28 | 2403.49 | 1880 | 1795 | 8.27 | 0.035 |
| 2 | 0.05 | 433.01 | 1853 | 1809 | 12.96 | 0.102 |
| 3 | 0.4 | 1689.39 | 1885 | 1817 | 6.98 | 0.040 |
| 4 | 0.32 | 1056.43 | 1876 | 1832 | 6.36 | 0.042 |
| 5 | 1.05 | 3071.82 | 1927 | 1852 | 5.37 | 0.024 |
| 6 | 11.29 | 7558.46 | 2828 | 1846 | 27.22 | 0.130 |
| 7 | 5.97 | 5808.14 | 2193 | 1851 | 10.28 | 0.059 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 8 | 0.46 | 1588.86 | 1931 | 1864 | 7.49 | 0.042 |
| 9 | 1.39 | 3605.05 | 2064 | 1880 | 9.55 | 0.051 |
| 10 | 0.23 | 1594.27 | 1924 | 1877 | 8.88 | 0.029 |
| 11 | 1.16 | 1754.69 | 1996 | 1905 | 11.47 | 0.052 |
| 12 | 0.14 | 250.63 | 1944 | 1937 | 6.98 | 0.028 |
| 13 | 0.43 | 913.77 | 2055 | 1965 | 6.82 | 0.098 |
| 14 | 0.39 | 1407.32 | 2115 | 1995 | 21.29 | 0.085 |
| 15 | 0.44 | 1614.27 | 2160 | 2061 | 11.28 | 0.061 |
| 16 | 0.82 | 2517.63 | 2213 | 2103 | 7.39 | 0.044 |
| 17 | 0.97 | 2940.67 | 2241 | 2104 | 7.23 | 0.047 |
| 18 | 0.14 | 669.05 | 2142 | 2112 | 6.24 | 0.045 |
| 19 | 0.17 | 892.61 | 2145 | 2114 | 6.59 | 0.035 |
| 20 | 31.34 | 15794.24 | 2908 | 2113 | 28.09 | 0.050 |
| 21 | 2.37 | 4190.79 | 2326 | 2116 | 10.29 | 0.050 |
| 22 | 0.67 | 1855.15 | 2288 | 2132 | 17.64 | 0.084 |
| 23 | 6.52 | 6172.38 | 2889 | 2176 | 36.15 | 0.116 |
| 24 | 1.43 | 2318.96 | 2773 | 2191 | 38.58 | 0.251 |

## II. Peak discharge estimation

In the context of hydraulic design, hydrological analysis provides estimates of flood magnitudes as a result of precipitation. These estimates consider processes in a watershed that transform precipitation to runoff and that transport water through the system to a project's location. In the design of facilities such as storm drain systems, culverts, and bridges, floods are usually considered in terms of peak runoff or discharge in cubic meters per second.

The method to be used to estimate the design peak flow depends upon the type and quality of data. Design flow is defined as discharge that may be expected from the several combinations of meteorological and hydrologic conditions that are reasonably considered to reflect characteristics of the area involved, excluding extremely rare combinations. For this project, the design flow is determined based on the statistical (frequency) analysis on historic records of rainfall and the associated hydrologic parameters for the concerned streams and catchments. Therefore, the following main steps were followed:

- Determination of the catchment area characteristics
- Determination of the time of concentration
- Design rainfall intensity
- Estimation of runoff

### Time of concentration

Time of concentration ($T_c$) is the time required for an entire watershed to contribute to runoff at the point of interest for hydraulic design. This time is calculated as the time for runoff to flow from the most hydraulically remote point of the drainage area to the point under investigation.

There exist different methods to determine the time of concentration; Kerby-Kirpitch was used for the small catchments while Passini formula was used for the big catchments.

Kerby-Kirpitch Formula is:

$$T_C = t_{ov} + t_{ch} = 1.44(lN)^{0.467}(S)^{0.235} + 0.0195(L)^{0.77}/(S)^{0.385}$$

Where:

l = the overland-flow length, in feet or meters as dictated by K
N = a dimensionless retardance coefficient (Table 2)
S = the dimensionless slope of terrain conveying the overland flow
$t_{ch}$: time of concentration for the channel flow

L: the longest flow path (m)

S: slope (m/m)

*Table 2: Kerby Equation Retardance Coefficient Values* (RTDA, 2014).

| Generalized terrain description | Dimensionless retardance coefficient (N) |
|---|---|
| Pavement | 0.02 |
| Smooth, bare, packed soil | 0.10 |
| Poor grass, cultivated row crops, or moderately rough packed surfaces | 0.20 |
| Pasture, average grass | 0.40 |
| Deciduous forest | 0.60 |
| Dense grass, coniferous forest, or deciduous forest with deep litter | 0.80 |

The value of N was taken the above table (Table 2).

Time of concentration by Passini formula:

$$T_c = 0.14 \times (A \times L)^{1/3} \times S^{-0.5}$$

Where Tc: Time of concentration (min)
A: watershed drainage area (ha)
L: length of flow (m)
S: Slope of flow (m/m)

**Rational Method**

The Rational Method can be adopted for estimating peak discharges for small drainage areas up to about 100 hectares (Rwanda Water Resources Board, 2017). This method determines the flow of water in a channel, q, based on the equation below:

$$Q = KCiA$$

Where Q: peak discharge for the return period in $m^3/s$

C: Runoff coefficient

i: Rainfall intensity in mm/hr depending on the time of concentration ($t_c$) and return period (T)

A: Catchment area in km²

K: conversion factor (0.28)

Design flood estimation for larger catchments up to 10 $km^2$ can be considered using modified Rational Methods, using the areal reduction factor. The effective area of the catchment is reduced by multiplying by the areal reduction factor (ARF) given by the following equation:

$$ARF = 1 - 0.04 \times t^{-\frac{1}{3}} \times A^{\frac{1}{2}}$$

Where:

t = storm duration in hours

A = catchment area in km2

When catchment areas exceed 10 $km^2$ up to 200 $km^2$, the preferred method for estimating design floods should be the utilization of the IDF curves (Annex 4). within the frame work prescribed by the East African Flood Model or the Generalized Flood Tropical Model (Rwanda Water Resources Board, 2017).

**Runoff coefficients**

Watershed runoff coefficients depend upon the land use, soil type and slope of the watershed. The runoff coefficients are needed to calculate storm water runoff rate using the Rational. Typical values of rational runoff coefficients for urban areas (RTDA, 2014) are presented in the tables below (Table 3 and Table 4).

*Table 3: Typical values of rational runoff coefficients for urban areas (RTDA, 2014).*

| Land use | Condition | Range of $C$ values |
|---|---|---|
| Lawns | sandy soil, flat<2% | 0.05-0.10 |
| | sandy soil, steep>7% | 0.15-0.20 |
| | Heavy soil, flat<2% | 0.13-0.17 |
| | Heavy soil, steep>7% | 0.25-0.35 |
| Residential | single family areas | 0.30-0.50 |
| | Apartment dwelling areas | 0.50-0.70 |
| Industrial | Light areas | 0.50-0.80 |
| | Heavy areas | 0.60-0.90 |
| Business | Downtown areas | 0.70-0.95 |
| | Neighborhood areas | 0.50-0.70 |
| Streets | Asphaltic | 0.70-0.95 |
| | Concrete | 0.80-0.95 |
| | Bricks | 0.70-0.85 |
| Roofs | | 0.75-0.95 |

*Table 4: Typical values of rational runoff coefficients for rural areas (RTDA, 2014).*

| Factor | | Component | Mean Annual Precipitation (mm) <300 | 300- 600 | >600 |
|---|---|---|---|---|---|
| $C_s$ | average slope of hillsides in catchment | 3.5% flat | 0.01 | 0.02 | 0.03 |
| | | 3.5%-11% soft to moderate | 0.04 | 0.06 | 0.08 |
| | | 11%-35% steep | 0.09 | 0.12 | 0.16 |
| | | >35% very steep | 0.18 | 0.22 | 0.26 |
| $C_k$ | Permeability of soil | very permeable | 0.02 | 0.03 | 0.04 |
| | | permeable | 0.04 | 0.06 | 0.08 |
| | | semi-permeable | 0.08 | 0.12 | 0.16 |
| | | impermeable | 0.15 | 0.21 | 0.26 |
| $C_v$ | Vegetation | Dense forest or very loose deposits | 0.02 | 0.03 | 0.04 |
| | | Cultivated land or thin forest | 0.04 | 0.07 | 0.11 |
| | | Grassland | 0.13 | 0.17 | 0.21 |
| | | bare rock | 0.24 | 0.26 | 0.28 |

**Note:**

1. For contour cultivated lands: $C = 0.80 \times (C_s + C_k + C_v)$
2. 100% dense wood : flat<3.5% $C = 0.60 \times (C_s + C_k + C_v)$ steep>11% $C = 0.80 \times (C_s + C_k + C_v)$
3. For lakes, swamps and dams $C = 1.00 \times (C_s + C_k + C_v)$

The overall runoff coefficient was estimated as follows:

$$C = 0.80 \times (C_s + C_k + C_v)$$

**Rainfall intensity**

Rainfall intensity ($i_T$): Rainfall intensity is the intensity of rainfall in mm per hour for a duration equal to the time of concentration. The total storm rainfall depth at a point, for a given rainfall duration and average recurrence interval, is a function of the local climate. Rainfall depths can be further processed and converted into rainfall intensities (intensity = depth/duration), which are then presented in the form of "Intensity-Duration-Frequency" (IDF) curves. The rainfall intensity was derived from the Montana Formula:

The Montana-type IDF-curve for precipitation was used.

$$i_T(t) = \frac{a}{t^b}$$

where t is the time of concentration and T is the return period of the event. The nominator a(T) is independent of the aggregation time so that the family of curves in T are parallel.

The constants a and b are Montana coefficient and were taken from the table below (Table 5) as they were computed by (Wagesho & Claire, 2016) in their publication of Analysis of Rainfall Intensity-Duration-Frequency Relationship for Rwanda. Regionalized IDF curves corresponding to 5 regions in Rwanda (Figure 35 in Annex 4) have been derived based on a total of data from 26 rainfall stations.

*Table 5: Rainfall data for various return periods in Sebeya Catchment as per* Wagesho & Claire (2016).

| | T=2 years | T=10 years | T=25 years | T=50 years | T=100 years | T=1000 years |
|---|---|---|---|---|---|---|
| **Maximum daily rainfall (mm) (from Gumbel distribution)** | 50 | 75 | 80 | 90 | 100 | 130 |
| **Coefficient b for Montana's formula** | 0.81 | 0.81 | 0.82 | 0.82 | 0.83 | 0.83[1] |
| **Coefficient a for Montana's formula** | 13.5 | 17.6 | 21.7 | 25.7 | 29.8 | 43.5 |

### v. Assessment of hydraulic capacity

This section aims at assessing the hydraulic capacity of the existing structures regarding the design peak flow and design an adequate storm water drainage system or adequate waterway which has the hydraulic characteristics to accommodate the maximum expected flow rate (design flow) of storm water for a given watershed or a portion/s thereof.

**Hydraulic Design of Drainage Structures**

Adequate storm water drainage system or adequate waterway is a system or a waterway which has the hydraulic characteristics to accommodate the maximum expected flow (design flow) of storm water for a given watershed or a portion/s thereof.

The adequate system:

1. should be designed to account for both off-site and on-site storm water, including storm water coming into a given tract of land from upstream;
2. should discharge the flow in to the natural drainage line or other appropriate outlets; and
3. should carry water to a point where it should flow downstream into a stream channel or water way.

Design flood standards are influenced by many factors including:

- safety
- the level of hydraulic performance required
- environmental impact
- construction and operation costs
- maintenance requirements
- serviceability and
- legal and statutory requirements.

#### I. Calculation of hydraulic parameters

The capacity of release of the existing and thrown hydraulic structures is verified by the formula of Manning-Strickler, expressed in the following way:

$$Q = K * A_w * R_h^{2/3} * S^{0.5}$$

Where Q: Discharge (m3/s),

K: roughness Coefficient (K=1/n, and n=0.02), the existing ditches are in masonry,

$A_w$: Wetted area, expressed in ($m^2$),

$P_w$: Wetted perimeter (m),

$R_h$: hydraulic radius = Aw/$P_w$, expressed in (m),

S: Slope of the natural flow, expressed in (m/m).

Therefore, the degree of filling of the hydraulic structure for the project flow should not exceed 0.75 (Norman et al., 2005).

## II. Pipe culverts

The function of a culvert is to convey surface water across a highway, railroad, or other embankment. In addition to the hydraulic function, the culvert must carry construction, highway, railroad, or other traffic and earth loads. Therefore, culvert design involves both hydraulic and structural design considerations. Culverts are available in a variety of sizes, shapes, and materials. These factors, along with several others, affect their capacity and overall performance. Sizes and shapes may vary from small circular pipes to extremely large arch sections or box culverts that are sometimes used in place of bridges.

**Design aspects**

- Minimum pipe diameter: Since small diameter pipes are often plugged by sediments and debris, a minimum pipe diameter should allow the easy operation and maintenance.
- Minimum slope: To minimize sediment deposition in the culvert, the culvert slope must be sufficient to maintain a minimum velocity of 0.9m/s during the average annual flow event (Norman et al., 2005). If the minimum velocity is not obtained based on the design slope and average annual flow event, the pipe diameter may be decreased, the slope steepened, a smoother pipe used, or a combination of these employed to increase velocity.

# 3. General Biophysical Characteristics of Sebeya

## a. General

Bounded between 1⁰52’13.6’’ to 1°37’ 19.2’’N Latitude and 29°15’45’’ to 29°28’10.7’’ E Longitude, Sebeya Catchment is the northern part of the Congo-Kivu catchment, which is part one of the two major basins, and one of the nine hydrological catchments of Rwanda (Figure 4). The catchment consists of four main rivers, namely: Sebeya, Pfunda, Karimbo and Bihongoro; and numerous feeder streams with a dense network of watercourses. It has a total area of 363.4 km², a perimeter of 105 km and an altitudinal range of 1,461 to 3,009 masl. The general biophysical characteristic of the catchment is given below.

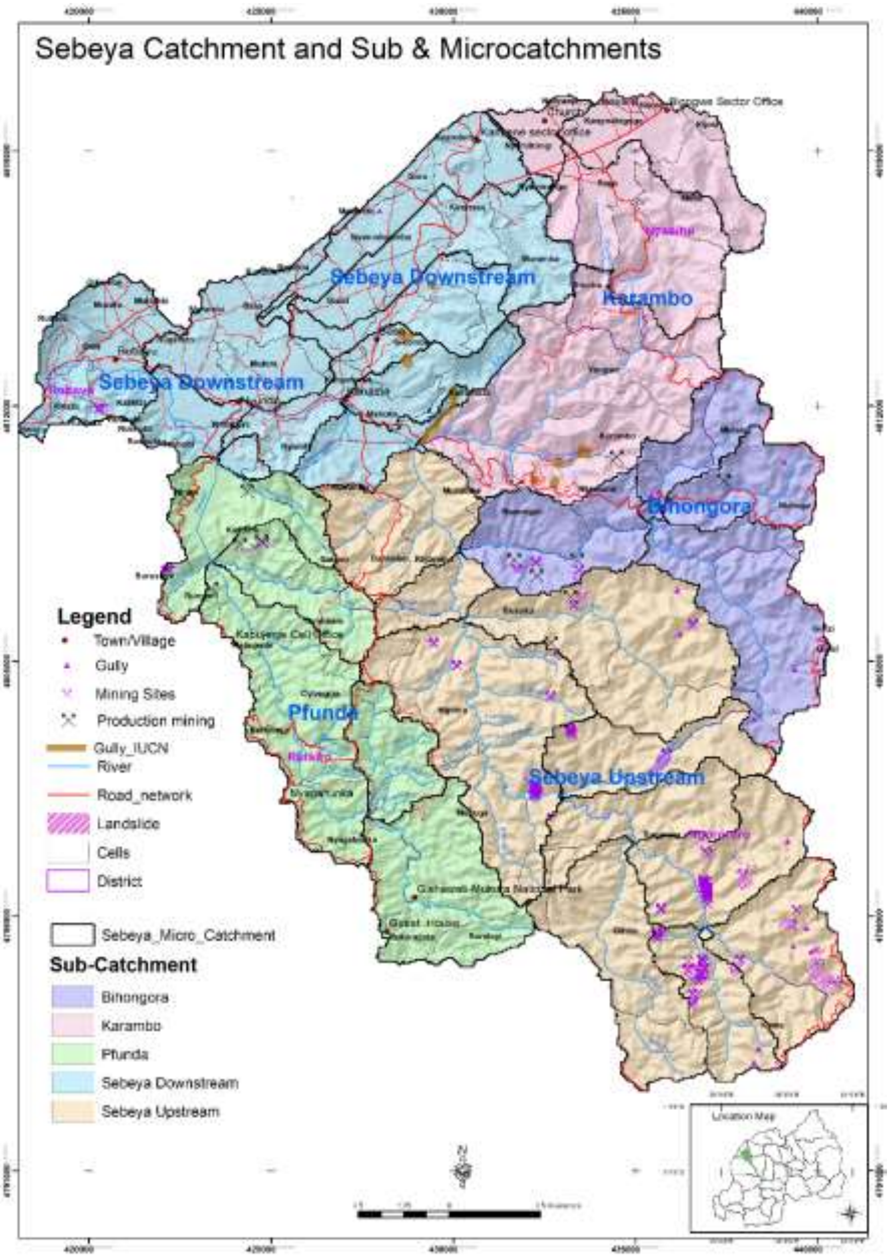



*Figure 4: Location Map of Sebeya Catchment and Sub-Catchment.*

## b. Geology and Structures

Previous studies on natural resources management and land restoration program give little emphasis to the geology of the catchment. However, geology and related processes are among the most determining factor in such catchments, with very rugged terrain and complex geological settings, like Sebeya. The bed-rock geology over which the roads are built, and their settings are the basis to choose appropriate GR4W measures. Geological map of the Sebeya Catchment, which was updated and prepared from the 1:250000 scale, Rwanda Carte Lithologique Du Rwanda (Institut Geographique de Belgique, 1981) shows three major rock units to exist in the Catchment (Figure 5). Multispectral Landsat 8 images are used for the update. The Crystalline Basement Rocks are the dominant geological units covering a total area of 28,397 hectares (77% of the catchment). These rocks form the highly dissected part of the catchment. It has a dominantly granitic composition with swarms of pegmatites. The Crystalline Basement rocks are highly weathered foliated and folded (Figure 6).

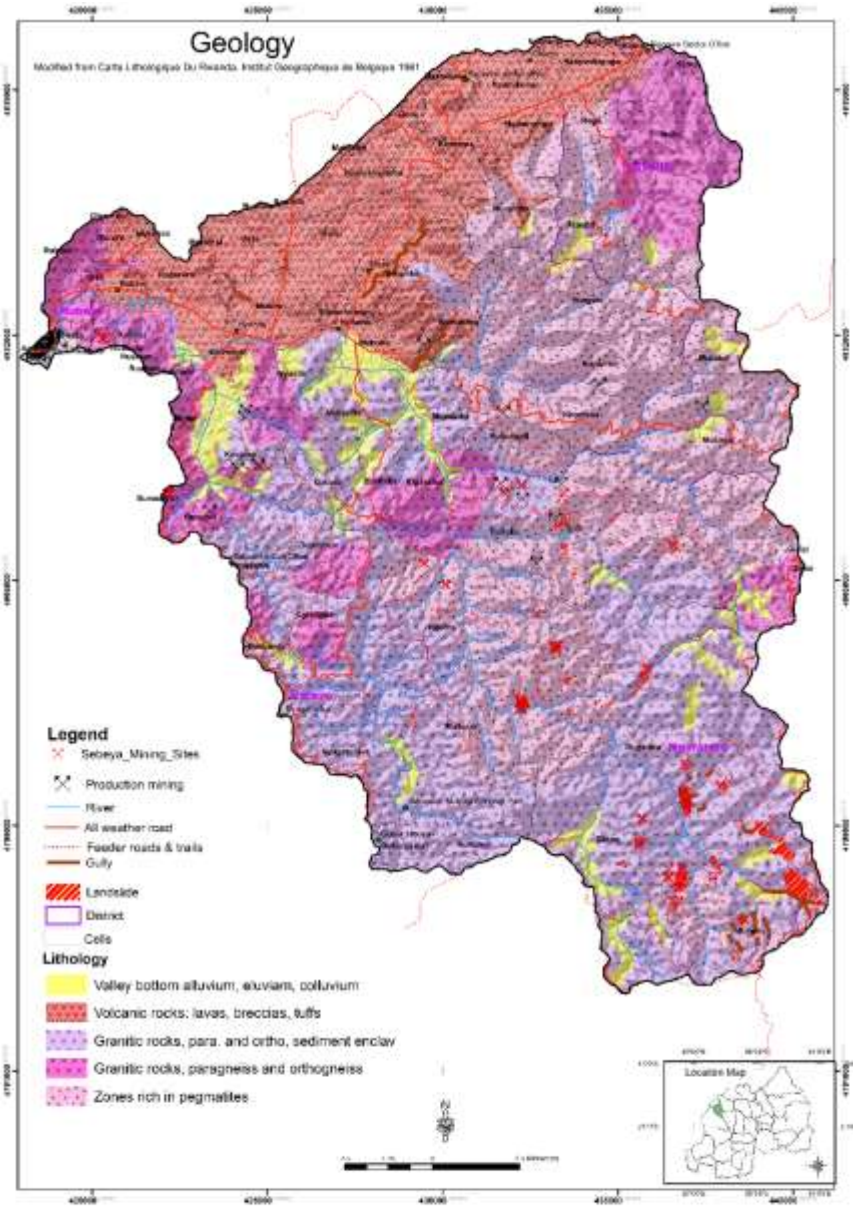



*Figure 5: Geology of Sebeya Catchment. (Updated and modified from Institut Geographique de Belgique, 1981).*

The northern part of Sebeya Catchment is part of the Quaternary volcanic rocks, which are part of the Northern Lavas, cover 17% of the catchment. These rocks cover the northern part of the catchment and form flat and gently sloping landscape. Alluvial sediments covering a total area of 2,182 ha form the valley bottoms between the Crystalline Basement hills in the southern parts and the flood plains in the northwestern part of the catchment.

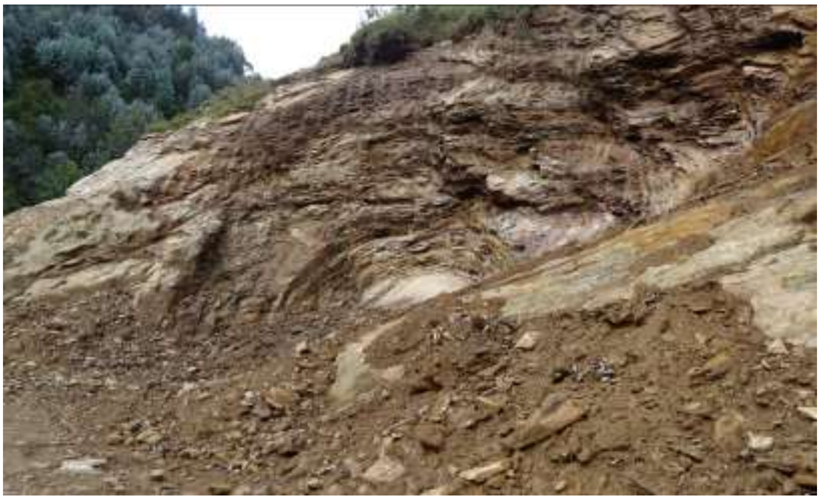


*Figure 6: Highly folded, foliated and weathered gneissic road-side outcrop.*

### c. Hydro-geomorphology

Terrain features such as slope, aspect and elevation of an area are decisive elements for the sustainability of roads and implementation of GR4W measureSoilss. The hydrogeomorphology and topographical characterization of Sebeya catchment were done using high-resolution DEM having 12.5 and 10 m resolution. Slope, aspect and other terrain analysis are made in a GIS system. Watershed delineation and drainage analysis is made using QSWAT model. Similar with most parts of Rwanda, Sebeya catchment is dominantly hilly. Except for the northern parts that have flat and undulating. The northwest and southeastern parts of western Rwanda have flat and undulating morphology, while the southern parts of the catchment are hilly with alternating narrow valleys. Elevation ranges from 1,462 at Kivu-Sebeya confluence to 3,002 masl at the northeastern part (Figure 7, Table 6).

More than 70% of the catchment is steep and extremely steep land which is under intensive use. The flat terrain that can be considered less susuptable to degradation is only 3% (Table 6). The bed rock and soil nature, the landuse practices and the climatic conditions of the catchment have also made the remaining part of the catchment vulnerable to land degradation.

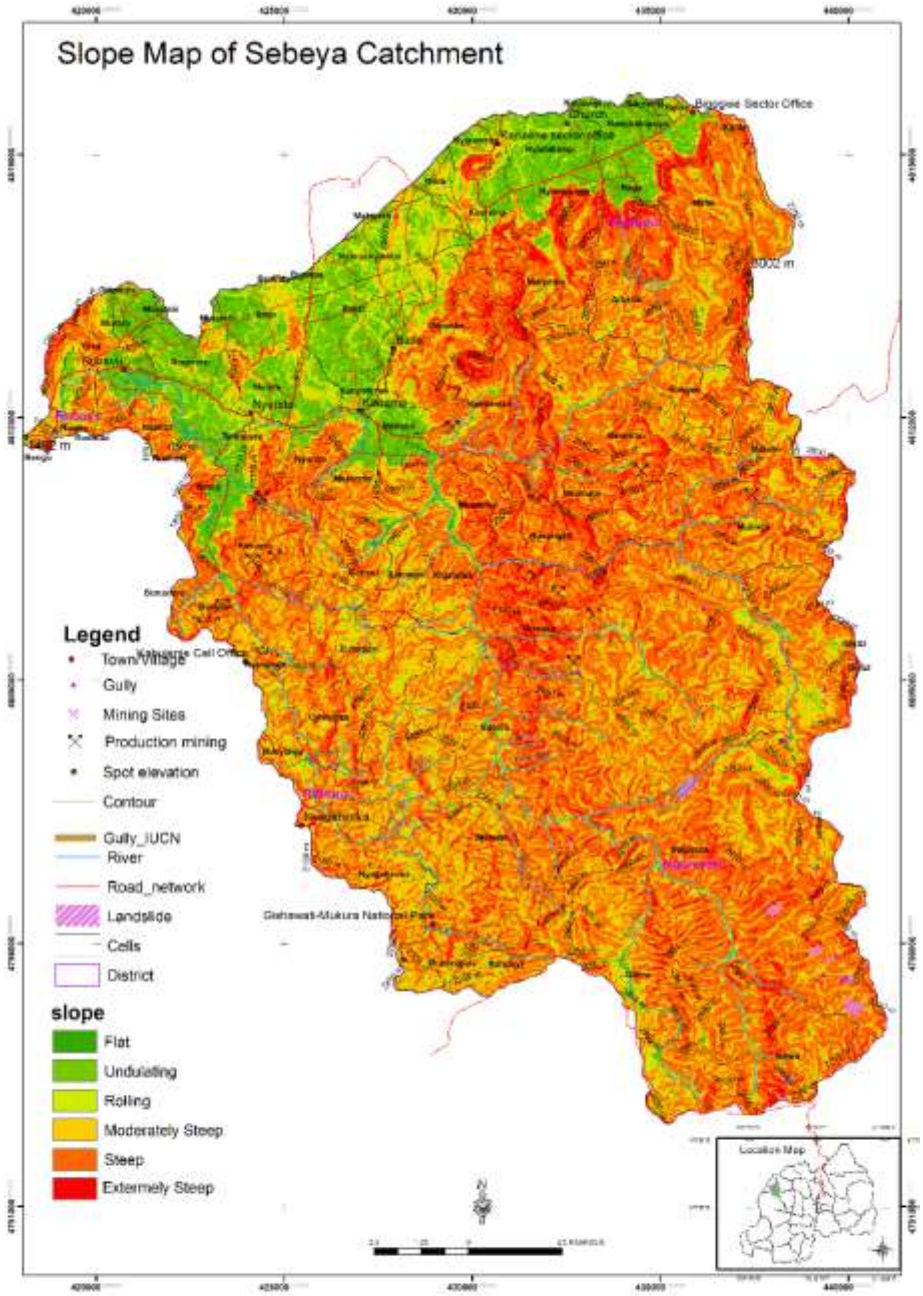



*Figure 7: Slope map of Sebeya Catchment, generated from 12.5 and 10M DEM.*

*Table 6: Slopes in Sebeya Catchment.*

| Slope Class | Slope in percent | Area in percent |
|---|---|---|
| Flat | Less than 2 | 2.9 |
| Undulating | 2 to 8 | 7.6 |
| Rolling | 8 to 15 | 6.6 |
| Moderately steep | 15 to 30 | 12.6 |
| Steep | 30 to 50 | 22.9 |
| Extremely steep | Above 50 | 47.5 |

### d. Soils

Understanding the nature and types of soils and the soil forming processes are among the important factors to consider in any road construction, and associated GR4W implementation. The soil types in Sebeya Catchment are products of the soil forming processes that are governed by the rugged morphology, the parent rock types, and climate elements. The dominant soils, covering 90 % of the catchment are Andosols, Alisols, Cambisols, Acrisols and Luvisols (Figure 8a, Table 7). Soils in the remaining 10 % of the catchment are: Regosols, Ferralsols, Phaeozems, Histosols and Gleysols. Andosols are the main soil type that covers about 33 % of the catchment. It covers most parts of Niyabihu and Rubavu districts. These soils are highly porous and dark-colored soils developed from parent material of volcanic origin. Although the underlying bedrocks are Crystalline Basement rocks these soils occur in northeastern part of the catchment. These soils have excellent water-holding and nutrient capacity.

Alisols covers about 27 % of the catchment, mainly in Rustiro and Ngorprero districts. Alisols are poorly drained soils prone to water erosion. These soils are characterized by the presence of a dense subsurface layer of accumulated clay of mixed mineralogy. The most suitable soil for agriculture, Cambisols, form the third biggest soil group with a total coverage of 14 %. These soils are characterized by the absence of a layer of accumulated clay, humus, soluble salts, or iron and aluminum oxides. Although they cover a significant portion of the catchment, the occurrence of Acrisols is patchy. The age, mineralogy, and extensive leaching of these soils have led to low levels of plant nutrients, excess aluminum, and high erodibility. Acrisols are defined by the presence of a subsurface layer of accumulated kaolinitic clays derived from the underlying granitic basement rocks. Soils in the south and central part the of Rubavu district are Luvisols. These soils have good drainage and form on flat or gently sloping landscapes. Gleysols occur in the flood-affected and waterlogged part of Nyabihi district.

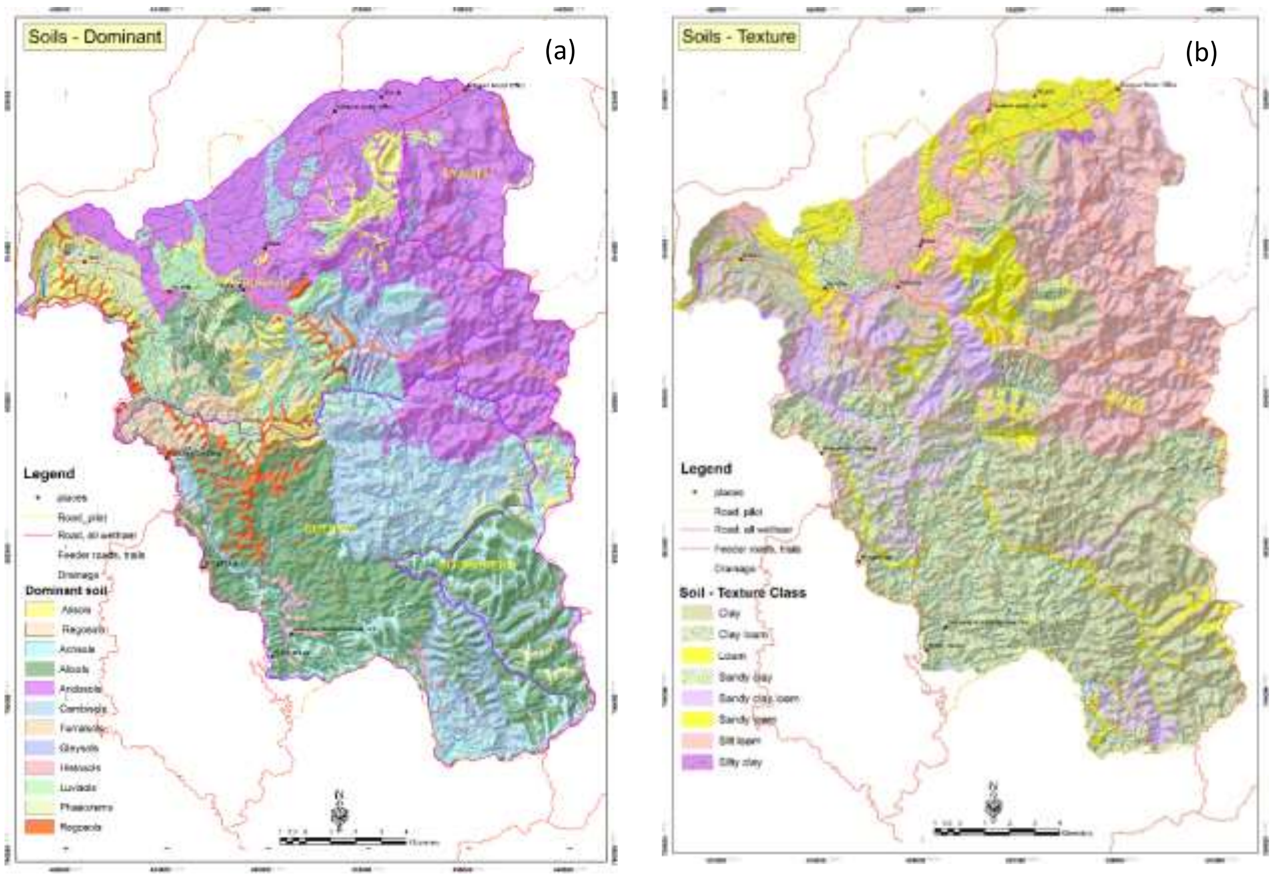



*Figure 8: Soil map of Sebeya Catchment, updated and modified from* Jones et al. (2013). *A. FAO Class. B. Texture Class.*

The SPAW (Soil-Plant-Air-Water) computer model from https://www.ars.usda.gov/ was used to convert the FAO soil group to USDA texture class, to help determine the hydrological properties of the soil types in Sebeya Catchment. The product shows about 29% of the soil cover in Sebeya has silt loam texture. However, the sum of all other classes shows clay and clayey soil texture (Figure 8b, Table 7).

*Table 7: Soils of Sebeya Catchment a. FAO class b. USDA texture class.*

| FAO Soil Group (Dominant Soil) | Area in ha | % |
|---|---|---|
| Regosols | 1246 | 3.4 |
| Phaeozems | 892 | 2.5 |
| Luvisols | 2193 | 6.0 |
| Histosols | 314 | 0.9 |
| Ferralsols | 1073 | 3.0 |
| Gleysols | 93 | 0.3 |
| Alisols | 9739 | 26.8 |
| Andosols | 11887 | 32.7 |
| Cambisols | 5207 | 14.3 |
| Acrisols | 3691 | 10.2 |

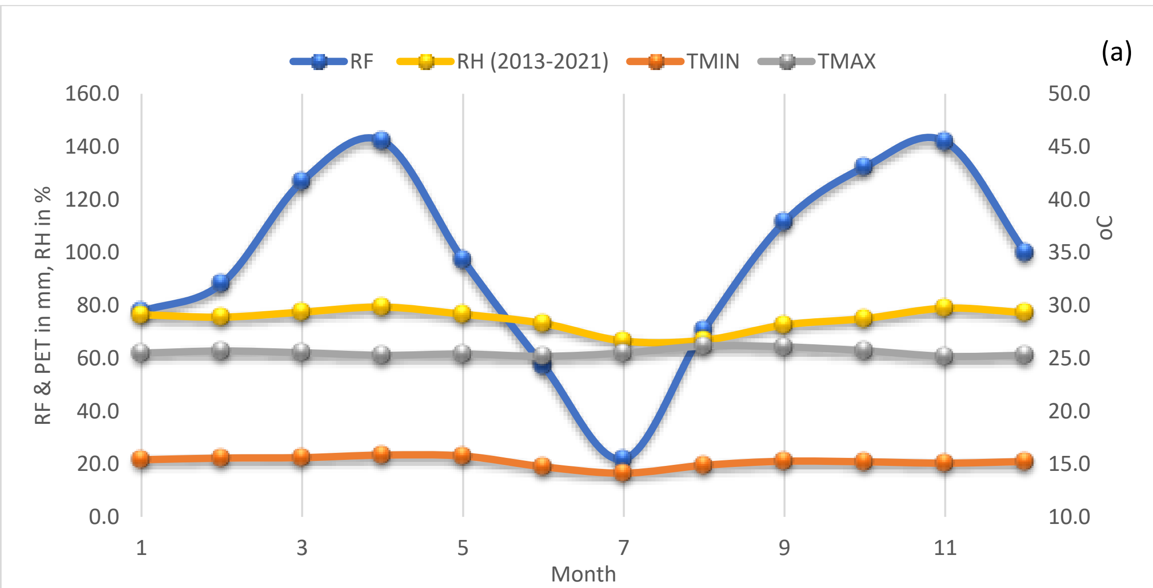
| Texture class | Area in ha | Depth | Depth Range |
|---|---|---|---|
| Clay | 8197 | 125 | 85 - 149 |
| Clay loam | 4718 | 136 | 100 - 155 |
| Loam | 3383 | 111 | 63 - 149 |
| Sandy clay | 5595 | 131 | 120 - 140 |
| Sandy clay loam | 3114 | 147 | 123 -160 |
| Sandy loam | 826 | 125 | 100 - 149 |
| Silt loam | 10397 | 142 | 38 -149 |
| Silty clay | 105 | 180 | 180 |

## e. Climate

Sebeya catchment seems to fall into two categories of Rwanda's four primary climatic regions: eastern plains, central plateau, highlands, and areas around Lake Kivu. Areas closer to Lake Kivu belong to regions around Lake Kivu and the mountainous regions to the highlands. The catchment has a humid tropical climate characterized by its hilly landscape and the Kivu Lake breath. The bimodal-type annual rainfall distribution shows the catchment to have four climactic seasons. The long rainy season is from March to May, followed by three months of relatively dry months. The dry months are followed by a short rainy season from September to November. Existing measured climate data were collected from Rwanda Meteorological Agency and were analyzed using statistical methods to determine the climate conditions of Sebeya Catchment see trends. However, due to the lack of enough observed data, found to be challenging to see the spatial and temporal variabilities of climate elements in Sebeya. Missing data for a considerably long-time (1994 to the end of 2001) makes it difficult to see trends.

However, the absence of a significant difference in Sebeya Catchment from that of the national average can easily be observed from the available data. Annual precipitation is 1,170.2 mm rainfall is experienced throughout the year in Rwanda, with the most significant rainfall occurring from September to May. The mean annual temperature for Rwanda is 19.1℃, with average monthly temperatures ranging between 19.5°C and 18.5℃ (World Bank, 2022). Long-term measured rainfall from Busasamana- Rubavu station shows annual average rainfall of 1168 mm. The mean temperature at Gisenyi station is 20.5°C, with a long-term average maximum and minimum temperatures to be 25.5°C and 15.2°C, respectively (Figure 9a).

The dry months of June and July are known for their windy nature, with windspeed exceeding 2.5m/s. On the other hand, March and April are the calmest months, with average windspeed staying between 1.11 to 1.18m/s. An almost similar trend is followed by relative humidity. The wind months are dry, with the average RH being between 66.5 to 66.8%. However, April and November are the most humid months, with average RH of 79.3 and 78.9%, respectively (Figure 9a). Estimated potential evapotranspiration (PET) shows a healthy trend, with the total average slightly exceeding the average annual rainfall. However, the period from May to August shows deficits (Figure 9b). Further discussion of the climate factors about the need for GR4W is made in Chapter 6.



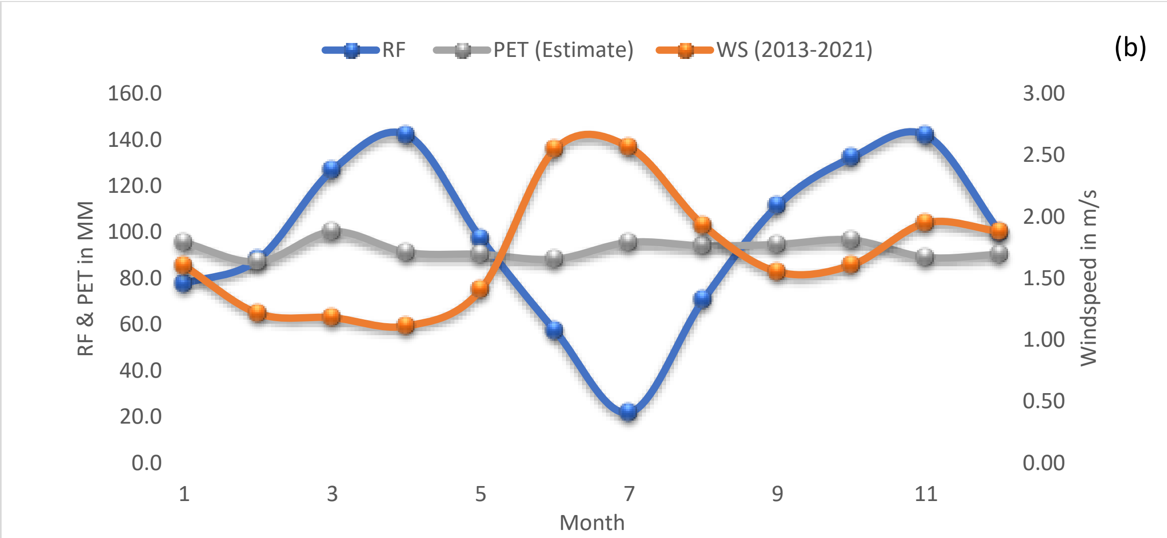



*Figure 9: Climate in Sebeya A. monthly distribution of Rainfall, temperature and relative humidity. B. Relationship between rainfall, PET, and windspeed*

### f. Landcover- Land use

The landcover and land use map of the Sebeya Catchment is updated and modified using previous landcover maps from Rwanda and The Regional Centre for Mapping of Resources for Development (RCMRD) Open Data Site (https://opendata.rcmrd.org/). World Imagery data from Digital Globe with high resolution was used with the 10m resolution ESA's Sentinel to generate the current landcover map of Sebeya (Figure 10). In addition to the nine landcover classes used by RCMRD, large-scale commercial tea plantation areas are added as 10th class, in this work. In addition to the landcover, the road network, which is the focus of this study, was updated and mapped during this work (Figure 10). Landslide and gully mapping was also made, and more than 400 ground control points collected with GPS and captured photos along the transect routes were used to validate maps produced during the desk work phase. Although the focus was to assess and map the land use and road conditions, the field assessment was also used to understand and map landslides and gullies. 76 landslides, as big as 67ha in size and 35 gullies are mapped from satellite images and validated in the field.

A critical review of the land use/landcover helps select the appropriate GR4W measure for effective water and nutrient stress mitigation measures. Sebeya catchment is a densely populated area with intensive agricultural use of the land. The intensively cultivated Rubavu District has more than 1500 inhabitants/km². The low population density southern part is mainly a Silvio-pastoral area with closed grassland. This land use type covers about 29% of the catchment. The dominant land use, covering about 35 % of the land in the catchment, is annual cropland with permanent crop intergrowth over almost every part of the catchment. This land use type is happening over the densely populated areas. Tea and banana plantation, beans, Irish potatoes, maize, soybeans, rice and vegetables are cultivated in the catchment. Commercial tea plantation has already covered about 10% of the land. About 20% of the catchment is covered by dense moderate, and sparse forest. The area occupied by settlements is rising by ~ 5% (Figure 10, Table 8). Water from roads and the landscape, if properly managed, can be used to supplement the stresses of the different uses.

*Table 8: Landcover/ uses in Sebeya Catchment.*

| Landuse/Landcover type | Area in hectar | Area in % |
|---|---|---|
| Annual Cropland | 12821 | 34.6 |
| Closed Grassland | 10723 | 28.9 |
| Shrubland | 16 | 0.0 |
| Dense Forest | 2829 | 7.6 |
| Moderate Forest | 2586 | 7.0 |
| Open Grassland | 90 | 0.2 |
| Perennial Cropland | 601 | 1.6 |
| Settlement | 1664 | 4.5 |
| Sparse Forest | 2293 | 6.2 |
| Tea plantation | 3456 | 9.3 |

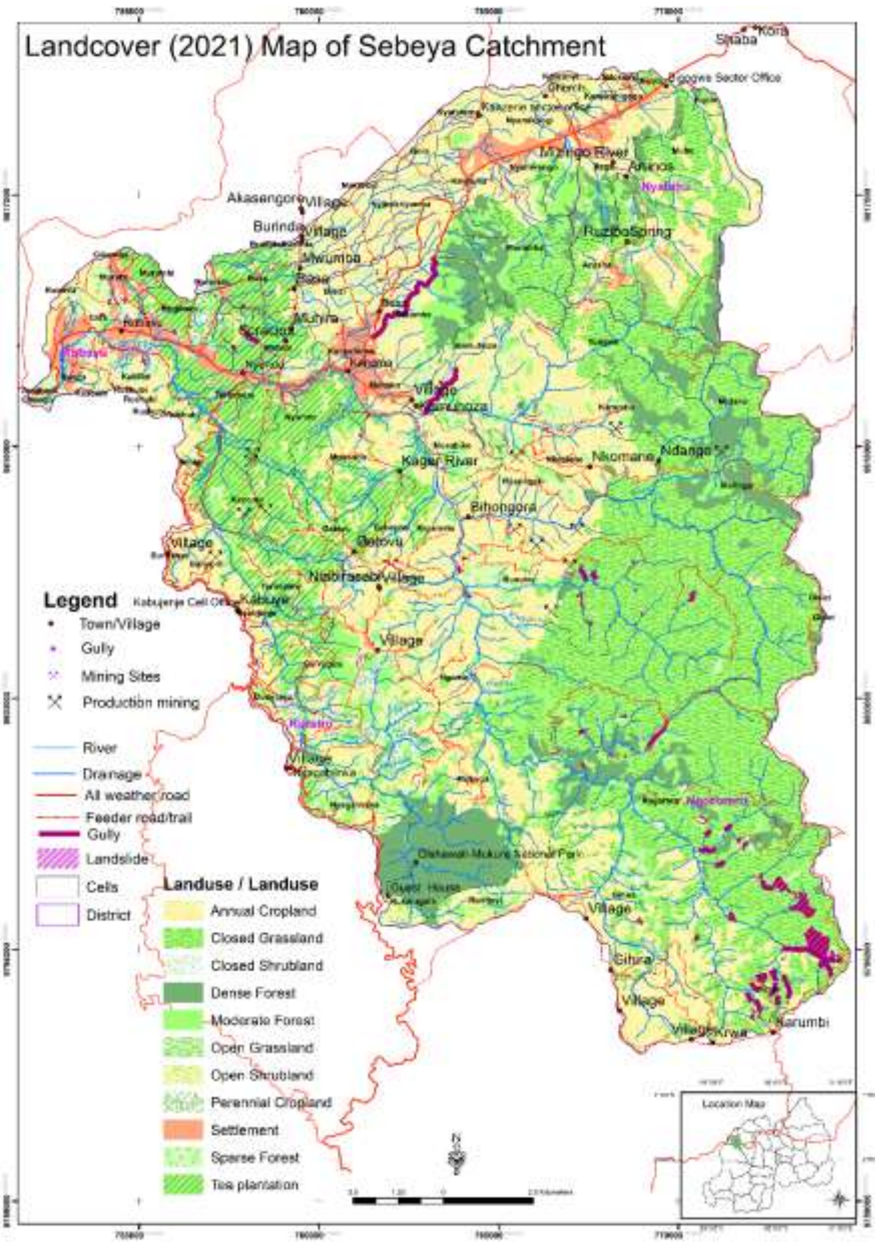



*Figure 10: Landcover /land use in Sebeya Catchment Source: Updated from RCS, 2015.*

# 4. Road Development in Sebeya: Status and Challenges

## a. Road

Complementing the Law No. 55/2011 of 14/12/2011 governing roads in Rwanda, public roads are classified into four classes:

- **National roads**: roads that link Rwanda with neighbouring countries, roads that link Districts or Districts and City of Kigali, roads that link areas of tourist significance and facilities of national or international importance such as airports;
- **District Roads Class 1**: roads that links different sectors' headquarters within the same district;
- **District Roads Class 2**: arterial roads that connect District roads to rural community centres;
- **Specific roads**: roads specifically constructed to connect national or District roads to Kigali City and other urban areas to the centers for private sector's activities such as agricultural productions or tourist sites.

Regardless of the hierarchical classification of roads in Rwanda, roads linking agricultural areas with commercial centers and/or processing plants either paved or unpaved are defined as "***Feeder roads***". The total road network in Rwanda covers 37,898 km, and this number includes paved, non-paved, classified and unclassified roads. The country has a road network density of 1.69 km/km$^2$, one of the densest in Africa. The table below gives the details on the current status of road development for all different types of roads (Table 9).

*Table 9: Current status of road development in Rwanda (Source: Petri (2019))*

| Road Classification | Length (km) |
|---|---|
| National Road paved | 1,390 |
| National Raid unpaved | 1,345 |
| District Road Class 1 paved | 106 |
| District Road Class 1 unpaved | 3,833 |
| District Road Class 2 paved | 132 |
| District Road Class 2 unpaved | 9,631 |
| Unclassified Road paved | 345 |
| Unclassified Road unpaved | 21,116 |
| **Total** | **37,898** |

The Rwanda Transport Development Agency (RTDA) is a public institution under the Ministry of Infrastructure and is in charge of the transport sector including the highway maintenance, feeder roads, gravel roads, and construction projects including bridges, retaining walls, roads, and culverts. RTDA was put in place by organic Law No. 02/2010 of 20/02/2010 establishing its mission, structure and functioning.

According to the results of the annual road condition survey of RTDA completed between September and October 2021, it was indicated that for the national paved road network, the riding quality was maintained at 96.8 % against sector target of 96 %; 47 % against 49 % for unpaved national roads, 86.3 % against 96 % for urban roads and 60.66 % versus 55 % for feeder roads.

The Agency also cumulatively upgraded 1,532.47 km of the unpaved national roads to paved against targeted 1,531 km; rehabilitated paved national roads up to 271.5 km against 321 km (the target was unrealised due to budget shortfalls during the year), maintained 887.4 km (plus 208 km of Kagitumba-Kayonza-Rusumo maintained by the contractor during Defect Liability Period (DLP) of the paved national roads against 1,015 km and 1,067.4 km compared to 1,063 km of the unpaved national roads. Collaboratively with other stakeholders, notably, the City of Kigali and the Local Administrative Entities Development Agency (LODA) record 494.35 km of urban roads constructed in the City of Kigali against 500.35 km and 243.86 km in secondary cities exceeding the 231.91 km projected by the year 2020-2021 as well as rehabilitated and maintained cumulatively 3,264.2 km of feeder roads compared to 3,855 km (RTDA, 2019). About the feeder road development, feeder roads play a key role in transforming the rural populace that depends on rain-fed agriculture.

In the year (2020-2021), 208.1 km were rehabilitated by World Bank/Multi Trust Donor Fund - 52.5 km and Government of Rwanda/Local Administrative Entities Development Agency-155.6km (WB/ MDTF-52.5km and GoR/LODA-155.6km); this brings the overall feeder roads upgraded and rehabilitated to gravel roads to 3,456.36 km against the projection of 3,855km. In fact, 52.5km of feeder roads rehabilitated under the World Bank/MDTF financing and 155.6 km rehabilitated under the GoR/ LODA financing bringing the overall length of feeder roads rehabilitated in the fiscal year to 208.1km. This extends the total length of feeder roads rehabilitated cumulatively to 3,456.36km in the fiscal year to facilitate access to markets and improve rural connectivity. According to RTDA report (2019); About the road upgrading projects, the cumulative length of the unpaved national roads upgraded to paved in the FY 2020-2021 transcended to 1,532.47km from 1,172km (2010).

About the urban roads and private sector development, a total of 494.35km of urban roads in City of Kigali and 243.86km in Secondary cities were constructed. Table 10 summarizes the road conditions of the Rwanda road networks currently.

*Table 10: Annual Road Condition of the road network (Source: RTDA, 2019)*

| Description | Total Length Surveyed (km) | Length in Good Condition (km) |
|---|---|---|
| National Paved Roads | 1,390.50 | 1,346 |
| National Unpaved Roads | 1,122.7 | 527.7 |
| Urban Roads | 606.049 | 523.02 |
| Feeder Roads | 3,456.36 | 2,096 |

As in its role of maintaining transport sector including the highway maintenance, feeder roads, gravel roads, and construction projects including bridges, retaining walls, roads, and culvert; RTDA follows protective, adaptive, and proactive approaches and the design of road, road construction technical standards and specifications including the bridge and geometric design manual, drainage design manual, and pavement design manual to tackle the issue of damaged roads caused by road water and lack of appropriate road water drainage system. However, there is no manual to manage road water, beneficial water management, land protection and climate resilience.

## b. Road Sector Development in Sebeya

### i. Road network

Apart from 2 paved roads, other roads are earthen made of varying quality and vulnerable to be damaged by heavy rainfall, floods, and landslides. The first paved road is located in the Northern part of the catchment between Rubavu and Musanze, while the second one connects Rubavu and Rutsiro Districts through Pfunda Tea Factory. The remaining part of the catchment is served by the unpaved road network leading to difficult accessibility of the hinterland. Although those roads carry a low volume of traffic, they are very important for the local community for selling their livestock and agricultural products. The present connection of roads such as the national paved road, national unpaved road, feeder roads, and District roads in Sebeya catchment are shown on the road network map (Figure 11).

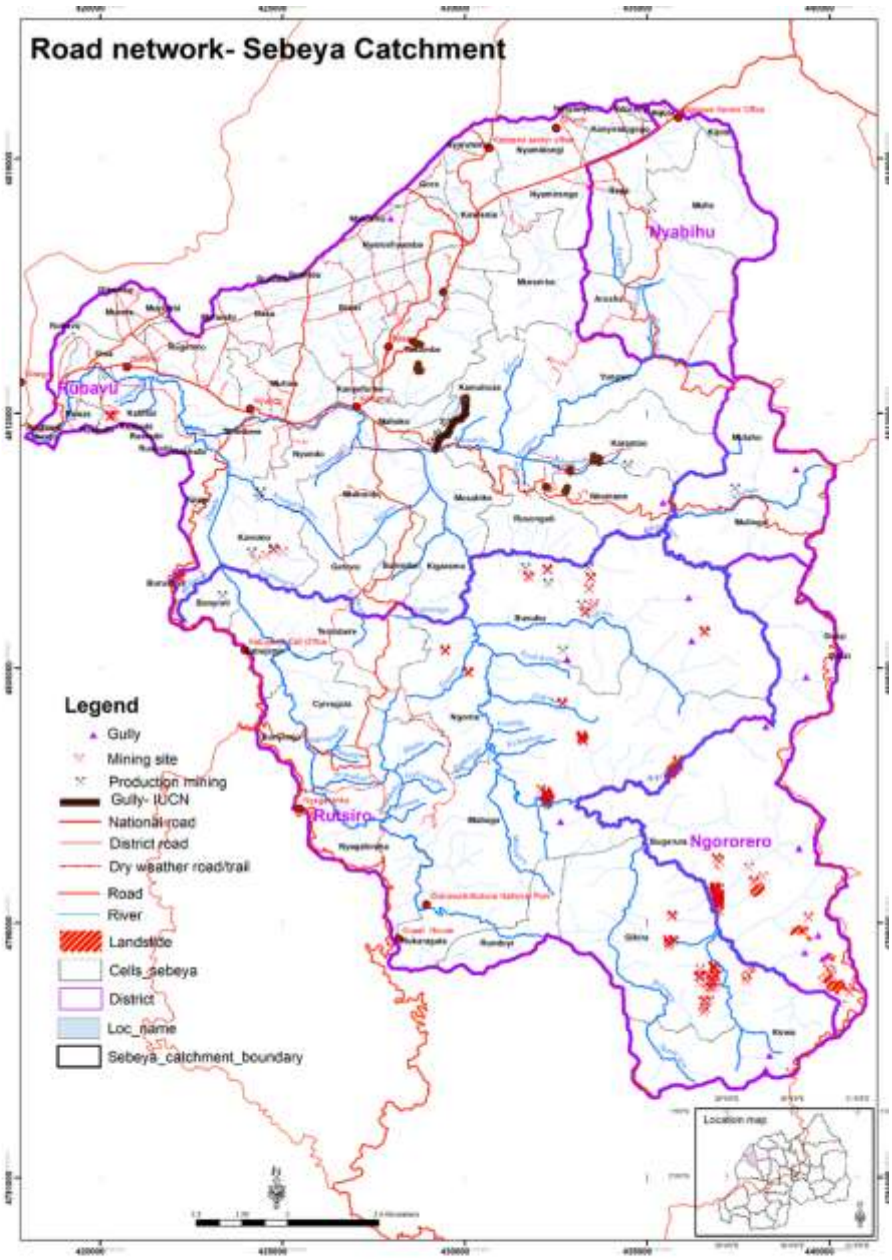



*Figure 11: - Road Network in Sebeya Catchment. Source Updated from RCS, 2015.*

### 4.2.2. Road drainage system

The road drainage system is a mechanism to effectively collect and divert all water that is gathered around the road. If adequately designed, it can help to manage a large part of the runoff from the catchment uphill of the road and avoid waterlogging upstream of the road.

During the assessment survey in Sebeya catchment, varying degrees of water-related road damage have been observed along the roads.  Gully development along roads that are lacking in water guidance structures and running across erosive thick soils, erosion downstream of drifts and culverts (Figure 12), and water-related slope failures are the most dominant forms of road damage.

Other water related problems we find are but not limited to: Culverts are clogged fully or partially (Figure 13), many road sections (segment) do not have the side drain and some available side drains  are not connected to the culverts or any other good location for runoff discharge, water crosses roadway and goes to communities building (Figure 14), the road banks are not protected (Figure 15), and this is probably one of the causes of their failures, no maintenance is done on existing hydraulic structures.

*Figure 12: Erosion downstream of culvert in Sebeya catchment.*

*Figure 13: Culverts partially and fully clogged on feeder roads in Sebeya catchment.*

*Figure 14: Road runoff crosses roadway posing risks to communities' buildings.*

*Figure 15: Road embarkment failure on feeder roads in Sebeya catchment.*

# 5. Water Management Practices in Sebeya and their implication on road and land stability

Water managements practices in Sebeya area are correlated with the agroclimatic nature of the catchment and consist in mitigating the challenges associated with draining excess high rainfall (more than 1400mm /year) on steep slopes in weathered bed rocks together with deep soil texture. Water management practices observed consist mainly in draining the water that is running from the runoff towards the lowland of various rivers in the Catchment and finally towards Lake Kivu. During the field visit we observed many drains, dykes, gabions, bridges, culverts that are constructed in masonry and other natural based solutions inside the catchment especially in line with agricultural development and flood mitigation.

**Water ways or Drains**

Masonry drains were observed that are constructed directly at the outlet of culverts in tarmac roads to divert water from the road into tea plantations downstream (Figure 16). The masonry drains are built on a gentle slope following the contour flow and designed in a way to reduce the runoff velocity and remove the slit before reaching the tea plantation. This was an excellent example of using road drainage for irrigation purposes while protecting the roadside environment from erosion and safeguarding the road from water-related damage.

However, at some other areas, which are often the case in many parts of the catchment, the majority of the culverts observed were draining water from roads without any consideration of the slope, soil and downstream impact. The consequences observed were hence creation of long drains that have been transformed into big ravines or gullies.


*Figure 16: Masonry drains constructed at the culvert outlet to divert road runoff to tea plantations downstream of the road in Sebeya catchment (a) Road runoff collected from tarmac road, (b) Masonry water way constructed at culvert outlet, (c) Tea plantation benefiting of road runoff.*

**Culverts and channels**

Many culverts at the intersection of hills were observed channelling water from the hills towards the downstream areas. Unfortunately, most of the observed culverts were causing excessive erosion at their outlets. Some of the consequences observed were big gullies generated downstream wgich often go with massive landslides (Figure 17). The concentration of flow into a culvert significantly increases the erosive ability of the flowing water at the culvert outlet since the flow has been accelerated. The accelerated flow travels for quite some distance before it can fan out again over a wide area after it has passed through the culvert. As time elapses, erosion or gullying increases, and scour control becomes more difficult and expensive. Culverts need to be designed taking into consideration their downstream impact. The cost of repairing the road due to erosion is often much higher than greening the drain.

*Figure 17: Road runoff causing erosion downstream of the culverts in Sebeya catchment.*

**Dykes, dams and gabion retaining walls**

To attenuate the frequent flood river of Sebeya, RWB has constructed some masonry structures such as dykes, gabions walls and dams around some critical tributaries of the Sebeya river.

A dyke is a long wall or embankment constructed along a riverbank or coastal shoreline to prevent flooding in the land behind the dike. It is typically made of compacted earth and outfitted with flood boxes, gates and pumps to help regulate the water level on the landward side of the dyke. In the case of Sebeya, the dyke serves as a flood mitigation and protection structure on the Sebeya river to store part of the flood volume and have it released later a lower flow rate (Figure 18). The dyke constructed in Sebeya is expected to have an effect on floods generated on Sebeya upstream catchment and floods generated on Karambo catchment.

*Figure 18: Dyke in Sebeya catchment. The construction of this dyke is part of the 'Embedding Integrated Water Resource Management in Rwanda (EWMR)' Project funded by the Embassy of the Kingdom of the Netherlands in Rwanda.*

A dam is a structure built across a stream or river to hold water back and protect from flooding. A dam under construction was observed in Rubavu district, aiming to help curtail severe floods in Western Province by the Sebeya river (Figure 19).

*Figure 19: Dam under construction Sebeya catchment.*

Gabion retaining walls are the ideal solution for heavily eroded river and stream banks. Gabions are wire mesh baskets normally filled with sandstone bluestone or river pebbles. Unlike concrete, gabions will not leach harmful chemicals into the water and will have a longer life span in the aquatic environment. Gabions are also naturally flexible, as they accommodate significant differential settlement and are permeable in their structure. As river sediments become trapped in the spaces between the rocks, vegetation growth is encouraged, further enhancing their stability. Gabion retention walls can be installed relatively quickly and are cost-effective compared to other types of structural walls. Gabion retention walls in Sebeya are mainly constructed along the riverbanks to help control riverbank erosion but also along road banks to protect the road infrastructure.

**Terraces**

Terraces are pretty spread throughout Sebeya Catchment (Figure 20). Terraces are principal water and soil conservation measures for catchment restoration and protection. They consist of ridges and channels constructed across the slope to slow down the runoff velocity, store water in the soil profile (or replenish the groundwater), keep nutrients and soil particles from washing away from the field and prevent erosion.

There are different types of terraces including radical terraces and progressive terraces.

- Progressive terraces are formed by establishing contour bunds with soil or stones in combination with ditches and vegetation as in the Fanyaa Juu. The progressive terraces are formed in time by the natural process of erosion and sedimentation. Contour bunds covered by nipia grass, a more passive and slower option are mostly preferred.
- Radical terraces are constructed on terrain with steeper slopes. Construction of the radical terraces is labor intensive and expensive. Terracing design takes in consideration the soil and subsoil. With a thin arable layer on rocky surface, it is not possible to build terraces. Radical

terraces might have lower initial production due to removed top layer with the organic material and soil microorganisms. The soil layers below are usually hard and not fertile. By removing and storing the top-layer and putting the top-layer back at the end, the production dip can be reduced. Still then it takes 3 seasons to get back to earlier levels. It is therefore recommended to add additional manure and organic material. Due to higher infiltration rate on the flattened terrace, nutrients easily dissolve and infiltrate with the water towards the deeper layers and become out of reach of the plant roots. The high water content due to infiltration of rainwater can increase the risk of unstable terraces and even provoke local landslides. Terraces observed in Sebeya Catchment have significantly contributed to the stability of the slope and infiltration of the rainwater into the soil and reduction of the soil loss, hence to the protection of the road.

*Figure 20: Terraces are quite widespread in Sebeya Catchment. Photo Jean Claude HABIMANA. IUCN Rwanda*

## Grass and indigenous trees

Grass is an excellent choice for erosion control because it covers the soil thoroughly and its fibrous roots spread deep and quickly holding the soil very well. Field observations in the Sebeya catchment showed that grass combined with indigenous trees is remarkably reducing soil erosion and sediment transport rate despite the steep slope and high rainfall intensity (Figure 21). Lack of erosion signs on drains under grasses and indigenous trees indicated the positive effect of grass and indigenous trees, especially in the upland of the Sebeya Catchment in the Gishwati area (Figure 22).

*Figure 21: Grass vegetation at the culvert outlet protects the roadside environment from road-induced erosion.*

*Figure 22: Grass vegetation at the high mountain of Gishwati is used to prevent soil erosion.*

Indigenous trees play an essential role in ecosystem preservation and land and water conservation. Some indigenous trees include Polyscias fulva, Podocarpus falcatus, Maesopsis eminii, Erytrina rubrostipulacea, Mitragyna rubrostipulacea, Ficus sp, among others, are considered natural trees and these were previously found in almost every home in Rwanda. These indigenous tree species have practically disappeared since farmers prefer to plant imported tree species which mature and bring in cash money in less than ten years. During our field visit, we saw that some of those indigenous trees combined with grasses play an effective role in soil and water conservation and contribute to stabilizing the slope (Figure 23). The good news is that Rwanda Water Forestry is encouraging to work with farmers in promoting the use of indigenous trees.

*Figure 23: Indigenous trees planted on high slopes in Sebeya Catchment for runoff reduction and erosion control.*

**Roadside tree planting**

Roadside tree planting can make significant improvements to the quality of roads and the environment and can protect key natural resources. Due to the deep root structure of roadside trees, the soil is more stable, and water is better retained in the soil, avoiding the loss of water to deep percolation. Also, trees slow down the flow rate of runoff water coming from the roads, improving the infiltration of water into the soil. The more stable soils, together with the lower runoff velocity, reduce the intensity of soil erosion. Other advantage of roadside tree planting is that the vegetation traps dust that rises from gravel roads, protecting crops on adjacent agricultural land from degradation. They also protect roadside communities and livestock from health issues. Next to these benefits, roadside tree planting can contribute to climate mitigation by absorbing CO2 from the atmosphere.

During the fieldwork, was observed that trees of eucalyptus, alnus and bambous were planted along the roads in Sebeya catchment to protect the roads and the roadside environment (Figure 24).

*Figure 24: Roadside tree planting with indigenous trees for protecting the roads and the roadside environment.*

# 6. Green Road for Water in Sebeya

## a. The need for Green Roads for Water in Sebeya catchment

The need for GR4W is assessed based on literature review, mapping exercise and discussion with the communities along the transected roads within and around Sebeya catchment. There is little interest in converting road water into a usable commodity, unlike the most common need in other countries where GR4W is introduced. The availability of enough rainfall for agriculture has made the demand for supplementary agricultural water non-existence. A deeper understanding of agronomy and creating a need for supplementary agricultural water in this part of Rwanda require further work.

However, the team has observed inadequate water supply for human consumption. Long waiting to fill a jerrican from roadside springs and floodwater harvesting have been observed in different parts of the rural areas and small settlement areas (Figure 25). This observation was made during the rainy season when both the flood and spring are found, and it is evident that the problem will get more severe during dry seasons.

*Figure 25: Domestic water supply in rural Sebeya Catchment: Community members fetching floodwater and water from road-side spring.*

What the team couldn't come across, is family wells developed in such high potential catchment for hand-dug wells that can supply domestic water requirements. GR4W measures augment such wells and contribute to tackling this problem.

The demand from the communities was to see the water-related road damages to be reduced or avoided, if possible. The focus of the field assessment was also to study the type and extent of these damages and investigate possible reasons; so that appropriate GR4W measures are proposed. From previous studies such as (a) the detailed biophysical and socio-economic baseline assessment for the Sebeya Catchment (Langenberg & Kabano, 2020), (b) the Volcanoes area flood management study by MoE (Water for Growth, 2017), (c) the research by Majoro et al. (2020) on Performance assessment of erosion remediation measures and proposal of the best management practices for erosion control in Sebeya Catchment and (d) the study of Habyarimana (2018) on Extreme rainfall events in Sebeya Catchment, critical issues, opportunities and challenges in Sebeya catchment were highlighted. This work adds to the existing knowledge by bringing GR4W into the planned land restoration programs and sustainable development agendas in the catchment. GR4W shall also be integrated into strategies to meet the targets of Vision 2050.

Sebeya catchment has multiple problems associated with catchment degradation emanating from its dominantly steep landscape, land use conversion, poor agricultural practices, mining and inappropriate road design. Issues related to road water are getting more intensified in recent decades following the construction of new roads. Soil Erosion (Figure 27), overflows that cause flooding in the northern part of the catchment along Sebeya river and sediment transport are among the good indicators of the degradation of the catchment (Figure 26).


*Figure 26: (a) Sediment transport, accumulation and riverbank erosion along Sebeya River. (b) Suspended load of Sebeya River entering Kivu Laker.*

Before this work, 84 km of district road class 1 and 43 km of paved and unpaved road network were mapped. Additional 330 km of feeder road and trails were mapped from satellite images and during the field assessment (Table 11, Figure 27). Except along the low volume roads where the problem is not much critical, very critical issues associated with road-water were seen almost along all visited roads.

*Table 11: Road types and length in Sebeya Catchment*

| Road type | Length in km |
|---|---|
| District Road Class 1 | 84 |
| National Road Unpaved | 17.6 |
| National Road Paved | 25.4 |
| Dry weather road- and trails | 329.7 |

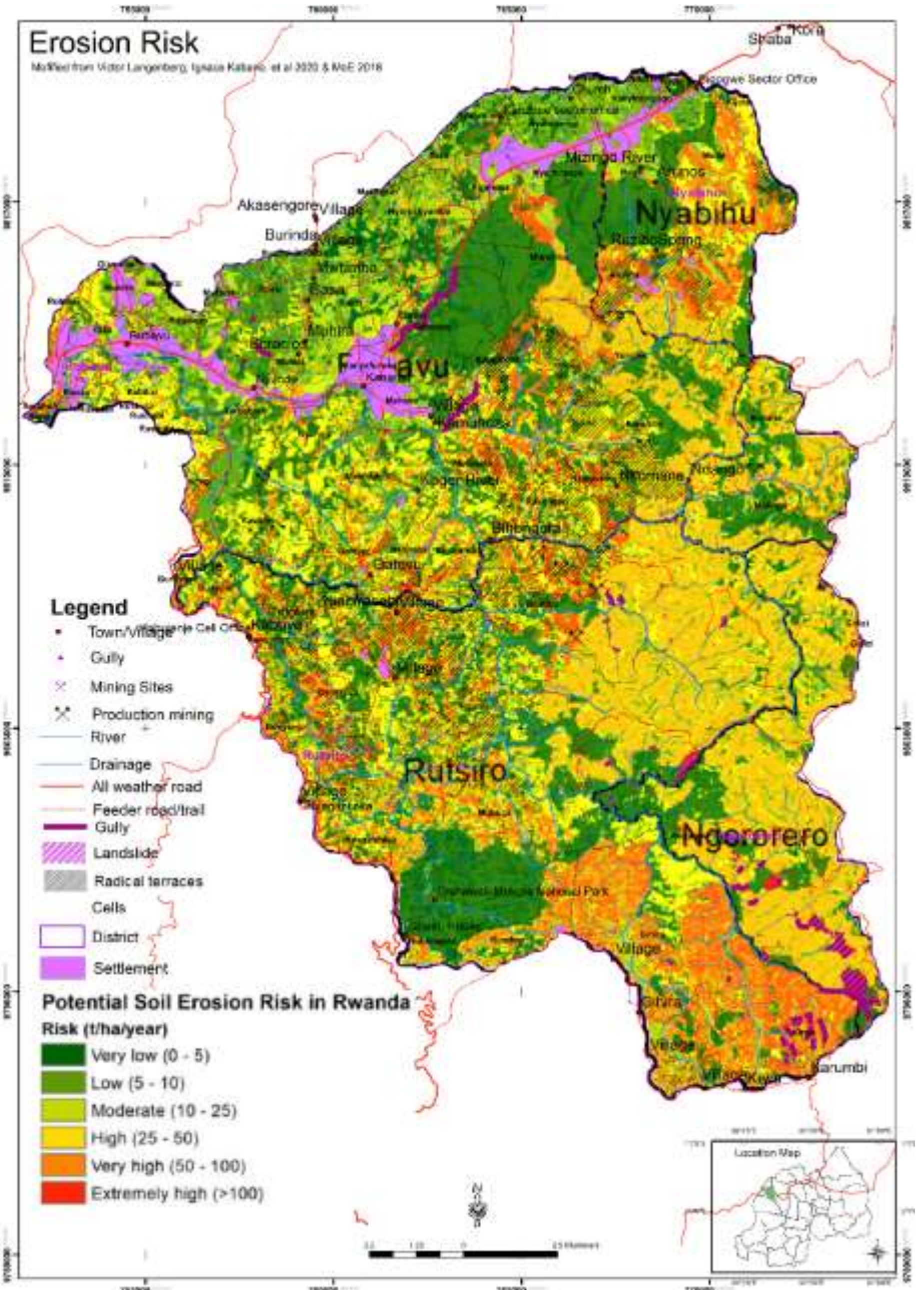



*Figure 27: Erosion risk map of Sebeya catchment (Modified from* MoE, 2018*).*

Gullies of different sizes are the main road related damages observed in Sebeya catchment. 35 big gullies that are big enough to be mapped from satellite images are shown in Figure 27. The development of most of these gullies is related with road-water management. From the preliminary analysis made on the 76 mapped landslides (Figure 27), although the main reason for landslides is associated with mining, road water has exacerbated the problem.

What makes the existing conditions alarming is the trend in rainfall, temperature and consequential environmental impacts. Temperature is on the rise, and it is expected to increase more during the coming decades (Figure 28 top). As seen from Gisenyi station, the past trend shows a significant rise in average minimum temperature from decade to decade. The 15.0°C in the 1980s raised to 15.1 and 15.7°C in the decades between 2001 to 2009 and 2010 to 2021, respectively. These have severe environmental consequences that exacerbate problems caused by road water.

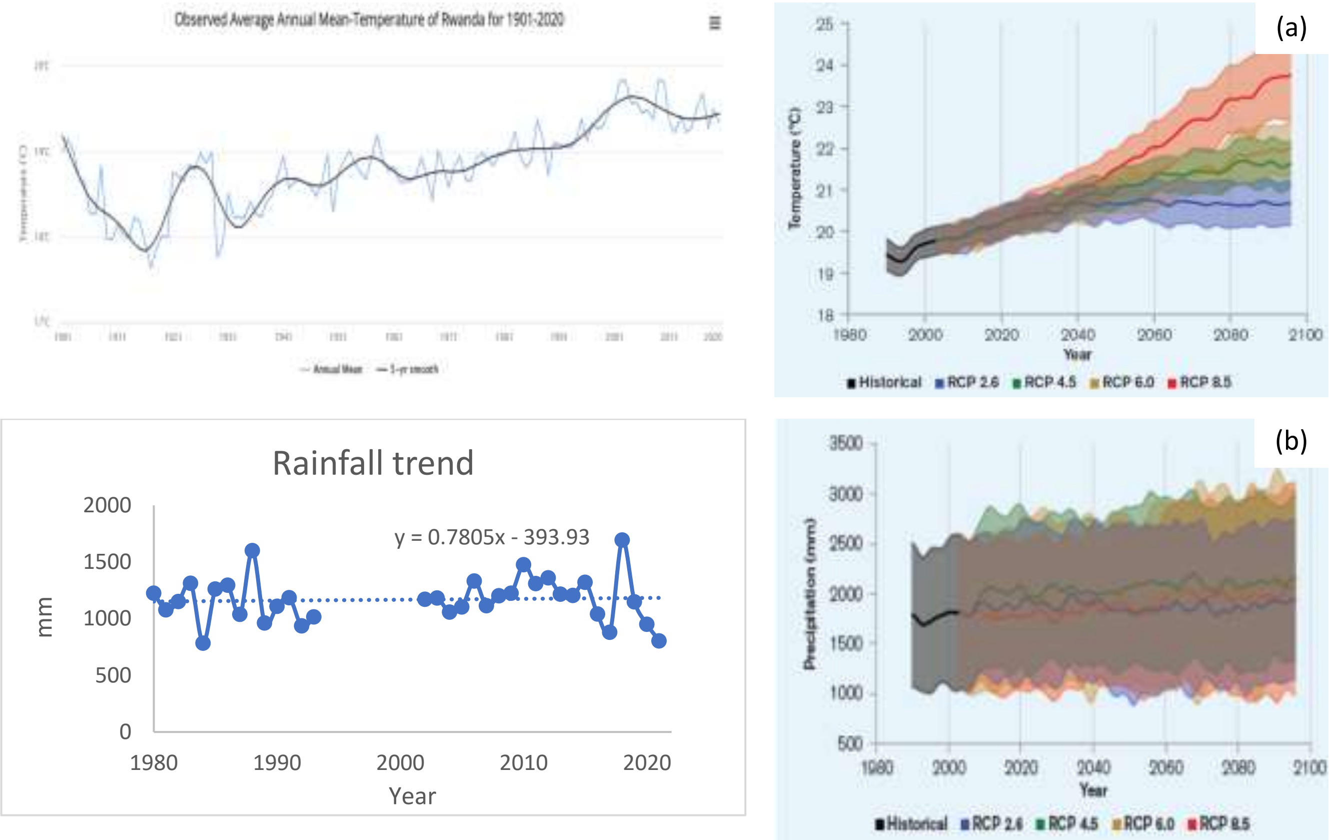



*Figure 28: Past trends in Sebeya Catchment for temperature (top) and rainfall (bottom) and future projection for Rwanda (Source: Rwanda MOA, The World Bank Group (2021)).*

There is no significant past trend in the average increase in rainfall (Figure 28 bottom). However, there is an observable change in rainfall pattern that resulted in changed pattern in river hydrograph and reduced annual flow (Figure 29). Rainfall patterns in the past decades showed closely similar annual rainfalls. This changed to low annual rainfall years followed by extremely high annual rainfalls. A good example is the lowest annual rainfall (879mm) in 2017 at Busasamana-Rubavu site, followed by the highest recorded rainfall in 2018 (1,692mm). The decreasing trend is also seen on rainfall days. The degradation of the catchment and the change in the rainfall pattern caused short-duration high flows followed by reduced long-term flows in rivers. The forecast shows an increase in rainfall but with extreme events. Such extremes are seen in rainfall patterns of the current and the past decades. The highest and most devastating daily rainfalls of 95 to 106mm fall during the 2000s. This very alarming situation threatens the sustainability of the catchment and affects the socio-economic condition of the fast-growing population of the catchment. Water (both surface and sub-surface), soil and soil nutrients are being lost at an increasing rate. Integrating GR4W in the development programs of Sebeya contributes to the mitigation effort of the current and future challenges.

From the above characteristics of the Sebeya catchment and the expected unfavourable climate condition, the introduction of GR4W is required for three main reasons: (1) maintaining hydrological connectivity across the landscape, (2) reducing/avoiding the water-related road and environmental damage, (3) ensuring the sustainability of roads by reducing road maintenance costs. Converting the 'enemy' water into beneficial water may come gradually.

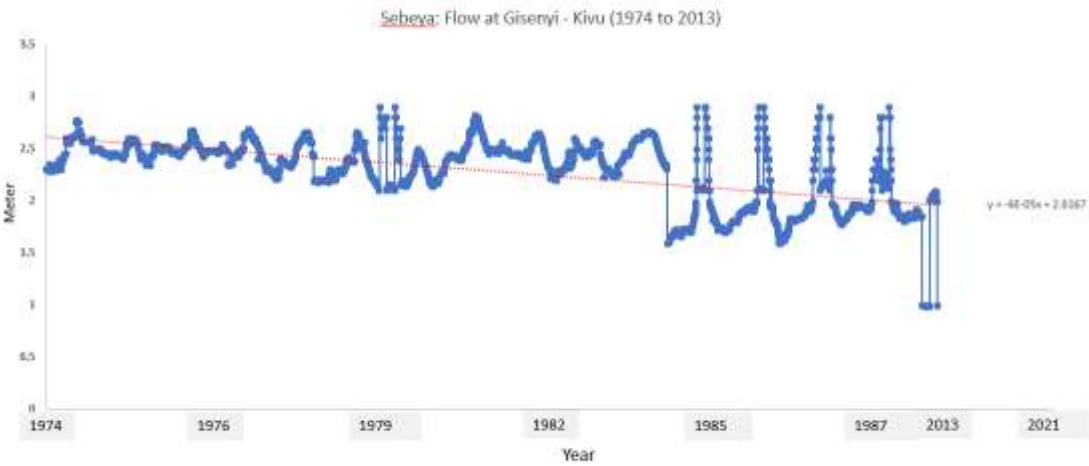



*Figure 29: Change in flow pattern: Sebeya river hydrograph showing alternating high and low flows and decreasing flow.*

### b. The Potential for Green Roads for Water

Implementation of GR4W can be done at different levels, and it can be started by villagers working on the road passing through their villages. Depending on resource availability, immediate interventions can be made on identified hot spots where problems may threaten villagers and the passability of roads. However, roads in the flood-prone areas and those with extensive gully development due to poorly guided water from culverts require priority. Incorporating GR4W in the ongoing road construction and rehabilitation of roads is an opportunity not to be missed.

# 7. Institutional arrangements and stakeholders' Interest

The Government of Rwanda through the Ministry of Infrastructures and Rwanda Transport Authority (RTDA) is coordinating all actors working in the Road Sector at national. Road Sector is part of the component of the Transport which is one of the key strategic pillars of economic growth of the country and the enabler of social inclusion and prosperity of the Rwandan citizens.

At central level, other key stakeholders include the Ministry of Finances (Minecofin), Ministry of Local Government (Minaloc), Ministry of Environment (MoE), Ministry of Information Communication Technology and Innovation (ICT), Ministry of Emergency (Minema), Rwanda Utilities Regulatory Authority (RURA), Rwanda National Police (RNP), Rwanda Development Board (RDB), Rwanda Water Board (RWB), Rwanda Meteorological Agency (Meteo Rwanda), Rwanda Standards Board (RSB), Rwanda Environment Management Authority (REMA), Development Partners in bilateral cooperation, UN Agencies, and International organisations.

At decentralized level the road sector is coordinated by Ministry of Local Government and include key stakeholders such as Local Development Agency or Local Administrative Entities Development Agency (LODA), Districts, City of Kigali, Private Companies, and Communities or Direct Beneficiaries.

The sector is regulated by RURA in general and implemented by RTDA LTD on national roads while the implementation on district roads is carried out by the Districts, Private Companies and communities. The full list of key institutions involved, and their roles is presented in the tables below (Table 12 and Table 13).

*Table 12: Institutional arrangements.*

| Roles | National Roads | District Roads 1 | Districts Roads 2 | Feeder roads | Level |
|---|---|---|---|---|---|
| **Policy formulation** | Mininfra, MoE, Minagri, Minaloc, Minema, MiniCT | | | | National |
| **Sector Planning, Coordination, M and E, Capacity building** | Mininfra, SWAP Secretariat Transport, RTDA, | | | | |
| **Financing** | Minecofin, RDB, Dev. Partners, | | | | |
| **Regulation** | RURA | | REMA, RWB, RSB | | |
| | RNP | | | | |
| **Project planning and implementation** | RTDA | Districts, COK, RTDA | | | District |
| **Service Provision, O and M** | RMF | LODA | | | |
| | | Districts, Communities | | | |

*Table 13: Major stakeholders related to road and water management and their roles.*

| Stakeholders | Roles |
|---|---|
| **MININFRA**<br>Ministry of Infrastructure | Oversees the designing national policies, guidelines and strategies for the Road Sector; enhancing institutional and human resource capacity; monitoring the implementation of government policies; leads road transport sector stakeholder coordination |
| **MINECOFIN**<br>Ministry of Finance and Economic Planning | Responsible for budgeting and financing of road infrastructures, including project approval, implementation and monitoring. Key actor in external aid coordination |
| **MINALOC**<br>Ministry of Local Government | Oversees decentralization process; ensures local institutions contribute to effective service delivery, aiming at community and socioeconomic development including development of roads infrastructures, bridges |
| **Ministry of ICT**<br>Ministry of Information Communication Technology and Innovation | Facilitates the integration and application of ICT in transport and road Sector |
| **Minema**<br>Ministry of Emergency and disaster Management | Responsible for disaster management and emergency coordination including disasters that affect the roads, bridges |
| **MoE**<br>Ministry of Environment | Responsible for designing policy and enabling environment for streamlining aspects of environment in road construction, road maintenance including green road and integration of climate changes factors |
| **MINAGRI**<br>Ministry of Agriculture and Animal Resources | Involved in formulating policies related to agriculture development including transport of agriculture produce and development of feeder roads in rural areas |
| **RTDA**<br>Rwanda Transport Development Agency | Key implementing institution of the Ministry of Infrastructures in charge of construction of all types of roads; responsible for planning for public and freight transport; responsible for the environmental and social monitoring of transport projects; review and approve E&S instruments; hiring and paying E&S Consultant; developing and managing procurement procedures; managing public transport service contracts; monitoring decentralized local administrative entities in terms of roads construction and maintenance; |
| **RURA**<br>Rwanda Utility Regulatory Agency | Issues regulations on public and domestic freight transport; advise the Government and local Authorities on public and freight transport matters; license a person to carry out public or domestic freight transport and related activities |
| **REMA**<br>Rwanda Environment Management Authority | Has the legal mandate for national environmental protection, conservation, promotion and overall management, including advisory to the government on all matters pertinent to the environment and climate change; Oversees the E&S monitoring for all project activities that have potential impacts on the environment in Rwanda; Undertake periodic monitoring of the investment projects by making regular site inspection visits to determine compliance with the investment projects ESIAs approved; Review submitted annual audit reports submitted for each investment project annually as required by Organic Law as a way of monitoring |
| **Rwanda National Police** | The RNP under its regulatory portfolio is safeguarding transport safety, and security |
| **RWB**<br>Rwanda Water Board | Responsible for availing hydrological data on water resources, catchment characteristics, flood issues for RTDA to design well the hydraulic infrastructures and bridges |
| **RSB**<br>Rwanda Standards Board | Establishes design standards for all types of land and water transport infrastructure in Rwanda |

| | |
|---|---|
| **LODA**<br>Local Administrative Entities Development Agency | Responsible for coordinating all Districts in preparation of budget required for road constructions and maintenance. |
| **Districts** | Assist RDB in organizing public hearings for ESIA of road projects; Hosts public hearings; Hosts individual consultations; Gather written comments from public and transmit them to RDB; Plan and complaints resolutions; Register and approve the expropriation projects |
| **City of KIgali (COK)** | Plan, design, implement, and maintain roads and other urban transport facilities; Develop an inventory of roads, bridges, terminals, depots, collection facilities, and other transport facilities |
| **RDB**<br>Rwanda Development Board | Is mostly involved in the process of Environment and Social management of Road Projects. Receive and register ESIA Applications (Project Briefs) submitted by developers; review ESIA reports and make decision on approval, organize chair public hearings, receive public comments and compile public hearing reports |
| **RMF**<br>Rwanda Maintenance Fund | RMF is in charge of collecting and manage resources to undertake periodic and routine maintenance works on national roads |
| **Development Partners** | Provide financial and technical support to successful implementation of various road projects in line with existing arrangements, and the Partner Division of Labour developed by MINECOFIN. |
| **Communities** | Are involved in attending community mobilization sessions on safeguards awareness; play a major role in identifying issues and ensuring that local knowledge and values are understood; participate when choosing between alternatives, in deciding on the importance of issues, and in framing mitigating measures, compensation provisions and management plans |

Several meetings have been held during the in-country field survey with various actors. During these meetings, the concept of GR4W and the scope of this study was introduced to the participants and the potential opportunities for GR4W in Sebeya catchment were discussed. In all of the discussions, the GR4W concept was highly appreciated, and the consulted organizations showed willingness to play their roles towards the implementation of GR4W in Sebeya catchment. More information on the discussions and agreements made during the meetings, refer to the minutes of the meetings at national and regional level at Annex 1.

# 8. Benefits from Implementation of Green Road for Water in Sebeya catchment

Integration of GR4W in road design, construction and rehabilitation phases will provide multiple benefits and can serve as a model for upscaling on projects to be implemented in the future and on existing roads. Among the many benefits and opportunities, the following are notable:

- Reduced water-related road damage; reduced road maintenance costs; reduced down-time of roads; improved road safety
- Healthier landscape around roads; reduced erosion and sedimentation upstream and downstream of the roads
- Reduced flood risk downstream
- Improved access to water for consumption and productive use
- Improved hydrological connectivity
- Employment opportunities in road maintenance by local community members linked to GR4W
- Enhanced soil and water conservation/land management practices that could be linked to road water management

# 9. Recommended GR4W measures and Implementation Guideline

Efforts have been made to control road runoff gully erosion and natural resources management activities in Sebeya Catchment. Mountain terracing is prominent activity that prompted the conversion of high-slop areas into agricultural farms. Gabion check dams, masonry cement check dams, loose stone check dams and soil bunds are also common. However, these conservation activities couldn't help to avoid road-water damages happening all over the catchment. In visited areas, most of the activities are not supported with biological measures and use it for productive efforts.

Recommended GR4W measures in Sebeya Catchment mainly depends on the three main purposes: maintaining hydrological connectivity across a landscape, reduce/avoiding the increasing damage from road-water and make roads sustainable and reducing its maintenance cost. However, the biophysical controls limit implementable options. What is suggested to follow is a landscape approach based on slope, type of rocks, soil and land use & landcover conditions. Factors like permeability, erodibility, saturation limits, soil thickness, slope (Table 14, Table 15 and Table 16) and road safety need to be considered. Recommended measures also need to be in harmony with existing policies, strategies and regulatory framework of the country. GR4W measures, may sometimes require for revision of the regulatory framework for infrastructure development.

Some common GR4W measures such as construction of ponds in Sebeya Catchment may not be a good option due to the soil and bedrock properties and lack of community interest. The widely applied terracing on the high slope areas in such high rainfall areas may not also be a recommended measure (Table 14). Similarly, inappropriate choice of groundwater recharge structures may trigger landslides in volcanic rock areas. Culverts built on unconsolidated sediments may fail due to erosion. Drifts/sand dam crossings built where the sediment composition is not sandy may fail to hold water. For this and many other reasons the reference table is developed to guide planning GR4W measures in Sebeya catchment (Table 14, Table 15 and Table 16). Typical design and design requirements for GR4W measures for some selected ones is give in Annex 3.

Focus on GR4W measures that can be constructed through the labor-intensive method which can reduce the costs, provide new green jobs and be incorporated in the existing Pilot Payment for Ecosystem Services (PES) scheme implemented by the EWWM project

**Where to apply GR4W measures**

*Table 14: Suitability of rocks for GR4W measures.*

| Major Lithology | Potential Challenge for GR4W | Remarks |
|---|---|---|
| Sandstone, and sandy recent sediments | Erodible ground | These formations are common in valleys cutting through the Crystalline Basement rocks |
| Crystalline basement rocks | Impervious base with erodible regolith tops | The ridges south and southeast of Sebeya catchment |
| Basalt, rhyolites, | Flows, Cones, Plugs- not suitable | Few spots in northern Sebeya |
| Basalt, trachyte, rhyolites | Moderate Water-Logged Ground | The northern part of Sebeya catchment |
| Sand, silt, SST, conglomerate, | Porous an erodible ground; capping and crusting in arid areas | Sediments in river valeys and |
| Basalt, trachyte, aluvial & lacustrine deposites | Waterlogged Ground | |

*Table 15: Suitability of soils for GR4W measures.*

| Soil type | Suitability for GR4W | Challenge | Intervention | Remarks |
|---|---|---|---|---|
| Clay Loam | low | Water logging (slightly), capping | with lining and spill way | See Figure 8 |
| Loam | Excellent | construction | With/without lining | |
| Rock Surface | Moderate | Lack of storage | Rock water harvesting | |
| Sand | Low | Infiltration | with lining/recharge | |
| Sandy Clay Loam | good | Infiltration | with lining/recharge | |

*Table 16: Slope suitability for GR4W measures.*

| RWH Technology | Rainfall (mm) | Slope % | Soil type | Catchment area (ha) | Remarks |
|---|---|---|---|---|---|
| Ponds & Pans | >200 | <5 | ➢ Sandy clay loam, Silty loam | <2 | See Figure 7 and Figure 8 |
| Check dams<br>Terracing | <1000<br>200–1000 | <15<br>5–30 | ➢ Sandy clay loam<br>➢ Sandy clay, clay loam and sandy loam | >25 | |
| Percolation tank Nala bunds | <1000<br><1000 | <10<br><10 | ➢ Silt loam, -Clay loam<br>➢ Silt loam | >25<br>>40 | |

*Table 17: Generalized Spatial GR4W Planning Guide.*

| Parent Rocks | | | Major derived soil texture type | Recommended GR4W Measures and Most Suitable Areas | | | | Allowable rainfall Range in mm | Slope range |
|---|---|---|---|---|---|---|---|---|---|
| Rock Group | Rock Type | Potential Threat for GR4W measure | | Technology type (in priority order) | Aridity zone class: Dry Sub-humid | Semi- arid | Arid | | |
| **Crystalline Basement/Metamorphic Rocks** | | | | | | | | | |
| Acid metamorphic rocks | – Schist, quartzite, gneiss, migmatite, slate, phyllite, pelitic | – Leaking Structures- faults, joints fractures | Unconsolidated soil layer & | • Sand dams, check dams, lined ponds, recharge wells, others | ✓ | ✓ | ✓ | <1200 | 0 to 50% |
| | | | Hard rock surface | • Rock surface water harvesting | ✓ | ✓ | ✓ | All range | 0 to 50% |
| Basic metamorphic rocks | – Schist, slate, phyllite, pelitic rocks, green, schist, gneiss rich in Fe–Mg minerals, marble, | – Leaking Structures- faults, joints fractures | Unconsolidated soil layer & | • Sand dams, lined ponds, recharge wells, check dams, others | ✓ | ✓ | ✓ | <1200 | 0 to 50% |
| | | | Hard rock surface | • Rock surface water harvesting | ✓ | ✓ | ✓ | All range | 0 to 50% |
| Ultrabasic metamorphic rocks | – Serpentinite, greenstone, | – Leaking Structures- faults, joints fractures (check for heavy metal concentration, objectionable test & odor)<br>- Water logging,<br>- Check for WQ | Coarse-grained sand/Sandy soils/sandy loam | • Sand dams, lined ponds, check dams & others | | ✓ | ✓ | <1200 | 0 to 50% |
| | | | Hard rock surface | • Rock surface water harvesting | | ✓ | ✓ | All range | 0 to 50% |
| **Igneous Rocks** | | | | | | | | | |
| Acid igneous rocks | – Rhyolite, diorite, grano-diorite, quartz- diorite, … | – Leaking structures- faults, joints fractures | Sandy soils - soils that contain full range of particle sizes, from gravel and sand to very fine clays. | • Ponds with lining, surface spread and GW recharge depending on soil conditions & others | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| | | | | • percolation pits, check dams, and bunds in areas of shallow bedrock conditions | ✓ | ✓ | ✓ | <1000 | 5 to 50% |
| Intermediate igneous | – Andesite, trachyte, phonolite, diorite- syenite | – Leaking structures- faults, joints fractures | - Sandy loam to clay soils | • - Same as above | ✓ | ✓ | ✓ | <1000 | 5 to 15% |
| Basic igneous rocks | – Gabbro, Basalt, dolerite | – Leaking structures- faults, joints & fractures<br>– Increased evaporation in arid areas as the black color of basalt causes the soil to warm quickly<br>– Water logging, | - Clayey and sticky alkaline soils. | • Ponds with special design consideration to clayey wall and evaporation | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| | | | | • check dams& other moisture harvesting methods | ✓ | ✓ | ✓ | <1200 | 5 to 50% |
| Ultrabasic igneous rocks | – Peridotite, pyroxenite, ilmenite, magnetite, ironstone, serpentinite | – Structures- faults, joints fractures<br>– Water logging,<br>– Increased evaporation in arid areas<br>– Check for WQ | - Clayey and sticky alkaline soils. | • Ponds with special design consideration to clayey walls, water quality and evaporation | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| | | | | • check dams & other moisture harvesting methods | ✓ | ✓ | ✓ | <1200 | 5 to 50% |
| Pyroclastic rocks | – Volcanic scoria/breccia, volcanic ash | – High permeability, piping and dispersion during high flood | most of it develops into good-quality sandy loam soils | • Ponds with lining, percolation pits, check dams, surface spread and GW recharge | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| | – Ignimbrite, tuff | – Water logging, | Clay/Clayey soils/ | • Ponds with special design consideration to clayey walls | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| | | | | • Check dams & & other moisture harvesting methods | ✓ | ✓ | ✓ | <1200 | 5 to 50% |
| **Consolidated Sedimentary Rocks** | | | | | | | | | |
| Clastic sediments | – Conglomerate, breccia, sandstone, greywacke, arkose, | – Highly permeable- Porosity Erodible; depending on the mineral composition of the cement. physical weathering can crack rock along | Sandy soils, Sandy- loam soils | • Ponds with lining, percolation pits, check dams, surface spread and GW recharge, if bed rocks are shallow | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| | | | | • Check dams & & other moisture harvesting methods | ✓ | ✓ | ✓ | <1200 | 5 to 50% |
| | – Silt, mud claystone, shale, ironstone | | silts produce fertile agricultural soils with excellent water-holding capacities | • Ponds with special design consideration to clayey wall | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| | – Shale | Rapid disintegration generally leads to deep soils, high in clay-size particles, so slow permeability for water. | Small particle size and poor cementation leads to rapid physical and chemical weathering. | • Ponds with special design consideration to clayey wall | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| **Unconsolidated Sedimentary Rocks** | | | | | | | | | |
| weathered residum | – Bauxite, laterite | Poor water quality-acidity objectionable test/odour | Clayey soils | Not recommended for direct use | | | | | |
| Fluvial | – Sand and gravel, clay, silt and loam | forms soils rich in topsoil materials brought | Sandy loam | • Ponds, diversions to farms, bunds with special design consideration to structure failures | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| Lacustrine | – Sand, silt, and clay | – possibility of salinity problem | Sandy loam, Sandy clay | • Ponds, diversions to farms, bunds with special design consideration to structure failures | ✓ | ✓ | ✓ | <1000 | 0 to 5% |
| Colluvium | – Slope deposits, lahar | – Porosity | Sandy soils, sandy loam | • Ponds with lining, percolation pits, check dams, surface spread and GW recharge, if bed rocks are shallow | ✓ | ✓ | ✓ | <1000 | 0 to 5% |

Adopted from draft Road Water Management Guideline for Ethiopia, 2017

# 10. Plan for implementing GR4W interventions on the pilot road

## 10.1. Assessing the capacity of drainage structures of the pilot road

The pilot road for implementing GR4W was selected based on its importance in regard to connectivity, the issues on its drainage system and its potential for GR4W interventions. Three different feeder roads were identified for piloting GR4W interventions during road rehabilitation, but this study focuses on one of the proposed pilot roads (Figure 32). The selected pilot road is close the most densely populated area of Sebeya (Figure 30 and Figure 31). This feeder road of 12.6 km is located in north part of Sebeya and crosses three sectors namely Rugerero, Nyakiriba and Cyanzarwe. It starts from Muhira Cell of Rugerero sector and takes end at Bazirete (Nyarushamba cell) of Nyakiriba sector. This road joins three small markets namely Muhira in Rugerero sector, Ryabizige in Cyanzarwe sector and Bazirete in Nyakiriba sector. This region is known to produce many agricultural products such as onions, cabbages, carrots and irish potatoes, so, this road is very important for transporting agricultural products to the markets.

The drainage problems observed on the selected pilot road were mainly due the improper maintenance (Table 18) and luck of hydraulic structures in some locations. The main drainage problems on the pilot road are listed below:

- Culverts are clogged fully or partially
- Many road sections (segment) do not have the side drain and some available side drains are not connected to the culverts or any other good location for runoff discharge
- Water crosses roadway and goes to communities building
- The road banks are not protected, and this is probably one of the causes of their failures
- No maintenance is done on existing hydraulic structures
- Mass movement blocked culvert and changed the road grade, consequently it became the flood prone area

*Figure 30: Selected pilot road on Google Earth.*

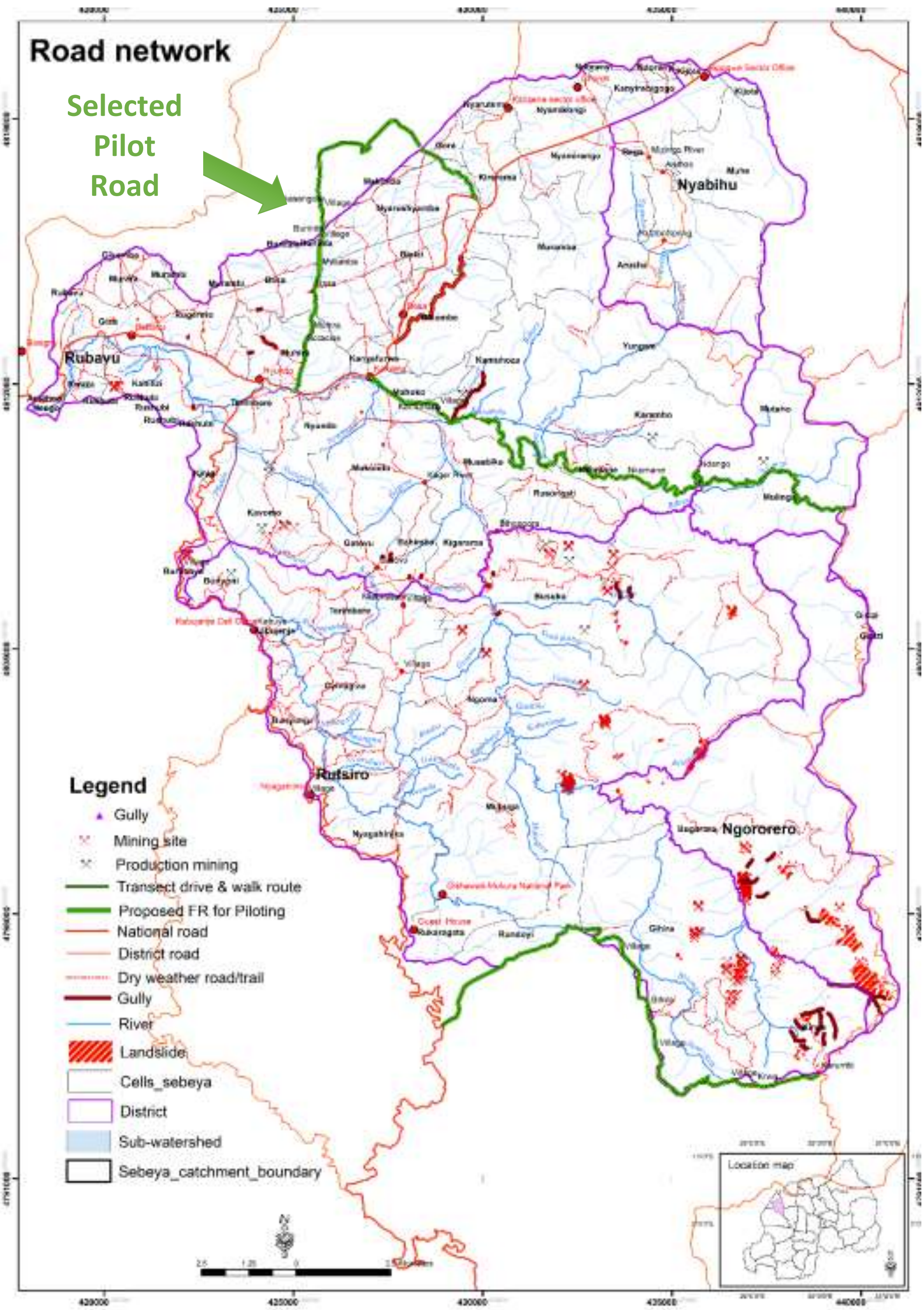



*Figure 31: Location of pilot roads for GR4W implementation.*

Data on the existing hydraulic structures on the pilot road and their conditions were collected during the detailed road assessment. In total 18 hydraulics structures were identified along the pilot road, 8 culverts and 10 side drains (Table 18).

*Table 18: Existing hydraulic structures on the pilot road.*

| No | | X | Y | Type of structure | Size [mm] | Physical conditions |
|---|---|---|---|---|---|---|
| **Crossing structures (culverts)** | | | | | | |
| 1 | | 425591.5941 | 4814245.311 | Pipe culvert | 800 | Fully Clogged |
| 2 | | 425649.6259 | 4817112.958 | Pipe culvert | 800 | Partially Clogged |
| 3 | | 426845.8539 | 4818281.697 | Pipe culvert | 800 | Partially Clogged |
| 4 | | 427170.9202 | 4818594.375 | Pipe Culvert | 800 | Partially Clogged |
| 5 | | 428547.1919 | 4818108.925 | Pipe culvert | 800 | Partially Clogged |
| 6 | | 428830.1145 | 4817962.648 | Pipe culvert | 800 | Partially Clogged |
| 7 | | 429381.1734 | 4817567.726 | Pipe culvert | 800 | Good |
| 8 | | 429561.8453 | 4817369.336 | Pipe culvert | 800 | Good |
| **Side drains** | | | | | | |
| 1 | From | 425088.1977 | 4811884.832 | Trapezoidal ditch | 400 x 700 x 450 | Not maintained |
| | To | 425095.2087 | 4811916.854 | | | |
| 2 | From | 425407.9209 | 4813252.032 | Trapezoidal ditch | 400 x 800 x 600 | Blocked by landslide |
| | To | 425449.0488 | 4813317.849 | | | |
| 3 | From | 425771.4254 | 4816027.933 | Trapezoidal ditch | 400 x 700 x 400 | Good |
| | To | 425777.4192 | 4816123.015 | | | |
| 4 | From | 425640.5004 | 4817171.972 | Trapezoidal ditch | 400 x 700 x 500 | Good |
| | To | 425709.3883 | 4817440.408 | | | |
| 5 | From | 425705.9652 | 4818136.714 | Trapezoidal ditch | 500 x 700 x 500 | Good |
| | To | 425839.2534 | 4818205.58 | | | |
| 6 | From | 426836.4382 | 4818181.434 | Trapezoidal ditch | 300 x 700 x 500 | Damaged |
| | To | 426825.3264 | 4818135.206 | | | |
| 7 | From | 428547.1919 | 4818108.925 | Trapezoidal ditch | 600 x 800 x 600 | Good |
| | To | 428604.1692 | 4818086.839 | | | |
| 8 | From | 429488.3768 | 4817465.712 | Trapezoidal ditch | 400 x 600 x 400 | Not maintained |
| | To | 429542.1353 | 4817446.638 | | | |
| 9 | From | 429561.8453 | 4817369.336 | Trapezoidal ditch | 600 x 800 x 600 | Good |
| | To | 429591.9544 | 4817335.53 | | | |
| 10 | From | 429784.0023 | 4816935.941 | Trapezoidal ditch | 400 x 700 x 800 | Good |
| | To | 429834.35 | 4816882.312 | | | |

*Table 19: Assessing the capacity of the side ditches on the pilot road.*

| Side drains | Estimated design runoff | Existing Dimensions | | Slope | Height (m) | 75%h | Area (m2) | Cross section (0.75h) | Slope distance | Wetted Perimeter | Hydaulic radius | Hydraulic Capacity | Difference | Observation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q (m3/s) | b | B | | h | | | A2 | | Wetted P | Rh | Q (m3/s) | | |
| 1 | **0.234** | 0.4 | 0.7 | 0.03 | 0.6 | 0.45 | **0.3** | **0.2** | **0.5** | **1.71** | 0.145 | **0.59** | **0.36** | Adequate |
| 2 | **0.05** | 0.4 | 0.8 | 0.024 | 0.6 | 0.45 | **0.4** | **0.3** | **0.5** | **1.73** | 0.156 | **0.61** | **0.56** | Adequate |
| 3 | **0.237** | 0.4 | 0.7 | 0.051 | 0.4 | 0.30 | **0.2** | **0.2** | **0.3** | **1.30** | 0.127 | **0.47** | **0.23** | Adequate |
| 4 | **2.186** | 0.4 | 0.7 | 0.105 | 0.5 | 0.38 | **0.3** | **0.2** | **0.4** | **1.50** | 0.137 | **0.89** | **-1.30** | Not adequate |
| 5 | **0.235** | 0.5 | 0.7 | 0.068 | 0.5 | 0.38 | **0.3** | **0.2** | **0.4** | **1.58** | 0.142 | **0.80** | **0.57** | Adequate |
| 6 | **0.265** | 0.3 | 0.7 | 0.013 | 0.6 | 0.45 | **0.3** | **0.2** | **0.5** | **1.63** | 0.138 | **0.34** | **0.08** | Adequate |
| 7 | **0.222** | 0.6 | 0.8 | 0.016 | 0.5 | 0.38 | **0.4** | **0.3** | **0.4** | **1.68** | 0.156 | **0.48** | **0.26** | Adequate |
| 8 | **0.474** | 0.4 | 0.6 | 0.09 | 0.4 | 0.30 | **0.2** | **0.2** | **0.3** | **1.27** | 0.118 | **0.54** | **0.07** | Adequate |
| 9 | **0.474** | 0.6 | 0.8 | 0.078 | 0.6 | 0.45 | **0.4** | **0.3** | **0.5** | **1.89** | 0.167 | **1.33** | **0.86** | Adequate |
| 10 | **1.159** | 0.4 | 0.7 | 0.037 | 0.8 | 0.60 | **0.4** | **0.3** | **0.6** | **2.12** | 0.155 | **0.92** | **-0.24** | Not adequate |

*Table 20: Assessing the capacity of the cross structures (culverts) on the pilot road.*

| Culverts | Length | Slope | Sticler coeff; | Diameter | Design discharge | Cross section | Wetted Perimiter | Hydraulic radius | Velocity | Velocity | Flow area | Estimated capacity of structure | Hydraulic capacity | Recommendation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | S | Ks | | Q25 | Aw | Pw | Rh | Vth | Va | | | | |
| N° | [m] | [m/m] | | [m] | [m3/s] | [m2] | [m] | [m] | [m/s] | [m/s] | [m2] | [m3/s] | [m3/s] | |
| 1 | 7.00 | **0.020** | 71 | **0.800** | 1.41 | 0.40 | 1.67 | 0.24 | 3.48 | 3.92 | 0.36 | 1.58 | Sufficient | To be relocated |
| 2 | 7.00 | **0.020** | 71 | **0.800** | 2.70 | 0.40 | 1.67 | 0.24 | 6.69 | 3.92 | 0.69 | 1.58 | Not sufficient | To replace |
| 3 | 7.00 | **0.020** | 71 | **0.800** | 1.09 | 0.40 | 1.67 | 0.24 | 2.71 | 3.92 | 0.28 | 1.58 | Sufficient | To be maintained |
| 4 | 6.00 | **0.020** | 71 | **0.800** | 1.23 | 0.40 | 1.67 | 0.24 | 3.04 | 3.92 | 0.31 | 1.58 | Sufficient | To be maintained |
| 5 | 6.00 | **0.020** | 71 | **0.800** | 0.55 | 0.40 | 1.67 | 0.24 | 1.36 | 3.92 | 0.14 | 1.58 | Sufficient | To be maintained |
| 6 | 6.00 | **0.020** | 71 | **0.800** | 0.98 | 0.40 | 1.67 | 0.24 | 2.42 | 3.92 | 0.25 | 1.58 | Sufficient | |
| 7 | 6.00 | **0.020** | 71 | **0.800** | 0.98 | 0.40 | 1.67 | 0.24 | 2.42 | 3.92 | 0.25 | 1.58 | Sufficient | |

The assessment of the hydraulic capacity of structures presented in Table 18 was done following the formulas indicated in methodology. The return period of 10 years was considered for side drains and 25 years for culverts. The obtained results are presented in Table 19 and Table 20. In general, the majority of the structures are sufficient to carry out the discharge, however side ditch 4, 10 and culvert 2 are not sufficient.

## 10.2. Recommendations for rehabilitating the pilot road with GR4W interventions

According to van Steenbergen et al. (2021), there are different approaches to resilience when looking at road design and development. The first level of resilience (basic resilience) is called "**Protective approach**" and its key objective is to protect the road infrastructure from water related damage. Under the protective approach to resilience, road infrastructure specifications are adjusted to account for specific climate risks such us higher flood peaks. This approach treats stresses as exogenous and follows traditional methods for engineering roads to withstand environmental stresses. The first downside of the protective resilience approach is that it often improves the resilience of the road at the expense of the resilience of the natural or human-made environment. Although protecting the road is essential for connectivity and accessing services and markets, larger cross drainage immediately passes the impact of extreme weather events onto the surrounding area, causing more severe floods, more inundation, and heavier erosion. Because roads often divert water from natural drainage paths and concentrate it, the volume of water passing through the enlarged drain may be far greater than natural flows. Although the road is protected, the landscape around it often suffers even more from the effects of climate change. These impacts may also harm the built environment, such as farmers' fields or downstream settlements. The second downside is that this protective approach does not use the road's potential to improve water management and the climate resilience of the surrounding area.

In the context of this study, measures under the protective approach include adjusting the road's hydraulic structures to hold the road runoff and protect the pilot road (Table 21).

*Table 21: Recommendations for improving the drainage system of the pilot road (Protective approach).*

| **Protective approach**<br>Recommendations for improving the road drainage system<br>based on the assessment of hydraulic structures of the pilot road | |
|---|---|
| Cross drainage structures/culverts | Cleaning of logged culverts number 2,3,4,5, and 6 |
| | Relocating culvert 1 because it's no longer functioning as the mass movement totally covered (buried) it. Culvert 2 needs to be redesigned in order to meet the size which is able to drain to discharge or if possible, the water must be controlled upstream. |
| | Additional of culverts for catchment 7 and 20 at the crossing points with road. There is also a need of culvert in catchment 1 in connection with ditch 1 as the water remain stagnant in road. These catchments are very big and are missing the crossing structures. |
| Side drains | Cleaning non maintained ditches numbers 1, 2, 8. For 2, there is a need to protect the embankment as it is susceptible to landslide. |
| | Repairing the damage segment for ditch 6 |
| | Connecting ditches 1 and 4 to culverts |

GR4W advocates alternatives to protective approach that could be called resilience "plus". The "plus" involves integrating water management into road development and design. This approach adapts or designs roads to fit within the landscape in various ways that allow them to support improved management of water and the local environment, including managing water for the benefit of nearby communities. In most cases, the resilience plus approach will reduce road damage from water just as well as the protective approach and will also reduce maintenance and sometimes even construction costs. The resilience plus approach is a preferable option compared with the protective or basic approach to climate resilience. There are two levels to this resilience plus approach. The first level is resilience plus 1 or "**Adaptive approach**". The adaptive approach makes use of road infrastructure as it is but adds measures to improve water management. This approach is used for rehabilitating existing roads and will be the central approach to resilience in the context of this study (Table 22). The second level is resilience plus 2 or "**Proactive approach**". The proactive approach calls for designing roads that optimally contribute to better land and water management, in addition to allowing for better communication and coordination among stakeholders involved in road design. This approach is mainly used when designing and constructing new roads.

*Table 22: Recommendations for GR4W interventions on the pilot road (Adaptive approach).*

| **Adaptive approach**<br>Recommendations for making the best use of and adapting to hydrological changes based on the observations from the road assessments | | | |
|---|---|---|---|
| Level/location of GR4W intervention | Purpose of GR4W intervention | GR4W strategy | Recommended GR4W measure |
| Upstream of the road | Stabilize the slopes upstream of the road, reduce the amount of water/runoff coming to the road and protect road infrastructure | Regreening | Planting grass, shrubs and trees (use of deep-rooted indigenous species – species to be selected in consultation with Rwanda Water Forestry) |
| | | Water and soil conservation measures | Progressive terrace on high slopes, soil and stone bunds on the low slope areas on non-clay soils. |
| At the road | Protect the road infrastructure | Road embankment protection | Reducing the slope of the road embankment (optimum slope: 45°) |
| | | | Planting grass, shrubs and trees (use of indigenous species) |
| | | | Use of gabions |
| Downstream of the road | Better manage the road runoff coming from the culverts, protect landscape around road and the road infrastructure, increase water availability for farming and livestock and drinking purposes | Erosion protection and water guiding systems | Packed or dumbed dry rock riprap (see Annex 3.1) |
| | | | Check dams (see Annex 3.1) |
| | | | Stilling basin (see Annex 3.1) |
| | | | Cascades (see Annex 3.1) |
| | | | Chutes (see Annex 3.1) |
| | | | Planting grass (use of indigenous species) |
| | | | Roadside tree planting (see Annex 3.5) |
| | | Channeling road runoff to farms along the pilot road or to surface | Mitre-drains for diverting water from main roadside drains |
| | | | Irrigation canals (lined or not) connected to side ditches or culverts |

| | | | |
|---|---|---|---|
| | | storage/groundwater recharge | V-shaped diversion structures constructed from soil and stones at culvert outlets |
| | | Water harvesting/water storage/groundwater recharge (depending on the interest of farmers/communities along the rod) | Detention/retention basin (see Annex 3.4) |
| | | | Micro basin from masonry/soil berm (see Annex 3.4) |
| | | | Sand dams (see Annex 3.3) |
| | | | Recharge wells (see Annex 3.4) |

### 10.2.2. Roles of stakeholders

Because GR4W approach is cross-sectoral, implementation of GR4W generally requires changes in road sector governance to encourage openness to cooperation and recognition of a multidimensional approach to sustainability and promote trust and transparency among major collaborating actors. The implementation of GR4W must take place at the landscape/watershed scale and actors must synchronize their actions, as fragmented efforts will fail to bring anticipated results.

Based on the discussions with various actors was understood that at district level, the coordination among major actors is at very good level to implement GR4W. A committee has been formed (District Project Management Committee, DPMC) consisting of members from various sectors responsible for planning interventions related to infrastructure development, roads and settlements with the objective to protect the environment and make sure that one actor does not hurt the other. This structure enables the environment for the implementation of GR4W at district level. However, this structure was not observed at watershed level. As mentioned before, the focus of this study is on feeder roads, but since the other types of roads (national, district roads etc.) have impact on the feeder roads, and the landscape, it is recommended that major stakeholders at national, watershed and district levels, work together towards the incorporation of GR4W in all phases of road projects (planning, design, implementation and rehabilitation). Table 23 shows the roles of key actors at district level towards the implementation of the recommendations above.

*Table 23: Roles of key stakeholders towards the implementation of the recommendations for rehabilitating the pilot road with GR4W interventions.*

| Approach to resilience | Key Actors at district level | Roles and responsibilities |
|---|---|---|
| Protective Approach (Basic resilience) | Infrastructures and One Stop Center Unit | • Identification of issues on roads, on culverts, designs<br>• Formulation of TOR<br>• Recruitment of Private Company<br>• Monitoring the implementation<br>• Coordinating the District Technical Management Committee |
| | Planning Evaluation and Monitoring Unit | • Compiling issues from one stop center and Agriculture and Natural Resources Units<br>• Costing of required budget<br>• Working with various partners for funds mobilization for implementation<br>• Liaise with LODA in submitting the required budget for infrastructures and watershed management |

| | | |
|---|---|---|
| Adaptive Approach (Resilience plus 1) | Agriculture and Natural Resources Unit | • Identification of issues on watershed that include the roads with issues<br>• Identification of issues upstream and downstream of the roads<br>• Planning and costing the measures for upstream and downstream based on watershed approach<br>• Coordinating partners in the districts for the implementation of recommended measures in line with watersheds approach<br>• Incorporate in District Plans the issues related to upstream and downstream culverts for LODA to provide resources |
| | Good Governance Unit (Joint Action Development Forum (JADF)) | • Play an important role in coordinating all actors at district level<br>• Raising awareness on importance of greening roads with other various actors at district level |
| | Communities | • Raising their voices on issues related to road infrastructures<br>• Participating in communities works (Umuganda) for conserving upstream and downstream the culverts but also for harvesting water for various purposes depending on their needs |

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# Annex

## Annex 1: Meeting minutes (national level meeting at Rwanda Water Board)

### Meeting at Rwanda Water Board, Date: 11 April 2022

Purpose: Presentation of the Inception process on Green Roads for Water scoping study in Sebeya Catchment

**Introduction**

In context of the scoping study on Green Roads for Water in Sebeya catchment by MetaMeta, there was a presentation of the inception process to the key stakeholders involved in aspect of road greening in Sebeya Catchment. The meeting took place at Rwanda Board Office on 11 April 2022 chaired by Davis Bugingo, Flood Management, Water and Storage Development Division Manager.

Participants to the meeting included MetaMeta Consultants, RWB, IUCN and RTDA staff. The full list of participants is presented below.

MetaMeta presented findings from desktop review in Sebeya Catchment, methodology to be followed, field work data collection approach, hydrological modeling to be used, workplan and deliverables including development of a Green Roads for Water guideline and an implementation plan for greening roads in Sebeya catchment.

**Participants**

- RTDA
  - Maxime Marius Mwiseneza, District and Feeder Roads Division Manager at RTDA, Tel: 0788465579
  - Cyprien NDAYISABA, Environment Specialist at RTDA
- IUCN
  - Tenaw Hailu Tedela IUCN, Technical Advisor, Forest and Landscape Restoration and Governance Program at IUCN, email :Tenaw.Tedela@iucn.org
- RWB
  - Davis Bugingo, Flood Management, Water and Storage Development Division Manager at RWB
  - Michel Murinda, Infrastructure Flood Control Specialist Team Leader at RWB, Tel: 0786792385, email: Mchel.murinda@rwb.rw
  - Sandrine Ishimwe, Road and bridge drainage and Flood control Specialist at RWB, Tel : 0788252475, email: Sandrine.ishimwe@rwb.rw
  - Rebero Emmanuel, Urban Hydrology Specialist at RWB, Tel: 0787148234, email: Emmanuel.rebero@rwb.rw
- MetaMeta team
  - Taye Alemayehu, Director of MetaMeta-Ethiopia branch, email: taye@metameta.nl
  - Anastasia Deligianni, Program Manager at MetaMeta, email: adeligianni@metameta.nl
  - Dusabimana Jean d’Amour, Consultant Road Engineer for MetaMeta
  - Vincent de Paul Kabalisa , Consulant Hydrologist for MetaMeta

Questions were raised for clarification on various aspects related to methodology, data and tools/software to be used, expected outcomes, unit of the study and integration of the road greening into the Sebeya catchment management plan.

**Answers by the MetaMeta team were provided and following suggestions were agreed upon.**

- Since this is a short scoping study to be carried out in short period, mainly secondary data will be used for assessing the biophysical conditions of the area. Regarding soil types and textures, no soils samples will be collected and analyzed but consideration of soils maps and other detailed highly resolutions maps and studies will be taken.

- Greening roads in Sebeya is a multisectoral exercise. Various sectors such as road, water, agriculture and environment need to work together to make sure that the one does not hurt the other. During the fieldwork (11-15 April 2022), big effort will be put by MetaMeta to introduce this concept to all relevant sectors at district level and get their views and feedback on this. To support the take up of this study, clear roles and responsibilities of all stakeholders will be included in the implementation plan.

- Specific Green Roads for Water measures and recommendations for Sebeya need to be well presented – Sebeya is a unique catchment with its specific issues.

- A guideline with specific measures for greening roads in Sebeya catchment will be included in the report. For each measure in the guideline, further information will be provided on area requirements (soil type, geology, slope etc.), so that it can be possible to replicate this approach to other catchments.

- The greening roads aspect should be incorporated in the Sebeya Catchment Management Plan. MetaMeta will keep a catchment approach and define roles of key stakeholders towards greening roads in Sebeya. It will be up to RWB together with concerned key stakeholders such as RWB, RTDA, REMA and districts of Rubavu, Rutsiro, Nyabihu and Ngororero to start implementing this approach together with other existing plans in the districts .

- Data to be used will include high resolutions maps, rainfall data from Meteo Agency and water flow data from regional measuring stations. The use of existing local secondary data was suggested by RWB and was agreed that those data will be provided to MetaMeta team upon request.

- The study will focus on feeder roads as indicated in the TOR but recommendations for other type of roads will be also provided if necessary.

- In regard to biological measures, the MetaMeta team will make sure that all proposed plant and tree species will be in line with guidelines from Forestry Authority.

- The recommended measures for greening roads in Sebeya will focus mainly on the sub catchment of the water intersecting the roads to be assessed – not only on roads but also on the area upstream and downstream of roads.

- The meeting approved the inception presentation after incorporating the agreed suggestions by participants

- It was also suggested to present to the interim presentation highlighting the findings from the field visit and the next steps in two weeks' time at end of April 2022.

The meeting ended finally at 17h00 and the MetaMeta Consultancy team departed immediately to the field.

### Meeting Minutes, Rubavu District, Data: 13 April 2022, 10 am CET

Purpose: Presentation and district level discussion on ongoing scoping study on Green Roads for Water in Sebeya Catchment

**Participants**

- Rubavu District
    - Innocent Harelimana, Acting Director of Natural resources and Environment
    - Gilbert Sindikubwabo, Director of One Stop Center
    - Leonard Niyonsenga, Engineer in charge of Infrastructures
    - Rwandanga Augustin, Agronome Officer in charge of Agriculture
    - Murego Vianney John, Soil and Water Conservation Specialist, Officer in charge of Water
    - Frederic Hakizimana, IUCN Hub Coordinator for Rubavu District
- MetaMeta team
    - Anastasia Deligianni, Program Manager at MetaMeta
    - Taye Alemayehu, Director at MetaMeta Ethiopia branch
    - Vincent de Paul Kabalisa, Consultant Hydrologist for MetaMeta
    - Dusabimana Jean d'Amour, consultant Hydraulic Road Engineer for MetaMeta

**Meeting Minutes and Outcome**

The MetaMeta team presented the Green Roads for Water (GR4W) concept, informed the participants about the ongoing scoping study (including workplan, timeframe and expected outcomes) and showed photos taken from the field highlighting the water-related issued on roads and the surrounding of the roads landscape in Sebeya catchment. After the presentation, the team asked the participants their views and feedback on the GR4W approach and the ongoing study.

Gilbert, the Director of One Stop Center showed big interest in the GR4W concept and its multisectoral approach for the benefit of all sectors including roads, infrastructure, environment, and agriculture. He mentioned that at district level, they already have formed a committee (District Project Management Committee, DPMC) to discuss and jointly plan activities together regarding infrastructure development, roads and settlements in order to protect the environment and make sure that sectors do not harm each other. He finally, asked the MetaMeta team clarifications on the ongoing study in terms of time frame and outcomes, involvement of One Stop Center, budget implication and follow up actions.

The MetaMeta team responded to Gilbert that the objective of this study is to assess the current issues on roads and the surrounding of roads environment, explore the potential of GR4W, draft guidelines on good practices and an implementation plan for rehabilitating one pilot road in Sebeya by applying the recommended practices. MetaMeta team, highlighted that after the finalization of the study, will share the findings and outcomes to One Stop Center and jointly explore possibilities for follow up activities including fund raising for implementation, capacity building and replication of the ongoing study to other roads in Sebeya.

Leonard, the road engineer, expressed his interest in the concept of road greening and he suggested selecting a road for piloting within Rubavu district. Leonard also raised a question on costs related to road greening and he expressed his concerns that it will be challenging to cover the cost for the additional greening measures from the already limited available budget for road construction. The MetaMeta team clarified that GR4W measures are low-cost compared to the total investment for road construction (only 5% of total road investments) and that all sectors involved (road, environment, water, agriculture etc.) are expected to cover part of the road greening related costs. Also, another recommendation was to involve individual farmers in this process for GR4W interventions at field level.

## Annex 2: Population size and density in Sebeya catchment

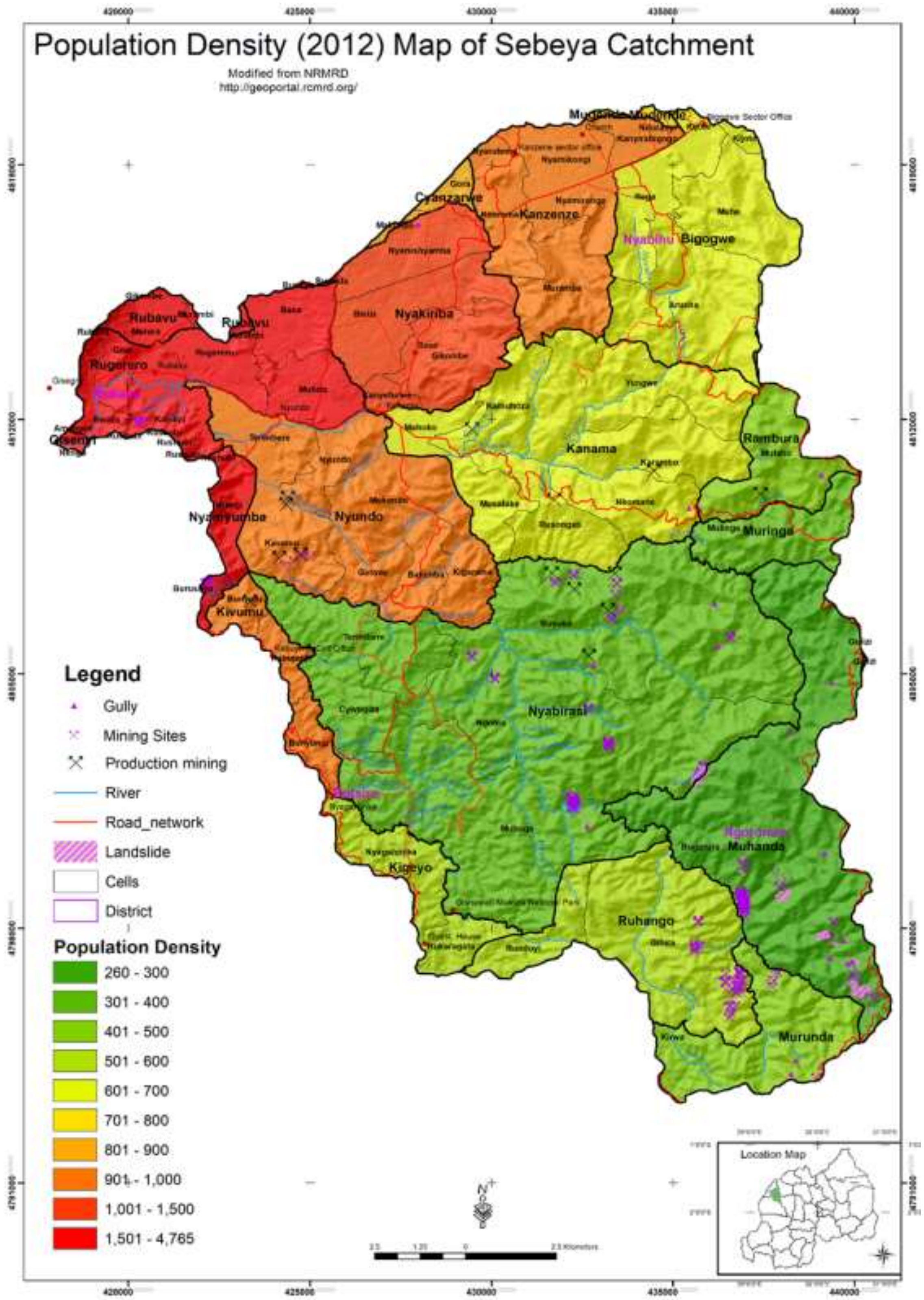



*Figure 32: Population size and density in Sebeya catchment.*

*Table 24: Calculations of population projection for 2021 in Sebeya catchment.*

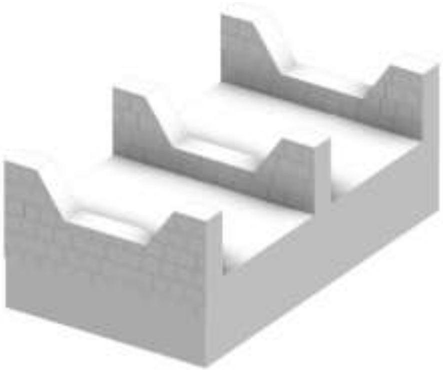
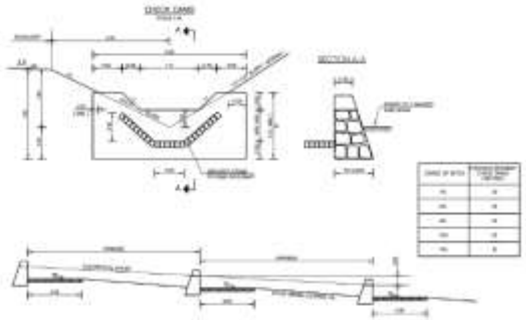
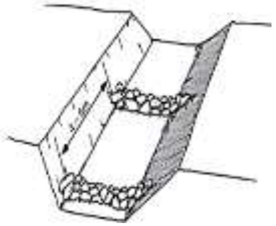
| District | Name | Population | | Density | Area in km² | | Percent in Sebeya | Pop in Sebeya 2012 | Pop in Sebeya 2021 | Percent increase |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2012 | 2021 | | Total | In Sebeya | | | | |
| Rutsiro | Kigeyo | 23080 | 31344 | 565 | 40.87 | 8.08 | 19.78 | 4565 | 6200 | 35.81 |
| Rutsiro | Kivumu | 28165 | 42193 | 972 | 28.96 | 5.82 | 20.08 | 5655 | 8471 | 49.81 |
| Rutsiro | Murunda | 18478 | 23653 | 408 | 45.32 | 11.97 | 26.42 | 4882 | 6249 | 28.01 |
| Rutsiro | Nyabirasi | 28971 | 37085 | 319 | 90.84 | 90.84 | 100.00 | 28971 | 37085 | 28.01 |
| Rutsiro | Ruhango | 28585 | 36596 | 507 | 56.34 | 21.17 | 37.57 | 10741 | 13751 | 28.03 |
| Rubavu | Cyanzarwe | 29615 | 37910 | 851 | 34.80 | 1.40 | 4.03 | 1192 | 1526 | 28.01 |
| Rubavu | Gisenyi | 53603 | 68616 | 4766 | 11.25 | 0.35 | 3.13 | 1677 | 2147 | 28.01 |
| Rubavu | Kanama | 29220 | 37404 | 681 | 42.91 | 42.91 | 100.00 | 29220 | 37404 | 28.01 |
| Rubavu | Kanzenze | 21309 | 27277 | 944 | 22.59 | 21.27 | 94.18 | 20068 | 25689 | 28.01 |
| Rubavu | Mudende | 26031 | 33322 | 786 | 33.10 | 0.50 | 1.52 | 396 | 507 | 28.01 |
| Rubavu | Nyakiriba | 30068 | 38490 | 1373 | 21.90 | 21.86 | 99.83 | 30017 | 38424 | 28.01 |
| Rubavu | Nyamyumba | 37491 | 47992 | 1606 | 23.34 | 3.79 | 16.22 | 6082 | 7786 | 28.01 |
| Rubavu | Nyundo | 30417 | 38936 | 966 | 31.50 | 31.50 | 100.00 | 30417 | 38936 | 28.01 |
| Rubavu | Rubavu | 42394 | 54268 | 1651 | 25.67 | 3.01 | 11.72 | 4967 | 6359 | 28.01 |
| Rubavu | Rugerero | 42574 | 54498 | 1682 | 25.31 | 21.42 | 84.62 | 36028 | 46119 | 28.01 |
| Nyabihu | Bigogwe | 31657 | 40524 | 606 | 52.21 | 27.07 | 51.84 | 16412 | 21009 | 28.01 |
| Nyabihu | Muringa | 22876 | 29283 | 335 | 68.24 | 6.98 | 10.22 | 2339 | 2994 | 28.01 |
| Nyabihu | Rambura | 28484 | 36462 | 448 | 63.65 | 7.67 | 12.05 | 3432 | 4393 | 28.01 |
| Ngororero | Muhanda | 28247 | 36159 | 266 | 106.25 | 35.78 | 33.67 | 9511 | 12175 | 28.01 |
| | | 581265 | 752013 | 1039 | | 363 | | 246573 | 317225 | 28.7 |

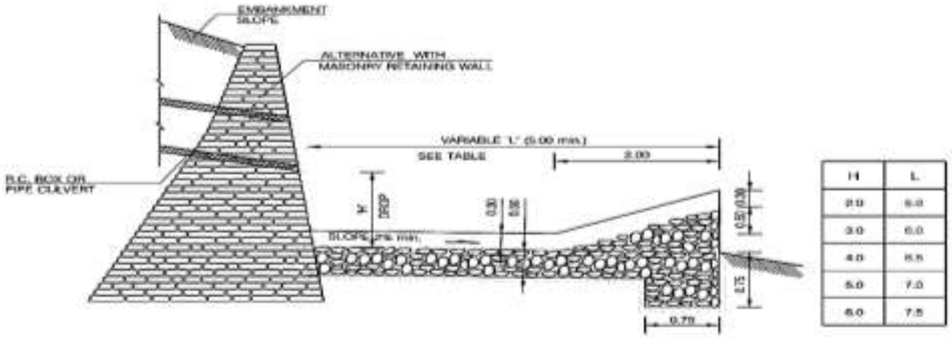
## Annex 3: Design Considerations and Requirements for GR4W Measures

### Annex 3.1: Erosion protections and water guiding systems - these are appropriate measures to take where excess water passing through culvers and road-side drains are causing flooding.

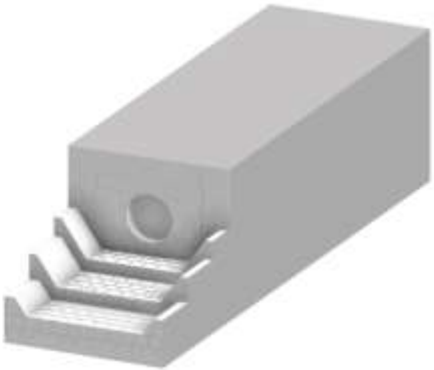
| Erosion protections and water guiding systems | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Packed or dumped dry rock riprap**<br>- Helps to avoid and / or restrict erosion | ▪ Upper slope catchment area<br>▪ Down slope area<br>▪ Rolling to mountainous terrain<br>▪ Fill slope surface<br>▪ Toe of fill<br>▪ Stream and river Bank as well as stream beds and water channels<br>▪ At outlet or inlet of drainage structures as energy dissipater structure. | ▪ Topography<br>▪ Soil types and their erodibility<br>▪ Availability of construction material / rock source | ▪ It enhances recharge by slowing down the run-off<br>▪ Serves as streambed erosion protection by reducing the scour in erodible canal |
| <br><br>Riprap used at outlet of culvert as energy dissipater Alamata-Mehoni Road | | ▪ Construction Considerations<br>Packed riprap<br>- constructed from rocks individually placed<br>- Space shall be filled with spall and smaller stones<br>- Stone shall be hard or quarry stone not susceptible to disintegration and resistant to weathering<br>Dumped riprap<br>- Shall be constructed by dumping stone and spreading with a bulldozer |  |

**Erosion protections and water guiding systems**

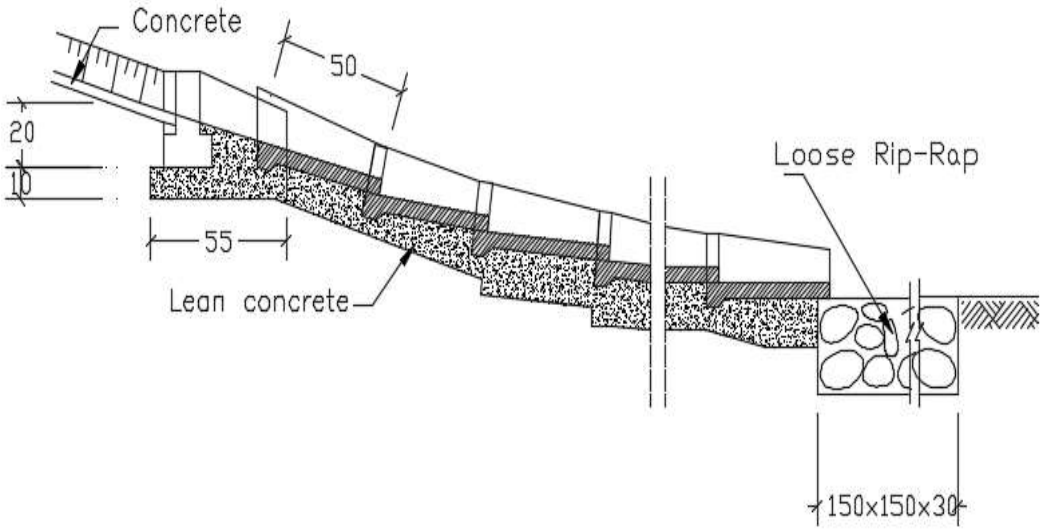
| Options | Possible area of application | Design Consideration | Remarks |
|---|---|---|---|
| **Check dams, dry and mortared**<br><br>- It controls erosion<br>- It controls sediment | ▪ On side ditches with slope greater than 7% | ▪ Road/ditch gradient<br>▪ Soil types and their erodibility<br>▪ Catchment area and rainfall intensity<br>▪ Community needs<br>▪ Availability of construction material source | ▪ It provides proper guide of ditch flow, especially in steep gradient road sections, to water harvesting systems<br>▪ It helps to minimize sedimentation to water harvesting systems and protects erosion |
| <br> | | ▪ Construction Considerations<br>- On steep gradient of ditch greater than 7%, apply mortared check dams<br>- Apply dry check dam on less erodible section grade less than 7% | <br><br> |

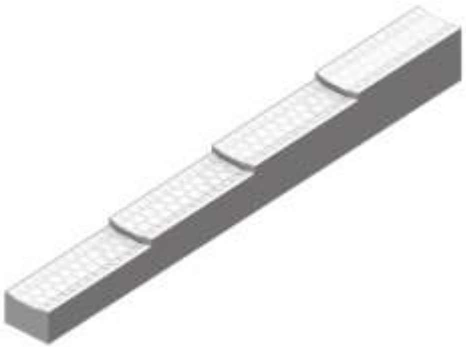
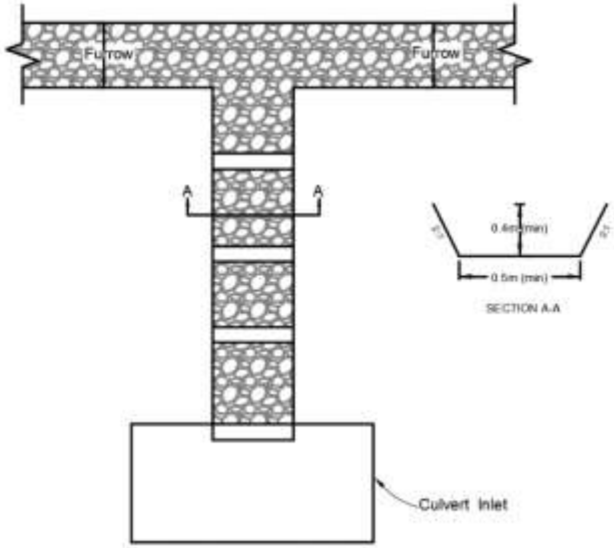
| Erosion protections and water guiding systems | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Dry stone wall** | ▪ At toe of fill as a barrier to divert surface flow to farm land<br>▪ As retaining structure<br>▪ River and stream banks<br>▪ Steep eroded land | ▪ Community needs<br>▪ Soil types and their erodibility<br>▪ Stone wall spacing<br>▪ Slope angle | ▪ It enhances groundwater recharge and guides surface flow to farm land |
| <br>Road surface water guiding using dry stone walls Mekele-Wukro road | | ▪ Construction Considerations<br>- When constructed at the toe of a fill to direct the road surface water flow, height of wall and thickness shall be minimum 40cm<br>- Back of the wall shall be supported by soil | |
| **Stilling Basin** | ▪ At culvert outlet: when invert level of outlet from the natural ground is 2m and above | ▪ Topography<br>▪ Catchment area and rainfall intensity<br>▪ Position of culvert location | ❖ It dissipates energy of water flow<br>❖ Protects erosion and retains sedimentation<br>❖ Regulates water for possible downstream use |
| | |  | |

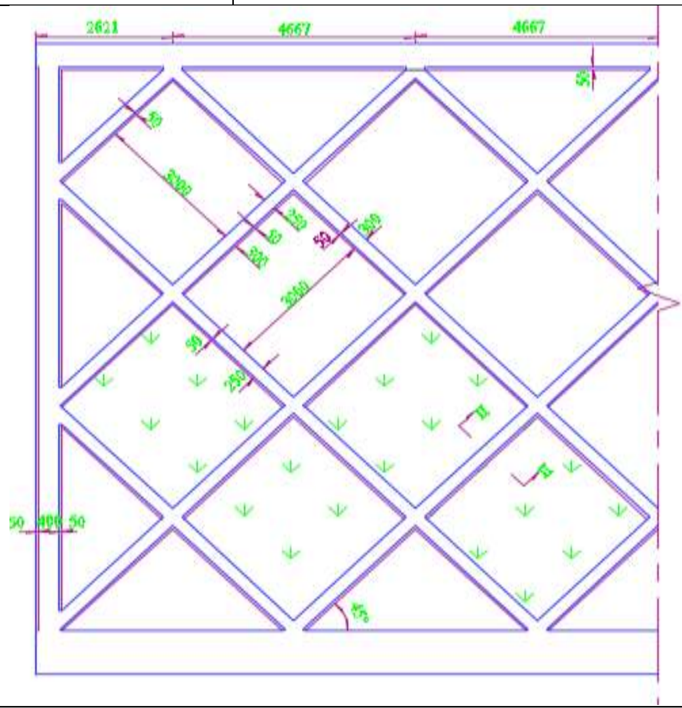
| Erosion protections and water guiding systems | | | |
|---|---|---|---|
| Options | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Cascades**<br><br>- It Controls erosion<br>- It is an energy dissipating structure | ▪ Upper slope catchment area<br>▪ Down slope area<br>▪ On steep water channels<br>▪ Built inside or outside of the road reserve including channels to direct the course of the stream | ▪ Topography<br>▪ Soil types and their erodibility<br>▪ Channel characteristics<br>▪ | ❖ It dissipates energy of water flow<br>❖ Protects erosion<br>❖ Guides water for possible downstream use |



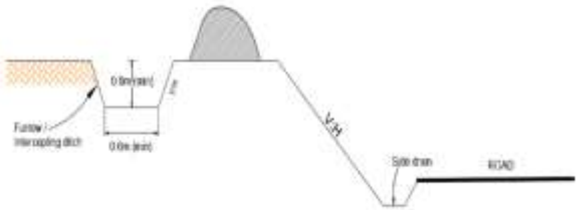
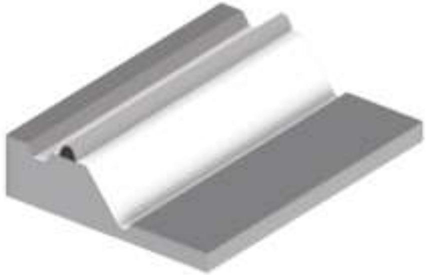
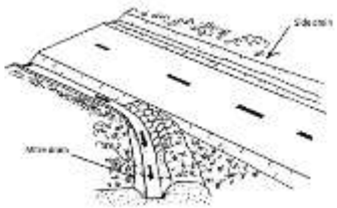
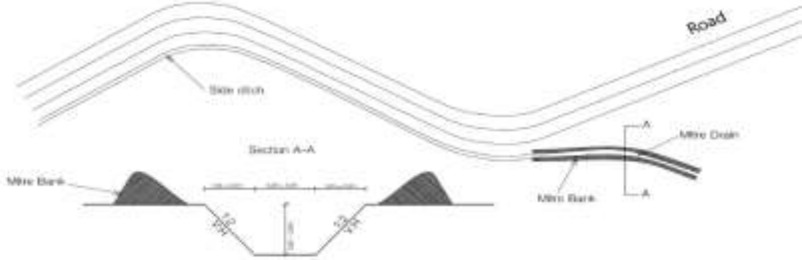
Cascade built at outlet of culvert
Alamata – Mehoni –Hewane Road

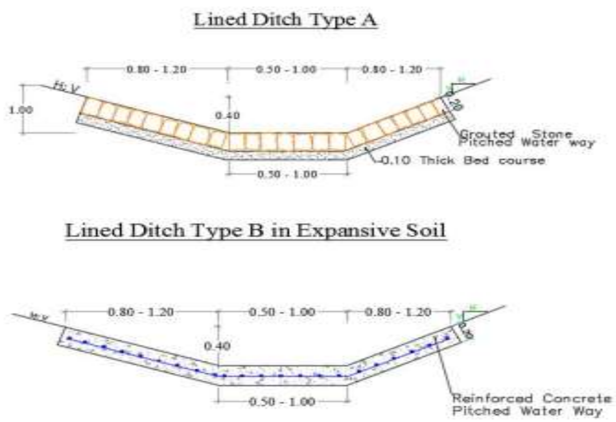
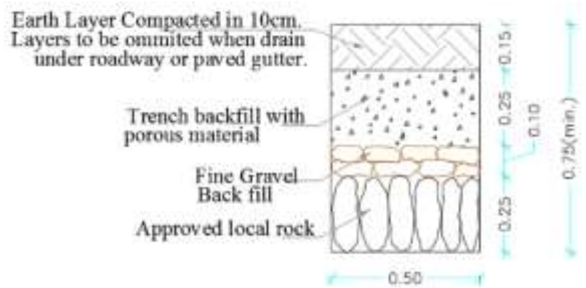


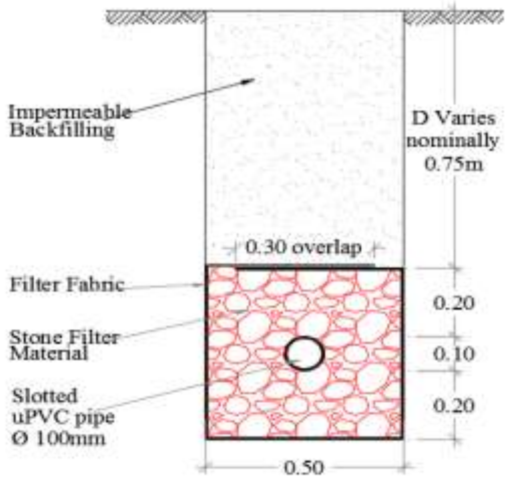
| Erosion protections and water guiding systems | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Chutes** | ▪ Upper slope catchment area<br>▪ Down slope area<br>▪ On steep water channels<br>▪ Transition from furrow ditch to culvert inlet or side drain<br>▪ Transition to pond or water reservoir | ▪ Topography<br>▪ Soil types and their erodibility<br>▪ Amount of flood (catchment area and rainfall intensity) | ▪ Protects erosion<br>▪ Facilitates transition to inlet of culverts<br>▪ Guides water for possible downstream use |
| <br> | | ▪ Construction Considerations<br>- When it is more than 6m length, provide check dam structure in between every 6m.<br>▪ The size of chute depends on the size of furrow or cutoff drain | <br> |

<table>
<tr><th colspan="4">Erosion protections and water guiding systems</th></tr>
<tr><th>Options</th><th>Possible area of application</th><th>Design Consideration</th><th>Remarks</th></tr>
<tr>
<td>Gridded channel on slopes<br><br>- Takes away surface water from top of cut or from road surface<br>- Supports the slope<br>- Protects erosion</td>
<td>▪ Cut slopes and high fill slopes</td>
<td>▪ Fill height/cut depth<br>▪ Soil types<br>▪ Cut off drain</td>
<td>▪ Protects erosion of slopes<br>▪ Guides water flow from the road surface and slopes towards ditch and culvert inlet or outlet and to water harvesting systems</td>
</tr>
<tr>
<td colspan="2"></td>
<td colspan="2">
</td>
</tr>
</table>

## Annex 3.2: Surface Drains

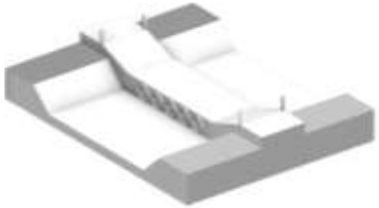
| Surface Drains | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Furrow/intercepting ditches** | ▪ Top of mountain<br>▪ Top of deep cut section<br>▪ Intercepting ditches at the top and bottom of the slopes | ▪ Topography<br>▪ Soil types and their erodibility<br>▪ Slope stability<br>▪ Cut depth | ▪ Enhance slope stability<br>▪ To control the flow of water: flow can be directed to nearest water harvesting system |
|  | |  | |
| **Mitre drains/ ditch out**<br> | A mitre drain is a drain constructed at an angle to the centerline of the road to divert water from the side drains. Mitre drains will include mitre banks placed across side drains.<br><br>▪ On side ditches/drains: to provide flow relief of the side drain | ▪ Length of side drains<br>▪ Road/ditch gradient<br>▪ Soil types and their erodibility<br>▪ Catchment area and rainfall intensity<br>▪ Community needs for water<br>▪ Suitability for water harvesting | ▪ Commonly practiced in many water scarce areas of the country to guide water from side drains to farm land and other water harvesting systems |
|  | |  | |

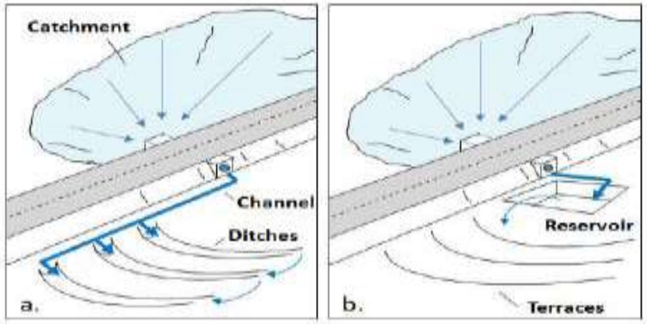
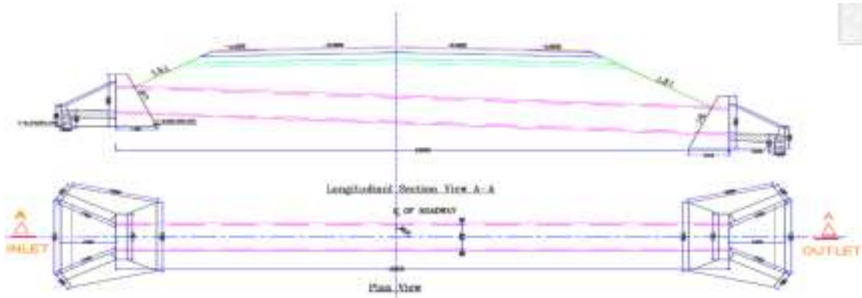
| Surface Drains | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Earthen or grouted stone pitched side drains** | ▪ Road side drains | ▪ Length of side drains<br>▪ Road/ditch gradient<br>▪ Soil types and their erodibility<br>▪ Topography<br>▪ Catchment area and rainfall intensity | ▪ Grouted stone pitching drains shall be considered where there exists: - erodible soil (regardless of gradient) and ditch gradient ≥ 5% |
| | |  | |
| **French drain** | ▪ Through side drains: especially in water logging area and springs | ▪ Topography<br>▪ Road/ditch gradient<br>▪ Amount of subsurface water | ❖ It is rock field trench<br>❖ Collects subsurface water and protects the road subgrade from saturation |
| | |  | |

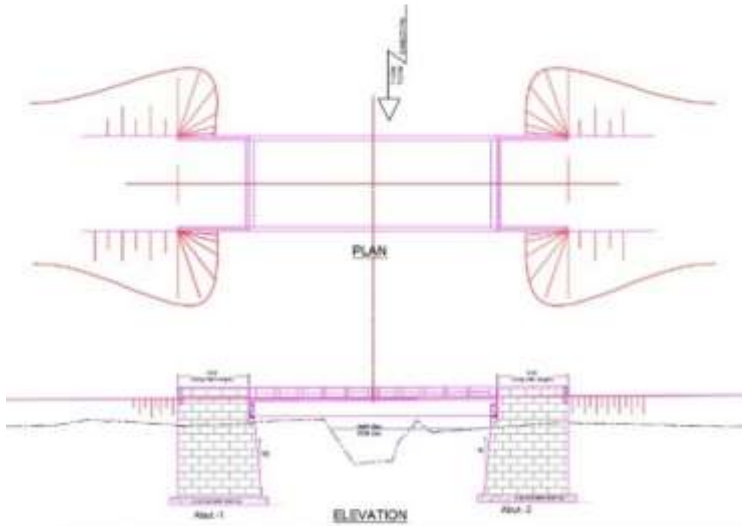
| Surface Drains | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Slotted or perforated uPVC pipes** | ▪ Through side drains: especially in water logging area and springs | ▪ Topography<br>▪ Road/ditch gradient<br>▪ Amount of subsurface water<br>▪ Diameter of slotted or perforated pipe<br>▪ Use of geotextile filter fabric | ▪ Rock fill to a certain depth from invert and filled with impermeable back filling<br>▪ Collects subsurface water and protects the road subgrade from saturation |
| | | <br>Subsoil Drain | |

Annex 3.3: Cross-drainage is suitable for crossing over streams and dry riverbeds on the crystalline basement rocks areas

<table>
<tr><th colspan="4">Cross-drainages</th></tr>
<tr><th>Options</th><th>Possible area of application</th><th>Design Consideration</th><th>Remarks</th></tr>
<tr>
<td>Drifts/ Ford<br>- suitable along sandy streams and dry river crossings<br></td>
<td>▪ On low volume roads</td>
<td>▪ Topography<br>▪ Crossing location<br>▪ River characteristics<br>▪ Provision of surface roughness<br>▪ Community needs: for use as part of water harvesting system<br>▪ For further detail refer ERA-LVR Manual Part E Section 4.1 & 5.2.1</td>
<td>▪ Structure can be grouted stone pitching or reinforced concrete<br>▪ Surface roughness should be ensured to avoid slippery characteristics<br>▪ Possibly the lowest cost form of watercourse crossing construction<br>▪ Ideal structure type for water harvesting by raising the crossing from the stream bed level<br>▪ Easy to integrate with other type of water harvesting systems</td>
</tr>
<tr>
<td>Construction Considerations<br>- Construct from stones not weathered<br>- Minimum thickness of stone shall be 200mm<br>- The top surface shall be roughened across the water flow to avoid growth of algae or other types of plant species</td>
<td colspan="3"> </td>
</tr>
</table>

| Cross-drainages | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Vented Fords/ Causeways** | ▪ On low volume roads | ▪ Topography<br>▪ Crossing location<br>▪ River characteristics<br>▪ Provision of surface roughness<br>▪ Community needs: for use as part of water harvesting system<br>▪ For further detail refer ERA-LVR Manual Part E Section 4.3 & 5.2.3 | ▪ Designed to be over toped during flood periods<br>▪ Can be integrated with water harvesting system: by providing appropriate wall upstream side for water storage/recharge |
| ▪ Construction Considerations<br>- Concrete pipe shall be encased on top with mass concrete C-20<br>- The running surface shall be roughened<br>- Install stone guiding post at the middle and corner part of the top running surface and paint with white marker | |  | |
| **Sand dams (with road crossings)**<br> | ▪ Low volume roads in combination with Fords<br>▪ High volume roads: 30m upstream and/or downstream of a bridge location | ▪ Topography<br>▪ Crossing location<br>▪ River characteristics<br>▪ Amount of sand deposition<br>▪ Catchment area<br>▪ Community needs: for use as part of sand sources and/or water harvesting system | ▪ It is a good structure for storing large volume of water in the river bed<br>▪ Structure can be grouted stone pitching or reinforced concrete<br>▪ Care shall be taken for timely removal of sand deposition otherwise it causes inundation of the surrounding area or farmland |
| ▪ Construction Considerations<br>- The running surface of the sand dam shall be roughened<br>- Install stone guiding post at the middle and corner part of the top running surface and paint with white marker | |  | |

<table>
<tr><th colspan="4">Cross-drainages</th></tr>
<tr><th>Options</th><th>Possible area of application</th><th>Design Consideration</th><th>Remarks</th></tr>
<tr>
<td>Culverts<br><br></td>
<td>▪ Low volume roads<br>▪ High volume roads</td>
<td>▪ Topography<br>▪ Catchment area<br>▪ Soil type and their erodibility<br>▪ Land use and land cover<br>▪ Crossing location<br>▪ Stream/channel characteristics<br>▪ Community needs: for use as part of water conveyance to harvesting system<br>▪ For further detail refer ERA-LVR Manual Part E Section 4.2 & 5.2.2</td>
<td>▪ Consider provision of proper inlet and/or outlet transition structure for water harvesting system<br>▪ Culvert outlets invert level shall consider down side water harvesting systems and vice versa<br>
</td>
</tr>
<tr>
<td colspan="2">▪ Construction Considerations<br>- If soft, spongy or other objectionable materials such as black cotton soil are encountered, it shall be excavated to a minimum of 30cm and replaced with granular material<br>- Pipe shall can be laid on Class A, B, C and D bedding</td>
<td colspan="2">
</td>
</tr>
</table>

| Cross-drainages | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Bridges**<br> | ▪ Low volume roads<br>▪ High volume roads | ▪ Topography<br>▪ Catchment area and rainfall intensity<br>▪ Soil type and their erodibility<br>▪ Land use and land cover<br>▪ Crossing location<br>▪ River characteristics<br>▪ Community needs: for use as part of water harvesting system<br>▪ For further detail refer ERA Bridge Design Manual 2013 | ❖ Sand dams can be provided 30m upstream and/or downstream side of the bridge location<br>❖ Diversion structures can be provided without endangering the bridge |
| | |  | |

## Annex 3.4: Water Storage systems

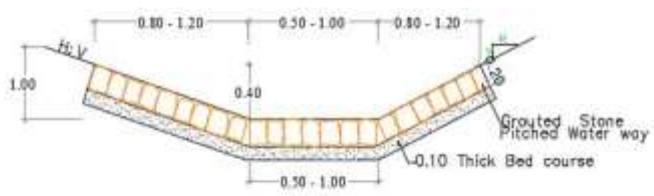
| Water storage systems | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Detention/retention basin** | ▪ Upper slope catchment area<br>▪ Down slope area | ▪ Topography<br>▪ Soil types and their infiltration<br>▪ Land use and land cover<br>▪ Catchment area and rainfall intensity<br>▪ Community needs<br>▪ Availability of land for basin development<br>▪ Distance of the basin from road and its effect on the safety of the road | ❖ The location of the basin should be outside of the road reserve |
| **Micro basin-from soil berm** | ▪ Upper slope catchment area<br>▪ Down slope area | ▪ Topography<br>▪ Soil types and their infiltration<br>▪ Land use and land cover<br>▪ Catchment area and rainfall intensity<br>▪ Seasonal characteristics of stream flow<br>▪ Community needs<br>▪ Availability of land for basin development<br>▪ Distance of the basin from road and its effect on the safety of the road | ❖ Micro basins are generally suitable to construct at locations with low storm water flow<br>❖ The location of the basin should be outside of the road reserve |
| **Ponds** | ▪ Upper slope catchment area<br>▪ Down slope area<br>▪ Borrow pits as ponds<br>▪ Sides of road (to collect roadside runoff) | ▪ Topography<br>▪ Soil types and their infiltration<br>▪ Land use and land cover<br>▪ Catchment area and rainfall intensity<br>▪ Community needs<br>▪ Availability of land for pond development<br>▪ Distance of the pond from road and its effect on the safety of the road | ❖ Down slope pond inlet invert level shall consider drainage outlets and vice versa<br>❖ The location of the pond should be outside of the road reserve |
| **Recharge wells** | ▪ Upper slope catchment area<br>▪ Down slope area<br>▪ Road sides | ▪ Soil types and their infiltration<br>▪ Community needs<br>▪ Availability of land for recharge wells development<br>▪ Distance of the recharge wells from road and its effect on the safety of the road | ❖ To increase the storage capacity of the recharge well, excavated material shall be stoke piled as a bank<br>❖ The location of the recharge well should be outside of the road reserve |

| Detention/ Retention basin | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Detention/ retention basin** | ▪ Upper slope catchment area<br>▪ Down slope area<br>▪ Road sides | ▪ Topography<br>▪ Soil types and their infiltration<br>▪ Land use and land cover<br>▪ Catchment area and rainfall intensity<br>▪ Community needs<br>▪ Availability of land for basin development<br>▪ Distance of the basin from road and its effect on the safety of the road | ▪ The location of the basin should be outside the road reserve |

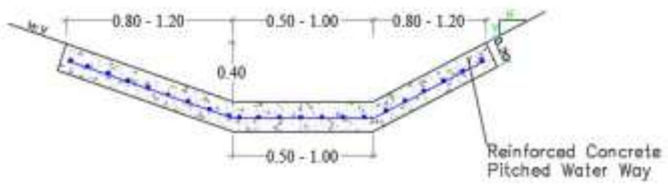
Linkage between Road and Water Harvesting System

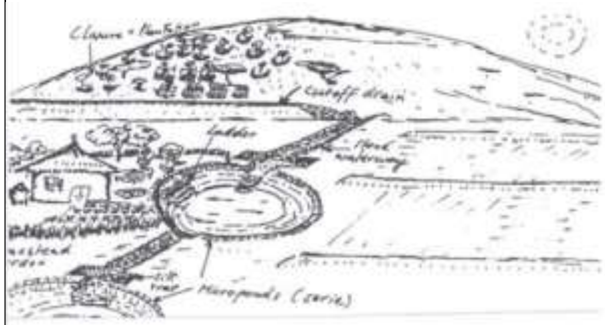
- Location of pond – Min. 50m from road slope-stake
- Linkage from side, mitre drains and / or cross drainage with provision of transit paved ditch (refer sketch)
- When transverse ground slope is greater than 20% consider provision of cascades, check dams (paved) etc.

Lined Ditch Type A




Lined Ditch Type B in Expansive Soil

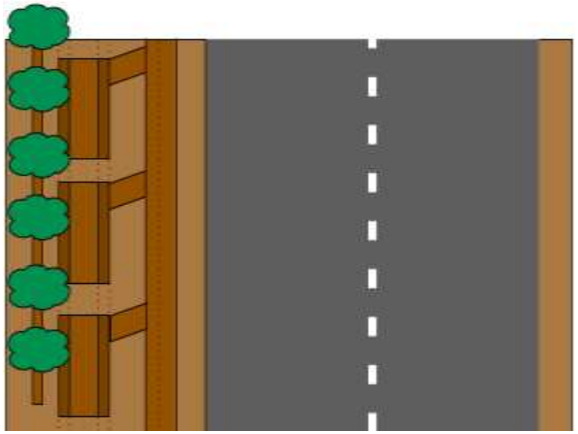


| Micro basin from masonry / soil berm | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | Remarks |
| **Micro basin from masonry / soil berm** | ▪ Upper slope catchment area<br>▪ Down slope area<br>▪ Roadsides drainages | ▪ Topography<br>▪ Soil types and their infiltration<br>▪ Land use and land cover<br>▪ Catchment area and rainfall intensity<br>▪ Seasonal characteristics of stream flow<br>▪ Community needs<br>▪ Availability of land for basin development<br>▪ Distance of the basin from road and its effect on the safety of the road | ▪ Micro basins are generally suitable to construct at locations with low storm water flow<br>▪ The location of the basin should be outside of the road reserve |
| <br>Unroofed Micro basin –built on the road side (Ethiopia) | | *Ensure Sustainability*<br>▪ Provide paved transition ditch if the surrounding soil is erodible<br>▪ Provide silt trap at entrance using dry masonry cascade<br>▪ Provide shade to minimize evaporation<br>▪ Provide shallow rooted trees/grass as shade to minimize evaporation<br><br>*Safety*<br>• Protect accidents by planting trees around the pond<br>• Protect accidents by fencing<br>• Provide access to the pond in defined direction<br>• Install signs which depicts prohibition of swimming | *Illustrative sketch*<br>1. Grass shade<br>2. Corrugated iron sheet<br>3. Trees<br>4. Safety Signs<br>5. Fence<br><br>Micro basin (Source: Desta 2005) |

| Ponds | | | |
|---|---|---|---|
| **Options** | **Possible area of application** | **Design Consideration** | **Remarks** |
| **Ponds** | ▪ Upper slope catchment area<br>▪ Down slope area<br>▪ Borrow pits as ponds | ▪ Topography<br>▪ Soil types and their infiltration<br>▪ Land use and land cover<br>▪ Catchment area and rainfall intensity<br>▪ Community needs<br>▪ Availability of land for pond development<br>▪ Distance of the pond from road and its effect on the safety of the road<br>▪ Design access in case of deep borrow pit to serve as pond | ▪ Down slope pond inlet Invert level shall consider drainage outlets and vice versa<br>▪ The location of the pond should be outside of the road reserve |
| <br>Pond used for roadside runoff that survived long drought period, Ethiopia. | | *<u>Ensure Sustainability</u>*<br>▪ Provide paved transition ditch if the surrounding soil is erodible<br>▪ Provide silt trap at entrance using dry masonry cascade<br>▪ Provide Bio engineering solutions to prevent erosions<br>*<u>Safety</u>*<br>• Protect accidents by planting trees around the pond<br>• Protect accidents by fencing<br>• Provide access to the pond in defined direction<br>• Install signs which depicts prohibition of swimming | *<u>Illustrative sketch</u>*<br>1. Planting of Grass/cactus around the pond<br>2. Safety Signs<br>3. Fence |

<table>
<tr><th colspan="4">Recharge well</th></tr>
<tr><th>Options</th><th>Possible area of application</th><th>Design Consideration</th><th>Remarks</th></tr>
<tr><td>Recharge wells</td><td>▪ Upper slope catchment area<br>▪ Down slope area</td><td>▪ Soil types and their infiltration<br>▪ Community needs<br>▪ Availability of land for recharge well development<br>▪ Distance of the Soak pits/dug-wells from road and its effect on the safety of the road</td><td>▪ To increase the storage capacity of the excavated material shall be stoked pile as a bank<br>▪ The location of the recharge well should be outside of the road reserve</td></tr>
<tr><td colspan="2"><br>Recharge well for recharging of groundwater along Mekele-Hewane route, Ethiopia.</td><td><u>Ensure Sustainability</u><br>▪ Provide paved transition ditch if the surrounding soil is erodible<br>▪ Provide silt trap at entrance using dry masonry cascade<br>▪ Provide bio-engineering solutions to prevent erosion<br><u>Safety</u><br>• Protect accidents by planting trees around dug wells / soak pits<br>• Protect accidents by fencing<br>Install signs which depicts prohibition of swimming</td><td><u>Illustrative sketch</u><br>1. Planting of Grass/cactus around the pond<br>2. Signs<br>3. Fence</td></tr>
</table>

## Annex 3.5: Roadside Tree Planting

| Roadside Tree Planting | | |
|---|---|---|
| **Options** | **Design steps on how to plant trees along a road stretch** | **Remarks** |
| **Roadside Tree Planting**<br> | 1. The trees are planted on a safe distance from the road.<br>2. Select tree species that:<br>○ Grow vertically<br>○ Are evergreen/remain green for most of the year<br>○ Tolerant of harsh conditions, indigenous to the area<br>○ Deep-rooted<br>○ Fast-growing and provide produce (timber/fruits/etc.)<br>3. Make the pits before the rainy season.<br>○ Pits to be 40cm by 40cm.<br>4. Plant trees during rains, shield the seedlings to prevent damage.<br>5. The spacing should be 3-4 meters<br>6. Where the road stretch is curved, the spacing should be increased to 10-12 meters | Benefits of roadside tree planting:<br>○ Reduce soil erosion by holding soil in place<br>○ Remove dust and other pollutants from the air, protecting crops and people<br>○ Flood control, by slowing and absorbing road run-off<br>○ Improved water quality by trapping sediment and increase water infiltration.<br><br>It is important to:<br>○ Ensure trees do not obstruct the visibility of the road for drivers<br>○ Young trees need management, water them regularly during the, apply mulching, and monitor regularly. |

# Annex 4: Results of the hydrological study for the pilot road

*Table 25: Obtained discharges*

| CAT No | Area km2 | Longest path (m) | Max (m) | Min (m) | Catch-avrg-slope (%) | Stream -Slope m/m | Overland length (m) | N | Tc (h) | **ARF** | I (mm/h) | C | Discharge (m3/s) for 10 years | Discharge (m3/s) for 25 years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.28 | 2403.49 | 1880 | 1795 | 8.27 | 0.035 | 527.35 | 0.3 | 0.795 | 0.951 | 21.184 | 0.22 | **1.560** | **1.928** |
| 2 | 0.05 | 433.01 | 1853 | 1809 | 12.96 | 0.102 | 311.71 | 0.3 | 0.365 | 0.987 | 39.798 | 0.28 | **0.156** | **0.194** |
| 3 | 0.4 | 1689.39 | 1885 | 1817 | 6.98 | 0.040 | 555.61 | 0.3 | 0.661 | 0.971 | 24.618 | 0.28 | **0.772** | **0.956** |
| 4 | 0.32 | 1056.43 | 1876 | 1832 | 6.36 | 0.042 | 518.23 | 0.4 | 0.580 | 0.973 | 27.350 | 0.28 | **0.686** | **0.851** |
| 5 | 1.05 | 3071.82 | 1927 | 1852 | 5.37 | 0.024 | 1976.53 | 0.4 | 1.277 | 0.962 | 14.437 | 0.28 | **1.144** | **1.406** |
| 6 | 11.29 | 7558.46 | 2828 | 1846 | 27.22 | 0.130 | 1623.59 | 0.4 | 1.519 | 0.883 | 12.547 | 0.34 | **13.644** | **16.753** |
| 7 | 5.97 | 5808.14 | 2193 | 1851 | 10.28 | 0.059 | 1359.76 | 0.4 | 1.371 | 0.912 | 13.629 | 0.28 | **5.818** | **7.151** |
| 8 | 0.46 | 1588.86 | 1931 | 1864 | 7.49 | 0.042 | 806.73 | 0.4 | 0.761 | 0.970 | 21.946 | 0.28 | **0.791** | **0.979** |
| 9 | 1.39 | 3605.05 | 2064 | 1880 | 9.55 | 0.051 | 562.15 | 0.4 | 0.954 | 0.952 | 18.281 | 0.28 | **1.897** | **2.340** |
| 10 | 0.23 | 1594.27 | 1924 | 1877 | 8.88 | 0.029 | 761.25 | 0.4 | 0.816 | 0.979 | 20.760 | 0.28 | **0.374** | **0.462** |
| 11 | 1.16 | 1754.69 | 1996 | 1905 | 11.47 | 0.052 | 414.18 | 0.4 | 0.677 | 0.951 | 24.152 | 0.34 | **2.566** | **3.176** |
| 12 | 0.14 | 250.63 | 1944 | 1937 | 6.98 | 0.028 | 233.32 | 0.4 | 0.334 | 0.978 | 42.829 | 0.28 | **0.470** | **0.586** |
| 13 | 0.43 | 913.77 | 2055 | 1965 | 6.82 | 0.098 | 797.86 | 0.4 | 0.580 | 0.969 | 27.358 | 0.28 | **0.922** | **1.143** |
| 14 | 0.39 | 1407.32 | 2115 | 1995 | 21.29 | 0.085 | 562.85 | 0.4 | 0.699 | 0.972 | 23.521 | 0.34 | **0.884** | **1.093** |
| 15 | 0.44 | 1614.27 | 2160 | 2061 | 11.28 | 0.061 | 601.05 | 0.4 | 0.704 | 0.970 | 23.386 | 0.34 | **0.991** | **1.226** |
| 16 | 0.82 | 2517.63 | 2213 | 2103 | 7.39 | 0.044 | 1315.92 | 0.4 | 1.003 | 0.964 | 17.555 | 0.28 | **1.129** | **1.391** |
| 17 | 0.97 | 2940.67 | 2241 | 2104 | 7.23 | 0.047 | 1768.14 | 0.4 | 1.127 | 0.962 | 15.980 | 0.32 | **1.389** | **1.710** |
| 18 | 0.14 | 669.05 | 2142 | 2112 | 6.24 | 0.045 | 341.97 | 0.4 | 0.444 | 0.980 | 33.986 | 0.32 | **0.426** | **0.530** |
| 19 | 0.17 | 892.61 | 2145 | 2114 | 6.59 | 0.035 | 417.36 | 0.4 | 0.536 | 0.980 | 29.159 | 0.32 | **0.444** | **0.551** |
| 20 | 31.34 | 15794.2 | 2908 | 2113 | 28.09 | 0.050 | 1664.89 | 0.4 | 2.600 | 0.837 | 8.118 | 0.38 | **27.355** | **33.406** |
| 21 | 2.37 | 4190.79 | 2326 | 2116 | 10.29 | 0.050 | 1459.27 | 0.3 | 1.181 | 0.942 | 15.382 | 0.32 | **3.076** | **3.786** |
| 22 | 0.67 | 1855.15 | 2288 | 2132 | 17.64 | 0.084 | 859.28 | 0.3 | 0.762 | 0.964 | 21.924 | 0.38 | **1.579** | **1.953** |
| 23 | 6.52 | 6172.38 | 2889 | 2176 | 36.15 | 0.116 | 929.24 | 0.3 | 1.215 | 0.904 | 15.035 | 0.38 | **9.531** | **11.729** |
| 24 | 1.43 | 2318.96 | 2773 | 2191 | 38.58 | 0.251 | 1070.41 | 0.3 | 0.862 | 0.950 | 19.841 | 0.38 | **2.897** | **3.578** |

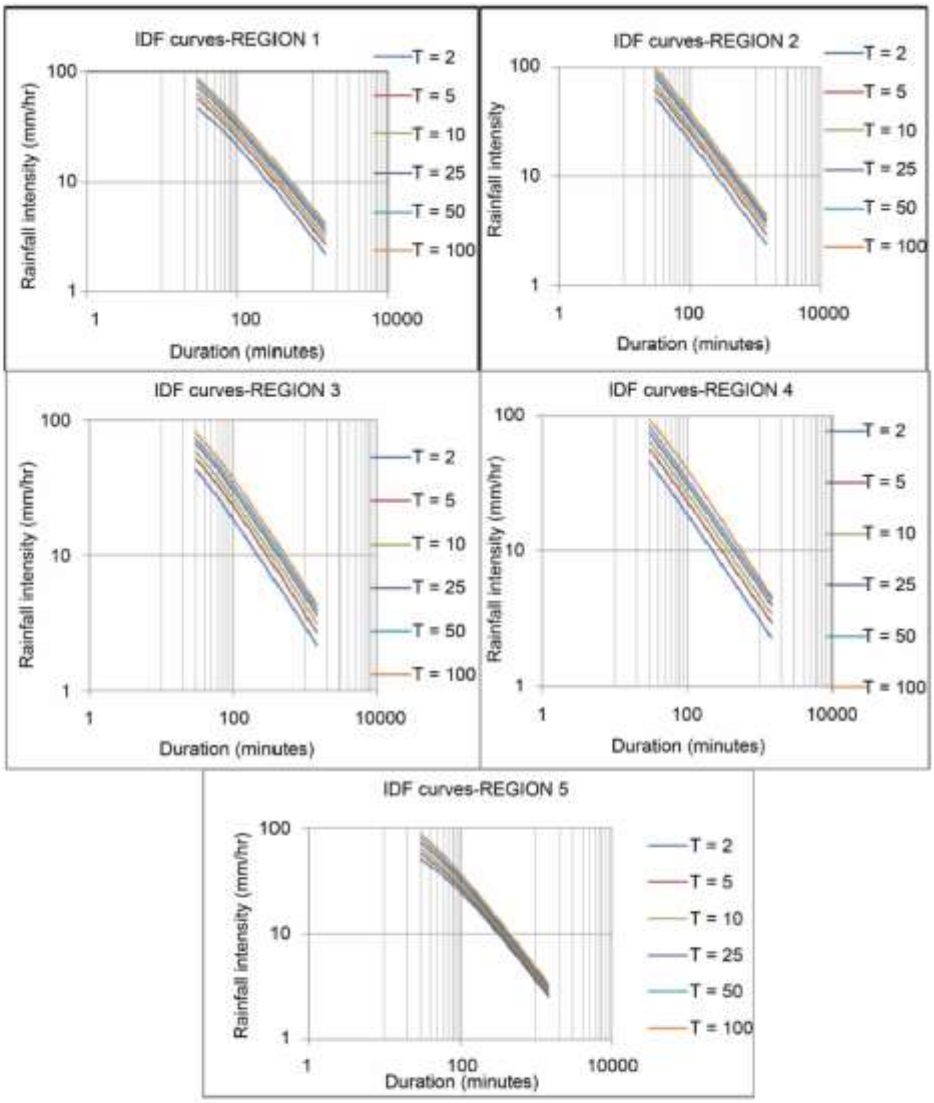



*Figure 33: Regional IDF curves for selected return period.*

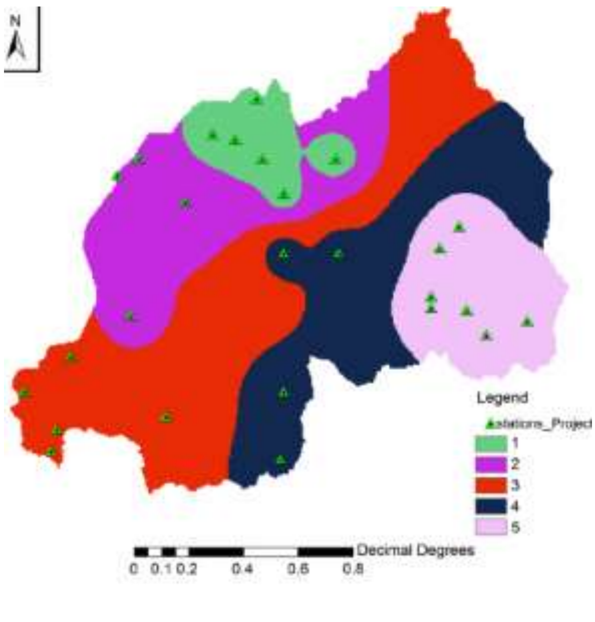



*Figure 34: Homogeneous regions identified based on rainfall frequency analysis (Wegesho and Marie-Claire, 2016).*