IWRM Programme Rwanda

IWRM Tool box and development of design criteria for hydraulic structures in Rwanda – Final Mission report

May 2017



Kingdom of the Netherlands

Issue and revision record

Revision	Date	Originator	Checker	Approver	Description
Final	22-054-2017	Benon Zaake	Rob Nieuwenhuis	Ebel Smidt Vincent de Paul Kabalisa	Final Mission Report 1

Water for Growth Rwanda is a platform to promote improved management of Rwanda's water resources. A joint Rwanda-Netherlands initiative, Water for Growth is supported by the IWRM Programme Rwanda, implemented by Euroconsult Mott MacDonald (lead partner) in association with SNV and SHER. www.water.rw

The Integrated Water Resources Management (IWRM) Programme Rwanda is led by the Government of Rwanda and supported by the Embassy of the Kingdom of the Netherlands (EKN). EKN Project number: 201501033.062; Mott MacDonald project nr: 348246. www.mottmac.com

Content

Summary

MR #	Summary of what has been accomplished	Future action points
MR01	**Mission Report 01 – May 2017** • During this fifth mission the expert focused on supporting the contributing towards formulation of the IWRM tool box and development of design criteria for hydraulic structures in Rwanda. • The tool box remains a work in progress and some elements are now in place. • Design criteria for design of hydraulic structures have been proposed. Regionalized Intensity duration curves for design of such structures are now available for use. A Manual for application the East African Flood Model is uploaded to share point for future use. • TOR for research agenda for further development of flood design estimation tools have been proposed. In summary, the TOR deliverables have been accomplished	• Further elaboration of design criteria for water harvesting structures; • Tool box completion • Improvement of the TOR for the Volcanoes Study

This document constitutes proposals for design criteria for hydraulic structures in Rwanda and elements of materials for an IWRM Toolbox. Structures covered include road drainage infrastructure, small flood protection levees and hydraulic structures for small scale water harvesting e.g. small dams and tanks for multi-purpose use. The proposals are described in a manual which is organized as follows:

Section 1 outlines criteria for design of road drainage hydraulic structures. Section 2 contains elements of a tool box for small dams/ponds and other water conservation structures. Section 3 elaborates research themes necessary for improvement of hydrological design methods in Rwanda and follow up actions. The manual is supplemented by annexures. The annexures contain proposed regionalized flood estimation methods for ungauged catchments in Rwanda.

1. Road drainage structures

1.1 Review of existing design criteria for road drainage hydraulic structures in Rwanda

Design criteria for road drainage hydraulic structures are often prescribed under road geometric design standards. A review of existing practices revealed that geometric and drainage road design practice in Rwanda used to follow French standards but has of recent started to use American standards. Burundi follows the French design standards. In contrast, Ethiopia, Kenya, Tanzania and Uganda use their own standards which were developed largely from the American and English practices. The standards for Ethiopia, Tanzania and Uganda provide comprehensive guidance concerning drainage. For purposes of developing appropriate criteria for design of hydraulic structures in Rwanda, material from manuals within the region has been utilized together with data sourced from Rwanda Meteorological Agency to ensure that:

- Design criteria for Rwanda take into account the relevant legislation and policies
- Content is generic and specific to Rwanda
- The criteria are in line with international practice
- Criteria are comprehensive and not lacking important information.

1.2 Surveys and data requirements

IWRMD will routinely review design reports for hydraulic structures submitted by consultant firms or other government agencies e.g. RTDA prior to issuance of permits for hydraulic works on rivers. Typical data that must be included in such surveys or studies for purposes of permit processing should include:

- Topographic Maps, Digital Elevation/Terrain Models (DEM/DTM), and Aerial Photographs;
- Soil Maps, Land Use/Land Cover Maps, Geological maps
- Larger scale plan showing location of the drainage structure in the catchment;
- What the site is used for currently; Size of the site;
- What hydraulic structure is proposed?
- Source of flooding on site/mechanisms of flooding;
- Location of watercourses/drainage ditches in the area;
- Location of stream flow/level gauge stations in the area
- Design Rainfall records
- Design discharge
- Historical highwater marks
- Flood Zone Maps, design flood levels, capacity analysis of cross drainage structures
- Design drawings
- Erosion control measures
- Designated flood plain areas
- Description of the hydraulic modelling approach where flood risk before and after the watercourse crossing structure needs to be demonstrated.

The following is a summary of standards and design criteria that must be used to appraise or evaluate hydrological and hydraulic analysis designs of hydraulic structures for purposes of issuance of permits for hydraulic works.

1.3 Design return period

The quantity of water that drainage systems must cope with is dependent on risk factors associated with damage, cost, potential upstream land use change which could reasonably occur over the anticipated life of the drainage facility, low maintenance practices etc.
Table **1** prescribes storm design period for different structures based on international practice and review of return period standards in the region. Span in the table is the total clear-opening length of a structure. For example, the span for a double 1.2-meter diameter pipe is 2.4 meters. A 20% flow allowance for climate change should be added to the above design flows.

Table 1: Indicative storm design return period (years) for different structures

Type of drainage structure	Design return period (years)
Gutters and inlets	5
Side ditches	10
Ford (stone drift)	10
Culvert (diameter < 2m)	15
Large diameter culvert (> 2m)	25
Short span bridge (6m < span < 15m)	25
Medium span bridge (15m < span < 50m)	50
Long span bridge (> 50m)	100
Check/review flood for bridges	200

Furthermore, drainage structures should be sized to ensure that flow velocities and afflux are acceptable. Specific issues to be addressed should include:

- Ensuring property and crops will not be affected by an increase in water levels or duration of inundation;
- Changes to flow patterns, and consideration of seasonal variations in hydraulic roughness linked to changes in vegetation cover.

1.4 Criteria for selection of cross drainage structures

The objective in selecting a structure for a water crossing is to choose the most appropriate design for each location. For small water-courses the choice of structure will, in general, be between a culvert and drift and, for larger watercourses, between a vented ford and a large diameter culvert, or possibly a bridge. Figure 1 below highlights the key issues and should only be used as a guide when determining the most appropriate structure.

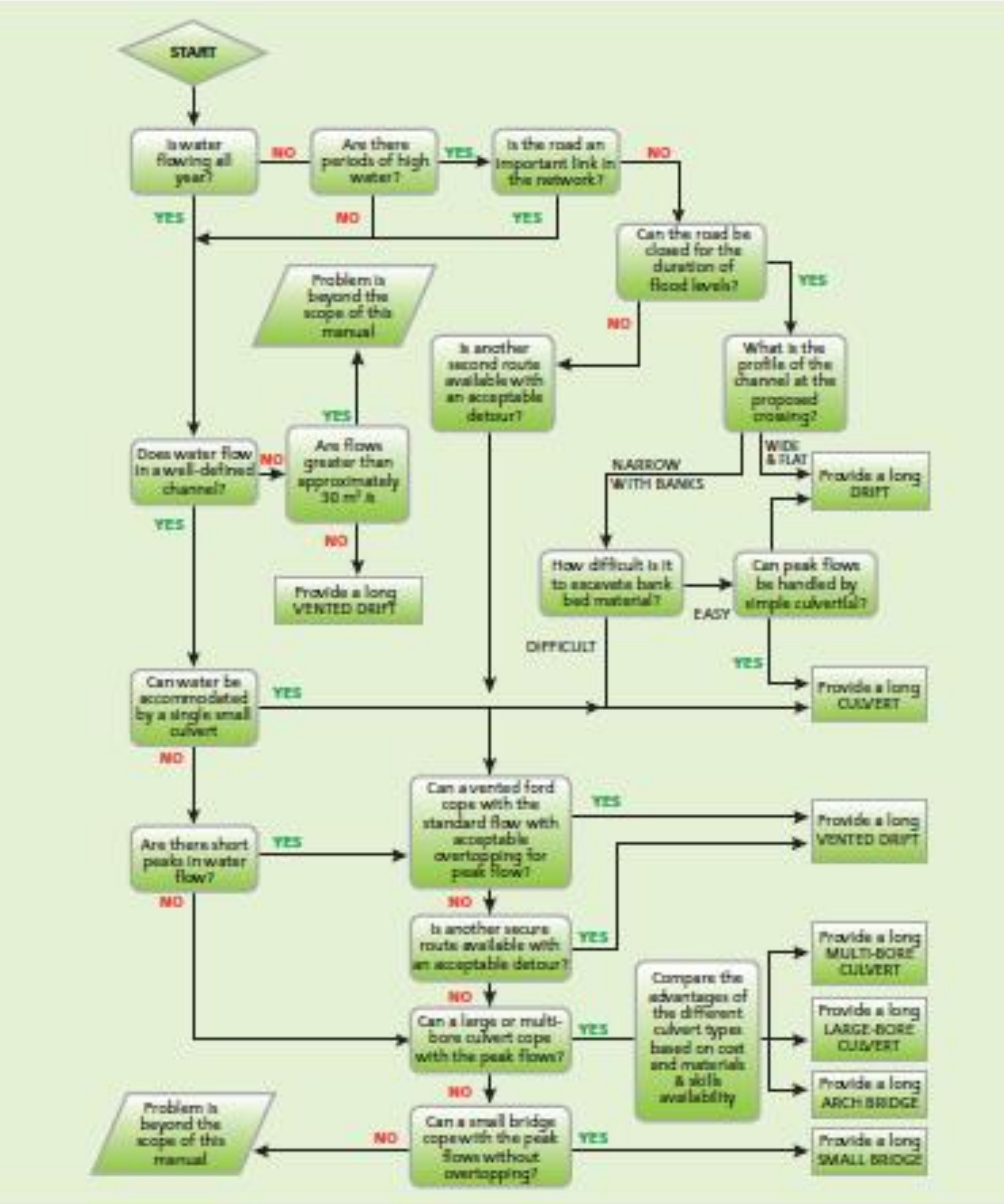


Figure 1: Recommended cross drainage structures (Source: Compiled from international Practice)

1.5 Backwater effects

Limiting backwater effects arising due to obstruction of flow due to limited capacity of hydraulic structures within is a key consideration during appraisal and regulation of proper design of these structures. Allowable backwater profile upstream of a bridge or large culvert can be a serious concern for communities and property owners within the affected vicinity. During the planning phase, any properties, infrastructure or other features upstream of the crossing must be reviewed. These structures then need to be considered in the design and the impact on flood levels at each of these must be included in the design process. When dwellings or other man-made structures are close to the drainage way, a limitation shall be placed on the maximum backwater effect to be tolerated for drainage structure design. Such a limitation may be phrased as follows:

"The maximum backwater effect at a drainage structure shall be 0.5 metres lower than the floor elevation of buildings or the floor level of dwellings is higher by 1.5 metres above the natural design flood elevation. Otherwise, the maximum backwater level shall be 1.0 metres lower than the floor elevation of upstream buildings or dwellings and the check flood elevation shall be 0.3 metres lower."

Application of hydraulic/river modelling software such as HEC-RAS is necessary to simulate or estimate backwater effects.

1.6 Erosion control and embankment protection

Side drains are normally utilised to collect water and run it along road embankments to a point where the water can conveniently be diverted, either away from the road prism or through it by means of a culvert. To avoid erosion, drains steeper than 3% may need scour protection (Figure 2), depending on the erodibility of the soil and the vegetative cover.

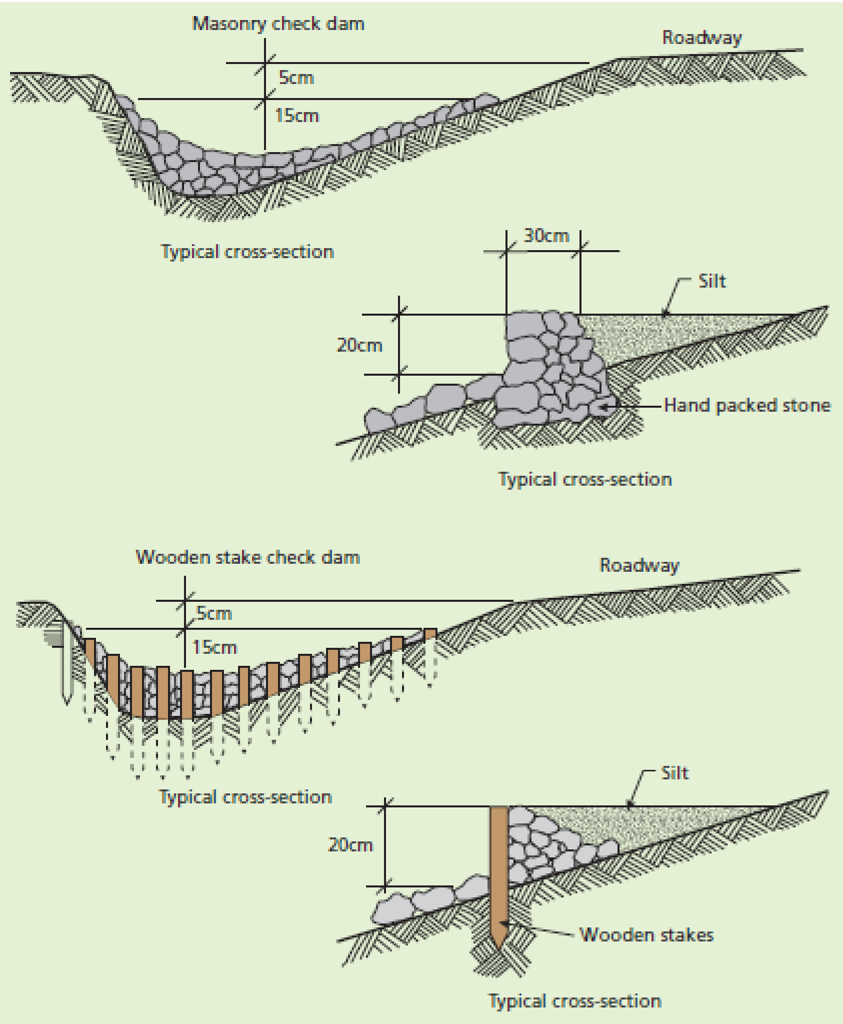


Figure 2: Typical design of scour checks

The distance between scour checks depends on the road gradient and the erosion potential of the soils. shows recommended values for normal soils. The spacing should be reduced for highly erodible soils

Table 2: Indicative storm design return period (years) for different structures

Road gradient (%)	Scour check interval (m)
3	Usually not required
4	17
5	13
6	10
7	8
8	7
9	6
10	5
12	4

Interceptor, cut-off or catch-water drains are also commonly used to prevent water flowing into vulnerable locations (e.g. down cut faces) by 'intercepting', 'cutting off' or 'catching' the water flow and diverting it to a safe point of discharge, usually a natural watercourse, as illustrated in Figure 3. Interceptor drains above cut faces should have a gradient of 2% on their full length and should be at least 3 to 5 m from the cut face. If steeper gradients in the drain are unavoidable then scour checks should be installed or the drain should be lined. The drain should also be lined where seepage will weaken the cut slope. Interceptor drains should be at least 600 mm wide, 400 mm (minimum) deep with sides back-sloped at 3:1 (vertical: horizontal) or less.

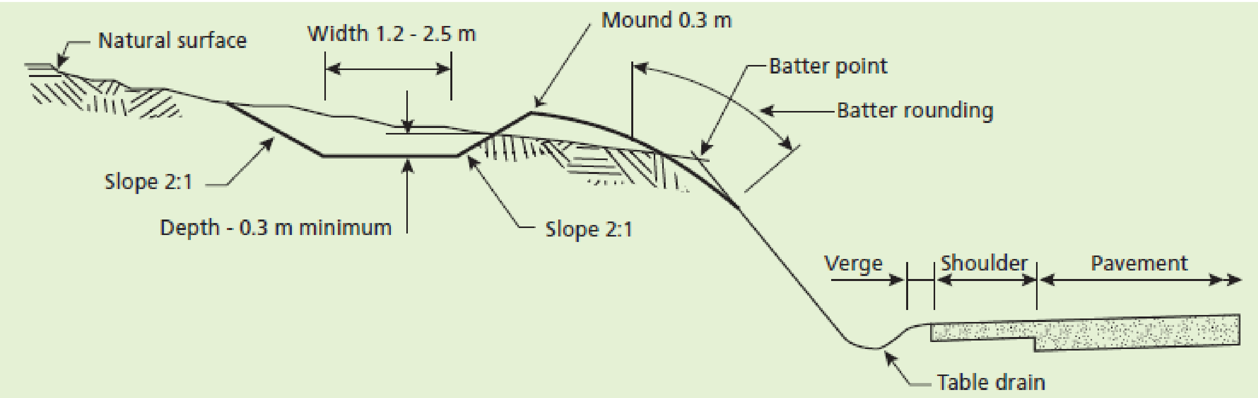


Figure 3: interceptor, cut-off or catchwater drain

Structures known as chutes are also deployed to convey a concentration of water down a slope that, without such protection, would be subject to scour. Since flow velocities can be very high, stilling basins are required to prevent downstream erosion. The entrance of the chute needs to be designed to ensure that water is deflected from the side drain into the chute, particularly where the road is on a steep grade. On embankments it may be necessary to lead water to the top of chutes using kerbing.

1.7 Hydrological flood estimation

This section provides guidance about hydrological aspects of drainage, such as the sizing of catchment areas, determination of run-off volumes and sizing of water crossings and drains to accommodate the flow. Details about the methodologies for designing individual features of the hydraulic structures are not covered as these are well-covered under standard texts for universal hydraulic design principles. Many hydrological flow estimation methods are available. The methods to be used and the circumstances for their use are listed below.

1.7.1 Regionalized design flood estimation for ungauged catchments

In instances where no runoff data is available, design flood estimation should be undertaken using analysis of 24-hour rainfall storm return period rainfall totals. The area of the drainage catchment (A) should be estimated from topographical maps or through the use of digital elevation models. The Rational Method (Equation 1-1) can be adopted for estimating peak discharges for small drainage areas up to about 100 hectares. This method determines the flow of water in a channel, q, based on the equation below:

$$Q\ (m^3/s) = 0.278 \times C \times I \times A \quad \text{.......... Equation 1-1}$$

Where:
C = the catchment run-off coefficient
I = the intensity of the rainfall (mm/hour) for the Tc (time of concentration of the catchment area)
A = the area of the catchment (km^2)

The 'Time of Concentration' for each catchment can be calculated by a number of formulas. For example the following form of the Kirpich Formula can be used:

$$Tc = (0.87\ L^3 / H)0.385$$

Where:

T_C = Time of concentration (hr)
L = the length of the catchment area in Km
H = the corresponding level difference in metres

Appropriate catchment runoff coefficients should be used depending on topography, soils and vegetation cover assessments and tabulated values documented in standard textbooks. The intensity of rainfall (I) is obtained from Intensity-Duration-Frequency (IDF) charts usually developed by the Rwanda Meteorological Agency. Such charts vary across the country[1] and locally derived[2] charts can also be used be used. Regionalized IDF curves corresponding to 5 regions in Rwanda (Figure 4) have been derived based on a total of data from 26 rainfall stations.

[1] Negash Wagesho and Marie Claire (2016). Analysis of Rainfall Intensity-Duration-Frequency Relationship for Rwanda

[2] G. R. Demar´ee and H. Van de Vyver (2013). Construction of intensity-duration-frequency (IDF) curves for precipitation with annual maxima data in Rwanda, Central Africa.

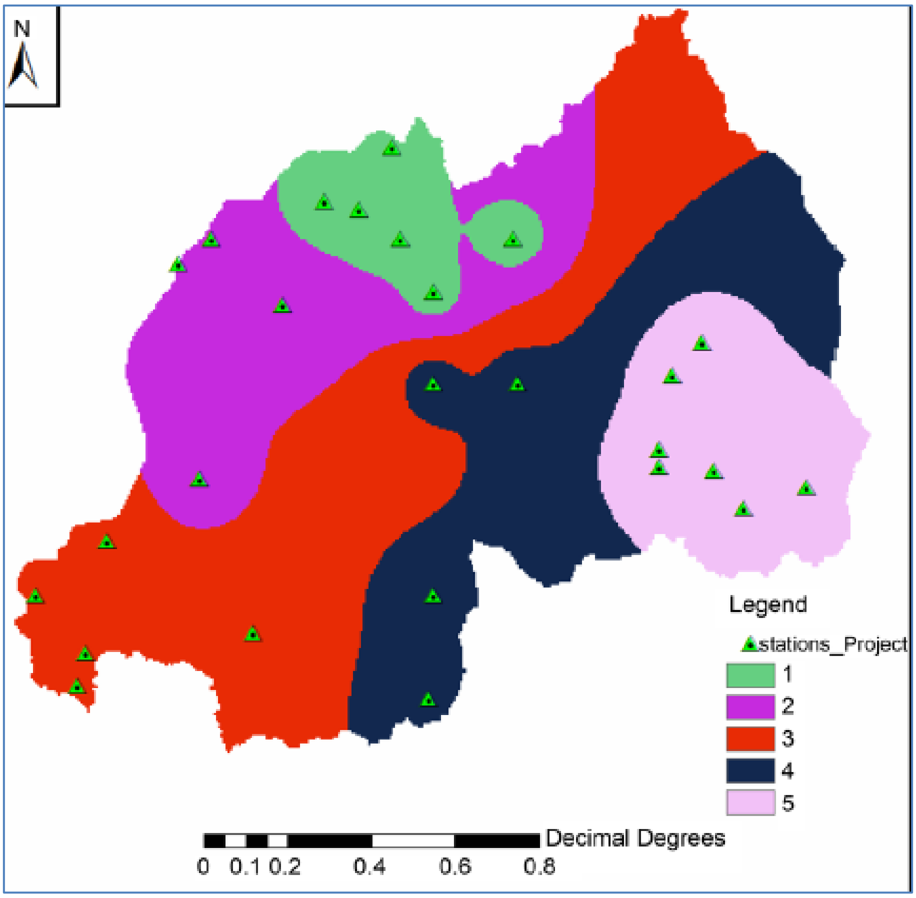


Figure 4: Homogeneous regions identified based on rainfall frequency analysis (Wegesho and Marie-Claire, 2016)

The Regional IDF curves that prescribe rainfall intensities for various durations and return period are presented in Figure 5. These are supplemented by IDF maps in Annex 1.

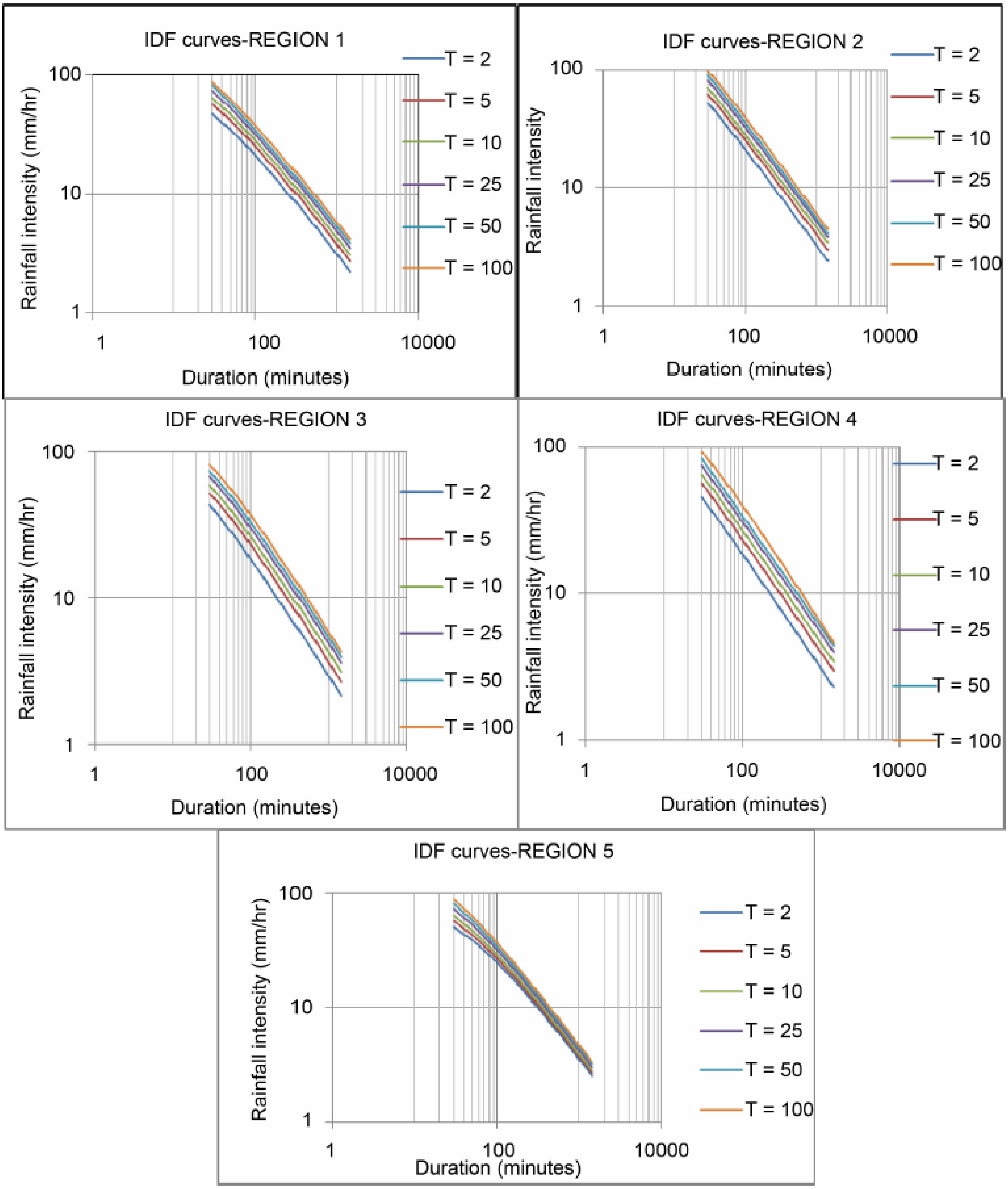


Figure 5: Regional IDF curves for selected return period

Design flood estimation for larger catchments up to 10 km^2 can be considered using modified Rational Methods, using the areal reduction factor shown in Equation 1-2 below. The effective area of the catchment is reduced by multiplying by the areal reduction factor (ARF) given by the following equation:

$ARF = 1 - 0.04 \times t^{-1/3} \times A^{1/2}$...Equation 1-2

Where:

t = storm duration in hours
A = catchment area in km^2

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 (Figure 5) within the frame work prescribed by the East African Flood Model[3] or the Generalised Flood Tropical Model[4]. Technical details relating to application of the method are presented under Annex 2.

1.7.2 Design flood estimation where flow records are available

For gauged catchments a number of established flood frequency models and rainfall-runoff models do exist that use annual maximum data or partial duration flood time series. Whenever possible, the determination of the expected peak flows should be based on actual and accurate stream flow data. When such data are available, a flood frequency analysis based on the annual maximum discharge series should be can be undertaken. Care should be taken to use the hydrological year (October – September), not the calendar year (January – December) to establish the annual maximum series. An open source statistical software (e.g. Easyfit) can be used to fit different probability distributions to the annual maxima data series. Care should be taken to select probability distributions appropriate for discharge analysis e.g.

- Gumbel – EV Type ;
- Frechet - EV Type II;
- Weibul - EV Type III;
- Log-Pearson Type III;
- Log Normal Distribution;
- Wakeby Distribution.

[3] D. FIDDES, The TRRL East African Flood Model. TRRL Laboratory Report 706, 1976.

[4] Fiddes and Watkins (1984). Highway and urban hydrology in the tropics

2. Small dams, pans and other water conservation structures

There exists a plethora of innovative technologies for water harvesting that can be applied in Rwanda (BOX 1). Some of these are illustrated below with accompanying descriptive text.

Box 1: Selected references on the design of small dams

- 2010. FAO Manual of small earth dams. A guide to siting, design and construction. Irrigation and Drainage Bulletin n° 64
- 2009. FAO. Farm Ponds for Water, Fish and Livelihoods
- 2006. DANIDA/ASAL Consultants. Water from small dams by Eric Nissen-Petersen
- 2001. FAO Small dams and weirs in earth and gabions materials. Misc.Publ. AGL n° 32
- 1991. FAO. Water harvesting - A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production
- 1975-1982. FAO. Small Hydraulic Structures.

2.1.1 Sand storage dams

Sand storage dams are relatively small and built into the bed of a seasonal river. During the wet season sand that is transported by the river accumulates behind the dam. As a result, a sandy layer is created in the riverbed that grows every wet season until it levels the top of the dam (Figure 6). This technology is can be applied in cascades within seasonal dry river beds in Muvumba. A combination of an infiltration gallery and hand pump that can be utilized to abstract water from such dams is illustrated under Figure 7. The costs of the construction of a dam is in the range of USD 8,000-12,000. Additional costs have to be added for the installation of 2-4 dug wells with a hand pump (total USD 2,000- 3, 000). The total investment costs therefore may vary between USD 10,000 - USD 15,000. A sand dam provides about 1,500 - 2,000 m^3 of storage during a rainy period. Assuming 2 rainy seasons, the total storage capacity is about 4,000 m^3/year. On an average, 25 families or about 150 persons use a dam.

Figure 6: Sand storage dam

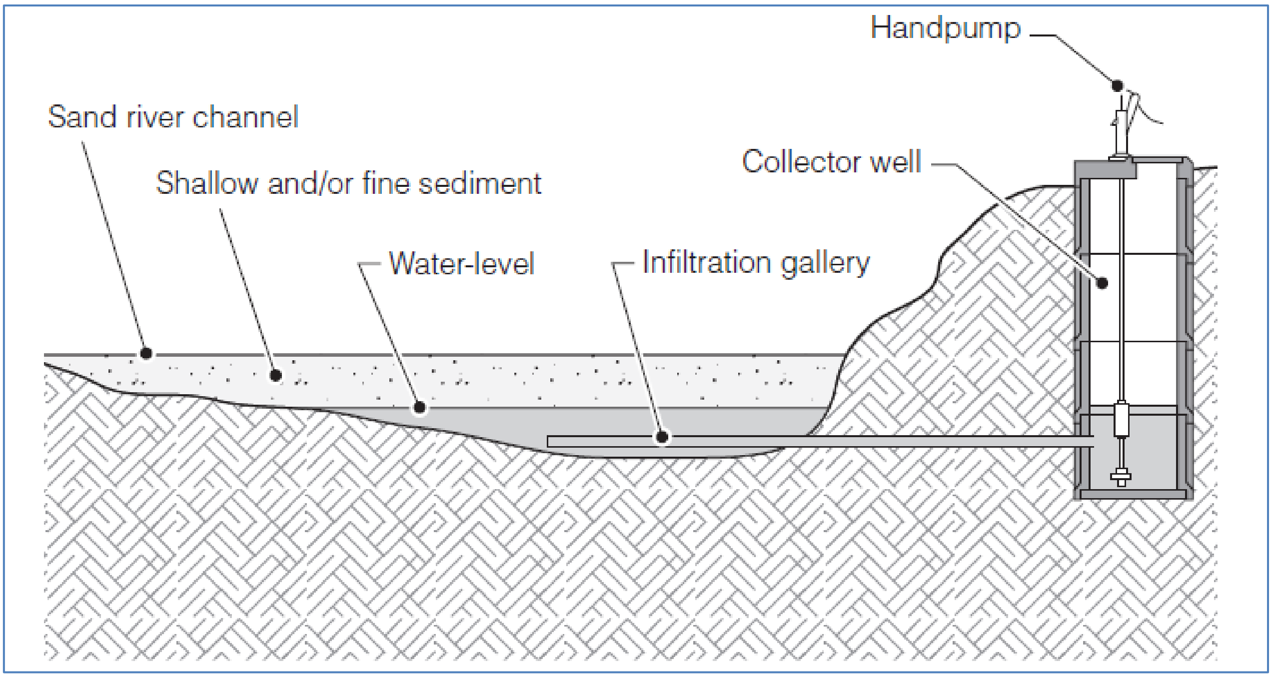


Figure 7: Cross-section of an infiltration gallery and collector well (Source: Water from Sand Rivers[5])

[5] Hussey (2007). Water from Sand Streams. *Guidelines for abstraction*. Water, Engineering and Development Centre Loughborough University

2.1.2 Earth fill dam

Earth fill dams are the technology of choice for development of Irrigation schemes by MINAGRI but it is important to upscale their implementation to include multi-purpose use and integrate farm-scale management practices to improve water productivity and efficiency. Better management of rain-fed agriculture and or use of supplementary irrigation is required while addressing gender gaps in agricultural productivity.

2.1.3 Low cost pedal pump systems

Smallholder farmers inhabiting areas that receive relatively less rainfall in Rwanda such as Nyagatare, Rwamagana, Gatsibo, Kayonza and Rwamagana can be supported to adopt low cost water abstraction technologies that extract water from sand dams, rivers and small earth dams to irrigate hillside areas as a means to grow more crop during dry seasons. The different technologies include bucket irrigation, gravity fed sprinkler and drip, treadle and pedal pumps, rope and washer and low cost diesel motorized pumps. Inexpensive and simple gravity and pump sprinkler systems for horticultural crops can be extremely profitable investments. Use of the pedal pump on valley bottoms has immense potential. The light portable pedal pump (Figure…) is an adaptation of the Asian treadle pump by a local NGO (Approtech). Nicknamed the "Moneymaker," these sell for about US$70 and can be actively marketed in towns and villages. The pump is most appropriate for smaller, subsistence farmers who see the opportunity to expand irrigation on small plots. Farmers who expand their production to grow cabbages, French beans, snow peas and other crops for export. Women, who do most of the field work, are expected to gain greater earning power. The success of the pump technology in Kenya is attracting a younger generation back to the farms.

Opportunity exists for the Water for Growth Program towards extending grants to farmers and small-scale entrepreneurs to produce and maintain equipment like low-pressure butterfly sprinklers and pedal pumps.

2.1.4 Useful contacts

The following is a list of some individuals, practitioners, organisations and commercial companies that have experience and an interest either directly in water harvesting or conservation or allied aspects and are prepared to offer assistance in their particular field.

3. Follow-up

(i) Review of existing design practices for hydraulic structures in Rwanda has revealed many areas that merit further improvement. These are summarised below:

- Lack of a clear methodology for estimating design floods for ungauged areas. Application of the Rational method with Regionalised IDF curves for Rwanda is recommended for catchment areas not exceeding 10 km2. The East African Flood Model has been proposed for larger areas. However, more research is required to update the parameters values its relies on to estimate the design flood e.g. land use factor, soil types factor etc.

- Regionalized flood and low flow frequency estimation methods based on observed flow data are not available in Rwanda. This is a potential are for research where various distributions can be fitted to observed annual or partial maxim flood magnitudes. This research can be conducted through development of a collaboration mechanism between IWRMD and the University of Rwanda, KIST and Delft University in the Netherlands

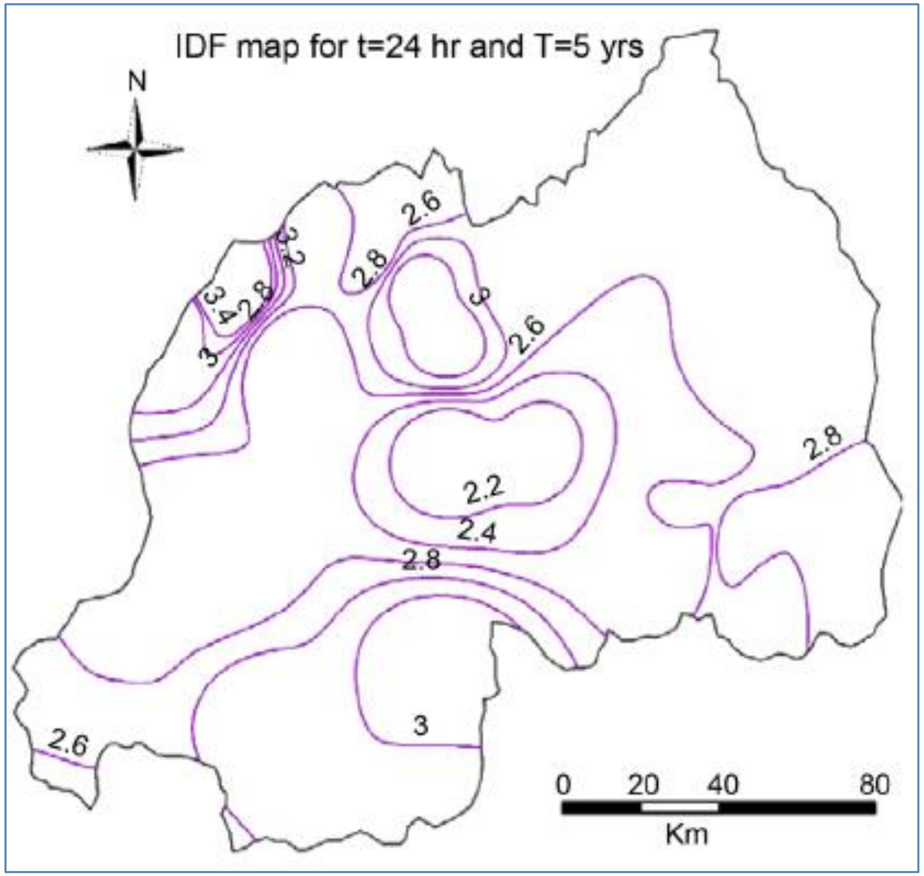
- A comprehensive design drainage manual needs to be developed by RTDA in collaboration with IWRMD. Consultants can be commissioned to develop the manual. This document should serve as a useful resource for such purposed. For purposes of complementing the drainage design manual, it will be necessary to develop a customised, user-friendly Design Flood Estimation Tool (DFET) containing the latest design rainfall information and recognised estimation methods used in East African flood hydrology. Further research will be required to demonstrate the use and functionality of the developed DFET by comparing and assessing the performance of the various design flood estimation methods in gauged catchments with areas ranging from 10 km^2 to 10 000 km^2. Research can be conducted by under a collaboration arrangement between RTDA, IWRMD and the Universities of Rwanda, KIST, and Delft in the Netherlands.

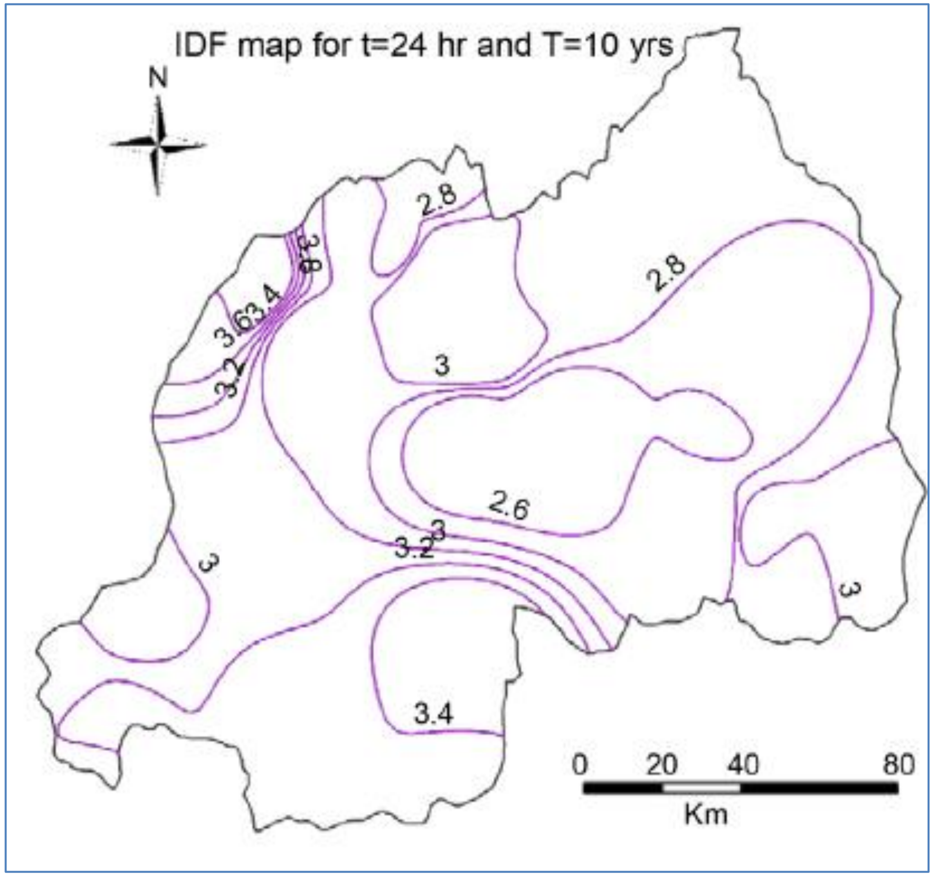
(ii) A practice manual for Practice Manual for design and construction of Small Dams, Pans and Other Water Conservation Structures in Rwanda needs to be developed. This is important given the fact that Inadequate water is the largest constraint to sustainable livelihoods in many parts of Eastern Rwanda. Such a manual can be developed in collaboration with MININFRA, MINAGRI, REMA and MINIRENA.

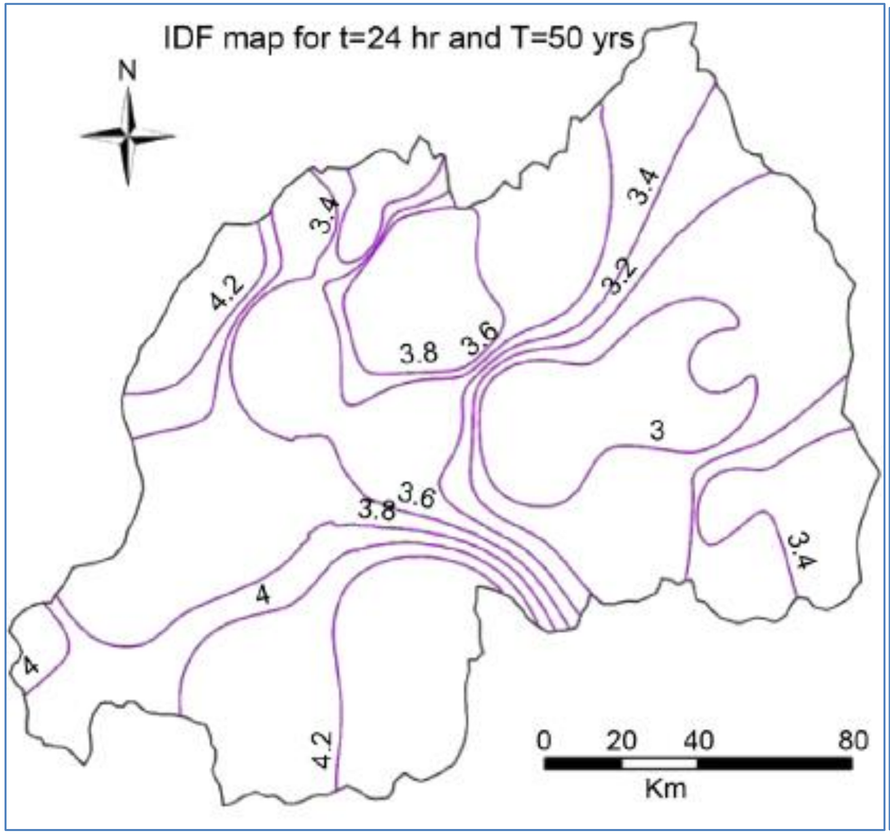
(iii) A TOR has been proposed to complete the Volcanoes Flood Study. The TOR require improvement and this can be achieved by allowing for additional input by the Water Resources Planner. It is envisaged this may best be accomplished by engaging a Consultancy Team with competencies in Feasibility studies and Detailed Design of Flood Management Hydraulic Structures. The expertise required is in the fields of flood sisk management, Hydraulic Design, EIA, Subsurface and Surface Drainage Hydrologic Design, Topographic surveying and Economic Analysis and Costing.

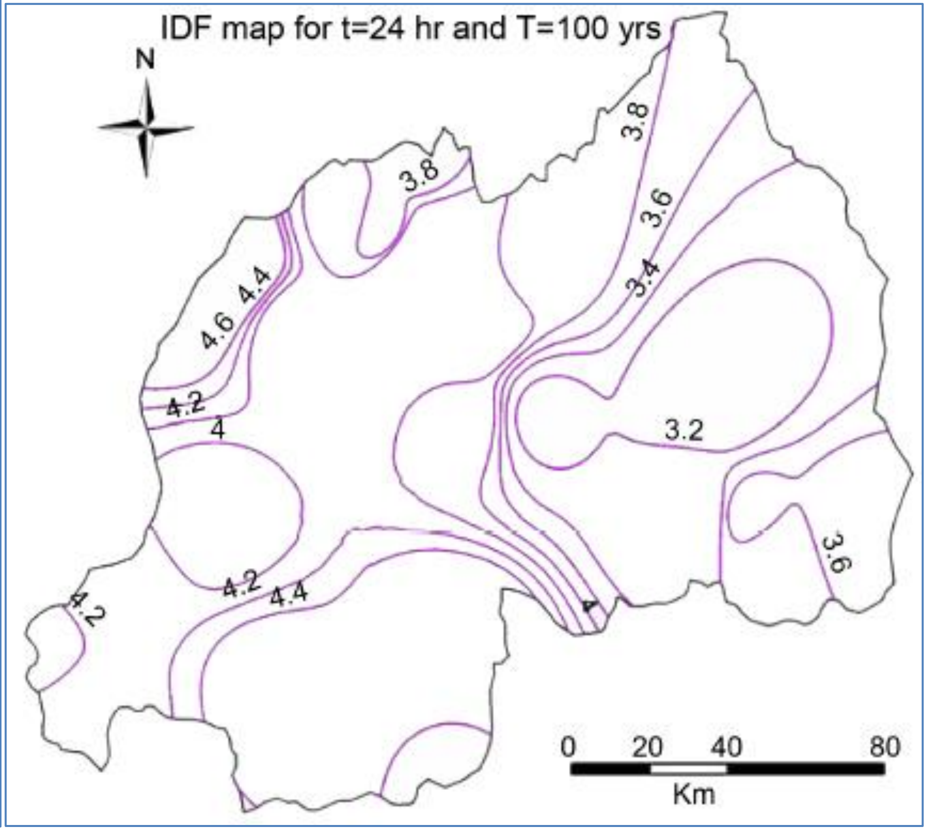
(iv) Completion of the Toolbox

Annex 1. Design Rainfall Intensity-Duration- Frequency (IDF) maps for Rwanda






IDF map for t=24 hr and T=50 yrs
N
4.2
3.4
3.8
3.6
3.4
3.2
3
3.8
3.6
4
4
4.2
3.4
0 20 40 80
Km


IDF map for t=24 hr and T=100 yrs
N
3.8
3.8
3.6
3.4
4.6
4.4
4.2
4
3.2
4.2
4.4
4.2
4
3.6
0 20 40 80
Km

Annex 2. The East African Flood model

Refer to pdf document enclosed.

Annex 3. TOR

3.1 Mission objective

Support the TA team with development of an IWRM best practice toolbox customised for Rwanda's land and water resource development and management at catchment scale level. In addition, provide additional support towards development of design criteria for hydraulic structures and their incorporation into the toolbox that is currently under development. A derived understanding of the TOR as proposed in a briefing by the TL and DTL prior to commencement of the mission on 8th May 2017 is summarized below.

3.2 Understanding of the Terms of Reference

Rwanda Transport Development Agency (RTDA) is a Government institution affiliated to the Ministry of Infrastructure (MININFRA). The main functions of RTDA that have a bearing on water include managing and controlling national road network with a view to achieving road safety and maintenance and management and control of waterways transport infrastructure. However, dilapidated or poorly designed hydraulic structures in Rwanda[6] frequently pose significant challenges related to enhancement of flooding, landslide occurrence and pollution of water sources.

The reformulated Water Law[7] mandates IWRMD to protect and manage the water resources of Rwanda through the implementation of a number of strategic actions and provisions such as

i) Develop and promote best practices of efficient and appropriate watershed management
ii) Institute measures for managing water related disasters and stresses e.g. floods,

As such, water uses and activities by means of works, structures and installations sanctioned by RTDA that are susceptible to modify the flow or the level of water resources, or to degrade their quality, or to threaten water-related ecosystems, wetlands, swamps and the environment shall be subject to water permitting. Currently existing guidelines for designs and maintenance of roads[8] issued by RTDA do not contain sufficient provisions relating to criteria for design of hydraulic structures for purposes of complying with the requirements for issuance of a water permit. Hence the development of such criteria is based on accepted standards and practice for drainage has been identified as a key task within the TOR. The criteria should be comprehensive and cover diverse issues such as:

a) Flood risk to nearby infrastructure
b) Information required to be submitted for hydraulic works permitting purposes
c) Appropriate design rainfall maps for Rwanda
d) Methods for determining design discharges, and estimation of runoff at ungauged sites
e) Flood plain mapping
f) Drainage designs methods for mitigation of gulley and landslides
g) Appropriate research and customised tools for design flood estimation for Rwanda that can be developed in collaboration with Universities and Rwanda Bureau of Standards.

3.3 Mission planning

The short-term mission lasted from the 8th – 19th of May 2017.

[6] IWRM Programme Rwanda (2017). TR26 – Volcanoes area flood management

[7] IWRM Programme Rwanda (2017). TR21 – Assistance in the Formulation of the Draft Water Law of Rwanda

[8] RS 267:2015; Feeder roads — Part 1: Guidelines for design and Part 2: Guidelines for maintenance

3.4 Scope of work

The scope and tasks of this assignment were as follows:

1. Assist with the development of the IRWM toll box;
2. Assist with the development of criteria for design of hydraulic structures and incorporation of appropriate methodologies into the IWRM tool.
3. Suggestions for TOR related to further work

3.5 Deliverables

The mission had the following expected deliverables:

1. Contribute to development of modules in the IWRM toolbox for water harvesting multipurpose utilization for small scale irrigation and aquaculture;
2. Contribution to development of modules in the IWRM tool box for design of hydraulic structures;
3. TOR and guidance for downstream work.