RWANDA IRRIGATION MASTER PLAN

March 2020

RWANDA AGRICULTURE AND ANIMAL RESOURCES DEVELOPMENT BOARD

SUBMITTED BY THE JOINT VENTURE

Z&A CONSULTING ENGINEERS INTERNATIONAL Ltd

SOCOSE Sarl

REPUBLIC OF RWANDA

RWANDA AGRICULTURE AND ANIMAL RESOURCES DEVELOPMENT BOARD

Improving and Updating Rwanda Irrigation Master Plan

Z&A CONSULTING ENGINEERS INTERNATIONAL Ltd

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EXECUTIVE SUMMARY

Overview

This "Master Plan Report" refers to the Contract "IMPROVING AND UPDATING RWANDA IRRIGATION MASTER PLAN" between Rwanda Agriculture and Animal Resources Development Board (RAB) and the Joint Venture composed of Z&A Consulting Engineers International Ltd (Z&A) and Socose Sarl.

The first IMP of Rwanda carried out in 2010. Due to the new irrigation technologies, the developing national policy thrusts and particularly the findings of the Water Resources Master Plan of 2013, the IMP requires updating to incorporate developments and inconsistencies provided in several reports and studies and the necessity to provide a comprehensive and harmonized framework for investments in irrigation development.

Thus, the objective of the consultancy is to review, update and improve the Master Plan. The plan will have to be technically feasible, environmentally and socially sustainable. The accomplishment of the above objective relies upon the following main activities:

- To identify and verify potential areas for Marshland and Hillside irrigation development opportunities from a variety of water resources;
- To update the mapping out of all potential areas for irrigation and establish the linkages that could enhance the profitability of the proposed irrigation interventions; and
- To develop prioritized irrigation development framework which will include time bound action plan and strategies for use by government and development partners as well as private sector and other non-state actors.

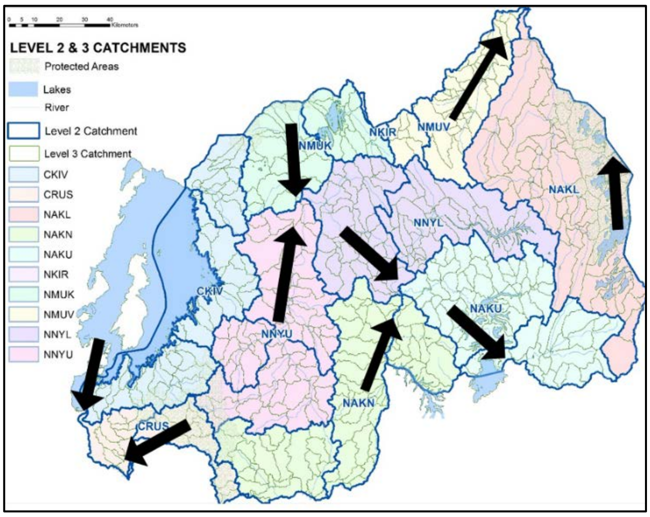
In more detail the steps that will followed are:

- ✓ A comprehensive analysis of the current situation and government's key objectives, opportunities and constraints.
- ✓ Review in detail the IMP (2010) and the Water Resources Master Plan (2013) in order to identify the inconsistencies.
- ✓ Identify the existing schemes in the country and analyze the lessons learnt from other irrigation projects of various sorts under the public, private etc.
- ✓ Evaluate the proposals of the existing Irrigation Master Plan, update the potential opportunities for irrigation.
- ✓ Identify strategic objectives and priorities of investment
- ✓ Development of a framework to assess and prioritize investment
- ✓ Prepare an Action Plan to include the recommended projects and involve the development
- ✓ Prepare the Update Master Plan.

Water Resources Assessment

The WR Master Plan completed in 2013, is a comparison of the available renewable resources with water demand from primary use (essentially water supply to sustain livelihood and the environment) and from numerous water using commercial ventures in different categories (industrial, mining, fisheries, livestock, irrigation, hydropower, navigation, recreation, etc.). Based on existing population data, growth projections thereof and identified development opportunities, water balances (water resources - water demand equilibriums) for the current situation and for 2020, 2030 and 2040 future dates have been estimated for nine (9) catchments throughout Rwanda. These results should be taken into account and incorporated in the IMP in order the two Master Plans to be in 100% compliance.

The nine (9) catchments are: 1. CKIV-Congo basin, KIVu Lake Catchment, 2. CRUS-Congo basin, RUSizi Catchment, 3. NMUL-Nile basin, MUKungwa catchment, 4. NNYU-Nile basin, NYabarongo Upper catchment, 5. NNYL-Nile basin, NYabarongo Lower catchment, 6. NAKN-Nile basin, AKaNyaru catchment, 7. NAKU-Nile basin, AKagera Upper catchment, 8. NAKL-Nile basin, AKagera Lower catchment, 9. NMUV-Nile basin, MUVumba catchment. Based on the WRMP, further Water Resources studies have been conducted for some of these level 1 catchments and the results have been incorporated in this report.



The delineation of the rivers in Rwanda, as indicated in the figure, show that most of the Level 1 catchments are interconnected. Rusizi river flows from River Kivu and along its upstream reaches, the river forms part of the border between Rwanda on the east with the Democratic Republic of the Congo (DRC) on the west. Nyabarongo river is the main river that runs through NNYU, NNYL and NAKU. Mukungwa river drains from the north and is connected with Nyabarongo river. In NAKU the flows from Akanyaru river, which forms the borders with Burundi, are also connected with Nyabarongo river, while Akagera river is formed by the flows of the six (6) catchments upstream.

The interconnection means that actions in a catchment have cumulative impacts on areas downstream. However, by following a holistic approach and in line with the principles of Integrated Water Resources assessment, the interconnection of the catchment basins can benefit the areas where availability of water resources (as derived from the WRMP) compared to the irrigation potential (as examined within the scope of this Master plan) is unfavorable.

Agronomic Assessment

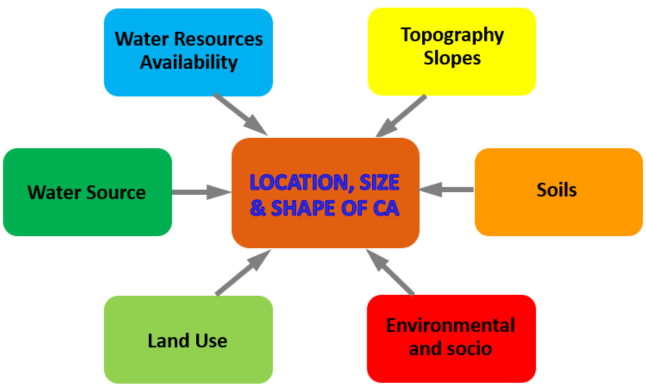
Following the availability of water examined with the WRMP, the IMP provides the general guidelines for crop selection, based on food security, markets, budgets, soils, climatic conditions etc. Cropping patterns are given and water demands are calculated in order to be used for the water balance and the availability of water for irrigation. The different irrigation technologies are given with proposals for climate resilience schemes. The irrigation schemes must provide alternatives for the changing climate, not just for increased irrigation water demand, but also for extreme floods and sediment loads. The schemes must be: hydraulically feasible, well designed and well operated.

Environmental Acceptability

From the Environmental view the IMP describes the conditions and rules that currently exist in Rwanda and the procedures that should be followed in order to make the schemes environmentally feasible. Provide also proposals for measures to mitigate the negative impacts from the implementation of an irrigations scheme, like locating the irrigation project on the site where negative impacts are minimized, improving the efficiency of existing projects and restoring degraded croplands to use rather than establishing a new irrigation project, developing small-scale, individually-owned irrigation systems as an alternative to large-scale, publicly-owned and managed schemes, using sprinkler irrigation and micro-irrigation systems to decrease the risk of waterlogging, erosion and inefficient water use, maintaining flood flows downstream of the dams to ensure that an adequate area is flooded each year, among other reasons, for fishery activities, strong sensitization program on HIV/AIDS and even the use of condoms by workers at irrigation development projects site etc. Monitoring of key parameters will ensure proper identification of raising issues in order to flag actions from relevant agencies.

Irrigation Potential

One of the most important aspects is to update the potential areas for irrigation and the respective maps, considering different parameters and create a data base with sites that can be used for planning. In line with the 2010 Irrigation Master Plan and in order to facilitate the selection and prioritization of the most cost-effective potential projects, Rwanda's irrigation



sector has been divided into Domains based on the type and nature of water abstraction. The six (6) Irrigation Domains have been identified:

- Dams: the domain requires the construction of large storage facilities
- River: use of pumping for abstraction of water from the large rivers
- Lake: use of pumping for abstraction of water from the large lakes
- Marshlands: using the river flow. The Ministerial order nº 006/03 of 30/01/2017 identified 120,000ha of marshlands which can be exploited under conditional use
- Ground Water: based on data provided by WRMP
- Runoff for Small Reservoirs: household small scale irrigation with the use of small storage facilities.

The analysis that conducted was based on the catchment level and the results for the total potential per domain and catchment are given below (all units are in ha).

Domains	CRUS	CKIV	NMUK	NNYU	NNYL	NAKN	NAKU	NAKL	NMUV	All
Runoff for small reservoirs domain	2,148	5,179	4,165	7,155	7,056	7,270	6,521	9,162	3,344	52,000
Dam Potential	167	1,447	172	7,058	15,610	12,859	894	1,430	12,464	52,100
River Potential	-	-	-	12,424	4,710	36,171	25,868	48,241	8,466	135,880
Lake Potential	-	23,909	-	-	28,372	9,125	26,816	14,142	-	102,364
Marshland Potential	3,700	4,702	6,398	9,060	8,998	26,656	33,184	22,731	7,735	123,164
Groundwater	3,000	5,000	5,000	7,000	4,000	5,500	2,500	3,000	1,000	36,000
SUM	9,015	40,237	15,735	42,697	68,746	97,581	95,783	98,706	33,009	501,509

The following supplementary to the above information should be highlighted:

- ✓ A number of projects have been already identified and designs have been conducted to different levels. This figure is up to 60,000ha.
- ✓ The river and lake domains refer to pumping from the water sources. Within these two domains SSIT technology is also included. The total available area used by pumping is estimated as 238,000ha, which is the largest group and gives a great potential for implementation.
- ✓ In order to enhance the amount of available water for catchments with scarcity like NAKU, NAKL and NMUV the following proposals are given:
  - In the case of full development of the areas, the agriculture of less water demanding crops by adjusting the cropping patterns and the use of more efficient technologies in order to reduce losses and the water demand per hectare, should be implemented.
  - In cases where the scarcity is allocated mainly during the dry period, implementation of water storage infrastructures should be considered.

- Based on the analysis, there is an excess amount of water from NNYU and NMUK catchments, in the order of 1,600Mm3 per year, that flows through Nyabarongo river, and continues to Akagera river. This external source of water should be utilized to support the needs of catchments NAKU and NAKL, especially through schemes developed in the vicinity of the rivers and the connected lakes.
- The catchment resources of NMUV are very stressed in order to cover the entire demand. The water that flows from Uganda side, through Muvumba river, is sufficient to cover all needs and shall be utilized accordingly.

Prioritization & Classification

The areas proposed as potential areas must be prioritized in order the most advantageous projects, from both technical and financial point of view, with the most benefits for the purpose to serve shall be developed in advance. Thus, a prioritization method is deemed necessary to be developed in order to group and classify the various opportunities. For this reason, a list of selection criteria was developed; to allow for comparison among different schemes, by quantifying as much as possible the various project characteristics. The prioritization is based on five (5) distinctive criteria categories, given also a rating to each of them based on the importance: Hydrology – Water Yield (40%), Command Area (30%), Environmental (10%), Social (10%) and Investment (10%). A detail procedure to compare projects is described in Annex 5 of the report. For the purposes of the Master Plan the results of the prioritization are:

- The high priority schemes are the large schemes at the east of the country which shall be supplied by the large rivers or lakes by pumping stations. The area provides large size command areas with good soils and gentle slopes, the water is secured since it is provided by pumping from the main larger rivers of the country and the need for development of the greater area and support the communities is very high.
- SSIT technology should also be prioritized as it is proved as a great benefit for the farmers.
- Due to the high capital cost, the projects that include storage facilities can be second priority unless specific projects have been identified with a cost in the order of 18,000$/ha or even less, and the capital cost has been secured from donors.
- Projects located within catchments NNYL, NAKU, part of NAKN also should be prioritized as medium priority. The sites have a potential to be attracted for investment due to easy access and proximity of Kigali. The existence of some difficulties like, less gentle slopes, high density areas, secured water etc should be considered but are not obstacle for the implementation of the respective projects.
- Low priority can be considered the areas at the west and north of the country. These areas have already developed rainfed schemes due to the high rainfall amounts, however

potential exists for supplementary irrigation and support the schemes during Season C and dry periods.

Another important tool for identification of sites is to classify and categorize them based on specific parameters. Given a specific code/name to each scheme can easily identify the basic parameters of the scheme. The proposal included in the MP is based on four (4) parameters: geographic location as per the 9-catchment division, the domain, the size of the project, and the score given to the site. As an example, a potential site of 1,200ha, which has scored 2.80 in a comparison list, is located within the Lake Kivu catchment and supplied by the lake water through pumping, lies within the CKIV/L/L/h class.

For the purposes of the MP a list of schemes that should be examined with priority is given. The list includes:

- ✓ Sites with Feasibility or Detail Design Studies with a total area of 51,680ha
- ✓ Sites with Prefeasibility Studies with a total area of 24,440ha
- ✓ Sites without studies with a total area of 41,600ha, 34,200 out of them under river and lake domains and 7,400 under marshland domain.

Market Linkages

The downstream marketing of irrigated produce requires the establishment of trust between the farmer and the buyer and is influenced by the reliability of quantity and quality, and economic factors such as transport cost and seasonal price fluctuations. An effective market system which is profitable for both the grower and the buyer, is critical to the success of an irrigation project and can simultaneously solve the challenge of financing inputs. In the IMP three main subareas are examined: a. Complementary on farm, b. Market orientation and c. Market linkages.

Complementary on farm means what we can do, while we are preparing an irrigation project, in order to improve operation and productivity. Specific proposals are given such as provide the farmers with access to equipment to improve efficiency (sprinklers, drip, tractors etc), provision of nurseries, stores, driers, access to poly-tunnels, green houses, trellising materials, training on water control, scheduling, improved application techniques, and maintenance, implement Market Information Systems while 4G coverage (92.5%) makes Rwanda well-placed to benefit from mobile and internet-based information systems, improve availability and affordability for farmers to purchase and apply fertilizers, lime and seeds for high values crops.

Market orientation is crucial for the selection of the most efficient cropping patterns in each case. An analysis is given for food crops versus high value crops and export versus local market. How the land is used will depend on a number of factors, not least of which is its geophysical characteristics, including elevation, climate, soil type, drainage, and proximity to markets. However, the wishes of the farmers and market-demand will ultimately determine what crops are produced, and it must be noted that these can change over time. While it is useful for planning purposes to allocate specific irrigation developments to specific markets, i.e. food crops, high-value local crops, or high-value export crops, it is necessary that market-orientation remains flexible throughout the planning, implementation and operation phases of an irrigation project.

Transport systems form the essential backbone of market linkages, and information technology will play an increasingly important role. The necessary linkages between farmers and markets include both the supply of farm inputs and equipment (upstream/backward), and the disposal of surplus production to processors, wholesalers, aggregators or retail markets (downstream/forward). For this reason it has to be noted that Rwanda is relatively well-connected by roads, speed up procedures for clearing and transit of goods at the borders should be implemented, the railway link from Isaka in Tanzania to Kigali should proceed, the Kigali airport and a new one in Bugesera should be well engaged for cargo purposes and coverage of electricity, especially in rural areas should be increased. In a review of market linkage interventions in developing countries, FAO have developed guidelines to improve the success rate of these activities and it is proposed to be considered accordingly while implementation of a project.

Costs and Financing

The investment costs can vary widely within a given domain, due to topography, distance from the water source to the irrigated area, complexity of the irrigation network, among many other factors. The table below shows the probable range of investment and operating costs expressed in USD per irrigated hectare.

Domain	Investment costs $/ha	O&M costs $/ha
Marshland, diversion, gravity	1,500-4000	50-100
Marshland, dam, gravity	16,000-20,000	150-200
Hillside, dam, gravity	20,000-30,000	200-300
River/lake, pumped	6,000-10,000	300-500
Groundwater, pumped	4,000-10,000	400-600
SSIT	3,500-6,000	600-800

In order to compare costs among the different types of schemes, an economic analysis was conducted, considering two scheme types: 1. Marshland/dam, gravity, 500 ha, $20,000/ha and $200/ha O&M and 2. River/lake, pumped, 500ha, $8,000/ha and $400/ha. It was proved that from a financial perspective, the river/lake projects are more attractive as the impact of higher future operating costs is outweighed by savings in the initial investment. Moreover, most publicly-funded irrigation schemes in Rwanda have been designed to be gravity-fed in order to eliminate energy consumption and reduce operational costs. While this has been a deliberate policy by GoR, the need to reduce investment costs and encourage private-sector involvement makes pumped schemes without storage a priority for future irrigation development. While diversion weirs are cheaper than dams, their application is limited by their particular hydrological requirements (perennial flow, low risk of flooding).

Cost recovery of O&M costs is achievable, whereas the recovery of investment costs in public irrigation schemes has proved to be very challenging, even in developed economies. In Rwanda, the level of water fees is still very low, such that even O&M costs are not adequately covered. Public investment in irrigation infrastructure is usually regarded as a "public good", as the cost of storage and conveyance is beyond the means of the beneficiaries. The recovery rates for O&M costs for public schemes will be determined by the "willingness to pay", which in turn depends on the net returns that farmers make from their crop production, which is based on target yields and good utilization of their plots throughout the year. Some guidelines on achieving cost-reflective water user fees are given in the following table.

Existing schemes	New schemes
Ensure full utilization, including season C if applicable	Conduct willingness to pay survey before project implementation
Improve crop productivity, cropping patterns, and market linkages	Decide on level of investment recovery required, O&M model, and design tariff structure (and escalation)
Ensure full fee collection	Agree tariffs with all stakeholders prior to implementation
Review O&M and improve efficiency; consider private-sector operator if applicable; agree annual budgets	Give due attention to market-linkages, training and support services to ensure high productivity
Agree fee escalation formula with users	Ensure full utilization, including season C if applicable, and full fee collection

As the objective of Rwanda's irrigation development moves from the imperative for food security to one of commercialization, there is increasing pressure to ensure that future schemes are commercially feasible. The results of the economic analysis conducted show that schemes with dams cannot be commercially feasible on the basis of irrigation alone, and that multipurpose use and some degree of public subsidy is required. Pumped schemes from rivers, lakes and groundwater can be commercially feasible if the investment cost is below $8,000/ha and the cropping pattern includes high-value crops. With concessional finance, private investment levels can be considerably enhanced, for example at an interest rate of 5%, the affordable borrowing for a maize/soya model is around $8,000/ha.

According to FAO, an investment framework is necessary to make a sound quantification of overall finance needs in relation to specific policy targets, and to be effective, it must generally define what needs to be done to achieve the objective in question. This investment framework will outline the processes that need to be followed to ensure that the short-term targets are achieved and that further expansion is commercially viable and justified by demand. Of prime importance will be adopting models of investment and operation which attract private-sector participation. For that reason two types of Investment frameworks have been developed, one for the existing schemes and one for the new schemes, detailing the procedures that should be followed for the sustainability of the projects.

Investment Plan

The investment plan is based on the analysis of the different components and a proposal of expansion of the irrigated land in order to achieve the respective targets. The plan is divided into short, medium and long term requirements covering the period 2020 to 2050 (30 years), with the objective of achieving 220,000 ha under irrigation by 2050, or roughly 50% of the country's potential based on projected renewable resources.

Planned command area development, ha

Domain	2020-2024	2025-2034	2035-2050	Total
Rehabilitation / modernisation	8,000	12,000	20,000	40,000
SSIT	13,000	12,000	3,000	28,000
River/lake projects	22,000	20,000	30,000	71,000
Dam/marshland projects	6,000	10,000	10,000	26,000
Groundwater projects	6,000	10,000	8,000	24,000
Private irrigation schemes	2,000	5,000	10,000	17,000
Total new area, ha [2]	**48,000**	**57,000**	**61,000**	**166,000**
Total area under irrigation, ha	102,000	159,000	220,000	
New ha p.a.	9,600	5,700	4,067	5,533 (avg.)

Proposed investment by domain, 2020-2050, $m

Domain	2020-2024	2025-2034	2035-2050	Total
Rehabilitation / modernisation	12	18	30	60
SSIT	59	54	14	126
River/lake projects	168	160	240	568
Dam/marshland projects	96	160	160	416
Groundwater projects	36	60	48	144
Private irrigation schemes	12	30	60	102
Total investment, $m	**383**	**482**	**552**	**1,416**
Average investment cost, $ per ha	7,719	8,140	8,549	8,169

The financing plan assumes that there will not be budget surpluses to channel into irrigation development. The requirement to achieve 102,000 ha under irrigation by 2024 is a substantial acceleration of irrigation development, and therefore requires substantial borrowing over a relatively short timeframe. The PforR program under PSTA-4, which runs until 2024, commits $30m on the achievement of a) 2,940 ha of new irrigation development under recognized PPP arrangement (DLI 5), and b) $11.5m of matching private investment in agricultural infrastructure projects (DLI 7). Continued support for SSIT from development partners is anticipated as it is a cost effective way to expand irrigated area with substantial private sector participation.

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ACZ	Agroclimatic Zone
AfDB	African Development Bank
ASAP	Adaptation for Smallholder Agriculture Programme
ASWG	Agricultural Sector Working Group
BSP	Base Saturation Percentage
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CAADP	Comprehensive Africa Agriculture Development Programme
CAPEX	Capital Expenditures
CBO	Community Based Organization
COSOP	Country Strategy and Opportunities Paper
CPS	Country Partnership Strategy
CSF	Community Seed Fund
CIP	Crop Identification Program
CEB	Council of European Development Bank
CBR	Cost Benefit Ratio
DBMS	Database Management System
DDPs	District Development Plans
DEM	Digital Elevation Model
DRC	Democratic Republic of the Congo
DFID	Division for International Development
DAP	Di Ammonium Phosphate
DISC	District Irrigation Steering Committees
DPCG	Development Partner Coordination Group
ESMP	Environmental and Social Mitigation Plan
ESAP	Environmental and Social Assessment Procedures
EDPRS	Economic Development and Poverty Reduction Strategy
EIA	Environmental impact assessment
FAO	Food and Agriculture Organization
FDI	Foreign Direct Investment
FBO	Food Business Operator
GEF	Global Environmental Facility
GLTF	Great Lakes Trade Facilitation Project
GDP	Gross Domestic Product
GIS	Geographic Information System
GoR	Government of Rwanda
GPS	Global Positioning System
Ha	Hectare
ICRAF	World Agroforestry Centre
ICT	Information & Communication Technology
ICT4Rag	Information & Communication Technology for Rwanda Agriculture
IFAD	International Fund for Agriculture Development

IMP	Irrigation Masterplan
INEAC	Institut National pour l'Étude Agronomique du Congo
IMCE	Integrated Management of Critical Ecosystems
IMSAR	Improving Market Systems in Rwanda for Agriculture
IWP	Irrigation Water Policy
IWR	Irrigation Water Requirement
IWRM	Integrated Water Resources Management
JADF	Joint Action Development Forum
LUC	Land Use Consolidation
LPG	Liquefied Petroleum Gas
LWH	Land husbandry, Water Harvesting and Hillside Irrigation project
MINAGRI	Ministry of Agriculture and Animal Resources
MINALOC	Ministry of Local Government
MINECOFIN	Ministry of Finance and Economic Planning
MINEDUC	Ministry of Education
MINICOM	Ministry of Trade and Industry
MININFRA	Ministry of Infrastructures
MINIRENA	Ministry of Natural Resources
MINITERE	Ministry of Lands, Resettlement and Environment, Government of Rwanda
MIGEPROF	Ministry of Gender and Family Promotion
MoD	Ministry of Defense
MoH	Ministry of Health
MoE	Ministry of Environment
NAEB	National Agricultural Export Development Board
NIRDA	National Industrial Research and Development Agency
NISR	National Institute of Statistics of Rwanda
NST	National Strategy for Transportation
NGO	Non-Governmental Organization
OPEX	Operative Expenditures
PAH	Polycyclic Aromatic Hydrocarbon
PIA	Potential Irrigation Area
PPP	Public Private Partnership
PSTA	Strategic Plan for the Transformation of Agriculture
RAB	Rwanda Agriculture and Animal Resources Development Board
RCA	Rwanda Cooperative Agency
REMA	Rwanda Environment and Management Authority
RGB	Rwanda Governance Board
RNRA	National Policy for Water Resources Management
RSB	Rwanda Standards Board
RSSP	Rural Sector Support Program
RWH	Rainwater harvesting
RWFA	Rwanda Water and Forestry Authority
RATIN	Regional Agricultural Trade Intelligence Network

RDB	Rwanda Development Board
REB	Rwanda Education Board
RTDA	Road Transport Development Agency
RLMUA	Rwanda Land Management and Use Authority
SSIT	Small Scale Irrigation Technology
SHER	SHER Ingénieurs Conseils - Belgian consulting engineering company
SSPs	Sector Strategic Plans
SST	Small Scale Technology
SACCO	Savings and Credit Cooperative Organization
SAIFSP	Sustainable Agricultural Intensification and Food Security Project
SOC	Soil Organic Carbon
SSWG	Sub Sector Working Group
ToR	Terms of Reference
TYS	Ten-Year Strategy
UN	United Nations
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
VCA	Value Chain Analysis
WBG	World Bank Group
WDA	Workforce Development Authority
WRMP	Water Resources Master Plan
WUA	Water User Association
CKIV	Congo basin, KIVu Lake Catchment
CRUS	Congo basin, RUSizi Catchment
NMUL	Nile basin, MUKungwa catchment
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CHAPTER 1. INTRODUCTION

1.1. Introduction

This "Master Plan Report" refers to the Contract "IMPROVING AND UPDATING RWANDA IRRIGATION MASTER PLAN" between Rwanda Agriculture and Animal Resources Development Board (RAB) and the Joint Venture composed of Z&A Consulting Engineers International Ltd (Z&A) and Socose Sarl, hereafter referred as the Consultant.

The report complies with the Contract requirements and the Terms of References and the Technical Offer submitted by the Consultant.

1.2. Contract Details

The "Rwanda Agriculture and Animal Resources Development Board" announced an invitation for proposals to provide the required updating of the IMP (2010) report, and Z&A Consulting Engineers International Ltd, in Joint Venture with Socose Sarl, were awarded with the Contract.

The commencement of the services is on the 18^{th} of June 2018.

1.3. Project Background

Rwanda is located in central-eastern Africa bordered by Uganda, Tanzania, Burundi and Democratic Republic of Congo. Agriculture is Rwanda's main economic activity, representing 31% of the country's GDP[1] and employing 69.7% of its inhabitants both directly and indirectly[2].

Rwanda is often perceived as a water-rich country due to its relatively high average rainfall, however precipitation is not evenly distributed over the country and recent trends show increasingly short and more intense rainy seasons, leading to increased erosion, flooding (in the Northern parts of Rwanda), alternating with recurrent droughts especially in the eastern parts of Rwanda. Moreover, with a population of over 12.6 million people spread over 26,338 km2, Rwanda is one of the most densely populated country on the African Continent. As a result, water availability per capita (500-600m3/pa)[3] remains low and Rwanda ranks amongst the world's water scarce countries based on this indicator, even though the current per year demand can be met, as it is proved with the analysis presented in the next chapters. Meanwhile, population growth and increasing urbanization are expected to push demand further, putting

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[1] *NISR. (2017), Gross Domestic Product, Kigali, National Institute of Statistics of Rwanda*
[2] *EICV (2013/2014), Rwanda Integrated Houdehold Living Condition Survey, Main Indicators Report, National Institute of Statistics of Rwanda*
[3] *http://www.un.org/waterforlifedecade/scarcity:Hydrologists typically assess scarcity by looking at the population-water equation. An area is experiencing water stress when annual water supplies drop below 1,700 m3 per person. When annual water supplies drop below 1,000 m3 per person, the population faces water scarcity, and below 500 cubic metres "absolute scarcity"*

the country at risk of severe water stress and decreased water quality due to increasing pollution[4].

The Government of Rwanda has recognized the fundamental importance of irrigation in the future economic and social development of the country and that increasing agricultural productivity is one the main strategies of poverty reduction. In line with Rwanda's development agenda and the milestones set within the Economic Development and Poverty Reduction Strategies ('EDPRS' I,II)-2010-2018, and the Irrigation Policy and Action Plan (2014), the Government continuously invests on the development of small, medium and large-scale irrigation development on both hillside and on marshlands. Before 2010 the country was short of an updated comprehensive irrigation master plan and investment framework which led to delayed and sub-optimal investment decisions in irrigation development.

The first comprehensive Irrigation Master Plan for the country was completed in 2010 with the publication of the Rwanda Irrigation Master Plan document. The IMP's objective was to provide Rwanda with a planning tool for rational exploitation of its soil and water resources for agriculture purpose. Following the evolving dynamics in irrigation trends and new technologies, the evolving of the national policies and the findings of the Water Resources Master Plan conducted in 2013, the IMP now requires updating.

1.4. Country's Irrigation targets

Increasing agricultural productivity is one the main strategy for poverty reduction in Rwanda considering that the agricultural sector contributes over 30% of the GDP[5]. The growth rate achieved, between 1993 and 2005 was in the order of 5%[6]. In 2014 the sector managed to register a 6% annual growth (following closely the national growth rate) demonstrating that the government is committed to increase growth through national policies, strategic plans and investments in agriculture. Vision 2020, a government development program launched in 2000 with main objective of transforming the country into a knowledge-based middle-income country, aspired for Rwanda's agriculture to transform into a productive, high value, market-oriented sector with forward linkages to other sectors, by setting an ambitious growth rate in the order of 8.5%[7]. The same rate was also envisaged in the Strategic Plan for the Transformation of Agriculture in Rwanda, (PSTA III) while Rwanda is also committed to Comprehensive Africa Agriculture Development Programme (CAADP) which sets a target of 6% growth in the agriculture sector. The new 50-year Vision for the period up to 2050, otherwise known as Vision 2050, will build on the achievements and the lessons learnt of the current Vision 2020. The Government of Rwanda has outlined the main pillars of the plan (Quality of life, Modern

[4] Water for Growth, http://www.water.rw/water-resource/
[5] NISR. (2017), Gross Domestic Product, Kigali, National Institute of Statistics of Rwanda
[6] PSTA II (2009), Strategic Plan for the Transformation of Agriculture in Rwanda – Phase II, Republic of Rwanda, Ministry of Agriculture and Animal Resources
[7] ICT4 (2016-2020), National ICT4Rag Strategy, Ministry of Agriculture and Animal Resources, Republic Of Rwanda

infrastructure and livelihoods, transformation for prosperity, Values, International cooperation[8]); however the actual report has not yet been made available to public.

According to the Economic Development and Poverty Reduction Strategy II[9], increasing the productivity of Agriculture is one of the four (4) main priority areas. To do so the country should focus on building on one of the sector's comparative advantages, irrigation. According to the Second Strategic Plan (PSTA II) the country's potential is favorable; the existence of 165,000 hectares of marshland of which 100,000 hectares can be developed and make agricultural intensification possible; abundant water resources that can be used for irrigation purposes on hillsides; relatively abundant rainfall; good markets for high-value products.

Since 2004, the Ministry of Agriculture and Animal Resources (MINAGRI) has developed and implemented three phases of Strategic Plans for the Transformation of Agriculture (PSTA), the main policy framework for agriculture development in Rwanda aiming at harmonizing the agriculture sector development activities with the national Economic Development and Poverty Reduction Strategies (EDPRS) and the Vision 2020. The sector has experienced significant progress over the last five years under the implementation of PSTA I, PSTA II, PSTA III, PSTA IV and EDPRS I & II. Rwanda has also signed the CAADP compact which establishes in its Pillar I on Land and Water management that the Government should allocate at least 2% of public funds for irrigation development. According to the PSTA III report the total area under irrigation in 2012 was over 25,590 ha, including 2,490 ha of hillside irrigation, 23,000 ha of marshland irrigation and around 100 ha of small scale irrigation[10]. As of 2018, 48,000ha are under Irrigation. The 2010 Irrigation Master Plan indicated that Rwanda has the potential irrigable area of ~590,000ha (596,810Ha); a figure which has placed agriculture and irrigation development at the forefront of the Country's development agenda by implementing strategic plans to transform the country's agriculture.

The 2018 target for the EDPRS 2 strategy was to develop a total of 100,000 ha under irrigation, of which 65,000 ha would be marshland and 35,000 ha hillside irrigation. According to the same report MINAGRI will develop 60,000 additional ha of irrigated land, two-thirds marshland and one-third hillside through public investments, and 20,000 ha through private sector investments[11]. MINAGRI has also a Mid-Term plan[6] with a cumulative development target of 8,000 ha of hillside and 32,000 ha of marshland irrigation schemes. This irrigation development will take place in line with the National Irrigation Policy, the law on Water Users Associations to

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[8] *MINECOFIN,2016, Claver Gatete http://www.minecofin.gov.rw/fileadmin/user_upload/Hon_Gatete_Umushyikirano_Presentation_2016.pdf*
[9] *EDPRS II (2013 -2018), Economic Development and Poverty Reduction Strategies, Republic of Rwanda*
[10] *PSTA III (2014), Third Phase of the Transformation of Agriculture Sector Program-for-Results Project – Phase II, The World Bank*
[11] *EDPRS II (2013 -2018), Economic Development and Poverty Reduction Strategies, Republic of Rwanda*

ensure effective water and irrigation infrastructure management, and the Irrigation Master Plan. The line of actions to meet the targets included the following:

- The implementation of the new national irrigation policy
- Training of farmer organizations in small scale irrigation technologies to support the country's irrigation vision
- The development of the private irrigation sector and the continuous evaluation and monitoring of the private schemes and their effectiveness
- Sustainable management of the irrigation developments and establishment of WUAs

The 100,000ha target of developed land under irrigation could not be achieved, as a result of the challenges the irrigation sector is facing today such as, the high cost of hillside irrigation, poor organization in schemes, lack of organization culture within communities, lack of investment portfolios. However, the lessons learned will be used in discussions for the way forward and in order to formulate an action plan which will support the implementation of the government's strategic targets with regards to the Irrigation Sector.

The PSTA 4 is the Strategic Plan for the Agricultural Sector under Rwanda's EDPRS 3, covering the period 2018-2024. The plan was approved on the 29th of May 2018 and is focused on innovative approaches for a productive, green and market-led agricultural sector. The Development objective of the fourth plan is to promote the commercialization of agriculture value chains in Rwanda[12]. As per the developed plan, the country currently practices irrigation on 48,500ha, but the government plans to expand this to 102,281ha in the next six years considering that the 100,000ha target of the EDPRS 2 strategy was not reached. In addition, the Ministry of Finance and Economic Planning is in the process of finalizing the EDPRS 3 strategy with World Bank being one of the key development partners.

Under the innovation spectrum MINAGRI has supported and sponsored the development of the Information & Communication Technology (ICT) for Rwanda Agriculture through the ICT4RAg strategy for the period 2016-2020. The strategy's mission is to provide a conducive environment for the development, adoption and use of ICT in Agriculture that is both affordable and accessible to all agricultural stakeholders and will accelerate the modernization of agriculture by addressing the identified challenges. The strategic plan introduces a number of applications and research activities such as the use of an Agriculture Management and Information system, the pilot use of automated Irrigation Systems mainly in Eastern Province, the use of Geographic Information systems (GIS).

[12] *Transformation of Agriculture Sector Program 4 Phase 2, Technical Assessment (2018), Republic Of Rwanda, The World Bank*

1.5. Assignment Objective

The IMP carried out in 2010 requires updating by taking into consideration the introduction of new irrigation technologies, the developing national policy thrusts and particularly by incorporating the findings of the Water Resources Master Plan of 2013. Following the inception of the IMP (2010) several key issues have occurred concerning some of the data provided in IMP (2010), such as the estimated irrigation potential and the figures of it being inconsistent compared to the Water Resources Master Plan as detailed in the following chapters. The requirement to update the old IMP becomes imperative considering the inconsistency of the data provided in several reports and studies and the necessity to provide a comprehensive and harmonized framework for investments in irrigation development.

Thus, the objective of the consultancy is to review, update and improve the 2010 Rwanda irrigation master plan and to prepare an associated investment framework to support investments in irrigation development. The plan will have to be technically feasible, environmentally and socially sustainable. The accomplishment of the above objective relies upon the following main activity:

- To identify and verify potential areas for Marshland and Hillside irrigation development opportunities from a variety of water resources with and/or without pumping in order to enable increased understanding for priorities of such development;

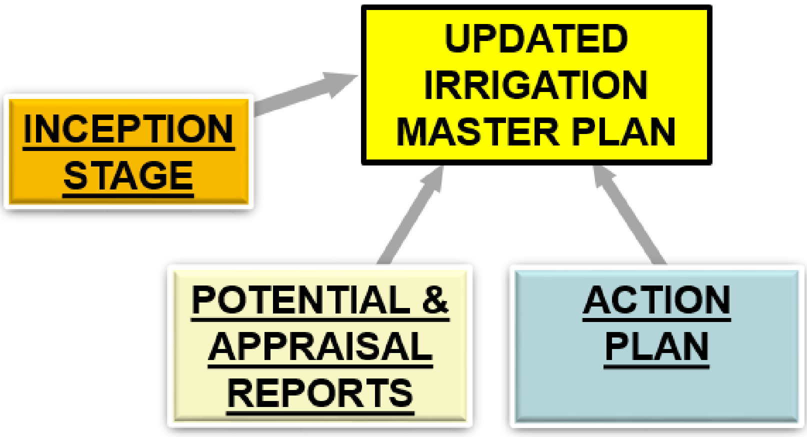
- To update the mapping out of all potential areas for irrigation and establish the linkages that could enhance the profitability of the proposed irrigation interventions; and

- To develop prioritized irrigation development framework which will include time bound action plan and strategies for use by government and development partners as well as private sector and other non-state actors.

Three separate reports have been submitted during the course of this project:

- **Inception and Objectives Report** which contains a summary of the objectives and key issues of the assignment, issues that the approval of the client is needed in order to proceed to the next steps, a description of the tasks to be executed; the preliminary findings from the discussion with the Client and data collection, the proposed approach by the Consultant for the fulfillment of the Contract obligations, an updated work program and time schedule and a more detailed methodology approach.
- **Irrigation Potential Report** which constitutes an analysis of the irrigation potential of Rwanda, considering the physical resources of ‘soil’ and ‘water’, the findings of the WRMP, combined with the irrigation water requirements as determined by the cropping patterns and climate.

- **Action Plan Report** which includes the recommended projects and shall also involve developing strategies to capitalize on opportunities and a respective funding plan



This report which is called the ***"Irrigation Master Plan"*** is prepared as a compilation of the findings of the three reports, in order to summarize and include the outcome of the project in one report.

CHAPTER 2. WATER RESOURCES ASSESSMENT

2.1. Water Resources Master Plan

Rwanda is a scarce water country with water being the most valuable of the natural water resources of the country. Although most of the country receives water it is unevenly distributed both spatially and temporally: the west receives most precipitation and the eastern part of the country is relatively dry, while there are long dry periods between rainy seasons. Due to the population and economic growth development of Rwanda, the Government has put in place the institutional framework for the conservation, protection, and management of the country's water resources resulted in the formulation of the water and sanitation policy of 2004, revised in 2011 which became the National Policy for Water Resources Management and the Water Law no. 62/2008 to strengthen the water resources management sub-sector. The policy has also given authority to Rwanda Natural Resources Authority (RNRA) to oversee the management of the Water Resources. In 2012, SHER was recruited by the RNRA to prepare the Rwanda National Water Resources Master Plan with the aim of assessing national water resources, water needs and uses over time (up to 2040).

The WR Master Plan is a comparison of the available renewable resources with water demand from primary use (essentially water supply to sustain livelihood and the environment) and from numerous water using commercial ventures in different categories (industrial, mining, fisheries, livestock, irrigation, hydropower, navigation, recreation, etc.). Based on existing population data, growth projections thereof and identified development opportunities, water balances (water resources - water demand equilibriums) for the current situation and for 2020, 2030 and 2040 future dates have been estimated for nine catchments throughout Rwanda. The estimation of the irrigation water demand is considered important for this project and it is examined in detail in chapter 6.

Rwanda is divided into two major drainage basins: the Nile to the east covering 67% and delivering 90% of the national waters and the Congo to the west which covers 33% and handles all national waters[13]. In the National Water Resources Master Plan, Rwanda is divided into nine (9) first order catchments (Figure 2.1) and numerous second or further order catchments, which jointly constitute the first order catchments – Level 1 (Figure 2.2). Seven of these are part of the Nile Basin and two (in the West, on the shores of Lake Kivu) are part of the Congo Basin. The nine (9) water catchments are shown in the figure below (figure 2.1).

[13] MINITERE (2005). Rapport du Projet de Gestion Nationale des Ressources en Eau. Composantes D: Etudes Techniques. Ministère des Terres, de l'Environnement, des Forêts, de l'Eau et des Mines (MINITERE), Kigali

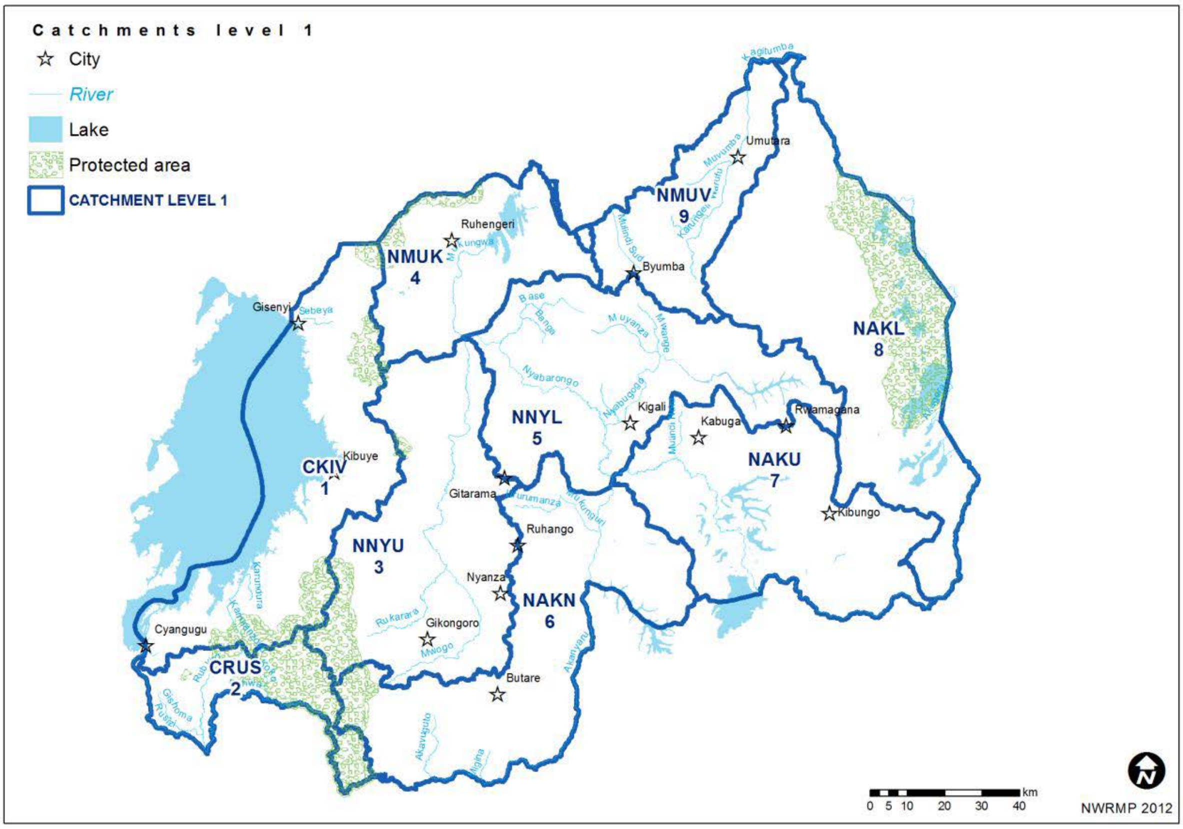


Figure 2-1: Level 1 catchment division of Rwanda

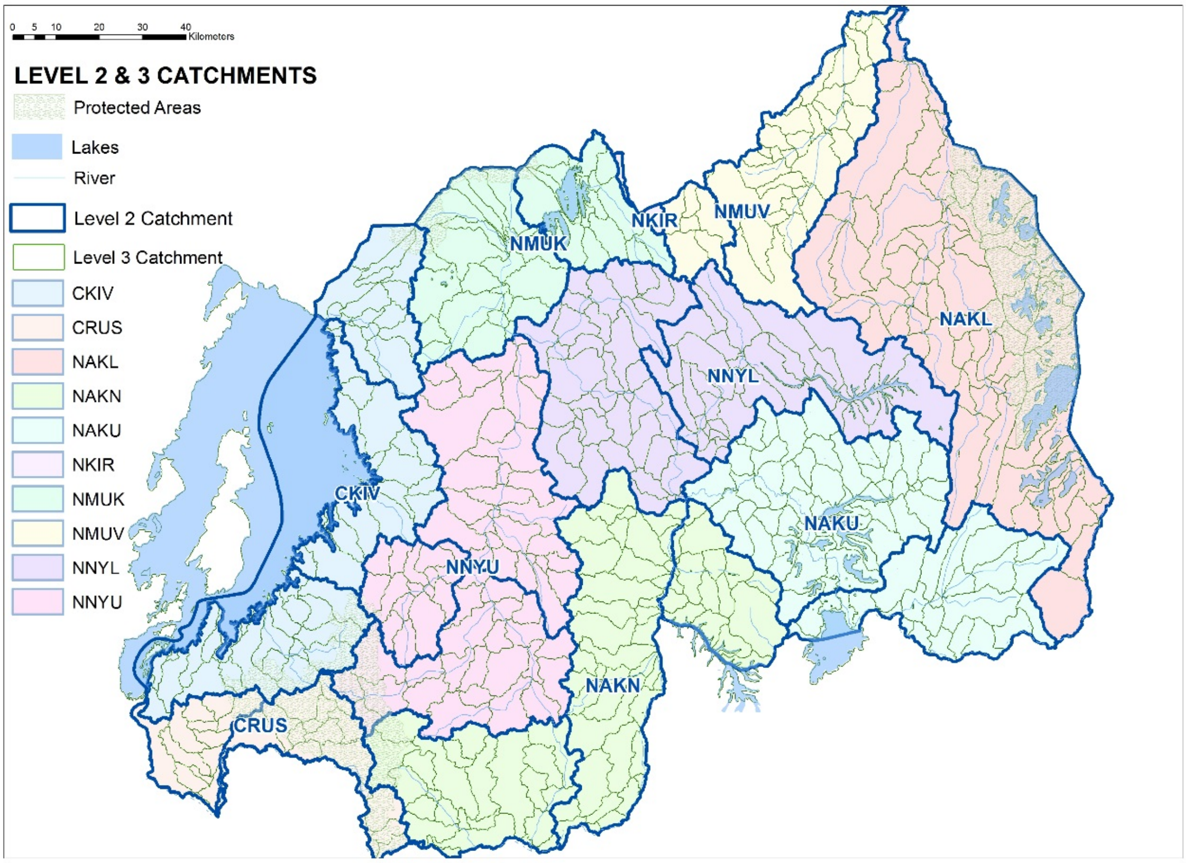


Figure 2-2: Level 2 & 3 catchment division of Rwanda

The characteristics of the nine water catchments are shown in the table below:

Table 2-1: The nine water catchments in Rwanda [14]

Catchment	Surface (Km^2)	Basin	Description
Lake Kivu (CKIV)	2,425	Congo	A headwater catchment, Lake Kivu is transboundary with the Democratic Republic of the Congo (DRC). It Includes several smaller catchments draining into Lake Kivu. There is one hydropower station.
Rusizi (CRUS)	1,005	Congo	A headwater catchment that comprises Rusizi, Rubyiro and Ruhwa rivers; it is transboundary with both the DRC and Burundi.
Nyabarongo upper (NNYU)	3,348	Nile	An inland headwater catchment of the Nyabarongo River and its tributaries springing from the Nyungwe Forest.
Mukungwa (NMUK)	1,887	Nile	An inland headwater catchment that drains the lava region, the Ruhondo and Burera Lakes and the protected Rugezi wetlands.
Nyabarongo lower (NNYL)	3,305	Nile	An inland downstream catchment that drains the area from the confluence of the Nyabarongo with the Mukungwa River down to the confluence of the Nyabarongo with the Akanyaru River.
Akanyaru (NAKN)	3,402	Nile	A transboundary (with Burundi) upstream catchment that springs in the Nyungwe forest and features a long, flat and wide wetland that drains the Cyohoha South lake along with a series of lakes in Burundi.
Akagera upper (NAKU)	3,053	Nile	A transboundary (with Burundi and Tanzania) downstream catchment that drains the area from the confluence of Nyabarongo and Akanyaru Rivers down to the Rusuma Falls. It features numerous lakes with significant evaporation losses and the confluence with the Ruvubu River (from Tanzania/ Burundi).
Akagera lower (NAKL)	4,288	Nile	A transboundary (with Tanzania) downstream catchment that drains the area downstream of Rusumo Falls up to the confluence of the Akagera with the Muvumba River. It features numerous lakes and two tributaries that typically run dry during the dry season.
Muvumba (NMUV)	1,565	Nile	An intricate transboundary (with Uganda) upstream catchment. The Muvumba catchment drains the Mulindi River that runs into Uganda to enter Rwanda after a 50 km detour as the Muvumba River that eventually forms the border with Uganda.

2.2. The Hydrographic network of Rwanda

Rwanda has a dense hydrographic network. Lakes occupy an area of 128,190 ha; rivers cover an area of 7260 ha and water in wetlands and valleys a total of 77,000 ha. The country is divided into two major water basins. To the west, Congo River Basin is lies which covers 33%

[14] RNRA. (2014b). Consultancy Services for Development of Rwanda National Water Resources Master Plan. Master Plan Report: Executive Summary and Policy Brief. Kigali: Rwanda Natural Resources Authority (RNRA

of the national territory, receives 10% of the total national waters and includes CKIV and CRUS catchments according to the Level 1 Catchment division of the WRMP. To the East lies the Nile River Basin whose area covers 67% of the territory delivers 90% of the national waters including the rest of the Level 1 Catchments. Waters of the Nile River Basin flow out the country through the Kagera River, the main tributary to Lake Victoria.

Kagera river begins in Burundi, flowing out from Lake Rweru. From the lake, it flows east along the Rwanda-Burundi and Rwanda-Tanzania borders to a confluence with the Ruvubu River. The waters of the Kagera are provided by two major tributaries, the Nyabarongo of Rwanda, which feeds Lake Rweru, and the Ruvubu of Burundi. From the confluence, the Kagera flows north along the Rwanda-Tanzania border, over Rusumo Falls and through Akagera National Park. It then takes a turn to the east, following the Tanzania-Uganda border and emptying into Lake Victoria in Uganda.

The Nyabarongo is a major river in Rwanda. At 297 km, it is the longest river entirely in Rwanda. The river begins its course at the confluence of the rivers Mbirurume and Mwogo in the South West of the country. From its start, Nyabarongo flows northward for 85 forming a natural border between the Western and Southern Provinces. At the confluence with the river Mukungwa, the river changes course and flows eastward for 12 km then to a more South Eastern course for the last 200 km. The river ends its course close to the border with Burundi. The Nyabarongo River empties both in Lake Rweru and Akagera river in a small delta.

One of the main tributaries of Nyabarongo River is Akanyaru. The river rises in the western highlands of Rwanda and Burundi, flows east and then north along the border between those countries, before joining the Nyabarongo River.

The delineation of the rivers in Rwanda, as indicated in the figure below, show that most of the Level 1 catchments are interconnected. CKIV catchment is considered a single management unit considering that all small catchment areas drain into lake Kivu. On the other hand, CRUS Catchment drains through Rusizi river in Lake Tanganyika in Central Africa. Rusizi river flows from River Kivu and along its upstream reaches, the river forms part of the border between Rwanda on the east with the Democratic Republic of the Congo (DRC) on the west. In NMUV catchment Karungeli river drains into Muvumba, which cuts across Nyagatare District and eventually flows into the Kagera river outside Rwanda. Similarly, NAKL catchment drains into the Kagera river. The rest of the catchments are interconnected, with NMUK and NNYU draining into NNYL, and NNYL and NAKN draining into NAKU.

The interconnection means that actions in a catchment have cumulative impacts on areas downstream. However, by following a holistic approach and in line with the principles of Integrated Water Resources assessment, the interconnection of the catchment basins can benefit the areas where availability of water resources (as derived from the WRMP) compared to the irrigation potential (As examined within the scope of this Master plan) is unfavorable.

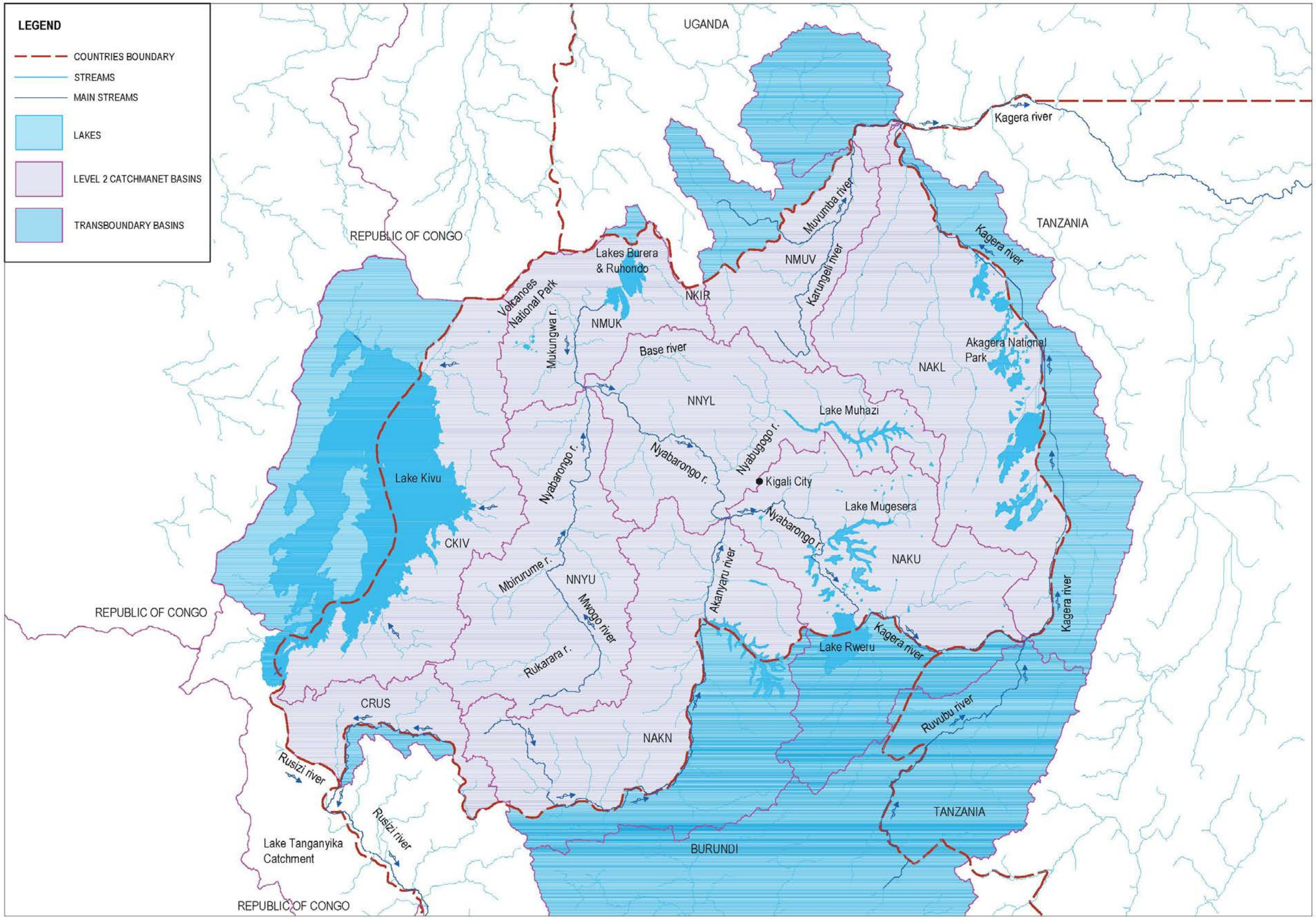


Figure 2-3: The Hydrographic & transboundary network of – Rwanda

2.3. Transboundary Catchments considerations

In addition to the national dependencies between the Level 1 catchments, there are upstream international dependencies between Rwanda and the neighboring countries that need to be considered.

- CKIV catchment covers 2,425 km^2 in Rwanda and 2,203 km^2 in the DRC. As mentioned in the previous section, the catchment is considered a single management unit, without any upstream national or international dependencies, considering that all small catchment areas drain into Lake Kivu.
- CRUS catchment covers 1,005 Km^2 in Rwanda. Part of the Tanganyika Catchment (368 km^2) is shared with the DRC and a smaller stretch (180 km^2) is shared with Burundi.
- NMUK catchment and Uganda share a small insignificant catchment of 62 km^2.
- NAKN and NAKU catchments have no upstream international dependencies, however the catchments share 1,926 km^2 and 13,714 km^2 with Burundi respectively.
- NAKL catchment shares 2,354 km^2 with Tanzania. The catchment receives flows from Burundi & Tanzania through Ruvubu river.
- NMUV catchment shares 2,146 km^2 with Uganda and receives flows from Muvumba River which cuts through the country.

Despite any upstream international dependencies, the available renewable resource for each one of the catchments, in which the present study will be based on to elaborate the irrigation potential of the country, is calculated based on the average annual surface run-off multiplied by the surface area of each Catchment in Rwanda. This means that no transboundary waters will be utilized and Rwanda's irrigation potential will be based on the country's resources.

The below table is extracted from Water Resources Master Plan indicating high lighting the available renewable resource for each one of the 9 Level 1 Catchments and the respective demands for irrigation and any other potential projected demand.

Table 2-2: Projected water use demand in the different catchments of Rwanda as per WRMP

Level 1 Catchment	Average Renewable Resource Mm3	Demand for Irrigation Mm3	Other Demand for Water Supply, Livestock, fishponds etc.	Overall Demand
CKIV	898	150	163	313
CRUS	432	10	36	46
NNYU	1,290	190	166	356
NMUK	905	13	139	152
NNYL	899	368	239	607
NAKN	798	370	171	541
NAKU	504	527	130	657
NAKL	907	410	67	477
NMUV	193	145	71	216

The numbers of the second column above are also confirmed as amounting to Rwanda's available resources by the following table:

Table 2-3: Calculation of the available renewable resource in the different catchments of Rwanda

		CKIV	CRUS	NNYU	NMUK	NNYL	NAKN	NAKU	NAKL	NMUV
		transbou	***transbou***	***closed***	***transbou***	***closed***	***transbou***	***transbou***	***transbou***	***transbou***
Base Flow	m3/s	19.22	11.15	31.00	19.90	17.27	24.43	11.13	17.00	3.50
MQ	m3/s	28.5	13.7	40.9	28.7	28.5	25.4	16.0	28.7	6.1
Recharge	mm/y	250	350	292	322	164.8	226.5	115	125	70.5
Area	km2	2425	1005	3348	1949	3304	3402	3053	4288	1565
Yield	hn3/y	6.1E+06	3.5E+06	9.8E+06	6.3E+06	5.4E+06	7.7E+06	3.5E+06	5.4E+06	1.1E+06
Rainfall	mm/y	1240	1295	1365	1315	1191	1225	925	835	995
Flow	mm/y	**370**	**430**	**385**	**464**	**272**	**235**	**165**	**211**	**123**
Water balance	mm/y	870	865	980	851	919	990	760	624	872
Base flow	mm/y	250	350	292	322	164.8	226.5	115	125	70.5
Base flow index		0.68	0.81	0.76	0.69	0.61	0.96	0.70	0.59	0.57
Rainfall	hm3	3.0E+07	1.3E+07	4.6E+07	2.6E+07	3.9E+07	4.2E+07	2.8E+07	3.6E+07	1.6E+07
Base flow	hm3	6.1E+06	3.5E+06	9.8E+06	6.3E+06	5.4E+06	7.7E+06	3.5E+06	5.4E+06	1.1E+06
Average Renewable Resource	Mm3	**898**	**432**	**1290**	**905**	**899**	**798**	**504**	**907**	**193**

Table 2-3 was derived in the Water Resources Master Plan to account for groundwater sustainable yield, but it also provides the long-term average water balance of the catchments. According to the Master Plan, the assessment is based on stream flow analysis providing base flow and mean annual flow for all major basins. The recharge rate has been calculated based on the base-flow and presented in both mm/y and as a flow rate per km² (specific recharge). The calculated base-flow is part of the total outflow of each catchment (see baseflow index line in table) and therefore the total simplified water balance is given by the following relationship (expressed in terms of the table above): Rainfall = Flow + Water Balance (i.e. actual evapotranspiration). The "Flow" is the available water that can be used for all uses, calculated as "Rainfall – Water Balance". In order to estimate the quantity od water in Mm3/year, "Average Renewable Resource", the "Flow" (mm/year) is multiplied by the "Area" of each catchment.

The Master Plan used the storage / recharge (or sustainable yield) ratio to validate the estimates. This ratio corresponds to the mean turnover time needed to exchange the water column in an aquifer completely. According to the Master Plan, the estimated turnover times were compared with the results of actual residence time analysis which was carried out as part of special investigations during the elaboration of the Master Plan. The calculated mean residence times were compared with the ones that were analytically determined and found to be in excellent agreement.

The total mean annual outflow from each catchment represents the average annual renewable resource available for exploitation. This figure can be translated into a specific volume value, (i.e. per unit area) to be used in subsequent estimates of water availability for irrigation. The specific values per hectare and catchment are given in the following Table 2-4:

Table 2-4: Average annual renewable resource in the catchments of Rwanda per unit area

	CKIV	**CRUS**	**NNYU**	**NMUK**	**NNYL**	**NAKN**	**NAKU**	**NAKL**	**NMUV**
Ha	242500	100500	334800	194900	330400	340200	305300	428800	156500
m^3/ha/y	3700	4300	3850	4640	2720	2350	1650	2110	1230

The balance of the water demand per catchment shall be conducted following the final determination of the potential areas, while transfer of water quantities between the different catchments will be also considered.

CHAPTER 3. AGRONOMIC ASSESSMENT

3.1. Introduction

This agronomical assessment is by necessity general in nature as the Irrigation Master Plan (IMP) covers the whole of Rwanda and a wide range of ecological conditions. As stated in the Inception and Objectives Report of July 2018, the intention is to harmonize the revised IMP with the Water Resources Management Plan (WRMP) developed in 2013, which identified nine Level-1 catchments. Three general climatic zones and two topographical strata have been used to develop proposed typical cropping patterns and their associated water demands and expected benefits in terms of crop gross margins.

3.2. Methodology

In producing the agronomical assessment, the following activities were undertaken:

- A review of the agronomic aspects of the Rwanda Irrigation Master Plan, 2010 and the Rwanda National Water Resources Master Plan, 2014;
- A review of relevant studies undertaken by or for GoR covering agronomy, soil and land suitability, marketing, and irrigation projects in Rwanda;
- An initial fact-finding mission by the agronomist during the period 13 – 17 August 2018, including meetings with officials in RAB, MINAGRI and NAEB and site visits to 3 operational irrigation schemes, namely Ntende (marshland rice), Kagitumba (pumped pivot/sprinkler, mixed cropping) and Nyanza (hillside gravity supply, mixed cropping);
- Collection of current and past 12-months input costs and market prices from MINAGRI, scheme management and agro-dealers;
- Development of realistic irrigated cropping patterns based on collected data, previous studies, and the Consultant's previous experience of irrigated cropping in Rwanda and Southern and East Africa;
- Estimation of irrigation water demand for selected cropping patterns and catchments using FAO's Cropwat 8.0 software with relevant climate and soil data;
- Development of per-hectare budgets for selected irrigated crops and estimation of annual gross margins for selected cropping patterns and catchments.

3.3. Review of 2010 IMP – Crops selection

Chapter 6 of the 2010 IMP (Criteria for crop selection and estimated crop water requirements) proposes a crop selection tool using several un-quantified criteria which could be used as general guide for developers of future irrigation schemes. As regards market potential, four irrigated export crops are examined and proposed: coffee, green beans, roses, and processed fruit (dried and juices). In terms of profitability, only sweet potatoes are examined in detail, as an example of the analysis procedure. Again, only the procedure of estimating crop water requirement using Cropwat software is demonstrated, using mangoes in three districts as examples. The revised and updated IMP provides a more comprehensive analysis that can be applied to all catchments.

3.4. Review of 2014 WRMP – Crop water requirements

As far as water demand for irrigation is concerned, the Water Resources Master Plan assumes that irrigation from surface or groundwater resources has a consumptive demand of between 6,000 m³/ha/year for the western areas and 8,000 m³/ha/year for the eastern areas, which appears to be a realistic estimate. However, for marshland development a demand of only 2,000 m³/ha/year (in addition to water use from undeveloped marshland) is assumed by WRMP. The plan uses the same demand figure for marshland irrigation, which could be an underestimate considering that the majority of marshland irrigation is devoted to paddy production. For example, the irrigation water demand for two seasons of paddy grown under average Rwandan conditions is in the region of 18,000 m³/ha/year, although some of the applied water runs off into drains or percolates into the soil profile and therefore returns to the catchment resource.

3.5. Rainfed crop production

The vast majority of Rwandan crop production is produced under rainfed conditions with the exception of paddy. The relatively high and well-distributed rainfall allows for two main growing seasons: Season A from September to December, and Season B from January to May. The potential annual production is therefore relatively high, but actual production is well below the what could be expected under the climatic conditions. This is due to a variety of reasons, including the low utilization of fertilizers and improved seeds, and the impact of pests and weeds on growing crops. The national average yields for some selected seasonal crops reported by seasonal agricultural surveys from 2016 to 2018 are shown in the following table.

Table 3-1: National average yields for selected crops 2016-2018, kg/ha

Crop	2016-2018 national average, kg/ha			Yield difference A v B
	A	B	All	
Maize	1,608	1,095	1,352	47%
Sorghum	1,358	985	1,171	38%
Bush beans	807	737	772	10%
Climbing beans	1,019	1,013	1,016	1%
Irish potatoes	8,455	7,047	7,751	20%
Soya beans	560	379	470	48%
			Average	27%
Paddy (incl. irrigated)	3,195	3,668	3,431	-13%

Source: NISR Seasonal Agricultural Surveys, 2016-2018

Season A yields are generally better than Season B for rainfed crops, which suggests that they may benefit from the better water supply during the long rains, but this could also be influenced by better preparation and higher input usage for Season A. Paddy, which is often irrigated, actually shows higher yields in season B.

Potential crop yields under specific conditions can be simulated with FAO's Aquacrop program. Running a simulation for maize planted on 15 October in Butare, Southern Province (season A rainfall 610mm), assuming moderate weed control and fertility gives a biomass yield of 11.7 t/ha and a dry grain yield of 5.7 t/ha (see figure below).

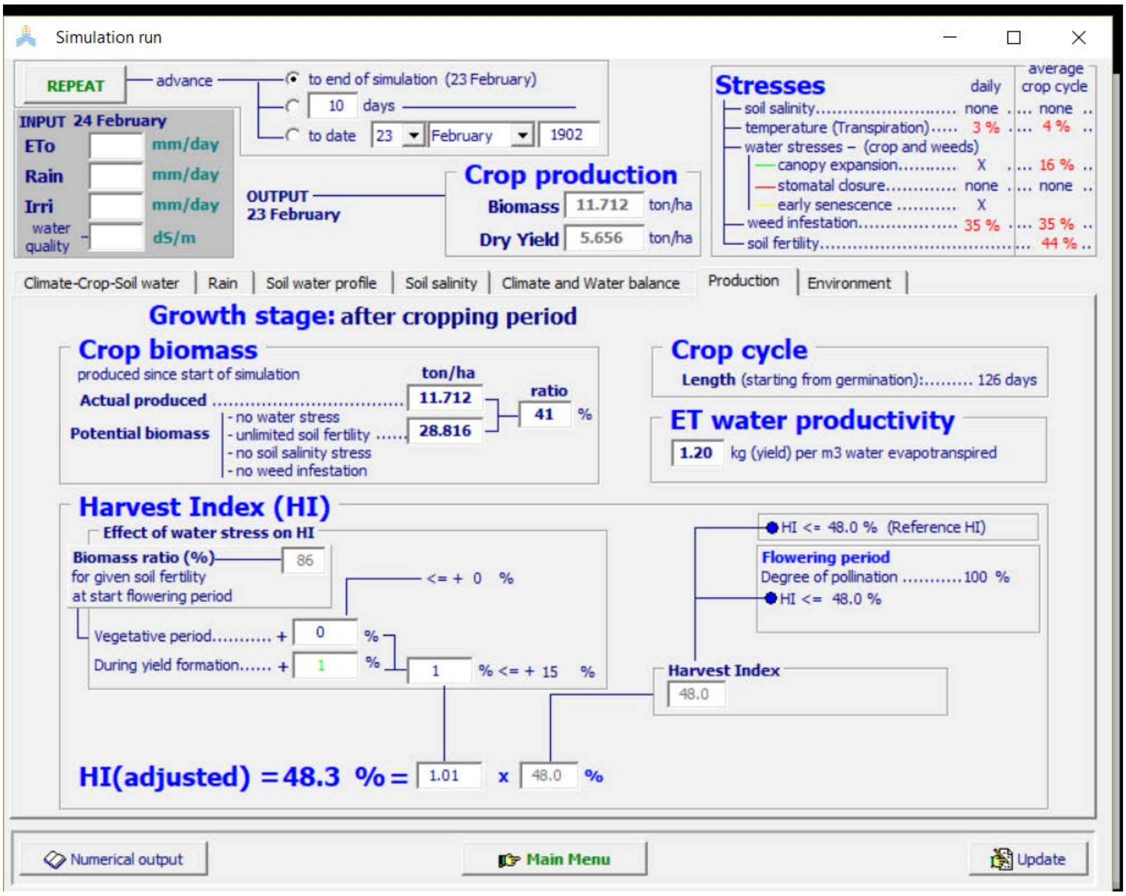


Figure 3-1: Simulation output from Aquacrop for Season A maize in Southern Province

The recorded average national yield is about 25% of the potential indicated by this simulation, which suggests that there are agronomic constraints that are limiting production which are more important than water supply. Rainfed maize yields over 5 t/ha are achievable in Rwanda and the wider region, given well-distributed rain, adequate inputs and good crop management.

Reducing the agronomic constraints to production should take priority over irrigation development - the costs are lower and spread more evenly over successive seasons, and the payback is faster. This was the rationale behind a component of MINAGRI's Crop Intensification Program (CIP) which started in 2007 and greatly increased the use of chemical fertilizers and improved seeds, particularly among cooperatives. However, recent seasonal agricultural surveys from NISR reveal that fertilizer and improved seed is still used on less than half of cultivated land at a national level. Access to appropriate inputs and finance, and technical knowledge of their use, must be priority areas for development.

The above conclusion has an important implication for the Irrigation Masterplan - in order to achieve the higher yields required to justify irrigation development, the agronomic constraints need to be addressed first.

3.6. Crop proposals

3.6.1. Rationale

For the purposes of this report on the irrigation potential, the main objective of the agronomical assessment is to estimate water demand for a range of beneficial and realistic irrigated cropping patterns for different strata (hillside, marshland). In determining the benefits of a particular pattern the profitability of the individual crops must be assessed. Realistic cropping patterns must be adapted to physical and social conditions, as well as market potential.

There is not a large difference in the crop water requirement between different upland field and horticultural crops in a given environment. The main variation in water demand depends on the choice between upland crops and more demanding crops like paddy and sugarcane, the method of irrigation, and the area which will be cultivated in the dry season C, which runs from June to August. Lowland paddy requires more water as it grown in flooded basins where evaporation and drainage losses are high, and sugarcane carries a large amount of foliage for most of the year so has a high transpiration requirement.

3.6.2. Physical conditions

Climate

When determining crop suitability for irrigation in Rwanda, the main climatic parameter is temperature, as water deficit would be addressed through irrigation provided that there are sufficient water resources. However, excess rainfall during harvest and crop senescence can eliminate some crops from selection. Sunshine, relative humidity, and wind all show seasonal variation but little spatial variation within the country. Temperature is largely determined by elevation of which there is a wide range in existing and potential irrigation sites, from >2,000 masl in the Highlands, to <1,000m in Bugarama Valley in Western Province.

Four general temperature zones in Rwanda were identified in the Irrigation Masterplan (IMP) of 2010 as follows:

- Eastern Plateau: altitude < 1500 masl, mean temperature 20–21 °C

- Central Plateau: altitude 1500–2000 masl, mean temperature 17.5–19 °C
- Highlands: altitude > 2000 masl, mean temperature < 17°C
- Imbo and Bugarama Valleys: altitude < 1200 masl, mean temperature 23–24 °C

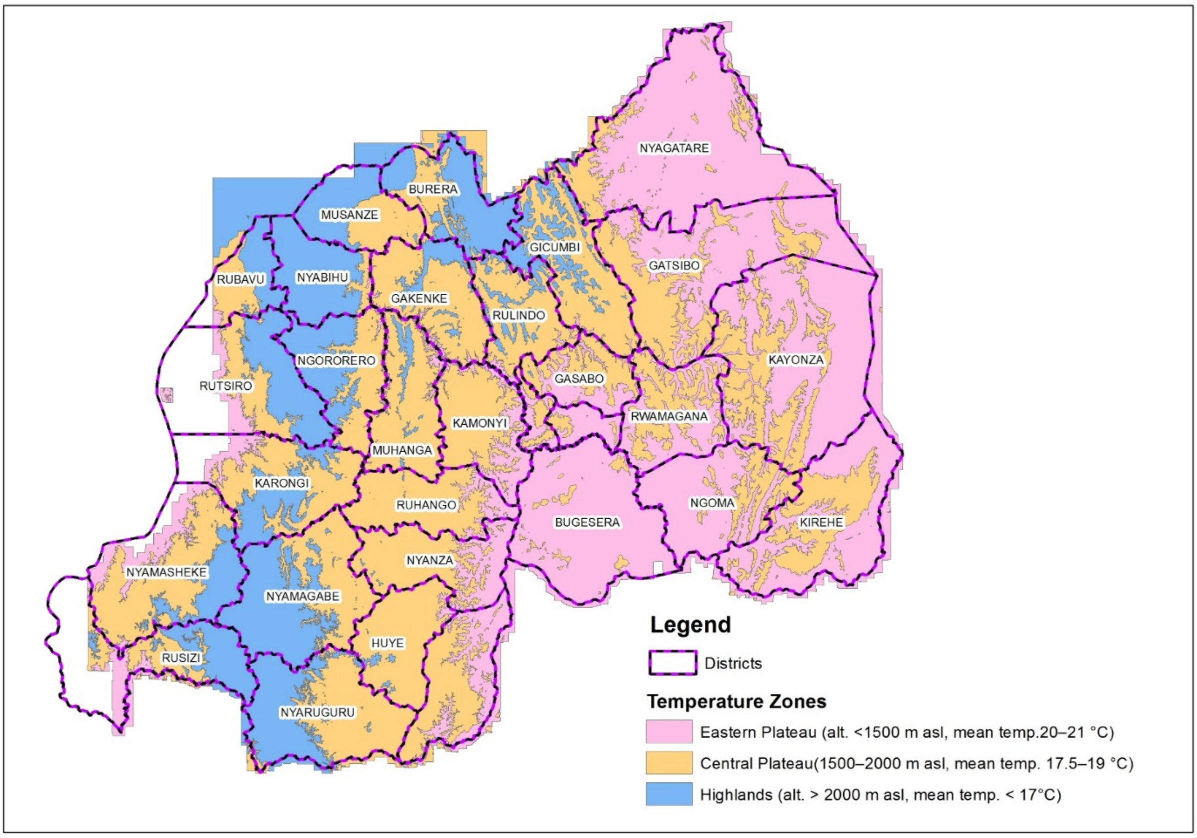


Figure 3-2: Temperature Zones

In greater detail, the IMP of 2010 described the 10 agro-climatic zones identified by Verdoodt and van Ranst. (2003). While these zones do not correspond with the Level-1 catchments identified in the WRMP (for delineation of level 1 catchments see chapter 6) there is some agreement, and the catchments generally contain only one or two agro-climatic zones, as seen in the table which follows.

Table 3-2: Level-1 catchments and agro-climatic zones in Rwanda (IMP 2010 and WRMP 2013)

Level1 catchment		**Avg. annual rainfall, mm**	**Agro-climatic zones**
No.	**ID**		
1	CKIV	1,240	Kivu Lake borders; Birunga
2	CRUS	1,295	Impara; Imbo; Congo Nile divide
3	NNYU	1,365	Congo Nile divide; Central Plateau
4	NMUK	1,315	Burubeka H'lands; Birunga
5	NNYL	1,191	Central Plateau; Eastern Plateau
6	NAKN	1,225	Mayaga & peripheral Bugesera
7	NAKU	925	Mayaga & peripheral Bugesera; Eastern plateau
8	NAKL	835	E Savannah & C Bugesera
9	NMUV	995	E Savannah & C Bugesera; Burubeka Highlands

Topography

The hilly nature of Rwanda makes it challenging to develop irrigation despite the abundance of water resources. Through the use of terracing, irrigation has been developed by the LWH project on hillsides in Rwanda with slopes of up to 40%. This technique is relatively expensive and often requires soil improvement and high maintenance costs, but does significantly expand the potential irrigated area in the country. There is a large area, over 100,000 ha, of marshland in Rwanda which can be conditionally developed, excluding the protected wetlands. With flood control and drainage and some leveling, gravity irrigation schemes can usually be developed at lower cost than hillside schemes. There are relatively few areas of level land which is not marshy which allow large-scale irrigation schemes. Irrigation schemes in these areas are generally grouped with hillside schemes e.g. Kagitumba and Nasho in Eastern Province.

Soils

Chapter 7 which follows describes the soil resource in Rwanda as it pertains to the development of irrigation, and an assessment of their suitability for irrigation.

3.6.3. Crop selection for irrigation

Rwanda is endowed with comparatively good and well-distributed rainfall over season A (Sept-Dec) and season B (Jan-May), so for a crop to justify irrigation at this time it must show a sufficient increase in yield due to additional water supply to cover the cost of developing and operating irrigation systems. It should be noted that other constraints to production such as nutrition and pests must also be addressed if the yield response is to be realized. The productivity of rain-fed crops in Rwanda is generally low by world standards and cannot be blamed on the lack of rainfall alone. According to a baseline study conducted on most of the irrigation sites across Rwanda [15], the main limitations to crop yields are the lack of inputs, use of unimproved seeds, and poor husbandry practices.

Maize varieties have benefitted from a vast improvement through breeding and high potential hybrid varieties are widely used and available in Rwanda. Under irrigation in Rwanda they regularly exceed 5 MT/ha, but have potential for over 8MT/ha under good management and high-input irrigated regimes[16]. **Sorghum** is more tolerant of drought but has a limited response to irrigation, and lower potential yield than hybrid maize.

Common bush beans are very widely grown with very few inputs but have a limited yield potential (1.5 - 2 MT/ha) and would not normally be irrigated. **Climbing beans**, however, have

[15] *Technical assistance in the establishment of a baseline of agricultural households using irrigation systems, Draft Final Report, Volume I, by Transtec/SHER/Agrotec for MINAGRI, 2013*
[16] *Irrigated maize yield on Bramin Farm in Eastern Province exceeded 8 t/ha in 2019, according to farm manager.*

a higher yield potential (2.5-4 MT/ha) if supported, and with adequate inputs and water can yield twice as much as bush beans. **Soya beans** can exceed these yields under warm conditions (3-4 MT/ha) with *Rhizobia* and good management. Both climbing beans and soya would benefit from irrigation to maximize yields**. French (green) beans** are grown primarily for the export market, and require irrigation to ensure year-round production and good quality. Yields of fresh beans are normally in the range of 8 to 12 MT/ha.

Irrigated **paddy** yields in Rwanda are above the regional average, in excess of 5 MT/ha. The National Rice Strategy aims to raise this to 7 MT/ha use of improved varieties and better crop management.

Irish potatoes are widely grown in the highlands under rain-fed conditions with average yields of around 10 MT/ha in Northern and Western Provinces. Under irrigation, with adequate inputs and clean seed, irrigated yields can exceed 25 MT/ha, although they are rarely considered for irrigation, possibly due to adequate supplies from rain-fed crops.

Most **vegetables** are perishable and producers should ideally aim to supply the market continually by making sequential plantings. Onions and garlic can be dried and stored for some weeks or months. Irrigation allows farmers to both increase yields and extend harvest periods.

Perennial fruit trees such avocado, mango and citrus will give a response to irrigation in the drier parts of Rwanda which receive less than 1,000mm p.a. of rain. Passion fruit is vine that starts yielding within its first year and can be kept in production for around 5-6 years before replanting, and it requires irrigation to maximize production. Bananas are commonly grown under rain-fed conditions where yields are only 3-5 MT/ha. With irrigation and high inputs yields of over 20 MT/ha can be achieved in warmer parts of Rwanda. Sweet (dessert) bananas fetch the best prices and would justify irrigation.

Sugarcane is a relatively minor crop in Rwanda, and normally grown in marshland areas without irrigation. It is better suited to regions other than Rwanda where there are larger expanses of land available with high levels of solar radiation. At the yields of 80 MT/ha reported in Rwanda the crop is marginal.

Flowers, either as cut-flowers or propagation material, for the international market are a promising high-value export crop for Rwanda. Its equatorial location ensures production of straight stems, and consistent temperatures allow year-round production of some species outside without greenhouses. Several countries in the region have well-established flower sectors, especially Kenya, and more recently, Ethiopia. Rwanda's flower sector is still relatively small with less than 50ha established, and consisting only of greenhouse roses. In the context of the national IMP, the flower sector will not be very significant in terms of land area or water consumption, but more so in export earnings. For comparison, Kenya's entire flower production comes from less than 4,000ha. Furthermore, flowers are capital and management intensive and are not well-suited to small-holder production.

There is growing interest in **stevia** production in Rwanda and the region. Stevia is a perennial herb and natural sweetener, suited to well-drained soils in a wide range of climatic zones. It requires 1,800mm of water, so requires irrigation in Rwanda, preferably drip or micro-jet, but could be grown under furrow-irrigation. The leaves are harvested at regular intervals throughout the year, every 2-3 months and need to be dried quickly, either in a kiln or sun-dried if weather permits. Currently the established area in Rwanda is estimated to be 200ha, but expansion is being promoted by NAEB and private companies. There is a growing world market, and the crop is well suitable for small-holder production, having relatively low input requirements but labour intensive, especially in weeding and harvesting. Yields can exceed 5MT dried leaf /ha p.a. under good management, although 2MT/ha is typical.

Coffee is grown as a low-input crop in the higher altitude zones which receive higher rainfall. It is unlikely that irrigation would increase yields significantly in these areas, and it would be more economical to increase input levels and improve varieties and management to achieve the required increase in production.

In **season C** there is insufficient rain to support most crops and there is a good opportunity for irrigation schemes to supply fresh produce from June to September. During this period, irrigation schemes should maximize their vegetable production, provided that it is within the limits of market.

3.6.4. Market considerations

Local market – The domestic food market still provides many opportunities for import substitution with locally grown crops, especially cereals. According to FAO estimates, over 170,000MT of cereals were imported in 2016 at a value of over $47m. Over half of this was maize (30%) and rice (23%). In terms of irrigated area, this represents 10,000 ha of maize (1 crop per year at 5 MT/ha) and over 5,000 ha of paddy (2 crops per year at 5.5 MT/ha/crop). Much of the imported rice is the long-grain and aromatic types preferred in urban markets, so additional local production should focus on these.

The local processors are under-supplied by soya beans, with the 2 main processors requiring 62,000 MT p.a. against a local supply of only 35,000 MT according to RAB[17]. This shortfall represents 13,500 ha at a yield of 2 MT/ha. The domestic market for fruit and vegetables is

[17] Tukamuhabwa, P., Feasibility study for implementation of the project on increased soybean production and productivity for sustaining markets, RAB, 2016.

normally well supplied by local growers although there are supply gaps during the year which could be satisfied by irrigated production

Export market – The most promising destinations in the regional export market are neighboring eastern DRC and Burundi which import much of their food requirements. However, Uganda, Kenya and Tanzania are relatively food-secure and have access to the world market through Indian Ocean ports for shortfalls in their own production. The relatively high cost of Rwandan produce makes it difficult to compete in these markets. The markets of Asia, Europe and USA have been more important for Rwanda, especially for traditional products like tea and coffee, which together exceeded $132m of export value in 2016/17 according to NAEB. There are growing exports of fresh vegetables and fruit to Europe and Middle East, but to access these formal export markets normally requires certification and high standards of quality, which can be provided by the organized structure of a commercial out-grower scheme.

Organic market – Although not yet important locally or regionally, the organic market is growing rapidly in developed economies. Rwandan farmers are by necessity used to growing crops with few chemical inputs, and the use of organic manures is common. However, accessing the international organic market demands compliance with stringent standards and hence a high degree of organization, usually supported by a commercial exporter or authority. As irrigation schemes require high output levels to justify their investment, they do not lend themselves to extensive low-input producer groups which are the basis of most organic export operations. Intensive organic vegetables and fruit can be produced on irrigation schemes under the strict control of a cooperative or private exporter.

3.6.5. Farmers’ capacity

The ability to make full and productive use of irrigated land requires experience, technical know-how, access to resources (e.g. inputs, labour or machinery, cash or credit), and a reliable market. Cooperatives, supported by GoR agencies or NGOs have succeeded in operating successful irrigation schemes, particularly in the rice sector. Rice schemes are well suited to this model as there is only one type of crop grown and they can offer centralized marketing, input supply, training and extension services. Where farmers are free to select the type and timing of their crops, centralized control and services are much more difficult, and the utilization of the irrigated area is generally lower. Privately-operated out-grower schemes can achieve good levels of productivity but are at risk of side-selling if there is more than one active buyer.

3.7. Proposed cropping patterns

3.7.1. Existing irrigation practices

The most common irrigated crop in Rwanda is paddy, grown under surface irrigation in developed marshlands. According to seasonal agricultural survey conducted by NISR, about 25% of intensively cultivated marshlands were irrigated in 2017. Hillside irrigation is relatively uncommon, with only 1% of the cultivated area under irrigation, but where practiced the main crops are maize, beans (including soya), vegetables and fruit, using traditional methods of irrigation. New hillside schemes developed by MINAGRI have adopted gravity systems using hose-furrow systems. Sprinkler and centre-pivot systems are still rare. Sugarcane is not usually irrigated, but is instead grown on reclaimed marshland.

3.7.2. Crop rotation

There is no crop rotation practiced on lowland paddy schemes, and farmers have managed to sustain or improve yields under continuous cropping provided that inputs and water are available. Upland crops, however, require rotation to improve soils and control pest and disease build-up, and fortunately rotating legumes with graminaceous (e.g. maize or sorghum) crops and vegetables is common practice in Rwanda.

3.7.3. Rationale

For the purposes of an Irrigation Master Plan it is not appropriate to prescribe all the potential cropping patterns that could be adopted, or a single universal pattern, but some standard patterns can be proposed which are suited to broad categories of climatic and topographical situations. The main purpose of proposing standard patterns is to estimate the irrigation water requirement for different climatic zones and the expected financial benefits that could be generated from schemes in these zones. Another outcome could be estimating the additional production that could arise from developing irrigation schemes, and therefore potential exports or import-substitution. Due to the challenges of marketing additional fresh produce both locally and internationally, the cropping patterns must be conservative when it comes to the area devoted to horticultural crops.

The standard proposals for irrigated cropping patterns take into account the physical conditions (climate, soil and topography), market demand and profitability.

3.7.4. Scenarios

At a national level, three broad climatic zones are considered:

- Eastern Plateau: altitude < 1500 m asl, mean temperature 20–21 °C
- Central Plateau: altitude 1500–2000 m asl, mean temperature 17.5–19 °C
- Highlands: altitude > 2000 m asl, mean temperature < 17°C

The Imbo and Bugarama Valley zone is omitted as it represents a relatively small area in the SW of the country.

Within each climatic zone two broad topographical cases are considered, a) marshland and b) hillside, which includes well-drained slopes and valley floors. This leads to the broad classification given below for which irrigation water demand and financial benefit are estimated.

Table 3-3: Scenarios selected for water demand and gross margin analysis

Zone / strata	Eastern plateau	Central plateau	Highlands N & W
Marshland	X	X	n/a
Hillside	X	X	X

3.7.5. Cropping patterns

The best proposition for marshland is lowland paddy, which is an established practice achieving good production of over 10MT/ha/year and with scope for import substitution if long-grain varieties are selected. Alternative cropping patterns for marshland are mixed food and horticultural crop rotations with furrow irrigation where soils have better drainage, or sugarcane.

There are three standard cropping patterns proposed for hillside irrigation: 1) mixed food and horticultural crops, 2) perennial fruit combined with food and horticultural crops, and 3) Irish potato combined with food and horticultural crops for highland areas.

In the proposed cropping patterns presented in the following table, food crops include maize, climbing beans and soya. Vegetable crops include tomato, onion, cabbage, carrots, garlic, watermelon, green beans and chilies. Fruit crops include avocado, mango, citrus, passion fruit and bananas. These selections do not include all the potential crops, but the range is sufficiently wide to calculate realistic water demands and gross margins which remain valid if some crops are substituted in the mixed cropping patterns (M2, H1, H2, H3).

Table 3-4: Proposed cropping patterns by strata and season

Stratum	Crop pattern	Season A	Season B	Season C
Marshland	**M1** Paddy	Paddy, 100%	Paddy, 100%	nil
	M2 Food + horticulture	Maize, 50%; soya 30%, vegetables 20%	Maize 50%; beans 30%; vegetables 20%	Vegetables 50%
	M3 Sugarcane	Sugarcane 100%	Sugarcane 100%	Sugarcane 100%
Hillside	**H1** Food + horticulture	Maize, 50%; soya 30%, vegetables 20%	Maize 50%; beans 30%; vegetables 20%	Vegetables 50%
	H2 Fruit trees + food + horticulture	Fruit 55%; maize 20%; soya 10%, veg 5%	Fruit 55%; maize 20%; beans 10%, veg 5%	Fruit 55%; vegetables 15%
	H3 Irish potatoes + food + horticulture	Potato 25%; maize 25%; beans 25%; veg 25%	Potato 25%; maize 25%; beans 25%; veg 25%	Vegetables 50%

Although maize is not a high value crop, it has been allocated a significant share of the mixed cropping patterns, due to the following rationale:

- In a rotation combined with high value crops the returns per hectare justify irrigation (gross margin of RWF 2.8m/ha p.a. for M2 and H1 – see section 6.10 below)
- Easy to produce and widely grown, and produces a large amount of crop residue for mulch, composting or animal feed;
- Good response to irrigation
- Ready market and scope for further import substitution.
- The share of irrigated land that can be planted to high-value crops such as fruit and vegetables will always be constrained by the market, either by local demand or access to export markets;

3.8. Irrigation systems

The determination of the gross irrigation water requirements must assume an irrigation efficiency (IE) which is the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation. This is the scheme efficiency including conveyance (ec) and field application (ea), calculated as IE% = ea% x ec%, as defined by FAO[18].

Lined canals or pipes have a conveyance efficiency of 95% or more, whereas earthen canals can have *ec* values ranging from 60% to 90% depending on soil type and length, according to FAO guidelines. The application efficiencies of the main irrigation methods are assumed as follows:

- Surface (furrow, basin, border) 60%
- Overhead (sprinkler, centre pivot) 75%
- Drip 90%

The system efficiencies for the different systems considered are given below:

- Marshland surface with lined primary canals and earthen (clay) secondary/tertiary canals: IE = 90% x 60% = **54%**
- Hillside surface with lined canals/pipes: IE = 95% x 60% = **57%**
- Hillside overhead with lined canals/pipes IE = 95% x 75% = **71%**
- Hillside drip with pipes = 95% x 90% = **86%**

There are considerable water savings to be had by using overhead instead of surface irrigation, but they are only applicable where topography permits and cannot be used on narrow terraces,

[18] *Irrigation Water Management: Training Manual No.4, Irrigation Scheduling, FAO 1989*

for example. Gravity conveyance networks can produce sufficient head for overhead (25-30m) systems in certain parts of hillside schemes which lie well below the intake, but elsewhere pumping is required.

Drip systems conserve more water and operate at lower pressures (10-15m) than overhead and can be adapted to hillside terraces. Drip can therefore be more widely used in hillside schemes than overhead irrigation. It can be retro-fitted to existing piped gravity schemes where conditions and farmers' capital allow. Drip emitters are easily clogged with suspended solids and algae, so are better suited to clean groundwater supplies. Surface water supplies generally require two-stage filtration (which incurs more head-loss), and drip-lines should be regularly cleaned with acid and/or chlorine. Due to the higher demands on capital, operation and maintenance, and replacement costs, drip irrigation is appropriate only for well-managed high-value crops on a limited area.

3.9. Irrigation water requirements

The gross water demand per hectare for irrigation has been calculated for the various scenarios described above using FAO's CROPWAT 8.0. The program calculates the net irrigation demand for each 10-day period for a particular cropping pattern and set of monthly climate data and soil type. Crop factors (K_c) specific to crop type and stage of growth are used to calculate the crop's evapo-transpiration (ET_{crop}) requirement under prevailing evapo-transpiration (ET_o) conditions:

$$ET_{crop} = K_c \times ET_o$$

The irrigation requirement, is the difference between the crop's evapo-transpiration (ET_{crop}) and the effective rainfall (R_{eff}), calculated for each 10-day interval throughout the growing season:

$$CWR = ET_{crop} - R_{eff}$$

Because vegetables are grown continuously throughout the year, without predictable planting and harvest dates, a weighted mean crop factor has been used to estimate water demand. The calculated K_c for continuous vegetable production is 0.88, based on published crop factors for a range of common vegetables grown in Rwanda, namely tomato, onion and cabbage.

The stations used for climate data for calculating the irrigation requirement for each zone are given below. The soil types assumed are heavy black clay for paddy on marshland, medium textured soils for upland crops and trees on hillside schemes, and heavy textured soil for sugarcane. The impact of **climate change** is discussed after the estimated demands based on historical climate data to 2010.

Table 3-5: Meteorological stations used for water demand calculation (30+ year means)

Zone	Rainfall	Climate (Eto)
Eastern plateau	Nyagahanga, EP	Kigali, KC
Central plateau	Rubona-Coline, SP & Kigali, KC	Rubona-Coline, SP & Kigali, KC
Highlands	Ruhengeni, NP	Ruhengeni, NP

Gross demand has been calculated using the appropriate irrigation efficiencies stated above. The annual requirements are displayed in the tables which follow. The CROPWAT output tables and monthly demands are provided in the Annex.

3.9.1. Irrigation demands under current climatic conditions

Table 3-6: Gross irrigation water demand under surface irrigation, m³/ha/year

Cropping pattern	System	Eastern plateau	Central plateau	Highlands, N & W
Mixed food & horticulture	Furrow	7,344	6,170	2,321
Tree crops + mixed food & horticulture crops	Furrow/basin	8,479	6,944	2,525
Irish potatoes + mixed food & horticulture crops	Furrow/basin	n/a	n/a	2,063
Paddy	Basin	19,535	18,057	n/a
Sugarcane	Furrow	13,691	11,933	n/a

Note: Irrigation efficiency for paddy = 54%, other systems = 57%

Paddy has 2.7 times the annual water demand of mixed crop patterns. Although there is no crop growing in season C in paddy schemes, there is a high water demand for land-preparation before season A starts, and significant losses through percolation from flooded basins. Sugarcane has 1.7 times the water demand of mixed crop patterns, explained by the large amount of foliage carried for most of the year.

The timing of plantings in relation to rainfall patterns has a significant impact on the irrigation water demand, particularly for heavy water users like paddy. For example, by delaying land preparation until the rains have started can significantly reduce the irrigation requirement since around one-third of paddy's crop water requirement is for puddling and preparation for transplanting. The following example for paddy grown on the Eastern Plateau using Cropwat shows a 10% saving in annual irrigation water requirement by delaying transplanting until 15 October.

Strategy	Transplant date		Gross IWR, m3/ha	% of Early IWR
	Season A	Season B		
Early	15-Aug	15-Feb	19,535	100%
Medium	15-Sep	15-Feb	18,346	94%
Late	15-Oct	15-Mar	17,533	90%

Due to the higher rainfall and cooler temperatures, the irrigation demand for crops grown in Highlands is 30-40% of the other zones, and the benefit-cost ratio of developing schemes to deliver only 2,000m³/ha/yr is expected to be lower than for schemes on Eastern or Central plateaus, depending on the crops grown.

The water demands using improved irrigation methods for the situations where it can be implemented are given in the following table. The reduction in demand compared to surface irrigation is direct function of the higher field application efficiency (ae).

Table 3-7: Irrigation water demand under improved irrigation, m³/ha/year

Cropping pattern	System	Eastern plateau	Central plateau	Highlands, N & W
Mixed food & horticulture	Sprinkler	5,875	4,936	1,857
	Drip	4,896	4,113	1,547
Tree crops & mixed food & horticulture	Sprinkler	6,783	5,555	2,020
	Drip	5,653	4,629	1,683
Irish potatoes & mixed food & horticulture	Sprinkler			1,651
	Drip			1,375
Sugarcane	Sprinkler	10,953	9,547	
	Drip	9,127	7,956	

Note: Irrigation efficiency for sprinkler = 71%, drip = 86%

Where conditions permit and water resources are limited relative to the available irrigable area, it may be appropriate to install overhead or drip irrigation, subject to its affordability by by investors and farmers.

3.9.2. Impact of climate change

The Stockholm Environmental Institute considered a suite of climate models covering Rwanda and found that projections indicate future increases in average monthly temperatures of broadly 1.5 to 3ºC, over the range of models by the 2050s[19]. The majority of the models indicate an increase in average annual rainfall (with a central value of typically 10% to 2050), particularly in September to November. A later analysis of four general circulation models and the expected impact on agriculture in Rwanda in 2050 was conducted by Tenge et al in 2013[20]. All four models predicted a mean annual temperature increase of between 1 and 3ºC affecting the whole country, but a wide variation in the predicted change in annual rainfall, from -100mm to +400mm. The warmer models tended to be neutral for rainfall.

[19] Downing, T., Watkiss, P., Dyszynski, J.; et al (2009). Economics of Climate Change in Rwanda.
[20] Tenge, N., Alphonse, M, and Thomas, T. (2013). Chap. 9 of East African Agriculture and Climate Change: A Comprehensive Analysis (ed. Michael Waithaka et al)

Based on the foregoing findings, two scenarios have been used to estimate future irrigation demand in the three general climate zones in Rwanda for the time horizons of 2030 and 2040: A) a linear increase in temperature and rainfall to 2050 levels of +2.5ºC and +10% rainfall (2030: +1.3ºC, +5% rain, 2040: +1.8ºC, +8% rain), and B) a linear increase in temperature to 2050 of +2.5ºC and no increase in rainfall.

Impact on irrigation water demand

The expected changes in evapo-transpiration were calculated in CROPWAT using uniform temperature increases across all months (2030: +1.3ºC; 2040: +1.8ºC), assuming that relative humidity, windspeed, and solar radiation remain at historically recorded levels. The projected temperatures result in only a modest increase in the annual average ETo (3% in 2030, 5% in 2040) as temperature is only one of the drivers of ETo. Rainfall in scenario a) has been increased by an average of 5% in 2030 and 8% in 2040, with a heavier weighting in the period September to November (as predicted by the models). The irrigation demands computed from historical data in 3.8.1 above are representative of the 2020 horizon. The projected demands for surface irrigation for the main cropping patterns in 2030 and 2040 are given in the following table.

Table 3-8: Projected gross irrigation demands with climate change (m³/ha/yr)

Scenario A	**2020**	**2030: +1.3°C, + 5% rain**		**2040: +1.9°C, + 8% rain**	
Eastern plateau	m³/ha p.a.	m³/ha p.a.	% change *	m³/ha p.a.	% change *
Mixed food & horticulture	7,344	7,813	6%	7,883	7%
Paddy	19,535	19,761	1%	19,863	2%
Central plateau					
Mixed food & horticulture	6,170	6,669	8%	6,735	9%
Paddy	18,057	18,296	1%	18,407	2%
Highlands, N & W					
Irish potatoes & mixed food/hort	2,063	2,198	7%	2,206	7%
Mixed food & horticulture	2,321	2,480	7%	2,489	7%
Scenario B	**2020**	**2030: +1.3°C, normal rain**		**2040: +1.9°C, normal rain**	
Eastern plateau	m³/ha p.a.	m³/ha p.a.	% change *	m³/ha p.a.	% change *
Mixed food & horticulture	7,344	8,167	11%	8,413	15%
Paddy	19,535	20,294	4%	20,659	6%
Central plateau					
Mixed food & horticulture	6,170	6,952	13%	7,167	16%
Paddy	18,057	18,756	4%	19,102	6%
Highlands, N & W					
Irish potatoes & mixed food/hort	2,063	2,350	14%	2,441	18%
Mixed food & horticulture	2,321	2,644	14%	2,743	18%

*Note: *increase over 2020 levels (i.e. current levels)*

As expected, increased rainfall compensates for rising temperatures (and ETo), but not completely, such that the annual irrigation demand for upland field crops would increase by 7-9% by 2040 even with increased rainfall. Without higher rainfall the demand would increase by 15-18%. The irrigation demand for flood-irrigated paddy is less susceptible to climate change (6% higher in 2040) as a substantial part of the water is used for puddling and land preparation. Although the annual water demands for all cropping patterns and scenarios increase with climate change, the peak demands are relatively unaffected, even under scenario B. This is because most of the increased demand comes from periods when the irrigation system is not working to capacity. This implies that conveyance infrastructure designed for 2020 demands will continue to be adequate in the future, but there will be higher demands on storage, and irrigation systems will have to operate for a longer time each year.

Other impacts

In addition to an increase in temperatures, and possibly rainfall, the climate models predict an increase in intensity of rainfall events, and variability of rainfall patterns. These may not affect the annual irrigation water demand but could impact irrigation schemes in a variety of ways:

- Flooding of fields, particularly in marshlands;
- Damage to spillways, weirs or embankments;
- Changes in seasonal availability of water; impacting schemes without storage, or delaying the recharge of reservoirs,
- Increased sedimentation in dams, weirs and canals;

3.9.3. Climate resilience schemes

A new irrigation schemes must provide alternatives for the changing climate, not just for increased irrigation water demand, but also for more extreme floods and sediment loads. The scheme must be:

- hydraulically feasible (for example in terms of raw water availability);
- well designed (for example in terms of storage capacity, conveyance capacities and control structures); and
- well operated (for example in terms of water allocation within the scheme).

Hydraulically feasible

Hydraulic feasibility is the basic requirement for any investment in irrigation infrastructure. If a scheme is not hydraulically feasible, it is not likely to generate economic and social benefits. On the contrary, it can be positively harmful to resource management and cultivation.

The hydraulic feasibility includes the balance between water demand and availability (for existing and future cultivation systems), possibly related to storage capacity. The raw water availability is a key consideration. A hydraulically feasible irrigation system is able to deliver a predictable and reliable amount of water, reflecting the raw water availability and the storage and conveyance capacity. A feasibility analysis must be based on knowledge (or realistic assumptions) about the overall, 'reliable' water availability. The following should be considered regarding this aspect:

- Adopt a basin-wide, IWRM-based perspective on water availability assessments. Storage capacity upstream can improve conditions downstream (including water availability and salinity control). The overall water allocation must provide a balance between demand for irrigation and other off-stream and in-stream demands of water, including domestic demands, livestock, and preservation of wetlands and other aquatic habitats.
- Conduct a climate assessment (of opportunities and risks) before deciding on any major investment.
- New technology can be attractive, but should be introduced with due caution, considering the risk of unexpected adverse side effects.

Hydraulic feasibility assessment can comprise by:

- hydrological analysis of general water availability;
- assessment of the adequacy of the available water as compared with the intended use (service area and cultivation cycles);
- assessment of hydraulic risks and side effects and related mitigation options: Flood risk, erosion, siltation, and connectivity; and
- identification of present and future competing uses, in-stream and off-stream, and upstream as well as downstream.

Design of irrigation infrastructure

A good design is a precondition for convenient operation and for achieving a good efficiency. Critical design aspects in connection with climate adaptation include:

- storage capacity;
- control of flow rates and water allocation within the command area;
- flood resilience;
- drainage; and
- salinity control (in affected areas).

The following should be considered regarding this aspect:

- Divide the command area into sections, to allow for orderly cultivation of a part of the area in case of water shortage.

- Concrete lining of distribution canals will reduce the seepage losses and prevent or reduce scour during peak flows (for example related to floods). Also, concrete canals occupy less land, and regulators are much easier to build. Other more efficient technologies should be examined.
- Dams should be provided with spillways. Provide excess capacity, or allow for subsequent capacity upgrading.
- Pumping is more efficient to be applied to high-value crops only, due to the high costs (or in connection with drought mitigation, where a short period of pumping may save the crop).
- Provide simple network diagrams with command area details, regulators, and conveyance and storage capacities.

Operation of irrigation infrastructure

The purpose of the operation is to serve the crop water demand. If the requirements for operation are not fulfilled, it will reduce the performance of the scheme, and hereby its value and even its feasibility. The following should be considered regarding this aspect:

- Provision of decision-support services (to scheme operators and farmers) should involve the provincial departments and should be coordinated between there users and the government.
- Provide access to meteorological data, real-time as well as historical records.
- Implement local rainfall monitoring (daily reading of a rain gauge). Short records can be compared with nearby long-term records and provide a highly useful information for a moderate cost. Also, site specific evaporation may be monitored.
- Keep track of actual irrigation supplies, as a basis for knowledge building and continued streamlining.
- Keep track of events storms, floods, drought, pest attacks, saline intrusion, and damage to structures, that affect the performance of the system, as a basis for decisions on improvements. Maintain a record with dates and a few lines about what happened.
- Assure that the fields are leveled.
- Maintain the supply network.
- Always keep drainage canals and structures operational.
- Protect reservoirs against siltation.

Key Recommendations

Below are listed some key considerations for successful climate adaptation of irrigation systems:

- High overall efficiencies of water dependent production systems

- Adequate hydraulic feasibility; good design; and good operation
- Balance between water demand and raw water availability
- Adequate drainage
- Construction of cut-off drains, silt traps and buffer zones to protect reservoirs, canals and irrigated fields;
- As much storage as possible
- Good control of water allocation over time and within the scheme
- Improved catchment management to reduce erosion and soil loss;
- Maintain of canals and drains;
- Limited losses
- Predictable and reliable water allocation
- Good collaboration between the farmers
- Good access to information about the normal and actual weather
- Improved meteorological data from across the country is required to monitor climate change, and design schemes using more recent and consistent rainfall data
- Good knowledge about management options, covering both cultivation and water management

3.10. Crop budgets

Crop budgets have been prepared for the irrigated crops included in the patterns proposed above. Current 2018 prices have been used for input costs, and 2017/18 annual output prices have been used for output value. For perennial crops such as fruit trees and passion fruit, average output and input values for the first 10 years from initial planting have been used so that financial returns can be compared with annual crops. Prices have been obtained from local agro-dealers, MINAGRI sources, and RATIN. More details on assumptions are given below.

3.10.1. Output

Expected yields have been estimated based on performance in existing irrigation schemes in Rwanda or the region. The yields assume an adequate supply of inputs and reasonable level of management by a small-scale farmer. They are considerably less than the potential irrigated yield achievable under high-input conditions as they need to reflect a realistic average across an irrigation scheme.

3.10.2. Labour

Labour is a major input for all crops in Rwanda, particularly for fruit and vegetables and where no machinery is used. For small-scale farmers, most of the labour is supplied by family members without wages, but in order to estimate the real cost of labour a rate of RwF1,500 per day of 8 hours is used for all unskilled labour. Current wage rates on farms are around RwF1,000 for 5-6 hrs of unskilled work. Intensively cultivated irrigation schemes have a high labour demand and are likely to create competition for labour and thus higher wage rates.

3.10.3. Crop inputs

Although several important crop inputs are subsidized by the government in Rwanda, for the purposes of the crop budgets the unsubsidized retail prices have been used. This avoids hiding costs that government would incur when considering the benefits of irrigation developments.

3.10.4. Summary of crop budgets

The detailed crop budgets are presented in the Annex, and the table which follows summarizes the output, variable or direct costs (VCs), and the gross margins (GM) for each irrigated crop.

Table 3-9: Estimated gross margins for irrigated crops

Crop	Yield, kg/ha	Price, RwF/kg	Income RwF/ha	VCs, RwF/kg	GM, RwF/ha	GM %
Food crops						
Maize	5,000	314	1,571,510	822,698	748,812	48%
Soya	2,000	582	1,164,360	692,750	471,610	41%
Beans, bush	1,600	517	827,822	598,786	229,036	28%
Beans, climbing	2,000	517	1,034,778	664,186	370,592	36%
Paddy, lowland	5,500	300	1,650,000	957,025	692,975	42%
Irish potato	20,000	180	3,600,000	1,569,500	2,030,500	56%
Sweet potato	12,000	210	2,520,000	1,334,300	1,185,700	47%
Groundnuts	2,000	677	1,354,769	699,700	655,069	48%
Vegetables						
French beans	9,000	372	3,348,000	1,119,100	2,228,900	67%
Chillies	10,000	440	4,400,000	2,417,067	1,982,933	45%
Tomato	15,000	397	5,955,000	1,675,400	4,279,600	72%
Onion	12,000	350	4,200,000	1,402,900	2,797,100	67%
Cabbage	20,000	200	4,000,000	1,334,600	2,665,400	67%
Carrots	8,000	474	3,789,497	1,381,400	2,408,097	64%
Garlic	5,000	1,250	6,250,000	2,049,900	4,200,100	67%
Watermelon	15,000	250	3,750,000	1,430,900	2,319,100	62%
Perennial crops						
Avocado	6.5	285	1,853,000	861,000	992,000	54%
Mango	3.9	375	1,463,000	826,000	637,000	44%
Oranges	3.3	492	1,600,000	923,000	677,000	42%
Passion fruit	4.6	739	3,413,000	2,179,000	1,234,000	36%
Banana, sweet	12.0	472	5,664,000	1,618,617	4,045,383	71%
Sugarcane	80.0	18,400	1,472,000	669,693	802,307	55%

3.11. Cropping pattern gross margins

Using the expected gross margin for each crop and its share of a particular cropping pattern, the average annual gross margin per hectare for the proposed cropping patterns can be estimated. This can be used to indicate the return on investment and ability to pay water fess for various patterns and schemes.

Table 3-10: Annual gross margin per hectare and per cubic meter of water used for proposed cropping patterns

Stratum	Crop pattern	Gross margin RwF/ha/yr	Water demand m^3/ha/yr	GM per m^3, RwF
Marshland	M1 Paddy	1,385,950	17,893 [1]	77
	M2 Food + horticulture	2,866,292	6,603 [1]	434
	M3 Sugarcane	802,307	12,514 [1]	64
Hillside	H1 Food + horticulture	2,866,292	6,603 [1]	434
	H2 Fruit trees + food + horticulture	1,844,976	7,711 [1]	239
	H3 Irish potatoes + food + horticulture	3,411,516	1,960 [2]	1,741

Notes: [1] average water demand for Eastern and Central plateau zones; [2] Highland zone water demand

It should be noted that the gross margin per cubic meter used for irrigation is not the ***marginal benefit*** of irrigation water supplied, which would require an analysis of the production gain due to irrigation. For example, the H3 pattern which is particular to the Highlands and includes Irish potatoes, has a high gross margin and a low irrigation requirement, hence the high GM/m^3 figure.

Calculating the component of water productivity which is due to irrigation requires complex analysis of all the factors that contribute to achieving higher yields, including land preparation, seed quality and variety, fertilizers, pest and weed control, and general crop management. This can only be done on a case-by-case basis, and it is difficult to arrive at general measures of the productive value of irrigation water in Rwanda. A catchment-wide study of the increase in irrigation water productivity (IWP) in an arid area of North-West China[21] revealed that agronomic factors were more important in driving the increase in IWP witnessed over a 30-year period than irrigation usage itself. It was found that fertilization and pesticide use contributed 33%, and 11% respectively to the increase of IWP, while irrigation counted for 21%, and the use of agricultural film (artificial mulch) was responsible for 42%. This highlights the importance of addressing agronomic constraints when implementing an irrigation project, and including the cost of remedial measures in financial and economic analyses.

[21] Xiaolin Li et al, Irrigation water productivity is more influenced by agronomic practice factors than by climatic factors in Hexi Corridor, Northwest China, Scientific Reports volume 6, Article number: 37971 (2016)

CHAPTER 4. SOIL ASSESSMENT AND LAND TENURE

The soil has many properties that fluctuate with the seasons. It may be alternately cold and warm or dry and moist. Biological activity is slowed or stopped if the soil becomes too cold or too dry. The soil receives flushes of organic matter when leaves fall, or grasses die. Soil is not static. The pH, soluble salts, amount of organic matter and carbon-nitrogen ratio, numbers of micro-organisms, soil fauna, temperature, and moisture all change with the seasons as well as with more extended periods of time. Soil must be viewed from both the short-term and long-term perspective.

4.1. Geology and Geomorphology

The geology and geomorphology of Rwanda are complex, resulting in a high diversity of parent materials.

4.1.1. Geology

Pure shale, and quartzite intervening with shale dominate the lithology of the country with an area extent exceeding 50%. Granite is the third most important parent material, covering 11% of the land. It is especially important in the northeastern savanna and in the agricultural zone of the Granitic Ridge. At some spots in the Congo-Nile Watershed Divide and the Central Plateau, the shale and granite have been slightly metamorphosed, resulting in the formation of schist, micaschist, and micaceous granite. Alluvial and organic materials occupy 4 and 3%, respectively. Other parent materials that occupy more than 1% of the total area are basic rocks, basaltic/calcareous rocks, volcanic ejecta and lava[22]. Soils derived from volcanic, basaltic and calcareous materials offer favorable soil property conditions for crop production, but their soil depth limits their suitability for irrigation development. On the other hand, soils developed from granitic, micaceous granitic, granitic–quartzitic, granitic–basic, quartzitic, and quartzitic–schistic parent materials are characterized by a shallow soil depth, low water holding capacity and high stoniness, which limit their suitability for irrigation development. Soils developed from shale, micaschist, and micaschist, when influenced by another lithological substrate such as volcanic ejecta, offer favorable suitability condition for irrigation development[23].

4.1.2. Geomorphology

The landscape of Rwanda is diverse with different variations of slopes. The alluvial plains and plateaus are relatively flat, with slope gradients ranging from 0 to 6%. The steepness of the valleys varies from 6 to 13%, while the landscape of thousand hills is characterized by slopes

[22] Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3
[23] Soil Survey Staff (1998). Keys to Soil Taxonomy. USDA. United States Department of Agriculture (USDA). Natural Resources Conservation Service (NRCS).

varying between 13 and 25%. The high-altitude areas of the “Congo-Nile Watershed Divide” and the “Buberuka Highlands” agro-ecological zones are very steeply sloping, with gradients exceeding 55% at some spots. The degree of inclination in the volcanic region is variable, ranging from 2 to 55% or even more[24].

Slope gradient in the range of 0 to 13% are classified as highly suitable for irrigation development when they are not limited by soil depth and degree of stoniness. The slope gradients in the range of 13 to 25% are moderately suitable, while slopes above 25% are marginal for irrigation development because they increase the risks for soil loss by water erosion[25].

4.2. Rwanda Soil Classification System

In Rwanda, different classification systems have been attempted to classify soils, and these include: (i) the FAO world soil legend (FAO – UNESCO soil classification system)[26]; (ii) the USDA Soil Taxonomy; (iii) the French soil classification[27]; and (iv) the INEAC soil classification[28]. FAO and USDA Soil taxonomy are the two soil classification systems widely recognized internationally. Rwanda has developed a “Soil Dataset” at scale 1:50,000, which was published in 1990[29]. The Rwanda Soil Database (“Carte Pédologique du Rwanda”) is described and classified using the USDA soil taxonomy[30]. Although the FAO system is worldwide recommended to classify soils, we will classify Rwandan soils using the USDA soil taxonomy as described in the existing Rwanda soil database. “Soil Orders and Soil Suborders” of the USDA soil classification will be provide with an equivalent of the soil group classified according to FAO World Soil Reference Base classification system[31].

The FAO Soil classification system is based on soil properties defined in terms of diagnostic horizons, properties and materials, which are measurable and observable in the field. The major soils (reference soil groups) are defined on the basis of soil physical property (i.e. texture, depth, drainage, profile development) and soil chemical characteristics such as cation

[24] Soil Survey Staff (1998). Keys to Soil Taxonomy. USDA. United States Department of Agriculture (USDA). Natural Resources Conservation Service (NRCS).
[25] FAO (1997). Irrigation potential in Africa: a basin approach. FAO land and water bulletin, 4. Paper No 56. Rome, Italy.
[26] FAO (1988). The FAO-UNESCO Soil Classification: A Reference System Based on Soil Landscape Associations.
[27] Duchaufour (1982). Pedology : pedogenesis and classification. George Allen & Unwin (ed). Boston. 448 p.
[28] Sys, C. (1961). La cartographie des sols au Congo: ses principes et ses methods. Institut National pour l'Étude Agronomique du Congo (INEAC). 141p
[29] Birasa, E.C., I. Bizimana, W. Bouckaert, A. Delflandre, J. Chapelle, A. Gallez, G. Maesschalck and J. Vercruysse (1990). Les Sols du Rwanda: méthodologie, légende et classification, Carte Pédologique du Rwanda. Kigali - Rwanda (Unpublished): CTB et MINAGRI.
[30] Soil Survey Staff (1998). Keys to Soil Taxonomy. USDA. United States Department of Agriculture (USDA). Natural Resources Conservation Service (NRCS).
[31] FAO (2006). World Reference Base for Soil Resources, World Soil Resources Reports 103, Rome

exchange capacity (CEC) of soil and clay, base saturation percentage (BSP), and other chemical characteristics[32].

In the USDA Key Soil Taxonomy, all of the keys are designed in such a way that the user can determine the correct classification of a soil by going through the keys systematically. The soils are classified step by step starting with the “Key to Soil Orders” and eliminate, one by one, all classes that include criteria that do not fit the soil in question. The soil belongs to the first class listed for which it meets all the required criteria. The user of the USDA Key Soil Taxonomy determine first the name of the first “Soil Order” which, according to the criteria listed, includes the soil in question. After identifying the right “Soil Order”, then the user systematically goes through the key to identify the “Soil Suborder” that includes the soil, i.e., the first in the list for which it meets all the required criteria. The same procedure is used to find the “Great Group” class of the soil in the “Key to Great Groups” of the identified soil suborder. Likewise, going through the “Key to Subgroups” of that great group, the user selects as the correct “Soil Subgroup” name, the name of the first taxon for which the soil meets all of the required criteria. The family level is determined, in a similar manner, after the subgroup has been determined.

Although various attempts to classify the soils of Rwanda have made, the most important remains to how to inform or communicate soil classification to the farmers or to the agricultural extension services using less sophisticated terms to identify soil types for specific soil management and cropping systems. Thus, Rushemuka et al. (2014)[33] attempted to classify the soils of Rwanda using local soil names based on farmer’s knowledge in soils. He correlated the local soil types with classes or orders of scientific classification systems such as Soil Taxonomy and to what extent the soil names could be used in farming systems research and extension in order to facilitate dialogue with farmers. Farmers’ knowledge of soil varies widely; normally they use certain criteria to classify soils, namely soil fertility (productivity), indicator plants (in fallow vegetation), soil depth, structure, texture (presence of stones and gravel), colour, consistence, drainage and subsoil characteristics. Soil fertility is the principal criterion used by all farmers, followed by depth, structure and colour. Farmers know that soil fertility, and consequently soil types are closely related to topography; besides, they know a number of processes, which influence certain soil properties, for instance, soil erosion, topography and manuring. On eroded hillside lands, on steep and convex slopes, shallow and stony soils, “Urusenyi”, dominate, while on the flat tops of hills (plateau), concave slopes and feet of hills deep soils with a fine texture, “Urunombe”, prevail. The valley bottoms are covered with dark or greyish colluvial and alluvial soils, “Urubumba”, with mostly fine texture as well.

[32] FAO (2006). World Reference Base for Soil Resources, World Soil Resources Reports 103, Rome
[33] Rushemuka, N.P., R.A. Bizoza, J.G. Mowo and L. Bock (2014). Farmers’ soil knowledge for effective participatory integrated watershed management in Rwanda: Toward soil-specific fertility management and farmers’ judgmental fertilizer use. Agriculture, Ecosystems and Environment 183: 145-159.

4.3. Major Soil types of Rwanda

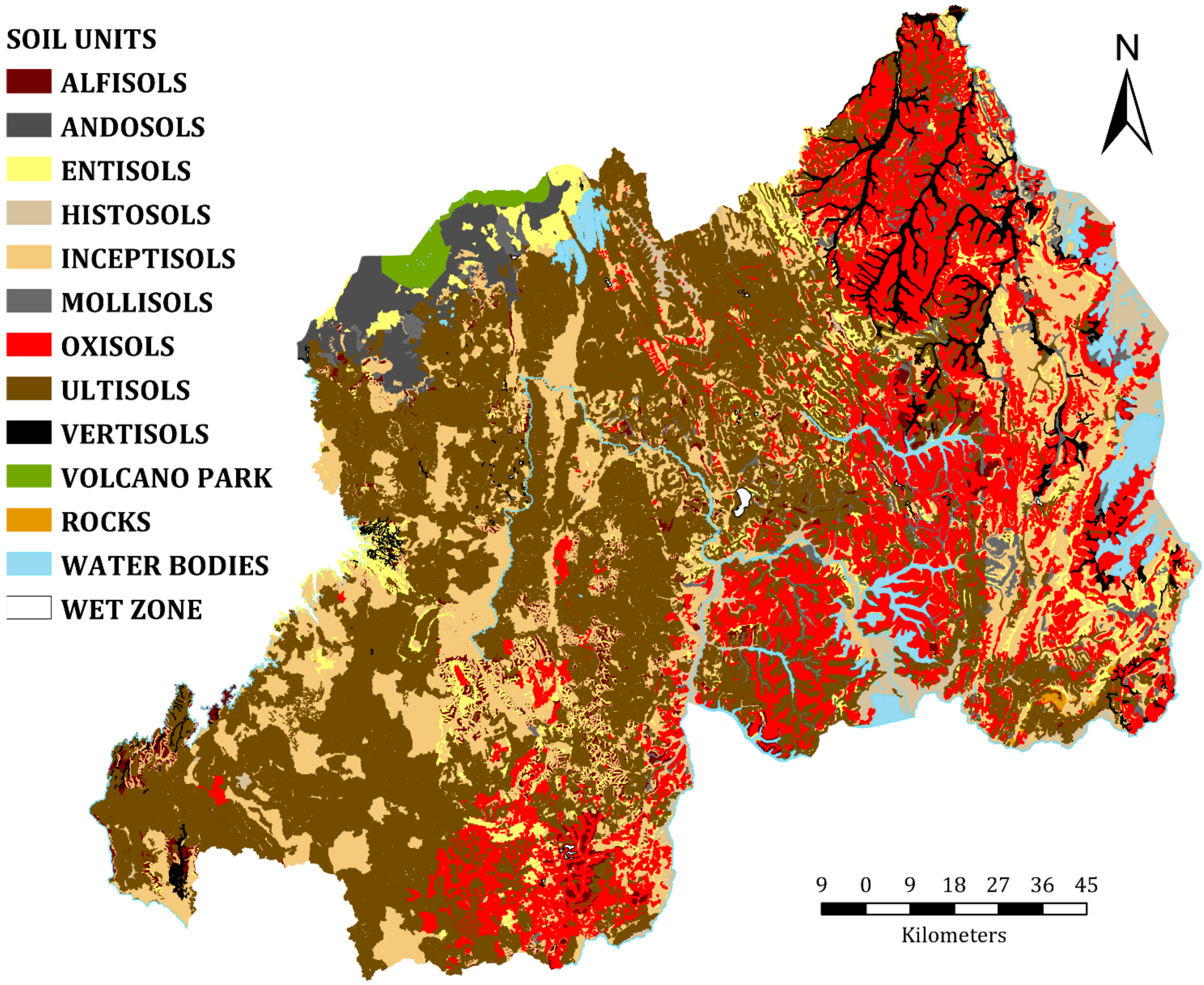
The Rwanda Soil Database has gathered essential information on major soil types at the scale of 1:50,000. The soils pattern in Rwanda is quite complex due to the complexity of the origin parent materials (i.e. geology and geomorphology), topography, variability in altitude and climate, drainage conditions, soil depth and soil texture. These factors have influenced differences between the major soil types in terms of soil chemical and physical properties. Apparently, all the soils derived from alluvial and colluvial deposits are deep, probably due to the nature of the parent materials and their topographical position. The soil depth (i.e. shallow: < 50 cm; moderately deep: 50–100 cm; or deep: > 100 cm) reflects the weathering rates of the underlying parent materials[34].

The major soil types are also well described by agro-ecological zones of Rwanda (fig 4-1). High elevation zones like the Volcanoes or Birunga region are dominated by the "Andisols", especially the "Eutrandepts" in the northwest and the "Dystrandepts" in the southwest parts; in general, "Tropepts" are also part of the dominant suborders that are identified around the Volcanoes and Congo-Nile watershed divide agro-ecological zones, where annual rainfalls vary between 1,250 and 2,000mm, with an udic moisture regime and where temperatures are mostly isothermic. In the medium elevation zones, "Udults" and "Humults" suborders occur along the Lake Kivu and the Central plateau agro-ecological zones. These regions are isothermic and the moisture regime is predominantly udic. "Humults", "Udults", "Tropepts", "Eutrustox", "Humox", "Orthox" and "Fluvents" are the most common and dominant soil suborders that occur locally; "Udults" and "Humults" often form associations with "Fluvents" and "Orthents" in the river valleys; "Histosols" occur locally in swampy areas on valley floors[35].

The low elevation zone with gentle slopes, covers 30% of the country, mostly dominated by the Eastern province, where the temperature regime is isohyperthermic and the moisture regime is ustic with less than 1000 mm annual rainfall. The predominant suborders are "Ustults", "Humults", "Humox", "Orthox", "Ustox", "Eutrustox" and "Ustalfs". Thus, the key major soil types occurring in Rwanda are mainly dominated by those with argillic B horizon (Ultisols - 29%), those with cambic B horizons (Inceptisols - 25%), and those that are highly weathered and developed with an oxic horizon (Oxisols - 18%). Other soil types include recently developed soil layers like Entisols (10%), soils with special argillic B horizon (Alfisols – 6%), poorly drained soils developed in organic materials strongly decomposed like Mollisols (3%), or partially decomposed like Histosols (4%) and Vertisols (2%). The Vertisols, Histosols or Mollisols can easily be found at large extent in the large valley bottoms, marshlands and wetlands of the Eastern region of Rwanda. Finally, recent developed soils from volcanic rocks (Andosols – 3%),

[34] Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3
[35] Birasa, E.C., I. Bizimana, W. Bouckaert, A. Delflandre, J. Chapelle, A. Gallez, G. Maesschalck and J. Vercruysse (1990). Les Sols du Rwanda: méthodologie, légende et classification, Carte Pédologique du Rwanda. Kigali - Rwanda (Unpublished): CTB et MINAGRI

mostly found in the volcano region of the Birunga agro-ecological zone (AEZ)[36;37]. The Andosols can also be found in valleys, where they are developed from alluvial and colluvial deposits, with a development of a cambic B horizon (Inceptisols). In addition, the hillside lands of the Central Plateau & granitic ridges agro-ecological zone and the Eastern region are generally dominated by the Ultisols, Alfisols and Oxisols; these soil types, particularly the Ultisols, are also dominated at the hillside lands of the Congo-Nile Watershed Divide and Buberuka highlands AEZ[38]. A detailed description of these soil types can be found in the USDA Soil Taxonomy[39].



[36] Nzeyimana, I., Hartemink, A.E. and V. Geissen (2014). GIS-based multi-criteria analysis for Arabica coffee expansion in Rwanda. PLOS One 9(10):e107449

[37] Birasa, E.C., I. Bizimana, W. Bouckaert, A. Delflandre, J. Chapelle, A. Gallez, G. Maesschalck and J. Vercruysse (1990). Les Sols du Rwanda: méthodologie, légende et classification, Carte Pédologique du Rwanda. Kigali - Rwanda (Unpublished): CTB et MINAGRI.

[38] Nzeyimana, I., Hartemink, A.E. and V. Geissen (2014). GIS-based multi-criteria analysis for Arabica coffee expansion in Rwanda. PLOS One 9(10):e107449.

[39] Soil Survey Staff (1998). Keys to Soil Taxonomy. USDA. United States Department of Agriculture (USDA). Natural Resources Conservation Service (NRCS).

Figure 4-1: Soil map of Rwanda. Soils were classified using the USDA Soil taxonomy (after Birasa et al., 1990)

4.4. Description of properties of Soils of Rwanda

Only soil properties that are related to land suitability analysis for irrigation will be described under this section.

4.4.1. Soil physical properties

Soil texture

Soil texture describes as proportions of particle size materials present in a soil, is an important physical property, especially when it comes to irrigate soils. The particle size materials are distributed in the soil as percentage of sand, silt, and clay particles (defined based on the size of the particles) and can be assigned a textural class. Soil texture affects strongly water retention capacity, infiltration rate and even nutrient availability to plants.

In Rwanda, we found a variety of soil texture, generally classified depending on location of the soil, the origin of its parent material and soil class. The spatial distribution of the dominant soil units of the soil map at scale of 1:250,000 shows that ten percent (10%) of the soils of Rwanda are fine clayey with > 60% of clay content - these soils are developing on the old volcanic materials of the Impara agro-ecological zone; the Vertisols of the eastern valleys are also characterized by a clay content over 60%. Seventy percent (70%) are clayey with a clay content varying between 35 and 60%. Seventeen percent (17%) are loamy soils with between 20–35% of clay - these soils are developed on granite or shale intervened by quartzite material; only 3% are organic soils; sandy soils (with less than 20% clay) are very rarely (less than 1%) (Table 4-1)[40].

Table 4-1: Areal extent of the texture classes of the soils of Rwanda (After Verdoodt and Van Ranst, 2003)[41]

Soil texture class (% clay)	Area (km^2)	Area (%)
Fine clayey (> 60)	2,378	10
Clayey (35 – 60)	16,193	70
Loamy (20 – 35)	4,086	17
Sandy (<20)	22	<
Organic material	807	3
Total	**23,487**	**100**

[40] Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3
[41] Ibid

On the other hand, clayey, clayey silt to silty clay soils are mostly developed from complete weathered soil types like Oxisols and Ultisols that can be mostly found on hillside lands, where they are particularly characterized as red Oxisols and black Ultisols; they are mostly resulted from granite or colluvial sediments materials. Following different weathering processes undergone by these types of soils, they resulted in clayey, clayey silt to silty clay soils[42]. Black soils across valley bottoms of Rwanda are particularly developed from Vertisols, Mollisols or Histosols, and are generally classified as sandy clay loam soils, particularly found in upper layers and sandy loam to clay loam in subsurface layers, depending with the physiographical location of the soils and their parent materials[43].

In addition, it is important to consider that, for irrigated lands, the soil texture will influence water retention and movement in the soil; for instance, water is much more retained in clay soils than in sandy soils. On the other hand, water movement in sandy soils often carry out soil nutrients along with it, making them not accessible for plant use.

Soil depth

Soil depth is an important physical characteristic that refers to soil profile thickness, which provide structural support and storage of nutrients as well as water to crops. The existence of shallow soils normally limits the rooting depth for crops and decreases availability of water for plants.

The areal extent and spatial distribution of the soil depth classes of the dominant soil units of the soil map at scale of 1:250,000 shows that sixty percent (60%) of the soils in Rwanda is deeper than 1 m. However, in steeply sloping areas, on quartzite, granite or volcanic materials, soil depth can be between 0.50 and 1.00 m, or even below 0.50 m – this represents 15% and 25% of the soils in Rwanda, respectively (Table 4-2). Volcanic ejecta limit soil depth in the Birunga. Laterite is frequently found in the strongly weathered soils of the East. Also, soils developing on granite, quartzite and sandstone, offering varying degrees of resistance to weathering, are often characterized by significant amounts of rock fragments, quartzite or sandstone gravel. Such soil depth limited by the presence of important amounts of stones and gravel represents 19% of the soils in Rwanda. In addition to high volumes of coarse fragments, soil depth can also be limited by the presence of a lithic, paralithic or petroferric contact. Shallow lithic or paralithic contacts are frequently found in the steeply sloping areas of the quartzite ridges and occupy 22% of the soils in Rwanda. Petroferric contacts limit soil depth in some strongly weathered soils of the East extending over 3% of the soils in Rwanda[44]. Shallow soils

[42] *Ibid*
[43] *Birasa, E.C., I. Bizimana, W. Bouckaert, A. Delflandre, J. Chapelle, A. Gallez, G. Maesschalck and J. Vercruysse (1990). Les Sols du Rwanda: méthodologie, légende et classification, Carte Pédologique du Rwanda. Kigali - Rwanda (Unpublished): CTB et MINAGRI.*
[44] *Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3.*

of less than 0.50 m and soils limited by a lithic, paralithic or petroferric layers are considered as physical constraint that limits irrigation development as they resulted in reduced workability, structural stability or limited water holding capacity.

Table 4-2: Areal extent of the soil depth class of the soils of Rwanda (After Verdoodt and Van Ranst, 2003)[45]

Soil depth class	Area (km^2)	Area (%)
> 50	5,936	25
0.5 – 1.0	3,409	15
> 1.0	14,141	60
Total	**23,487**	**100**

Soil bulk density

Soil bulk density is a basic soil property influenced by the amount of organic matter in soils, the soil texture, and minerals. Knowledge of soil bulk density is essential for soil management and to provide information regarding soil compaction, soil consolidation, amount of the organic carbon content, soil texture constituent, and minerals. Thus, the bulk density (BD) is an indicator of the soil compaction, soil organic carbon content and soil texture; it is also a dynamic property as it varied with the soil conditions[46]. High bulk density values reduce soil infiltration rate and soil porosity, and restrict rooting depth, water retention capacity, plant nutrient availability and soil micro-organism activity. Most of the top surface soil layers, where most of agricultural plowing activities occur, the bulk density varies in the range of 0.9 to 1.8 Mg m^{-3}. Values below 0.9 Mg m^{-3} could characterize volcanic or organic soils (under forest land use), or better soil aggregation; values above 1.8 Mg m^{-3} indicate compacted soils or soils with high gravel percentage[47].

Research studies in Rwanda had demonstrated that the bulk density of cultivated lands falls under this range, where the highest value of the bulk density recorded was 1.7 Mg m^{-3} [48]. Thus, good to moderate bulk density values range between 0.9 to 1.3 Mg m^{-3}; this could indicate the availability of water and plant nutrients in the soil, a good soil porosity and increased root growth with lower cone penetration resistance and bio-pores due to high organic matter content[49].

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[45] *Ibid*

[46] *Sharma., B. and S. Bhattacharya. 2017. Soil Bulk Density as Related to Soil Texture, Moisture Content, Ph, Electrical Conductivity, organic Carbon, Organic Matter Content And Available Macro Nutrients of Pandoga Sub Watershed, Una District of H.P (India). International Journal of Engineering Research And Development, Vol. 13 (12), pp72-76*

[47] *Brady, N.C. and R.R. Weil 2002. The nature and properties of soils. New Jersey: Pearson Education Inc., Upper Saddle River.*

[48] *Bizuhoraho, T., A. Kayiranga, N. Manirakiza and K. A. Mourad. 2018. The Effect of Land Use Systems on Soil Properties; A case study from Rwanda. Sustainable Agriculture Research; Vol. 7, No. 2.*

[49] *Bandyopadhyay, K. K., A. K. Misra, P. K. Ghosh and K. M. Hati. 2010. Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. Soil Tillage Res., 110, 115-125. https://doi.org/10.1016/j.still.2010.07.007.*

Besides, values of the bulk density are also influenced by the type of soil texture. Aggregates of clayey soil possess lower density than a sandy or gravelly soil where their particles (clay) lie closer, making values of the bulk density for sandy textured soils usually high (above 1.54 Mg m^{-3})[50]. Thus, for a particular soil texture, the key soil types as observed on the Rwanda soil map (namely Andosols, Alfisols, Histosols, Inceptisols, Mollisols Oxisols, Ultisols and Vertisols), will have a wide range of bulk density values depending on the soil conditions; this could indicate that, other factors such as organic matter content, soil consolidation and compaction history, soil management practices, soil texture, etc., have an important influence on the bulk density. High degree of positive correlation was found between sand or gravel soil and bulk density while negative correlation was observed between clay and bulk density, or silt content and bulk density; this indicates that sandy soils had more effect on bulk density than the other soil texture. In addition, research findings had also demonstrated that the bulk density decreases when the organic carbon content increases[51].

Soil drainage

Soil drainage is also important physical property as it controls continuous movement of water and salt through the soil profile. Based on the soil texture, soil drainage condition is usually classified based on soil texture. The areal extent and spatial distribution of the soil drainage classes of the dominant soil units of the soil map at scale of 1:250,000 shows that the soils of Rwanda are generally well to excessively drained as they occupy 95% of the surface area mainly on hillside lands. Exceptions are found in the valleys of highlands and lowlands, where the soils are moderately to imperfectly drained, representing around 2% of the cases (Table 4–3). Imperfect and poor drainage conditions severely limit the suitability of growing commo crops.

Rwanda also has poorly or very poorly drained soils, particularly located in wetlands that are permanently flooded, representing around 3% of the cases – in most of the cases, these are heavy clay soils like Histosols or Vertisols[52], that are particularly suitable for production of irrigated rice.

Table 4-3: Areal extent of the soil drainage classes of the soils of Rwanda (After Verdoodt and Van Ranst, 2003)[53]

Soil texture	Soil drainage class	Area (km^2)	Area (%)
Sand, loam sand, sand loam, sandy clay loam, loam, sandy clay	well to excessive	22,236	95

[50] Sharma., B. and S. Bhattacharya. 2017. Soil Bulk Density as Related to Soil Texture, Moisture Content, Ph, Electrical Conductivity, organic Carbon, Organic Matter Content And Available Macro Nutrients of Pandoga Sub Watershed, Una District of H.P (India). International Journal of Engineering Research And Development, Vol. 13 (12), pp72-76
[51] Sharma., B. and S. Bhattacharya. 2017. Soil Bulk Density as Related to Soil Texture, Moisture Content, Ph, Electrical Conductivity, organic Carbon, Organic Matter Content And Available Macro Nutrients of Pandoga Sub Watershed, Una District of H.P (India). International Journal of Engineering Research And Development, Vol. 13 (12), pp72-76
[52] Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3.
[53] Ibid

Silt, silt loam, silty clay loam	Imperfect to moderate	413	2
Heavy clay, clay, silty clay, clay loam	Very poor to poor	838	3
Total		**23,487**	**100**

4.4.2. Soil chemical properties

Soil Acidity

The soils of Rwanda are mainly derived from Precambrian and Quaternary parent materials. Plinthite and ironstone are found in the strongly weathered soils of the eastern and southern parts of the country. A major soil fertility constraint to crop production in Rwanda is soil acidity. About 75% of the soils are acid with pH below 5.5; these soils tend also to have low levels of organic matter (i.e. <3%)[54].

Soil acidity includes high exchangeable Al and possible Al toxicity for sensitive crops. As soil pH decreased below 5.5, extractable Al levels increased markedly. High Al toxicity levels are also found at the Congo-Nile watershed divide and Buberuka highlands agro-ecological zones[55]. Plant growth and production on acidic soils is limited by increasing depletion of N, P, Ca and Mg, high P adsorption (1,500 to 3,000 mg kg^{-1} of soil), low permanent charges (-0.5 to -2.45 $Cmol^{+}$ kg^{-1})[56]. Liming these acid soils is not absolutely essential but maintaining soil pH of about 5.6 to keep extractable Al low is a desirable management practice; various studies have shown lime requirement applications of 4 to 5 tons per ha over a 4-year period.

Soil organic Carbon (SOC)

Generally, soil organic carbon (SOC) is low in the Rwandan soils with the exception of soils in the valley swamps and natural forests like Nyungwe and Gishwati forests, where the C concentrations may exceed 10%[57]. High values of SOC have been also observed in the Birunga, the Congo-Nile Watershed Divide, the Buberuka Highlands, the Eastern Plateau, Impara and the Imbo agro-ecological zones, where the SOC content generally exceeds 1.2%. In the other agricultural zones, the SOC content is strongly variable, but generally lower than 1.2%. High variability in SOC content has been recorded at the Granitic Ridge, Mayaga, Bugesera, and the Eastern Savanna; differences are due to changes in microclimate, parent material, topographic position and land use. The turnover rate of organic matter is clearly higher in the warm East than in the cool West[58].

[54] *Beenart, F.R. (1999). Feasibility Study of Production of Lime and/or Ground Travertine for the Management of Acid Soils in Rwanda. Brussels, Belgium: Pro-Inter Project Consultants*

[55] *Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3*

[56] *Mukuralinda, A. (2007). Influence of phoshorus resources on soil phoshorus dynamics and crop productivity in Rwanda, Makerere University, Uganda.*

[57] *Mukuralinda, A. (2007). Influence of phoshorus resources on soil phoshorus dynamics and crop productivity in Rwanda, Makerere University, Uganda.*

[58] *Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3*

Management strategies that increase the soil organic carbon content (SOC) of the topsoil might have a beneficial effect on maintaining key essential soil nutrients (N, P, K, ca, Mg, and Ca), increasing crop yield and improving other soil properties; the SOC can stimulate soil aggregation, which lowers bulk density, increases porosity, and hence elevates saturated hydraulic conductivity (K_S). Saturated hydraulic conductivity (K_S) is a critical property affecting water and solute movement in soils. Research studies had demonstrated that SOC is an is generally assumed to be positively correlated with K_S; but recent studies of pedo-transfer functions suggested a possible negative K_S-SOC relationship that still needs further investigations[59].

Total nitrogen (N)

Most soils in Rwanda are mostly deficient in nitrogen with content ranging between 0.11 and 0.26% N. Soils in the volcano region present high levels of total nitrogen, with large amounts ranging between 0.6 and 1.63% N. Soils under natural forests like Nyungwe and Gishwati forests are also high in nitrogen content. The subsoils have up to 50% less total nitrogen (N) than the surface soils. N deficiency are mostly found in the central and southern parts of the country; deficiency in N content can limit crop yield[60].

To maintain the soil N levels, there is a need to add organic matter like crop residues, green manure crops and animal manures to the soil. Nitrogen fertilizers are also necessary to obtain better crop yields[61].

Phosphorus (P)

Most soils in Rwanda with excessive acidity and high Al are phosphorus deficient; the majority of Rwandan soils have very low phosphorus content. Phosphorus is usually immobilized or complexed by Al^{3+} and Fe^{3+}, and this resulted in low soil fertility levels[62]. However, soils belonging to the “Eutrustox” and the “Humult” groups absorb less phosphorus; these soils represent part of the eastern and southern provinces, respectively.

Phosphorus (P) is the main element which limits crop yield; most soils in Rwanda would require around 30 mg P kg^{-1} of soil to boost crop yields[63]. Although lime may increase the availability of P, it cannot compensate P deficiencies. Additional applications of inorganic phosphorus fertilizers are needed to compensate P losses; in all the agro-ecological zones of Rwanda,

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[59] Zhao C., M. Shao, X. Jia, M. Nasir and C. Zhang (2016). Using pedotransfer functions to estimate soil hydraulic conductivity in the Loess Plateau of China. Catena 143: 1-6.
[60] Mbonigaba, J.J., I. Nzeyimana, C. Bucagu and M. Culot (2009). Caractérisation physique, chimique et microbiologique de trois sols acides tropicaux du Rwanda sous jachères naturelles et contraintes à leur productivité. Biotechnologie, Agronomie, Société et Environnement 13: 545-558.
[61] Ibid
[62] Mbonigaba, J.J., Nzeyimana, I., Bucagu, C., Culot, M. (2009). Caractérisation physique, chimique et microbiologique de trois sols acides tropicaux du Rwanda sous jachères naturelles et contraintes à leur productivité. Biotechnologie, Agronomie, Société et Environnement, 13, 545-558.
[63] Mukuralinda, A. (2007). Influence of phoshorus resources on soil phoshorus dynamics and crop productivity in Rwanda, Makerere University, Uganda.

phosphorus is usually added to soils as Di-ammonium Phosphate (DAP) to obtain higher crop yields.

Exchangeable cations and sum of basic cations (K, Mg and Ca)

Potassium (K) is generally low in most soils in Rwanda, with the exceptions of the Eastern plateau (namely Ngoma District) and volcano regions. Particularly, very low contents of K were observed at the Imbo, Impara, Congo-Nile watershed divide, granitic ridges and Mayaga-Bugesera agro-ecological zones[64].

Exchangeable calcium (Ca) and Magnesium (Mg) levels differ considerably across the country. Ca and Mg deficiencies are common throughout the country due to high Al toxicity in acid soils, which cover the majority of the Rwandan soils. However, soils derived from volcanic ash and soils from the Eastern region of the country have high exchangeable Ca, Mg and K.

Based on physical characteristics like the level of the soils' weathering, parent material and climate, the spatial distribution of the exchangeable cations (Ca, Mg and K) of the soil map at scale of 1:250,000 shows that the sum of the basic cations, recorded in the upper 0.25 m of the soil surface, is a more reliable indicator of the availability of nutrients. The availability of nutrients in soils developed on shales and schists also depends on the leaching strength of the climate and the development stage of the soil profile. Thus, the sum of the exchangeable basic cations increases from West to East, except for the soils located in the Birunga and the Imbo agro-ecological zones (AEZ), which are characterized by a sum of exchangeable basic cations exceeding 11 $Cmol^{(+)}\ kg^{-1}$ soil. The sum of the exchangeable basic cations is then higher in the lowlands than in the highlands, where the nutrient level strongly decreases with an increase in weathering intensity[65].

In addition, alluvial, calcareous and/or volcanic soils, soils derived from basic parent material or soils characterized by vertic properties are characterized by a sum of exchangeable basic cations exceeding 5 $Cmol^{(+)}\ kg^{-1}$ soil. Soils developing on quartzitic material generally have a sum of exchangeable basic cations ranging between 2.0 and 3.5 $Cmol^{(+)}\ kg^{-1}$ soil, except in the eastern lowlands, where the sum of exchangeable basic cations exceeds 5 $Cmol^{(+)}\ kg^{-1}$ soil. Soils derived from granitic material in the Kivu Lake Borders, the Congo-Nile Watershed Divide, the Eastern Plateau and the Eastern Savanna AEZs are also characterized by a sum of exchangeable basic cations ranging between 2.0 and 3.5 $Cmol^{(+)}\ kg^{-1}$ soil. In the Central Plateau, Granitic Ridge and Mayaga AEZs, the lowest sum of exchangeable basic cations has been reported in soils developed on granite with an intergrade argillic-oxic horizon[66].

[64] Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3.
[65] Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3.
[66] Ibid

Base saturation

The base saturation (BS) status of most soils in Rwanda is not only dependent on their development stage. BS is also strongly related to the leaching strength of the climate and to the composition of the parent material. Both parameters were two of the main determinants for the delineation of the agro-ecological zones. The general trend of the BS is that they increases from the highlands to the lowlands. One fourth of the total land area is occupied by soils with a BS between 20 and 35%. This class groups the soils in the agro-ecological zones of the Kivu Lake Borders and the Central Plateau and also the strongly weathered soils of the Mayaga. High BS values are also characteristic for the volcanic region. The strongly leached soils of the Impara, the Congo-Nile Watershed Divide in the West and the poor soils developing on quartzite ridges in the East are characterized by a very low BS not exceeding 20%. However, extremely low BS was found in the agro-ecological zone of the Congo–Nile Watershed Divide, due to its high rainfall amounts and poor parent material. Most soils of the Impara, and especially those with an advanced weathering stage, have a comparably low base status. The shallow soils with an entic development stage of this region, however, show very high amounts of retained basic cations. Near the Kivu Lake and in the Buberuka Highlands, the BS varies from moderate to very low with increasing development stage and weathering. Soils of the Central Plateau with an argillic or intergrade argillic-oxic horizon have a high or a very low base saturation. Often, these differences correspond to the effects of adding fertilizers or organic material. In the agro-ecological zone of the Eastern Plateau, soils have a favourable nutrient status, except for those developing on quartzite ridges, showing an entic development stage and a very low base status. The highest base status has been recorded in soils showing an argillic horizon[67].

4.5. Rwanda Land Suitability Classification

Land suitability evaluation is an essential procedure to assess opportunities, potentials, and limitations that a given parcel land can offer for agricultural purposes[68]. Various approaches of land suitability evaluation with specific methodology have been developed to study land-use suitability[69;70]. Geographic information systems (GISs) have been also used for mapping and analyzing land-use suitability[71]. Various GIS-based models have been developed[72;73]. In a land

67 Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3
68 Rossiter, D.G. (1996). A theoretical framework for land evaluation. Geoderma 72: 165-190.
69 FAO (1976). A Framework for Land Evaluation. Rome: Soil Resources Development.
70 Rossiter, D.G. (1996). A theoretical framework for land evaluation. Geoderma 72: 165-190.
71 Malczewski, J (2004). GIS-Based land use suitability analysis: a critical overview. Progress in Planning 62: 3-65.
72 Ibid
73 Walke, N., G.P. Obi Reddy, A.K. Maji and S. Thayalan (2012). GIS-based multicriteria overlay analysis in soil-suitability evaluation for cotton (Gossypium spp.): A case study in the black soil region of Central India. Computers and Geosciences 41: 108-118.

suitability classification, the land is classified according to its suitability for the cultivation of a specific crop in comparison with the crop-specific requirements and the actual or potential land characteristics. The procedure uses climatic and edaphic/soil properties required to optimize yield for a specific crop.

4.5.1. Land suitability analysis for Irrigation

Worldwide, 20% of the total land cultivated receives irrigation water to produce about 40% of the world's total food[74], and the Sub-Saharan Africa (SSA) accounts for only 4%[75]. 22% of the country's land area[76] is identified as potential land for irrigation. However, only 9% of the potentially irrigable land is currently under irrigation[77]. The importance of such suitability study analysis is to identify the potential lands for sustainable irrigation development and their constraints/limitations, on a master plan basis.

To identify potential irrigable land, generally a combination of irrigation suitability factors such as soil type, slope, land use/cover, availability and proximity of water source, etc., must be taken into consideration[78]. The assessment of the irrigation suitability factors will provide the information about the limitations of the land for irrigation development based of quality criteria of the land.

Soil suitability analysis

The soil depth, soil texture and drainage are the most important soil physical properties used to assess the potential suitability of the soils for irrigation. For such analysis, the soil mapping units were used for analysis. The physical properties of each soil mapping units i.e. soil depth, texture and drainage were obtained from the Rwanda “Soil Dataset” (at scale 1:50,000 published in 1990[79]), and were used for interpretation and analysis, and mapped using ArcGIS software.

The soil depth refers to soil profile thickness, which provide structural support for water storage to crops; a shallow soil normally limits the rooting depth for crops and decreases availability of water for plants. The soil depth is the main limitation factor for highly to moderately suitable soils for irrigation; its weighting ratio is estimated to over 50% in the overlay analysis.

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[74] FAO (2015). AQUASTAT database. 〈http://www.fao.org/nr/water/aquastat/main/ index.stm〉 (Accessed 22 April 2015.

[75] Burney, J.A., Naylor, R.L., Postel, L.S., 2013. The case for distributed irrigation as a development priority in sub-Saharan Africa. Proc. Natl. Acad. Sci. USA 110 (31), 12513–12517. http://dx.doi.org/10.1073/pnas.1203597110.

[76] Source: Minagri, 2010. Rwanda Irrigation Master Plan

[77] Source: RAB Irrigation Implementation Progress Report (June, 2019)

[78] FAO (1997). Irrigation potential in Africa: a basin approach. FAO land and water bulletin, 4. Paper No 56. Rome, Italy.

[79] Birasa, E.C., I. Bizimana, W. Bouckaert, A. Delflandre, J. Chapelle, A. Gallez, G. Maesschalck and J. Vercruysse (1990). Les Sols du Rwanda: méthodologie, légende et classification, Carte Pédologique du Rwanda. Kigali - Rwanda (Unpublished): CTB et MINAGRI.

The soil texture is an important factor as it determines pore spaces of the soils which influence the soil permeability and infiltration rate. The weighting ratio of the soil texture is estimated to 30% in the overlay analysis. For not suitable soils for irrigation, the combination of both soil depth and soil texture are the main factors that limit irrigation development.

Soil drainage condition is also important factor in assessing the potential suitability of the soils for irrigation development. Without proper drainage, the soil profile might accumulate salt levels that may be harmful to the landscape as the result of improper irrigation or soil management practices or inadequate drainage.

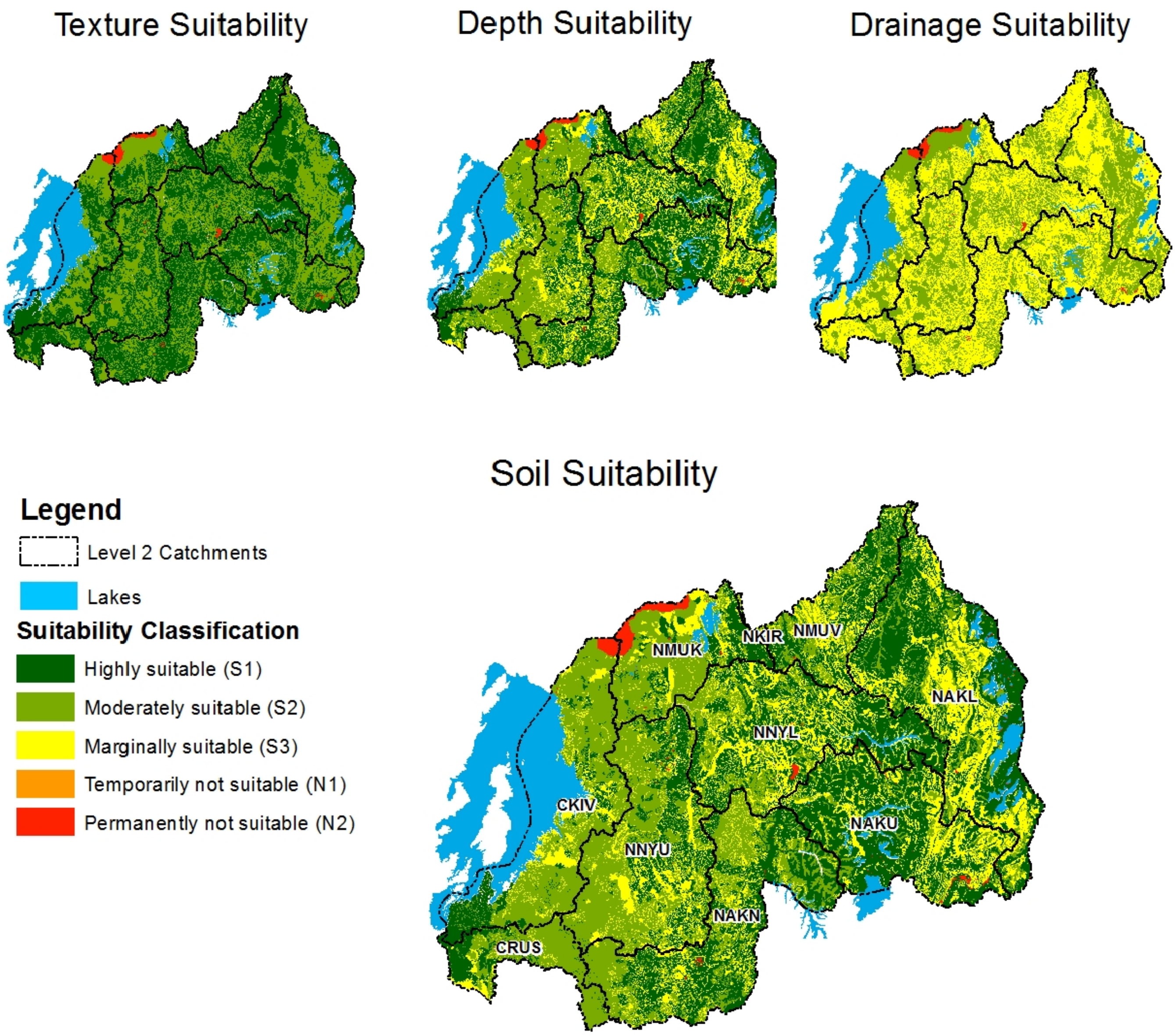

Figure 4-2: Rwanda soil suitability map for irrigation – a combination of soil texture, soil depth, and soil drainage maps' suitability

Based on the soil texture, soil drainage classes were classified using FAO guidelines[80]: ***(1)*** *Sand, loam sand to sandy loam:* ***excessively well drained****;* ***(2)*** *Sandy clay loam, loam to sandy clay:* ***well drained****;* ***(3)*** *Silt, silt loam, silty clay loam:* ***(4)*** *Silty clay, clay loam to silt clay loam:* ***moderately to imperfectly drained; (5)*** *Heavy clay, clay, silty clay to clay loam:* ***poorly to very poorly drained****.* The weighting ratio of the soil drainage is estimated to 20% in the overlay analysis.

The above are presented in figure 4-2.

Loamy and clayey soils of above 0.50m of soil depth are classified as highly to moderately suitable for irrigation; the highly suitable soils for irrigation are particularly clayey soils of more than 1m soil depth. Highly suitable soils for irrigation are mostly found in the Eastern Province and in the southern part of the Western Province of Rwanda. However, most Rwandan soils (i.e. more than 90%) are classified as suitable to moderately suitable for irrigation. Poorly to not suitable soils for irrigation are mainly limited by the presence of a lithic layer at less or within 0.50m of the mineral soil surface; these are predominately found in the volcanic region in the Northern Province and the Northern part of the Western Province, and at the rocky mountains of the Congo-Nile Watershed Divide, Central Plateau and granitic ridges, Buberuka highlands, Eastern savanna and Eastern Plateau agro-ecological zones.

Slope

The study of slope is an important factor for land suitability analysis for irrigation. Defined slope classes for irrigation development is important to avoid erosion hazards and to define the type of irrigation system. The slope classes (S_1: 0 to 6%; S_2: 6 to 16%; S_3: 16 to 25%; S_4: 25 to 40%; S_5: >40%) were derived from DEM analysis using masking layer with ArcGIS software.

[80] FAO (1979). Land evaluation criteria for irrigation. Report of an Expert consultation, 27th Feb – 2nd March 1979. World Soil Resources Report No. 50. FAO, Rome 219.

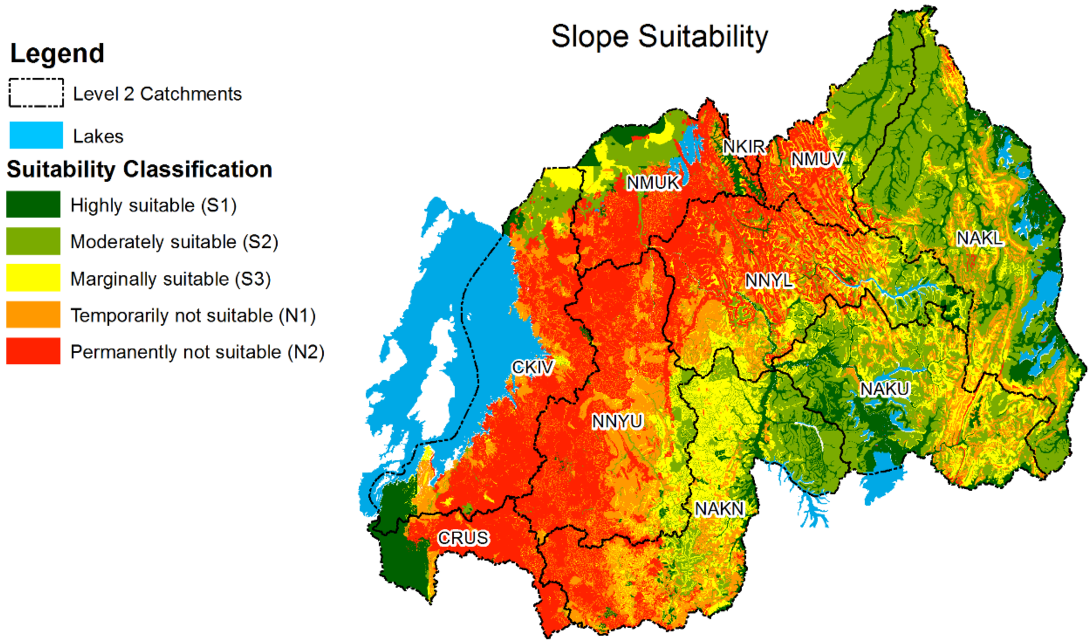

Figure 4-3: Rwanda slope suitability map for irrigation

The alluvial plains and plateaus are relatively flat, with slope gradients ranging from 0 to 6%, and are highly suitable for irrigation; the peneplains with steepness varying from 6 to 16%, are moderately suitable for irrigation; the landscapes of thousand hills characterized by slopes varying between 16 and 25%, are marginally suitable for irrigation. The high-altitude areas of the Congo-Nile Watershed Divide and the Buberuka Highlands are very steeply sloping, with gradients exceeding 40 %, are classified as temporarily to permanently not suitable for irrigation (Fig. 4-3).

Land use

Land use is also an important factor for land suitability analysis for irrigation. Since rural lands are involved with different land use/cover types, their suitability assessment for irrigation also provides guidance in cases of conflict between agricultural rural land use, urban or industrial expansion, by indicating which areas of land uses/land covers are most suitable for irrigation[81]. Fig. 4-4 illustrates the agricultural lands in Rwanda based on data collected by RLMUA.

[81] Mandal B., G. Dolui and S. Satpathy (2018). Land suitability assessment for potential surface irrigation of river catchment for irrigation development in Kansai watershed, Purulia, west Bengal, India. Sustain. Water Resour. Manag. 4:699 – 714.

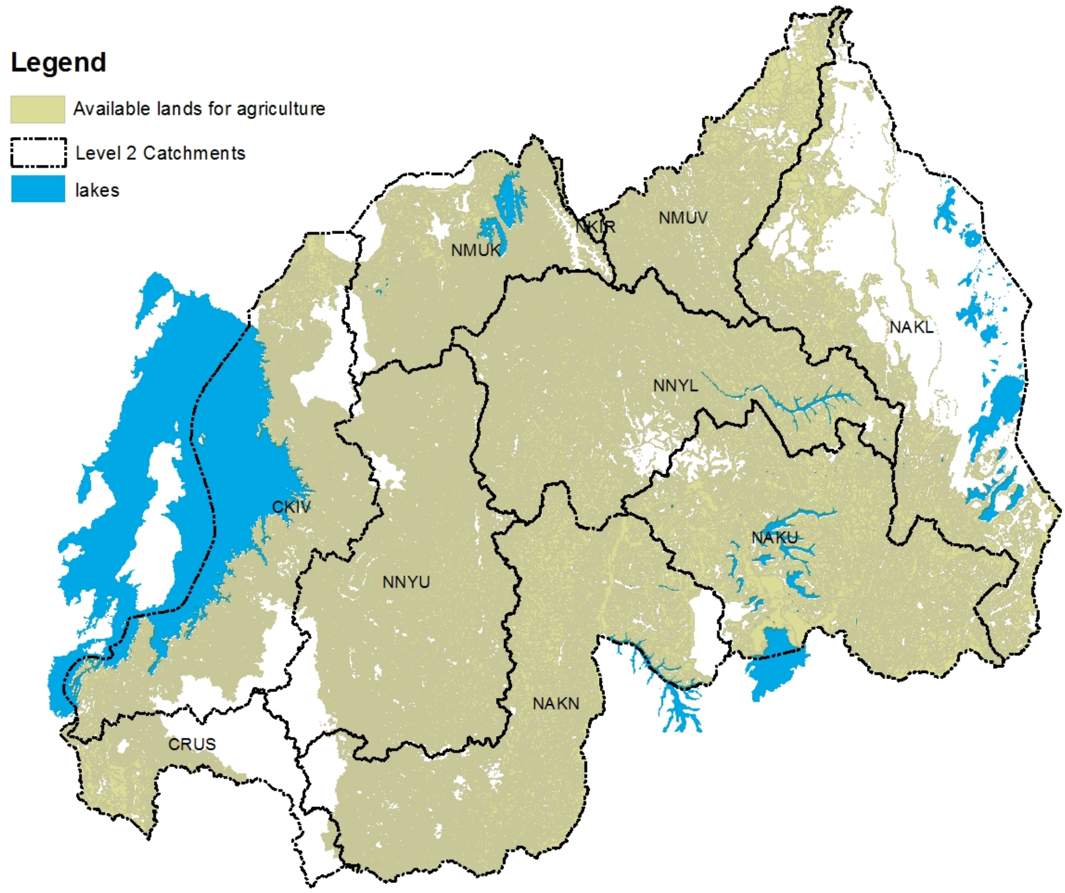

Figure 4-4: Rwanda agricultural lands

Weighted overlay analysis – Multi-criteria analysis model

To find suitable land for irrigation development, a suitability model was created using a model builder (Fig. 4-5 and 4-6). The multi-criteria model was used to combine the different layers of data (*i.e. soil texture, soil depth, soil drainage, slope, and land use*) to identify the potentially irrigable lands. The multi-criteria analysis used each input raster as a decision variable for sequential GIS interactions between layers (Fig. 4-5). Data were later processed using the spatial-analysis tools of ArcGIS. The geo-spatial analysis allowed the combination of the input rasters using weighted overlay analysis in the Model Builder to generate output shp files (Fig. 4-6)[82]. Each cell value in each input shp file was assigned a new, reclassified score value on an evaluation scale of 1 to 5 (*where 5 represents the lowest suitability – worst unit, and 1 the highest and best unit for the irrigation development*) as guided by FAO (1979)[83].

[82] Nzeyimana, I., A.E. Hartemink and V. Geissen (2014). GIS-based multi-criteria analysis for Arabica coffee expansion in Rwanda. PLOS One 9(10):e107449.
[83] FAO (1979). Land evaluation criteria for irrigation. Report of an Expert consultation, 27th Feb – 2nd March 1979. World Soil Resources Report No. 50. FAO, Rome 219.

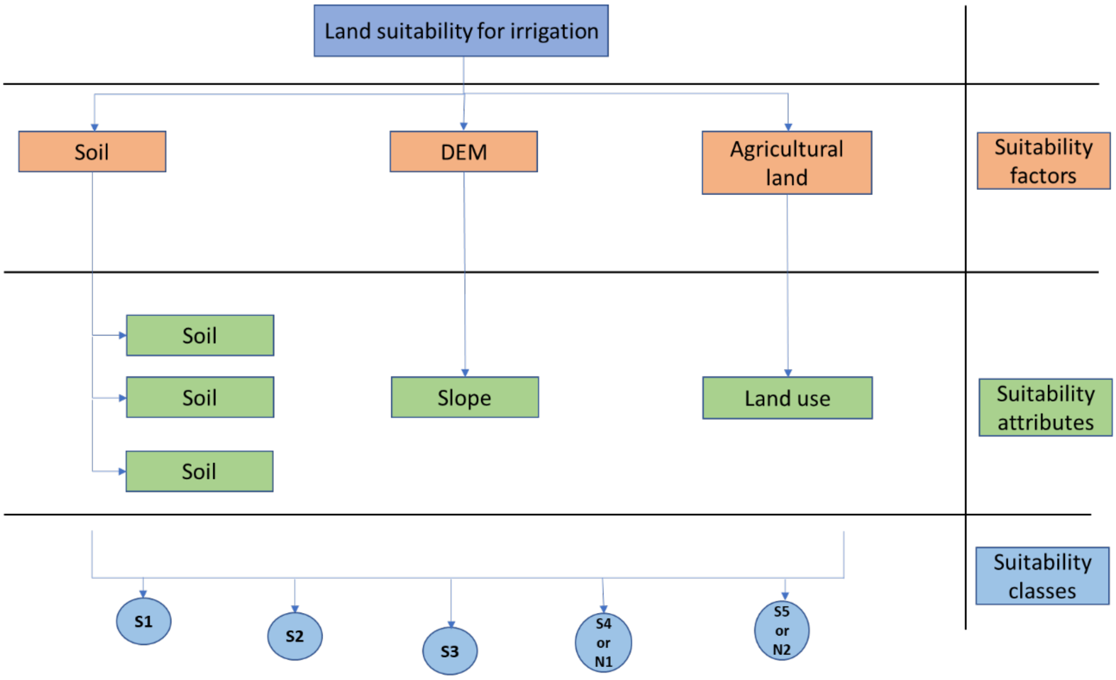

Figure 4-5: Hierarchical organization of criteria

According to FAO (1979[84]; 1997[85]), land suitability for irrigation are generally classified into two classes, i.e. suitable (S) and/or not suitable (N). These classes are further classified based on their degree of limitations:

- S1 (highly suitable): land having no significant limitation to sustained application of a given use;
- S2 (moderately suitable): land having limitation which in aggregate are moderately severe for a sustained application of a given use;
- S3 (marginally suitable): land having limitation which in aggregate are severe for a sustained application of a given use and will reduce productivity or benefits;
- S4 or N1 (temporarily not suitable): land having limitations which may be surmountable in time, but which cannot be corrected with existing knowledge at currently acceptable cost;
- S5 or N2 (permanently not suitable): land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land of a given land use.

[84] *Ibid*
[85] *FAO (1997). Irrigation potential in Africa: a basin approach. FAO land and water bulletin, 4. Paper No 56. Rome, Italy.*

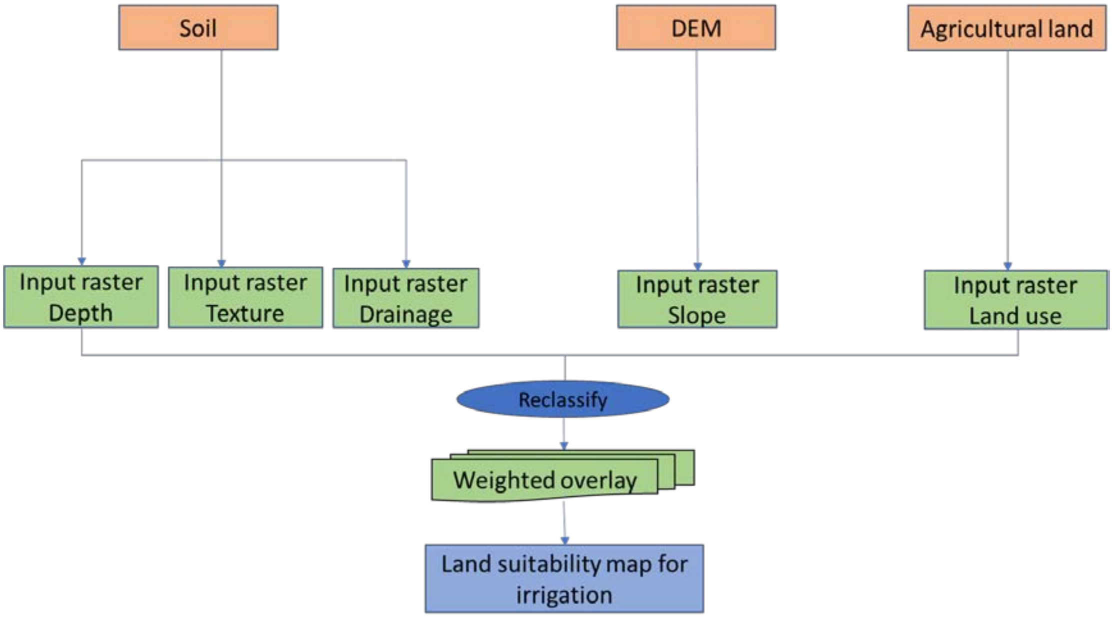

Figure 4-6: Flow diagram method of land suitability for irrigation development

Due to the size of the data files to be analyzed at country scale, the land use layer was not included in the analysis; thus, the soil and slope layers were considered as most important for land suitability analysis for irrigation. Considering that the irrigation will be developed on identified suitable agricultural lands, only the new "soil and slope" reclassified input shps were later weighted by assigning a percentage influence value. Slope being the most determinant factor to define the type of irrigation system, it was then allocated the highest influence percentage (i.e. 60%) in the weighted overlay analysis for the land suitability analysis for irrigation. Considering also the case where one of the parameters (soil or slope) is classified not suitable (N or N2), then land unit is automatically classified not suitable for irrigation

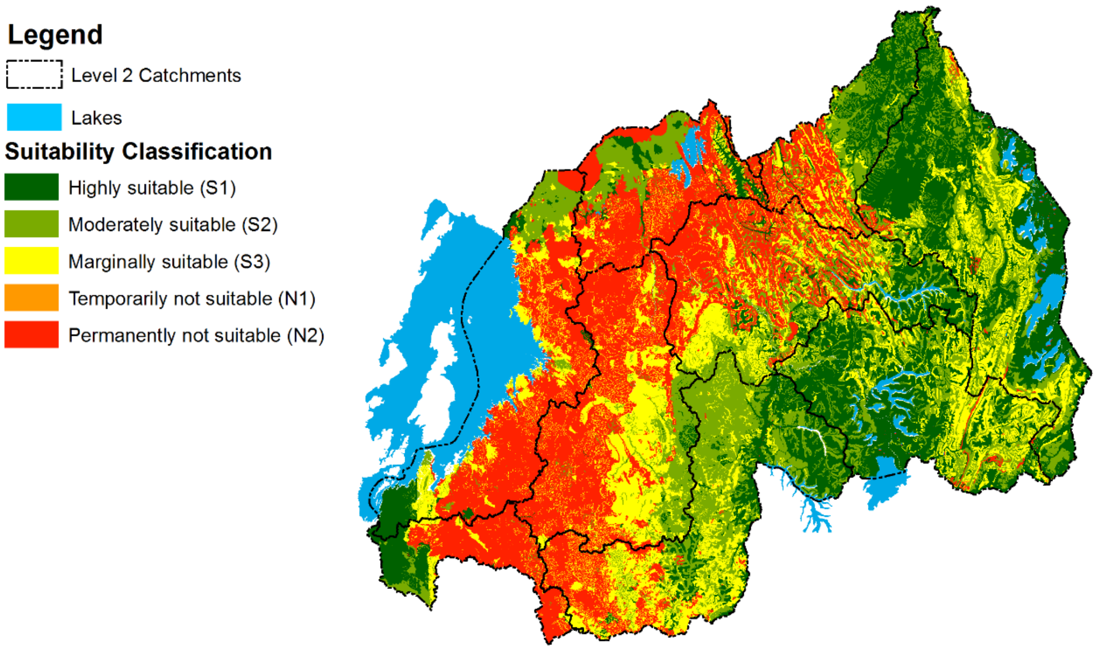

Figure 4-7: Rwanda land suitability map for irrigation

Highly to moderately suitable lands for irrigation are mostly found in the northern, eastern, and southern parts of the eastern Province, particularly in the eastern plateau, eastern savanna and Bugesera agro-ecological zones (AEZs). They are also found in the southern part of the Western Province of Rwanda, in the "Impala" agro-ecological zone. Poorly to not suitable lands for irrigation are mainly limited by slope above 25% and are predominately found in the highlands of the northern (Birunga and Buberuka highlands AEZs) and southern (Congo-Nile Watershed Divide AEZ) provinces, the northern and southern parts of the Western Province (Kivu Lake Borders AEZ), and at the rocky mountains of the central plateau and granitic ridges agro-ecological zone (Fig. 4-7).

4.5.2. Land suitability classification for common crops

For Rwanda, land suitability evaluation has been studied at scale of 1:250,000 to assess 12 crops, namely common/bush beans, maize, sorghum, pea, cassava, Irish potato, sweet potato, groundnut, soybean, banana, Arabica coffee and tea[86].

Common/bush bean is grown in all agricultural regions. With respect to the land suitability classification, the actual suitability to produce common bean generally increases from the West to the East. The granitic ridge, Eastern plateau, Eastern savanna, Bugesera, Mayaga Imbo and Impara, have been identified as moderately suitable to produce bush beans[87].

From a climatic point of view, maize is more sensitive to water shortage or low temperature; from an edaphic viewpoint, maize requires a higher chemical soil fertility level than common bean. The most production regions for maize are the Imbo, Impara, Central Plateau, granitic ridges, Eastern Plateau, Mayaga, Birunga, Congo-Nile Watershed Divide and the Buberuka Highlands. However, the land suitability classification has identified favourable conditions for maize production in all agro-ecological regions, except for the dry Eastern Savanna and for the central part of the Bugesera[88].

Sorghum is highly produced at Imbo, Impara, Kivu Lake Borders, Granitic ridge, Central plateau, Mayaga, Bugesera, Eastern plateau and Eastern savanna agro-ecological zones. The land suitability classification for sorghum has also confirmed this actual distribution. The agricultural zones of the Impara and Kivu Lake Borders have been identified as potentially very suitable regions for sorghum production[89].

The cultivation of pea is mainly limited to the high altitude areas of the Birunga, Congo-Nile Watershed Divide and the Buberuka Highlands. This distribution corresponds very well to the

[86] *Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3.*
[87] *Ibid*
[88] *Ibid*
[89] *Ibid*

results of the land suitability classification. In addition, the agro-ecological zones of the Impara and Kivu Lake Borders have been identified as potentially very suitable to moderately suitable[90].

Cassava can be cultivated in all lowlands and at the middle altitudes of Rwanda; the land suitability classification also confirmed this trend. In the western agro-ecological zones of the Impara and Kivu Lake Borders, additional management related to erosion control and chemical fertility might be required to improve the yields[91].

Optimal climatic conditions for the cultivation of Irish potato have been reported in the high altitude regions of Rwanda, namely Birunga, Congo-Nile Watershed Divide and Buberuka Highlands. Literatures also reported that comparable yields have been reported in the Bugesera and Eastern Savanna agro-ecological zones, but according to the land suitability classification, high temperatures of these regions limit the performance of the Irish potato in the lowlands[92].

Groundnut is mainly cultivated in the lowlands, particularly in the Imbo, Mayaga, Bugesera, Eastern Plateau and the Eastern Savanna, where it has been reported to be moderately suitable. With appropriate management practices, the crop can also performed successfully in the Central Plateau and Granitic Ridge agro-ecological zones. On the other hand, soybean is cultivated in all agricultural zones. According to the land suitability classification, the Eastern Savanna, Eastern Plateau, Birunga and Mayaga have moderate suitability for soybean[93].

Banana is mainly produced in the Imbo, Impara, Kivu Lake Borders, Eastern Plateau and Eastern Savanna. However, according to the land suitability classification, banana is moderately suitable in the East, Bugesera and Mayaga agro-ecological zones, and potentially suitable at the Kivu Lake Borders[94].

Arabica coffee is a top export commodity and an important source of revenue in Eastern and Central African countries[95]. In Rwanda, Arabica coffee is predominantly grown along the shores of Lake Kivu in the West, on the plateau in the central part of Rwanda, and in the Mayaga agro-ecological region[96]; this matches with the results of the land suitability classification[97]. The Central Plateau had the largest area of coffee production, covering about 32% of the total area

[90] *Ibid*
[91] *Ibid*
[92] *Ibid*
[93] *Ibid*
[94] *Ibid*
[95] *FAO (2014). FAOSTAT - Statistical database. FAO. Rome.*
[96] *Nzeyimana Innocent, Alfred E. Hartemink, Violette Geissen. (2014). GIS-based multi-criteria analysis for Arabica coffee expansion in Rwanda. PLoS ONE 9 (10): e107449.*
[97] *Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3.*

under coffee cultivation. High yields are obtained around the Lake Kivu region (Imbo, Impara, and Kivu Lake Borders zones), the potential suitable area[98].

Tea is the second export commodity in Rwanda after coffee. The main tea producing regions in Rwanda include the Impara, Kivu Lake Borders, Birunga, Congo-Nile Watershed Divide and Buberuka Highlands, which have also been identified by the land suitability classification[99].

4.6. Land Tenure and Land Use

Land tenure systems in Rwanda can be described into three (3) broad categories: (i) Land tenure system in pre-colonial; (ii) Land tenure in colonial; and (iii) Land tenure after the independence, from the first Republic to after the genocide period. Under this Chapter, it is described only the current land tenure system used currently in Rwanda, i.e. after the genocide period.

4.6.1. Current Rwanda Land Tenure Systems

Land tenure system can be considered as a set of modes or procedures of land acquisition and ownership. It is, in other words, a combination of rules that define the modes of access, use and control of land and its renewable natural resources. Therefore, it is a relationship between men or social groups and land or its underlying resources. Besides, land tenure has a multidisciplinary dimension that includes social, technical, economical, institutional, legal and political aspects.

In the present land tenure system, land can be through customary law or conceptions or by rules of the written law. According to custom, land ownership is held by whoever occupies the land first. However, the provisions of the decree-law No. 09/76 of 4th March 1976, article 1, stipulate that "*all land not held under the written law and affected or not by customary law or land occupation belongs to the Stat'*", meaning that all vacant land belongs to the State.

Customarily, land can also be acquired from inheritance, where land rights are passed on from father to children. The current land law included also women, who were before excluded from inheritance of the family land from the father. Concerning inheritance rights of widows, the custom merely gives them the right to use the land that belonged to their deceased husbands. In addition, land is a family property that belonged to the ancestors, as well as to present and future generations. With the introduction of the subdivision of land into individual plots due to successive inheritance procedures, each family owner of a plot of land was considered as the real owner of the plot, having the right to dispose of it as it wishes. However, Article 2 of the

[98] Nzeyimana Innocent, Alfred E. Hartemink, Violette Geissen. (2014). GIS-based multi-criteria analysis for Arabica coffee expansion in Rwanda. PLoS ONE 9 (10): e107449.
[99] Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3.

decree-law No. 09/76 of 4th March 1976, stipulates that nobody may sell off his land rights except with the written authorization of the Minister of Lands upon the recommendation of the Municipal Council where the land is located.

Land can also be acquired by prescription; ownership through prescription originates from the written law since traditionally; title deeds were unheard of. Rwandans consider that once a right has been acquired or recognized, even customarily, it is indefeasible. Land acquired through written law can be identified as:

I. Tenancy contracts of plots for building purposes for a 3-year period in urban areas;
II. Long lease contracts of land for agricultural purposes for a period of 15 years or more in rural areas;
III. Free assignment contracts in both rural and urban areas to natural or legal persons for social activities with real impact on the welfare of the people;
IV. Sale contracts and title deeds for plots that are built in urban areas. This is a system of land tenure by urban residents who first lease plots with the contractual obligation of developing them. The Ministry of Lands delivers the title deeds after confirming that the plots have been developed;
V. Right of access – a mode of land acquisition which is common for public institutions.

Apart from the above-mentioned different modes of land acquisition and land ownership, there is the case of the landless people who live in rural areas and who must live from farming. These are mostly the refugees of 1959 who were forced into exile for political reasons and left their land behind. These same refugees have now returned to their country and find themselves landless. They cannot claim back their previously owned land, which has been occupied by other Rwandans who remained in the country, because the Arusha Peace Accords fixed the time limit for acquisition by prescription to 10 years.

4.6.2. Land Use and land management

The land use in Rwanda is related to a range of biophysical factors, among other, the climate, landscape, and soil conditions. The spatial and temporal variability of the climate is much influenced by the country elevation (i.e. altitude) and landscape. Lowlands are found in the Eastern part of the country, and are characterized by high temperature (i.e. >24°C) and low annual rainfalls (<1000mm). Most lowlands are covered by the Eastern plateau and Eastern savana agro-ecological zones. Highlands in Rwanda (i.e. > 2,000m of altitude) are found in the South, North and Northern West part of the country, including the Congo-Nile Watershed Divide and the Buberuka agro-ecological zones. Midlands (i.e. 1,400 – 1,800m) covers the Central plateau, granitic ridges and Lake Kivu boders agro-ecological zones; they are characterized by cool and moderate temperatures (i.e. 20 - 24°C) and moderate annual rainfalls (i.e 1,300 – 1,500mm)[100].

Land use and land planning issues

Land related issues are multiple and varied in Rwanda. Some issues originate from the morphology and physiology of the land, while others are rooted in the socio-demographic and socio-economic situations. Being a densely populated country, Rwanda faces serious problems related to the scarcity of land, the mode of human settlement and the protection of the environment. With the process of modernization of the agriculture sector, the land resource is being badly managed, and yet about 96% of rural households rely directly or indirectly on the land for their livelihoods[101]. With the high population density, Rwanda is experiencing excessive pressure on the land resources due to continuous cultivation of land, cultivation of steep hillside or marginal slopes, deforestation, development of settlements on agriculture lands, lack of reliable soil and water conservation structures, lack of culture to adopt conservation agriculture practices, misuse and mismanagement of crop residues, etc. These issues have accelerated land fragmentation, land productivity degradation and soil fertility depletion resulting from soil erosion and sub-optimal agricultural practices.

Generally in Rwanda, the agricultural plots are generally small (average plot size is 0.6ha often divided into three-four sub-plots). About 30% of the households cultivate less than 0.2ha (accounting for about 5% of total arable land), while about 25% cultivate more than 0.7ha (accounting for 65% of the national farm-land). About 15% of rural household farm less than 0.1ha; many of which are female-headed households, cultivating only 1.32% of national cultivable land [102] .

Land Governance and land fragmentation under irrigation

In Rwanda, there is no particular land governance policy for irrigation. Irrigation is being developed both on public lands (mainly marshlands) and private lands (mainly on hillside). More than 80% of the irrigated lands are fragmented with an average of 2.7 and 3.0 plots. In the public marshlands, the main reason for land fragmentation is the distribution of land among farming households though the cooperatives, formed by smallholder farmers. On the other hand, inheritance and purchase of land are the two main reasons for land fragmentation in hillside irrigation areas. The average and median farm size in the irrigated marshlands is 0.16 and 0.10ha compared with 0.41 and 0.40ha in the hillside irrigation areas[103].

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[100] Verdoodt, A and E Van Ranst (2003). Land evaluation for agricultural production in the tropics: A large – scale land suitability classification for Rwanda. Ghent: Laboratory of soil science, Ghent University. ISBN: 90-76769-89-3.
[101] Ibid
[102] IPRI calculations, based on EIVC 4 data 2013/2014
[103] RAB/MINAGRI and European Commission (2016). Final Report on the Technical assistance in the establishment of a baseline of agricultural households using irrigation systems.

Land conflicts

Despite the issues of land fragmentation, Rwanda also faces land disputes because of the importance of land and its economic considerations in the Rwandan culture. Besides, land is a traditional foundation of belonging and social status. For most rural Rwandans, land is much more a sense of belonging and a symbolic relationship between people than a source of food production. Land disputes are complex; in the most cases, common sources of disputes are inheritance, boundary encroachment, polygamy, and land transactions, with the majority of disputes being within extended families[104].

Land Use Consolidation

Land Use Consolidation (LUC) is not a new concept and has been implemented in a number of different countries dating back to ancient China and the Roman Empire; for example, it has been practiced in European countries like Germany, Netherlands, France, Belgium, Luxembourg, Austria, Switzerland, Finland, Norway and Sweden[105]. In Rwanda, LUC is defined by consolidation in use of land and not consolidation in ownership and so land is joined together but ownership of component smaller plots is retained by the original individual households. In many parts of the world, LUC has simply been a method of tapping economies of scale. Rwanda, having a land scarce society, LUC is also crucial for economic and optimal use of physical space. Under the LUC program, the minimum size of a consolidated plot should be 5ha[106]. Farmers retain individual ownership of their parcels under LUC, but agree to consolidate aspects of their operations within the program[107]. Participating farmers in LUC agree to grow a single priority crop that has been identified by MINAGRI as best suited to local conditions and consistent with Rwanda's overall agricultural strategy and priority crops, which include beans, maize, Irish potatoes, cassava, wheat, rice, soybeans and banana[108]. LUC is a large-scale initiative and by end of 2017, approximately 74% of the total land area under cultivation in Rwanda was under LUC[109]. As part of the larger crop intensification programme (CIP), LUC allows farmers to benefit from other services like availability of inputs (improved seeds and inorganic fertilizers), proximity extension services, post-harvest handling and storage facilities, irrigation and mechanization support through cooperatives and Government support. The

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[104] *Sagashya, D. and C. English. (2009). Designing and Establishing a Land Administration System for Rwanda: Technical and Economic Analysis*
[105] *Nyamulinda, B., Bizimana, C. Niyonzima, T. and Herman Musahara, H. (n.d) Assessment of the Economic, Social, and Environmental Impacts of the Land Use Consolidation Component of the Crop Intensification Program in Rwanda, Final Report, USAID, Land Project and University of Rwanda.*
[106] *MINAGRI (2012). Farm Land Use Consolidation in Rwanda: Assessment from the Perspectives of Agriculture Sector. Kigali: Republic of Rwanda.*
[107] *USAID (2007). Agricultural Land Use Consolidation and Alternative Joint Farming Models Facilitation Program and Projects Implementation Strategy, USAID Land Tenure Office. Washington, DC*
[108] *Nyamulinda, B., Bizimana, C. Niyonzima, T. and Herman Musahara, H. (n.d). Assessment of the Economic, Social, and Environmental Impacts of the Land Use Consolidation Component of the Crop Intensification Program in Rwanda, Final Report, USAID, Land Project and University of Rwanda.*
[109] *National Institute of Statistics of Rwanda (NISR) (2018). Seasonal Agricultural Survey – Season A2018*

results of the 2018 Season A indicate that the four main cultivated crops in terms of area cultivated through LUC were maize consolidated on 218,179ha of land, bush-bean (202,996ha), Cassava (194,717ha), and Banana (111,213ha).

Impact of land use consolidation

The positive impacts of LUC programme include:

- ✓ Increased farmer's crop yield. For instance, the impact of LUC on maize production showed that maize yield has increased by 347%, rice by 30%110, whilst the area under crop cultivation increased by 18 times between 2008 and 2012[111]. Other positive impacts include
- ✓ Improvement in soil fertility, quality of erosion control infrastructures and prevention of soil erosion,
- ✓ Fodder availability, livestock integration and the prevalence of tree plantations[112].

Issues and challenges in land use consolidation

The followings are issues and challenges that have been identified in the implementation of the LUC programme in Rwanda:

- *Comprehension of terms of arrangements under LUC* - One common fear amongst farmers is that they will lose their houses and land rights without fair compensation. This is mainly due to mistrust and lack of clarifications from officiating intermediaries on the terms of agreements related to LUC.
- *Lack of access to storage and post-harvest facilities and markets for crops in most of the consolidated areas* – Various initiatives aimed at improving the handling and storage of harvested farm produces commenced in 2011, including inventorying and repairing available community storage facilities; constructing public drying areas in each district; and acquiring small tools and equipment for improving the current practices of post-harvest processing and storage by farmers. However, it appears that enough has not been done in these areas. The GoR could consider facilitating the establishment of agro-processing industries that will add value to the produce thereby enhancing its marketability. Farmers also need education on establishing organized or

[110] *Ekise I. E., Nahayo, A., Mirukiro, J. D. and Mukamugema B. (2013). The Impact of Land Use Consolidation Program on Agricultural Productivity: A Case Study of Maize (Zea mays L.) Production among Households in Nyabihu District, Western Rwanda, Nature and Science, 11(12):21-27*

[111] *Kathiresan, A. (2012). Farm Land Use Consolidation in Rwanda: Assessment from the Perspectives of the Agriculture Sector, Republic of Rwanda, Ministry of Agriculture and Animal Resources.*

[112] *Nyamulinda, B., Bizimana, C. Niyonzima, T. and Herman Musahara, H. (n.d). Assessment of the Economic, Social, and Environmental Impacts of the Land Use Consolidation Component of the Crop Intensification Program in Rwanda, Final Report, USAID, Land Project and University of Rwanda.*

concentrated markets rather than the current fragmented markets in consolidated areas in order to be competitive.

- *Some farmers feel pressure to participate in LUC though LUC is voluntary by law, which makes them resistant to the program.* Though such instances are isolated, this needs to be addressed. The way forward is dialogue with farmers and working with them to understand the need to participate in LUC (not by coercion) and to address any problems or concerns they might have. This could be achieved through the organization of periodic forums or workshops for the farmers.
- *Lack of understanding of the terms of arrangements under LUC due to mistrust and lack of clarifications from officiating intermediaries on the terms of agreements*. More education of farmers on the terms of arrangements under the LUC program and its benefits is required in order to gain the trust of the farmers. As in the above recommendation, educational programs could include the organization of periodic forums or workshops for the farmers.
- *Lack of adequate capacity on the part of service providers of inputs to monitor/integrate with local administration who implement LUC in conjunction with MINAGRI.* There is the need to build the capacity of these service providers via appropriate training programs, such as workshops where they are educated on how to monitor or integrate with local administrations.

Local authorities driven by indicators under their performance contracts. In some cases, this leads authorities to force farmers to engage in LUC by destroying other crops regardless of the stage of crop growth which often results in resistance and worsens the already misplaced fears of losing the land rights amongst farming communities. This practice is inappropriate and the need to encourage farmers to participate in consolidation of their farm lands by educating them on the benefits of LUC cannot be overemphasized.

4.6.3. Proposed land use and management options for irrigation development

In a developing country context, land is a key asset for the rural population, often constituting the primary source of their livelihoods. In Rwanda, land is scarce and considered as one of its most precious natural resources. This makes the political economy of land complex, as it involves not only economic, financial, and institutional factors, but also has emotional and cultural underpinnings. The organic land law No.43/2013 of 16/06/2013 governing land in Rwanda determines modalities for use and management of land in Rwanda. Looking at the land use data as reported by the Rwanda Natural Capital Accounts, land is used for various reasons between and within different sectors; agriculture has the biggest share (60.6%) of the total land use in Rwanda compared to other land use categories: forestry (9.3%), industrial

(0.2%), livestock (5.7%), settlement and housing (8.5%); unclassified land is estimated at 13.5% and others (2.2%)[113].

In order to ensure an effective and efficient land utilization and management for agriculture production and support investment promotion in agriculture, land tenure regularization and secure land rights are important. Poor land tenure systems and weak land rights may deter investment for irrigation development, reduce the ability of borrowers to use land as collateral, and inhibit land transactions meaning that potential gains from trade are lost and induce landowners to divert valuable resources. In addition, establishing a well-functioning system for land use and management is a central concern. Thus, defining land use models for all consolidated agricultural lands, and particularly irrigated lands is crucial for future investments for irrigation development, and will improve the management and the optimal use of the land developed using public funds.

To develop individual land using goverment funds, the Government should conclude an agreement with land owners; such agreement should show roles and responsibilties of each party, commitment of the two parties and obligations of the land owners to effectivelly manage and use the developed land and to ensure the proper management of the public infrastructures installed. The following models are proposed for best management of the developed land and for improving land productivity: (1) Faciltated contract farming; (2) Optimal use of land under cooperatives; (3) Optimal use of land under farming corporation; (4) Optimal use of land under Non Governmental Organizations (NGOs); (5) Optimal use of land under land sub-lease.

Option 1 - Optimal use of land under faciltated contract farming agreement: Under this agreement, the selection of crops grown will depend on market requirements or the buyers. Every farmer will maintain his/her right to his/her irrigated land while the small plots are consolidated to ensure the prodution of the same crop required at the market. This option is currently implemented in Rwanda, where individual farmers or cooperatives sign contract farming agreement with maize off-takers like Minimex, Prodev, AIF (Africa Improved Food), etc, or horticulture off-takers like Garden Fresh, Nature Fresh Foods, LOTEC, ProxiFresh, etc.

Option 2 - Optimal use of land under cooperatives for agriculture production: The cooperative farming agreement shall be established in accordance with the Law on the cooperatives in Rwanda. This option is also currently implemented by most of the cooperatives registrered with Rwanda Governance Board (RGB) and Rwanda Cooperative Agency (RCA). When the consolidated lands are individual private smallholder plots, members of the cooperative will maintain their rights on the irrigated land. Cooperative farming agreement can also be established on state irrigated lands such as marshlands particularly for rice and horticulture (i.e. vegetables) value chains – in such case, members of the cooperative have no

[113] *NISR (2018). Rwanda Natural Capital Accounts - Land. National Institute of Statistics of Rwanda*

rights on the irrigated land, and respect the proposed land use and management. Marshlands are generally developed using public funds and can be rented to groups of farmers in cooperatives or investors to be able to optimaze their use and to ensure their effective management.

Option 3 - Optimal use of land under farming corporation for agriculture production: Under this agreement, companies involved in agricultural production will be established according to the Law regulating companies in Rwanda. The corporate agricultural production company will agree with the landowners to use their irrigated land. By establishing the corporate agricultural company, the investors may contribute to the farming coorporation by buying shares in cash while farmers shares will be their own land. Landowners may also form a farming corporation based on their own land as shares, and the investors may also form a separate farming corporation based on the value their shares, and the two corporate companies may enter into a joint venture. Rights, obligations and benefits of all parties shall be established in the agreement signed according to the national laws.

Option 4 - Optimal use of land under sub-lease for agriculture production: There are private individual lands where the Government has made or would like to make investments for irrigation development; thus, options of leasing the public infrastructures to Corporates have to be strengthened. Under a Corporate model, a company is jointly setup by private investors and owners of the developed land for the exploitation of invested public infrastructures. The Government has to agree to lease the infrastructures for use by the Corporate Company under negotiated conditions, and the farmers can lease their land to the corporate company. Under this agreement, landowners and the investor will agree on the terms of sub-lease of the land allocated to the agricultural activities. The investor will bring in matching investment capital. The resulting Corporate Company will utilize the irrigated land as a commercial farm and shareholders will be paid dividends periodically. In order to reduce the risks associated with the production process, the Government must set up Sovereign guarantees to buffer the private Corporate Company from such risks.

CHAPTER 5. ENVIRONMENTAL ACCEPTABILITY

5.1. General

The prime minister's order nº **006/03 of 30/01/2017** draws up a list of swamp lands, their characteristics and boundaries and determines modalities of their use, development and management. However, there are activities that are authorised to be carried out in unprotected swamp lands and those are the following:

- ✓ agriculture;
- ✓ fish farming;
- ✓ recreation;
- ✓ tourism development;
- ✓ quarrying;
- ✓ research;
- ✓ energy generation

It is important to recall that there protected areas where all activities are prohibited in order to preserve the environmental protection and sustainability. Those protected areas are defined by the environmental organic law **n° 04/2005 of 08/04/2005** determining the modalities of protection, conservation and promotion of environment in Rwanda (Art 52).

Rwanda Environment Management Authority (REMA), has updated, listed and delineated those protect areas and these maps will be available shortly.

5.2. Environmental screening

Screening is perhaps the most important step in safeguard management tool for the project. Screening will be based on an assessment of project components and site sensitivity. Initial screening will identify potential safeguard issues to be addressed in Feasibility Studies. Once projects are identified, and enough details are known on their typology, detailed screening will be carried out and then depending on the type, location and sensitivity of the project and the nature and magnitude of its potential environmental impacts, the proposed project has to be classified. At the project identification phase, the screening exercise focuses on the environmental and social dimensions of a project.

For different financial institutions, **category A** projects are likely to have 'important adverse environmental and/ or social impacts that are irreversible, or to significantly affect environmental or social components considered sensitive. This category includes projects that may generate the most severe adverse environmental or social impacts such as, among others, direct pollutant discharges in the natural environment, large scale physical disturbance of the project site and its surroundings, significant migration or displacement of affected populations, significant changes in socio-cultural patterns, adversely affect vulnerable groups, destruction or degradation of substantial biological resources, significant increase in health and safety risks, or major changes in the hydrology or water quality.

For example, the Council of European Development Bank (CEB) requires:

- **Category A**, the Project is likely to cause significant adverse environmental and/or social impacts which may be irreversible, cumulative, diverse or unprecedented. Environmental and Social Impact Assessment (ESIA) is mandatory for such Projects.
- **Category B**, the Project is considered to have a limited number of potentially adverse environmental and social impacts, which are generally site-specific, largely reversible, and readily addressed through mitigation measures. Such Projects may be subject to a full ESIA or to an abbreviated assessment focused on specific environmental and/or social risks and adverse impacts
- **Category C**, the Project is likely to have minimal adverse environmental and social impacts. Category C Projects generally do not require environmental or social impact assessment. However, standard environmental and health and safety precautions may apply to such Projects, e.g. those involving small construction sites.

While carrying out the environmental screening, it is very important to determine the sensitivity of the site. The following matrix should be applied for identifying potential issues.

Table 5-1: Site Sensitivity and safeguard policies

Safeguard Policy or Site Characteristic	**SITE SENSITIVITY**		
	Low Sensitivity	**Medium Sensitivity**	**High Sensitivity**
Natural Habitats	No natural habitats present of any kind	No critical natural habitats; other natural habitats occur	Critical natural habitats present
Resettlement	No new sites are required. Project site is already acquired and is free of squatter; legal tenure is well defined.	Project site has tenant renters. Yet to be acquired.	Project site will entail resettlement of vulnerable
Indigenous Peoples	No indigenous population	Dispersed and mixed indigenous populations; mainstream (highly acculturated) indigenous populations	Indigenous territories and reserves; vulnerable indigenous populations
Natural Hazards vulnerability; flood; soil stability/erosion	Flat terrain; no potential stability/erosion problems; no known volcanic/seismic/flood risks	Medium slopes; some erosion potential. Medium risks to volcanic/seismic/flood/ hurricane	Mountainous terrain; steep slopes; unstable soils; high erosion potential; volcanic, seismic or flood risks
Physical Cultural Resources	No known or suspected cultural heritage sites	Suspected cultural heritage sites; known heritage sites in broader area of influence	Known heritage sites in project area

Source: http://www.worldbank.org/content/dam/Worldbank/ (consulted on 6/09/2018)

The Organic Law No. 04/2005 of 08/04/2005 and the ESIA Decree of the Republic of Rwanda determine the modalities of protection, conservation and promotion of environment in Rwanda. The law in its article 67 stipulates, “every project shall be subjected to environmental impact assessment before obtaining authorization for its implementation”. The constructions of dams for irrigation purpose are included in the list of projects that need the EIA prior to their implementation.

As per Rwanda’s legal requirements, a Public Hearing is also required to be conducted for the project to inform the stakeholders about the project and its impacts and also to solicit their views on the same.

5.3. Potential environmental impacts of irrigation development project

Irrigation has contributed significantly to poverty alleviation, food security, and improving the quality of life for rural populations. However, the sustainability of irrigated agriculture is being questioned, both economically and environmentally. The increased dependence on irrigation has not been without its negative environmental effects. Major capital-intensive water engineering schemes have been proposed without a proper evaluation of their environmental impact and without realistic assessments of the true costs and benefits that are likely to result.

The sustainability of irrigation projects depends on the taking into consideration of environmental effects as well as on the availability of funds for the maintenance of the implemented schemes. Negative environmental impacts could have a serious effect on the investments in the irrigation sector. Adequate maintenance funds should be provided to the implementing organizations to carry out both regular and emergency maintenance.

The expansion and intensification of agriculture made possible by irrigation has the potential for causing: increased erosion; pollution of surface water and groundwater from agricultural biocides; deterioration of water quality; increased nutrient levels in the irrigation and drainage water resulting in algal blooms, proliferation of aquatic weeds and eutrophication in irrigation canals and downstream waterways. Poor water quality below an irrigation project may render the water unfit for other users, harm aquatic species and, because of high nutrient content, result in aquatic weed growth that obstructs waterways and has health, navigation and ecological consequences.

The potential direct negative environmental impacts of the **use of groundwater** for irrigation arise from over-extraction (withdrawing water in excess of the recharge rate). This can result in the lowering of the water table, land subsidence, decreased water quality especially when there is no a quantitative & qualitative study conducted before.

Upstream land uses affect the quality of water entering the irrigation area, particularly the sediment content (for example from agriculture-induced erosion) and chemical composition (for example from agricultural and industrial pollutants). Use of river water with a large sediment load may result in canal clogging. This problem of erosion has been observed in most of dams in Rwanda, leading to decrease the water quantity for irrigation (see picture below).

Figure 5-1: Rwamagana irrigation project

The environmental organic law in its article 85 stipulates that: “with exception of activities related to protection and conservation of streams, rivers and lakes, an agricultural activities shall respect a distance of ten (10) meters away from the banks of streams and rivers and fifty (50) meters away from the banks of lakes. In such distances there shall be no agricultural activities permitted to be carried out.” However, the law doesn’t say anything about dams protection and yet it is recommendable.

In general, the potential negative environmental impacts of most large irrigation projects include: waterlogging and salinization of soils, increased incidence of water-borne and water-related diseases, possible negative impacts of dams and reservoirs, problems of resettlement or changes in the lifestyle of local populations.

Waterlogging and salinization

Waterlogging and salinization of soils are common problems associated with surface irrigation. Waterlogging results primarily from inadequate drainage and over-irrigation and, to a lesser extent, from seepage from canals and ditches. Waterlogging concentrates salts, drawn up from lower in the soil profile, in the plants' rooting zone. Alkalization, the build-up of sodium in soils, is a particularly detrimental form of salinization which is difficult to rectify.

Irrigation-related salinity has adverse effects not only on the production areas, but also on areas and people downstream. The rivers, particularly in arid zones tend to become progressively more saline from their headwaters to their mouths. The aquifers interrelated with the river are highly saline and the salts discharged to the river system from saline aquifers adversely affect downstream water users, particularly irrigated agriculture.

Water-borne and water-related diseases

Water-borne or water-related diseases are commonly associated with the introduction of irrigation. The diseases most directly linked with irrigation are malaria, bilharzia (schistosomiasis) and river blindness (onchocerciasis), whose vectors proliferate in the irrigation waters.

Other irrigation-related health risks include those associated with increased use of agrochemicals, deterioration of water quality, and increased population pressure in the area. It has been reported that HIV/AIDS which has the potential to weaken a scheme's work-force has been recorded to increase in the locality of irrigation schemes, probably as a result of the influx of seasonal workers and crop traders (National irrigation policy,2013).

The reuse of wastewater for irrigation has the potential, depending on the extent of treatment, of transmitting communicable diseases. The population groups at risk include agricultural workers, consumers of crops and meat from the wastewater-irrigated fields, and people living nearby. Sprinkler irrigation poses an additional risk through the potential dispersal of pathogens through the air.

Potential environmental impacts of dams and reservoirs

The benefits of a dam project are flood control and the provision of a more reliable and higher quality water supply for irrigation, domestic and industrial use. Intensification of agriculture locally through irrigation can reduce pressure on uncleared forest lands, intact wildlife habitat and marginal agricultural land. In addition, dams create reservoir fishery and the possibilities for agricultural production on the reservoir drawdown area, which more than compensate for losses in these sectors due to the dam construction.

However, large dam projects cause irreversible environmental changes over a wide geographic area and thus have the potential for significant impacts. Criticism of such projects has grown in the last decade. Severe critics claim that because benefits from dams are outweighed by their social, environmental and economic costs, the construction of large dams is unjustifiable.

In some cases, environmental and social costs can be avoided or reduced to an acceptable level by carefully assessing potential problems and implementing cost-effective corrective measures.

It has been demonstrated also that increased pressure on upland areas above the dam is a common phenomenon caused by the resettlement of people from the inundated areas and by the uncontrolled influx of newcomers into the basin catchment. On-site environmental deterioration as well as a decrease in water quality and increase in sedimentation rates in the reservoir result from clearing of forest land for agriculture, grazing pressures, use of agricultural chemicals, and tree cutting for timber or fuelwood.

Socio-economic impacts irrigation schemes

The objective of irrigation projects is to increase agricultural production and consequently to improve the economic and social well-being of the rural population.

However, changing land use patterns may have other impacts on social and economic structure of the project area. Small plots, communal land use rights, and conflicting traditional and legal land rights all create difficulties when land is converted to irrigated agriculture. Land tenure/ownership patterns are almost certain to be disrupted by major rehabilitation works as well as a new irrigation project.

5.4. Alternatives to mitigate the negative impacts of irrigation projects

Although there are negative impacts of irrigation projects, alternatives exist to mitigate adverse effects of irrigation development. Some of them are listed below:

- locating the irrigation project on the site where negative impacts are minimized;
- improving the efficiency of existing projects and restoring degraded croplands to use rather than establishing a new irrigation project;
- developing small-scale, individually-owned irrigation systems as an alternative to large-scale, publicly-owned and managed schemes;
- using sprinkler irrigation and micro-irrigation systems to decrease the risk of waterlogging, erosion and inefficient water use;
- using treated wastewater, where appropriate, to make more water available to other users;
- maintaining flood flows downstream of the dams to ensure that an adequate area is flooded each year, among other reasons, for fishery activities.
- strong sensitization program on HIV/AIDS and even the use of condoms by workers at irrigation development projects site.

5.5. Addressing Indirect Long-Term Impacts

An adaptive management approach is proposed to address long-term impacts. General mitigation measures that are proposed to minimize some of the impacts are presented in the following table. Monitoring of key parameters will ensure proper identification of raising issues in order to flag actions from relevant agencies.

Table 5-2: Management of Long Term Impacts

Issue	Proposed Mitigation Measures	Implementation Schedule	Source of Funding
Water contamination	Law enforcement in Catchment area Agriculture extension for integrated pest management Law enforcement for illegal pesticide	After catchment conservation action plan is developed & agriculture extension network & system are strengthened	Agriculture extension cost
Soil salinity	Canal lining for those canal sections affected by saline/akali soil and properly maintain Application of gypsum wherever available & feasible Agriculture extension for suitable cropping pattern and soil fertility management	Since project construction phase	Bill in quantity for canal rehabilitation Agriculture extension cost
Water logging	Proper maintenance after good rehabilitation of canal and drainage system with people participation	Since construction phase	Annual maintenance
Sedimentation	Proper maintenance after good canal rehabilitation with appropriate sedimentation trap or extractor Flushing the canal as frequently as possible Develop and implement participatory operation and maintenance of canal and drainage system	Since construction phase	Annual maintenance
Increase of Pest and Weed	Effective agriculture extension for integrated pest management and cropping system management	When agriculture extension system is in place	extension cost
Accessibility constraint	Integrate accessibility pattern of local community into design and construction of canal rehabilitation Due diligent to maintain the accessibility options/route/bridge by both ID and community	Annually	Annual maintenance

Source: http://www.worldbank.org/content/dam (consulted on 7/09/2018)

5.6. Irrigation Project benefits

Irrigation is the important to the health of the agricultural industry. Improving the viability of individual farming and increasing the efficiency and economic stability of the command area and also contributing to the economic and social objectives of the region where the command area is located, are the expected outcomes of the irrigation scheme. Some of the project benefits are listed below:

- ✓ The project improves total farm outputs and hence raises farm income
- ✓ The project improves yields through reduced crops loss due to erratic, unreliable or insufficient rainfall.
- ✓ It allows a greater area of land to be used in areas where the rain fed production is impossible or marginal.
- ✓ Extensive agricultural production supplies raw materials to the nearby small-scale industries thereby increasing the economy in the region.
- ✓ Increased income from flood control, soil erosion, Etc.
- ✓ Population belonging to the command area benefit directly under the irrigation scheme;
- ✓ Creation of jobs for local communities during the construction phase
- ✓ Further, indirect labor opportunities will be sustainably improved since larger area will be brought under irrigation;
- ✓ No forest land is required for implementation of irrigation scheme. The agro forestry shall be taken up in command area and it improves the ecosystem services.

5.7. Protected Areas

Information on the Environmental Protected areas and Wetlands, was collected from the Convention on Wetlands, called the Ramsar Convention and Rwanda Environment Management Authority (REMA).

In 2008 REMA conducted a wetlands inventory through the Integrated Management of Critical Ecosystems (IMCE) project funded by GEF and World Bank. Within the outputs of the above task, a number of 38 marshlands (56,120ha), approximately 20% of Rwanda’s total marshland coverage, were proposed for full protection. Based on a new definition and counting conducted by REMA recently in order to be included in the Prime Minister’s order No006/03 of 30/01/2017 *“Drawing a list of Swamp Lands, their characteristics and boundaries and determining modalities of their use, development and management”*, the new figure is 46,920ha.

Ramsar’s vision is “the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world”. Rwanda currently has 1 site designated as Wetlands of International Importance (Ramsar Sites), with a surface area of 5,909 hectares. The Rugezi Marshland is located near Rwanda’s northern border with Uganda and is also included within REMA’s list of proposed wetlands for full protection.

The Ministerial order No. 006/03 provided information on the use, development and management of protected and unprotected swamp lands. As stated in articles 8 and 9, plans for the exploitation and use of unprotected swamps are the responsibility of the authority in charge. All plans must be approved by the Minister in charge of land who is also authorized to change if required the prescribed use of each swamp.

Apart from the wetlands the national parks of Rwanda are considered to be protected ecosystems and wildlife reserves. These include the Akagera National Park, the Nyungwe Forest and the Volcanoes National Park.

The following picture depicts the location of Rwanda's protected areas.

Figure 5-2: Map or Rwanda's Protected Areas

5.8. Classification

Environmental screening of the proposed project operation is undertaken to determine the appropriate extent and type of Environmental Assessment (EA) to be carried out. Depending on the type, location and sensitivity of the project and the nature and magnitude of its potential environmental impacts, the proposed project should be classified. At the project identification phase, the screening exercise focuses on the environmental and social dimensions of a project. For example, within the Environmental and Social Assessment Procedures (ESAP) of AfDB, any project is to be categorized in one of the four possible Categories, 1 to 4. World Bank and the Council of European Development Bank (CEB) have almost the same categorizations.

Generally, different financial institutions, category A (or 1 depending of the institution) projects are likely to have 'important adverse environmental and/ or social impacts that are irreversible, or to significantly affect environmental or social components considered sensitive. This category includes projects that may generate the most severe adverse environmental or social impacts such as, among others, direct pollutant discharges in the natural environment, large scale physical disturbance of the project site and its surroundings, significant migration or displacement of affected populations, significant changes in socio-cultural patterns, adversely affect vulnerable groups, destruction or degradation of substantial biological resources, significant increase in health and safety risks, or major changes in the hydrology or water quality. The projects assigned to Category1 require a full ESIA, including the preparation of an ESIA report and ESMP.

One of the important requirements from those international financial institutions is that during the ESIA process for Category 1(or A) projects, the project proponent is required to conduct meaningful consultations with relevant stakeholders, including potential beneficiaries, affected groups, Non-Government Organizations (NGOs) and local authorities, about the project's environmental and social impacts and take their views into account. We may notice that even as per Rwanda's legal requirements, a Public Hearing is also required to be conducted for the project to inform the stakeholders about the project and its impacts and also to solicit their views on the same.

The Organic Law No. 04/2005 of 08/04/2005 and the ESIA Decree of the Republic of Rwanda determine the modalities of protection, conservation and promotion of environment in Rwanda. The law in its article 67 stipulates, "every project shall be subjected to environmental impact assessment before obtaining authorization for its implementation". The irrigation projects are included in the list of projects that need the EIA /ESIA prior to their implementation.

5.9. Objectives of EIA/ESIA Study

As a part of the EA process, an EIA/ESIA study carried out for irrigation project, to identify and evaluate the potential impacts of the project on the environment. The objectives of the EIA/ESIA

Study include assisting the client (RAB), the concerned stakeholders and the governmental authorities in recognizing environmental, social and economic impacts of the proposed project, increasing awareness about the project and its potential impacts and recommending appropriate control, mitigation and monitoring measures.

The proposed irrigation project should aim at the following objectives:

✓ ***Dam exploitation***

- Develop and manage the dam in an environment friendly manner according to the regulatory requirements and best environmental practices, whilst ensuring economic viability.
- Maximize operational flexibility
- Optimize natural resources use
- Develop and operate the dam to meet community expectations in terms of environmental outcomes and cost.

✓ ***Environmental aspects***

- Protect the surrounding during operation of proposed dam project with appropriate environmental and social safeguards,
- Ensure that ecological balance of the area is not adversely affected by air emissions, wastewater discharge, solid wastes, etc.
- Protect native flora and fauna
- Protect quality of local surface and groundwater
- Minimize noise and vibration impacts on surroundings (pumping system)
- Minimize public health risks

✓ ***Socio-economic aspects***

- Improvement in direct and indirect means of livelihood
- Improvement in the living standard of local inhabitants
- Improvement in the infrastructure of the area
- Establish monitoring programme and provide procedures for resolution of community concerns, if any.

CHAPTER 6. IRRIGATION POTENTIAL

The irrigation potential of Rwanda has been determined considering the physical resources of “soil” and “water” combined with the irrigation water requirements as determined by the cropping patterns and climate discussed in previous chapters. However, mapping the irrigation potential can be a complex procedure involving the consideration of various parameters, other than physical resources, in such a way as to facilitate and ensure a sound planning and sustainability of the irrigation developments in the future. The assessment of Rwanda’s irrigation potential has resulted in the generation of potential maps for each one of the nine (9) Level 1 catchments. The parameters, the criteria and the data used in order to delineate the irrigable areas are elaborated in this chapter. Summarized results are given at the last section of this chapter.

6.1. Data collection

The procedure of data identification and collection has started even from the Contract negotiation phase. The **main** sources consulted for the identification of Rwanda’s irrigation potential are listed below.

6.1.1. Available Reports and documents

- Irrigation Master Plan (Ebony Enterprises Ltd & World Agroforesty Centre (ICRAF) 2010). The identification of the potential irrigable areas was primarily based on the findings of the IMP.
- Rwanda National Water Resources Master Plan (WRMP). The delineation of Rwanda’s potential in several zones was based in the Catchment Division of the WRMP. In addition, the report was consulted in order to analyze the available renewable resources and water demands per catchment.
- The new catchment plans for Nyabarongo Upper, Nyabugogo, Muvumba and Sebeya catchments available for use (https://waterportal.rwfa.rw/publications/catchment_plans).
- The Marshland Survey as described in the previous section.
- The Ministerial order No. 006/03 as described in the previous section.
- Technical assistance in the establishment of a baseline of agricultural households using irrigation systems (EU Baseline Surveys)

6.1.2. Technical assistance in the establishment of a baseline of agricultural households using irrigation systems (EU Baseline Surveys)

With respect to the above assignment a number of baseline surveys were conducted, under the European Union funding, to identify schemes currently under irrigation or under development. Data from the surveys were correlated with all other available information on already developed or ongoing projects, with the objective of generating a completed registry of Rwanda's implemented irrigation projects.

6.1.3. District Land Use Data

Land use data were also collected from the Rwanda Land Management and Use Authority (RLMUA) and were processed using ArcGIS software to identify any land use information that affects the delineation of the potential irrigable areas. In particular planned urban areas or other areas of public interest were taken into account. Additional data on agricultural land were also collected to update the information.

Other than the District land use data, orthophotos and Google earth images were also used to identify and confirm land uses affecting the delineation of the potential command areas.

6.1.4. Potential sites Proposed by the IMP

The GIS data of the IMP concerning potential irrigable areas was interpolated with all data collected, concerning schemes either already completed or under design, potential schemes identified by the consultant, land use data and information on the protected areas and wetlands.

It must be noted that the country has a vast marshland irrigation potential based on the Marshland Survey findings and the first IMP conducted. The delineation of marshlands was established in two periods. First period was in 2009 and second period in 2017. Since the IMP was conducted in 2010, the figures used were based on the marshland assessment of 2009. The update of the IMP is based on the figures of 2017 assessment.

6.1.5. Other Potential Sites

Information on other potential sites includes:

- Known LWH and RSSP projects with completed or ongoing designs
- Other Large-Scale projects with completed or ongoing designs
- Sites Identified by the Consultant

6.1.6. Sites under irrigation or under development

Information on already implemented schemes or currently under development was mainly based on the EU baseline surveys, discussions and meetings with the client and local experts and the extended knowledge of the Consultant on the irrigation status for several parts of Rwanda.

6.1.7. Sites under Small Scale Irrigation Technology (SSIT)

The Feasibility Study for the Identification of Potential Small-Scale Irrigation Areas was completed in September 2018 by Rwanda Agriculture and Animal Resources Board (RAB)[114]. The study's objective was to quantify the actual potential area for SSIT, carry out economic and financial analysis, and make proper recommendations in order to boost small scale schemes across the country. The current SSIT being widely used in Rwanda includes portable water pumps connected to open hose or to sprinkler systems. With the aim of moving forward to more efficient methods, Rwanda adopted the "Subsidized Farmer led Small Scale Irrigation Development Program" in 2014. The program targeted the use of portable diesel/petrol water pumps and/or treadle pump, delivery pipes, and dam sheet technology to irrigate relatively small plots/farms ranging from 0,5ha to 10ha. Since 2014 the program has resulted in numerous schemes being equipped with SSIT.

The Study concluded in a total number of 84,704ha of potential irrigable land through SSIT, and in a number of only 5,000 ha of developed land out of the total potential. It should be mentioned that part of the areas included under this category have been already identified by the IMP and were counted in other categories (domains). In the results and maps, only the command area of SSIT practice that do not overlap with other potential areas are presented.

The main conclusions of the feasibility of SSIT is important also to be mention in this report:

- The Government needs to leverage the potential SSIT for implementation as this technology has the least cost development per hectare,
- Integration of the SSIT production into value chain systems need to be prioritized since the SSIT farmers have shown a preference for producing vegetables which are perishable but have high value.

6.2. Irrigation Domains

In line with the 2010 Irrigation Master Plan and in order to facilitate the selection and prioritization of the most cost-effective potential projects, Rwanda's irrigation sector has been divided into Domains based on the type and nature of water abstraction. The partition into Domains is a common procedure in order to better refine the biophysical and climatic features that affect the mode of abstraction and utilization. As a result, six (6) Irrigation Domains have been identified:

- Runoff for Small Reservoirs
- Runoff for Dams
- Direct River

[114] RWANDA AGRICULTURE AND ANIMAL RESOURCES BOARD, "Feasibility Study for the Identification of Potential Small Scale Irrigation Areas In Rwanda (Final Report)", Sept 2018

- Lake Water Resources
- Marshlands
- Ground Water

The six (6) irrigation domains are discussed in the following sections.

6.2.1. Runoff for small reservoirs domain

This Domain pertains to small-scale rural landholders making use of simple technologies to irrigate the land, most often where they reside. The first IMP estimated a number of 7.6 million rural landholders based on the 2010 census data. The above estimate corresponds to approximately 80% of the 2010 population. Considering the large family units of Rwanda (six children per couple) it was calculated that 855,000 households have an average of 1ha per household and can effectively irrigate 0.2 ha (2,000 m^2). The IMP based on the above assumptions concluded a total irrigable area of 125,627ha for this domain.

According to the 2017 Agriculture Household Survey (AHS), during the Agricultural year September 2016 - June 2017, Rwanda had an estimated 2.1 million agricultural households. This constitutes about 80.2% of total estimated households of the country while the average size agricultural household is 4.5 persons per/hh. Of the estimated 2.1 million agricultural households in Rwanda, 76.4% have main activity of crop production and livestock, followed by 21.8% whose main activity is crop production, thus 98.2% are engaged in agriculture.

The fourth Population and Housing Census in Rwanda[115], was conducted in August 2012. The 2012 census data indicated a total population of 10.5 million. The same report calculated the size of the resident population to be projected at 11.84 million in 2017, out of which 9.49 million is the estimated rural population, which is 100% in line with the estimated figure by AHS. The rural population shall be increase to 9.7 million by the year 2018 and to 11.8 million by the year 2032, resulting to 2.6 million of households.

According to USAID's knowledge sharing platform focused on land tenure and property rights116, more than 66% of households has average landholdings less than 0.6 hectares, while 36% less than 0.11 hectares. The above is supported by the African Journal of Agricultural and Resource Economics[117] which reports that a structural change in the small farm sector is identified, with the average farm size to be decreased from 0.76 to 0.43 hectares, following by significantly increased labour use and much increased capital use. Furthermore, it is stated in all reports that not all agricultural land owned by households is irrigated.

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[115] Fourth Population and Housing Census (RPHC4), Rwanda 2012
[116] https://www.land-links.org/country-profile/rwanda/#land
[117] African Journal of Agricultural and Resource Economics Volume 11, December 2016, Long-term structural change and determinants of agricultural output in small-scale farming in Rwanda

During the discussions with the client and project stakeholders, it was agreed that an effectively irrigated land of 0.04ha (400 m2) on average per household forms a realistic figure for the size of the small irrigated areas within the vicinity of their houses, however only 50% of them are irrigating by their houses, since many of them are irrigating only in more organized areas with a water source and not in their houses, while the capacity of water storage by their houses is very limited. This is also in line with the experience of the consultant in irrigation projects for several parts of the country and moreover with the comment included in WRMP that this potential of 125,000ha is unrealistic.

With this regard, and following the methodology used by the IMP to calculate the small housing farming potential of the country, the following estimations can be elaborated:

- Number of Rural Households: 2,600,000
- Total small-scale irrigable area (0.04ha per household): 52,000 ha

The technologies and infrastructure used to irrigate the land under this domain are mentioned within the IMP and include: above ground storage tanks, underground tanks, ponds, and simple abstraction methodologies. Irrigation of the small areas in the vicinity of the house or near the water supply, using these practices, is endorsed. Further training of farmers is needed in order to boost participation.

Small household reservoirs are recommended for supplemental irrigation during the rainy seasons to be used only as needed during dry spells to boost productivity. It is not feasible to construct small reservoirs for dry season irrigation as the volume of water required is large, making the cost too high. The current RAB SSIT program which provides a 50% subsidy to farmers for purchasing small scale irrigation equipment, includes 1mm thick HDPE plastic sheet lining for small reservoirs. However, the quality of the lining proved to be sub-standard and was not UV radiation resistant resulting in a life span of only one or two years when it should last more than 10 years. Future imports of HDPE lining should be tested by baking a sample in an oven to make sure it contains at least 2.5% carbon black by weight to protect it from UV radiation damage.

The LWH Project constructed several types of small lined reservoirs including; stone masonry, lightly reinforced concrete, puddled clay protected by riprap, and compacted clay soil protected by riprap. The most cost effective design is the compacted clay soil lining which has very little infiltration loss and low installation cost if the excavated material from the site has enough clay content, which is the case in many locations in Rwanda.

6.2.2. Runoff for dams

Dam potential sites were identified in locations where slopes meet the limit set by FAO (<40%) and in locations having a good potential to generate adequate runoff. The supply of the water to the downstream command area is considered to be performed by gravity. In order to calculate the available command areas, the most favorable locations for the construction of dams were selected. The catchment areas and the available water resource (as calculated in the Water Resources assessment) was calculated for each proposed dam location in order to delineate the command area boundaries.

Besides storing runoff for irrigation purposes, dams also provide other multi-purpose benefits such as water supply, hydropower, and flood control. Water supply demands are relatively small and can usually be catered for with minimal impact to irrigation. Hydropower is non-consumptive and in most cases can be incorporated without any conflict of water use for irrigation. Flood control for irrigation development downstream of the dam is one of the most critical benefits of dams, greatly reducing the cost of flood control embankments and drains and can result in increased crop production even without the use of irrigation.

Flood control is needed to make irrigation development of many marshlands economically feasible, most critically for the lower Nyabarongo and Akanyaru valleys. The feasibility study carried out by Feedback Infra for the Nyabarongo-2 dam at Shyorongi showed that irrigation development of these two valleys is only feasible after both the Nyabarongo-2 and the Akanyaru dams are constructed. The gross area of potential marshland that will benefit from the flood control provided by these two dams is approximately 25 – 30,000 ha not including the additional 10 – 15,000 ha in Burundi between the dam located on the border and downstream of Lake Cyohoha South.

Muvumba dam is another large multipurpose project, that should be mentioned separately. The Muvumba river, belongs to the Nile River basin and is located at the Eastern part of Rwanda at Nyagatare District. The dam is located 10km upstream of Nyagatare town and according to the study of KOICA of 2016, the benefit of the project shall be 125 Mm3/year, while 78 Mm3/year for irrigation, resulting to approximately 13,000ha.

6.2.3. Direct River

Similarly, to the definition given within the IMP, this Domain refers to water resources abstracted to the command area through pumping directly from rivers. Following discussion with the client and all project stakeholders, irrigation areas were decided to be divided into three lifting zones. The first one refers to a pumping static head of 0-50m, the second one to a static head of 50-80m and the third to a static head of 80-120m. The division into three zones expands the irrigation potential compared to what was proposed in the IMP (single pumping zone up to 100m) and offers the designers the flexibility to design with an optimal combination of arrangement of canals/pipes and pumping stations resulting in lower operational costs.

In some cases where the dry season flow and topography are adequate, irrigation can be developed without pumping by use of stream diversion, night storage reservoirs, and gravity distribution by canal or pipe networks.

6.2.4. Lake Water Resources

Potential command areas pertaining to this domain are located adjacent to lakes. Based on the collected studies[118][119][120], lakes to be considered are:

- Lake KIvu
- The Northern Lakes of: Bulera, Ruhondo
- The Central Lake: Muhazi
- Lakes Cyohoha and Rweru
- The Gisaka Lakes: Sake, Mugesera and Birara
- The Bugesera Lakes: Rumira, Kidogo, Gaharwa, Kirimbi, Mirayi and Gashanga
- The Nasho Basin Lakes: Nasho, (Rwa)Mpanga, Kagese, Cyambwe, Rwakibare
- The Akagera National Park Lakes: Ihema, Mihindi, Kivumba, Hago, Rwanyakizinga

Lake Kivu lies on the border between the Demographic Republic of the Congo and Rwanda. It covers a total surface of 2,370 km^2 with 42% of the surface area within Rwanda. The lake has a maximum depth of 490m.

Twin lakes Bulera and Ruhondo are located close to the border with Uganda, surrounded by steep hills and large waterfalls and are characterized as deep lakes.

Lake Muhazi forms a long thin shallow flooded valley and empties into Nyabugogo river having a capacity of 330Mm3, water surface area 32.90Km2 at the elevation of +1434.50 which is the spillway crest level of the Muhazi dyke.

Lake Rweru forms the part of Rwanda and Burundi and has a total surface area of 100 km2 with 20km2 within Rwanda. Together with the rest of the Bugesera lakes they cover a total area of 12,000ha and have an average depth of 3-5m.

Lake Cyohoha is located at the borders with Burundi, with the larger part of the respective catchment to be located in Burundi.

The Gisaka Lakes: Birara, Mugesera and Sake, are located on the left bank of the Nyabarongo river and south-east of the city of Kigali and south of the city of Rwamagana. Birara and Sake lakes are located at Ngoma district, while Mugesera lake is shared between the districts of Rwamagana and Ngoma.

The Bugesera lakes are located on the right bank of the river Nyabarongo, that is, west of the river, and southeast of the cities of Kigali and Nyamata. The lakes Gashanga, Kidogo, Rumira are located north of the village of Gashora. Kidogo and Gashanga Lakes were once one lake,

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[118] Source Book for the Inland fishery resources of Africa, Vol 1, FAO
[119] Projet d'Etudes d'Elaboration des Plans d'Aménagement Intégré et de Gestion pour 17 Lacs Intérieurs au Rwanda, Projet d'Appui à l'Aménagement Intégré et à la Gestion des Lacs Intérieurs (PAIGELAC), EGIS BCEOM, 2008
[120] J.Rutaisire, " Master Plan for fisheries and fish farming in Rwanda submitted to the Ministry of Agriculture and Animal Resources (MINAGRI) / Integrated Development and Management Support Project (PAIGELAC)", 2011

which is visible on the administrative map of 1988. They are now definitely separated from one another since 1992. Lakes Mirayi, Kirimbi and Gaharwa are located south of the village of Gashora. The storage capacity of the lakes is very low, thus should not be considered as a source for irrigation projects.

Lakes Rwakibare and Kagese are located in Kayonza district of Ndengo sector. Rwampanga Lake is located in the Kirehe district, Mpanga sector. The waters of Lake Nasho are included in the Kayonza district, but the south shore is an integral part of the Kirehe district. (Nasho sector). The waters of Lake Cyambwe are shared between the districts of Kayonza (Ndego sector) and Kirehe (Mpanga and Nasho sectors). Rwakibare, Cyambwe and Rwampanga lakes communicate directly with the Akagera River, at least during the rainy season. These lakes are very close to the Tanzanian border to the east.

Similarly, to the “Direct River Domain”, water from lakes is considered to be abstracted through pumping. It was agreed that irrigation areas will be divided into three lifting zones (pumping static head of 0-50m, 50-80m and 80-120m), following the same methodology of river domain.

In order to assess the capacity of the lakes and evaluate the performance during abstracting water for irrigation, estimations on the volumes stored in the lakes that are considered major irrigation sources are given, based on the information gathered.

Table 6-1: Lakes’ Characteristics

Catchment	Lake	Volume (Mcm)	Surface (ha)	Average depth (m)	Maximum depth (m)
CKIV	Kivu	550	237,000	2400	490
NNYL	Muhazi	330	3,290	2.5	16.8
NAKN	Cyohoha	395	7,600	5.2	11.0
NAKU	Rweru	210	12,600	2.1	3.9
NAKU/Bugesera	Gaharwa	3	167.7	2.0	3.2
NAKU/Bugesera	Kirimbi	2	100.0	2.5	3.3
NAKU/Bugesera	Mirayi	9	381.6	3.5	4.7
NAKU/Bugesera	Rumira	4	256.1	2.0	2.8
NAKU/Bugesera	Kidogo	5	237.0	3.0	3.5
NAKU/Bugesera	Gashanga	7	325.5	3.0	3.1
NAKU/Gisaka	Mugesera	100	3,950	3.0	5.2
NAKU/Gisaka	Sake	50	1,430	4.5	5.4
NAKU/Gisaka	Birara	23	540	6.0	8.8
NAKL/Nasho	Mpanga	33	950	5.2	6.3
NAKL/Nasho	Cyambwe	60	2,287	4.1	5.4
NAKL/Nasho	Nasho*	37.4	1,600	2.3	4.3
NAKL/Nasho	Rwakibare*	17.6	400	4.4	6.5
NAKL/Nasho	Kagese	2	205	0.9	1.2
NAKL	Ihema*	325	9,600	3.4	6.3
NMUK	Burera	4,500	5,180	80	179
NMUK	Ruhondo	1,000	2,600	30	68

* *Nasho, Rwakibare and Ihema Lake data updated from recent SMEC bathymetric surveys*

6.2.5. Marshlands

As stipulated by the Ministerial order nº 006/03 of 30/01/2017 Rwanda has ~121,580ha of marshlands which can be exploited under conditional use. Fully protected wetlands cover an area of 46,920ha and are rendered within the drawings to highlight the areas which cannot be exploited. Marshland potential sites are displayed in the drawings in two different layers: those identified by the ministerial order which can be irrigated, developed and managed according to the modalities determined in the ministerial order and those identified by the consultant and IMP which can be irrigated with no restrictions applied. Summarized results are given in the final section of this chapter.

It has to be noted that the previous figure used in the IMP is 219,793ha, based on wetlands inventory conducted by REMA in year 2008, through the Integrated Management of Critical Ecosystems (IMCE) project funded by GEF and World Bank. The new estimated figure by REMA is considered more accurate due to the use of recent and more accurate technology for the identification and definition, but compare with the initial figure is approximately 100,000ha less.

Major challenges associated with developing marshlands include; permanent and seasonal flooding, and lack of water available for irrigation during the dry seasons. Many of the remaining undeveloped marshlands require either flood protection dikes and improved drainage sometimes requiring pumps, or upstream dams to reduce flood levels and store water for irrigation.

6.2.6. Groundwater Resources

The effective use of Groundwater reserves entails a clear policy guidance, drought mitigation measures, institutional arrangements and can face several constraints and risks such as water quality, risk of salination of aquifers, impacts on natural aquifer discharge etc. In IMP of 2010 Groundwater Resources forms a Domain with a total groundwater potential of 36,432ha, however it was not made clear how resulted to this figure.

In addition to the above a new groundwater study was recently conducted for the eastern province of Rwanda. The report was prepared as part of the IWRM programme known as Water for Growth Rwanda and was funded by the Government of The Netherlands. The study among other objectives assesses the existing boreholes status, the availability of ground water, possible yields and water quality in addition to recommending the optimum sites for long-term production boreholes.

In addition, the study gives an insight of the groundwater potential of the Eastern Province of Rwanda and discusses all interventions required for a sustainable groundwater development. The maps presented within the report provide an initial conceptual model on where to look for potential groundwater resources. However, to develop a groundwater source (planning and location of new productive boreholes) in order to meet the demands of a master plan requires detail information on rainfall data, groundwater and surface water abstraction data, groundwater level fluctuations, water quality which are not yet available in detail, except of only few cases in eastern province

Based on the above observations and during the discussions with the client, it was agreed that the potential for irrigation using groundwater source can only be roughly estimated since hydrogeological assumptions should be tested with reliable field data. The below analysis is based on the data provided on the WRMP.

6.2.6.1. Resource

As analysed in chapter 6, the total mean annual outflow from each catchment represents the average annual renewable resource available for exploitation, which includes both groundwater and surface water. The information given is resulting to volumes of groundwater that can be stored and volumes that can be safely abstracted and which forms part of the total volume of renewable water.

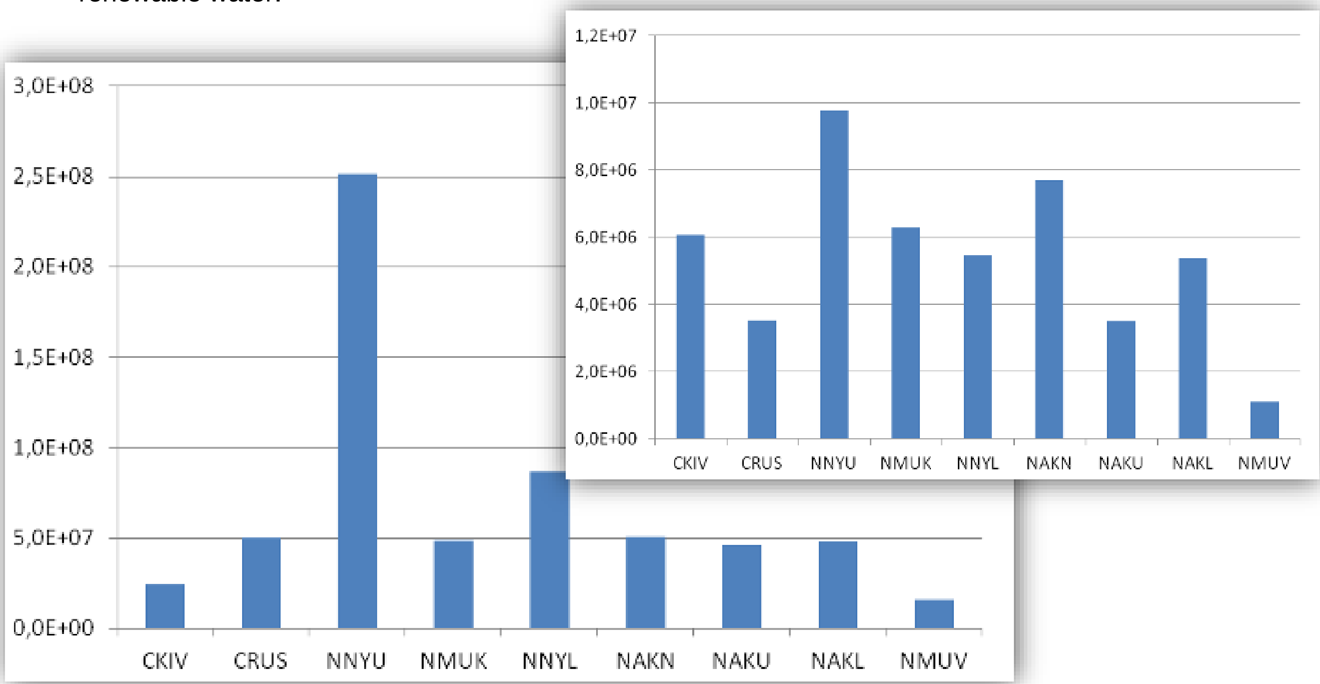


Figure 6-1: Groundwater storage per basin in hm3 and Safe yield (axis X: Mm3, axis Y: catchments)

According to the figures above, can be derived that only a very small part of the ground water volume can be safely abstracted.

6.2.6.2. Groundwater catchments and aquifers

A hydrogeological map of Rwanda was prepared for the purposes of the WRMP and can be also used in this report (figure 6-2). This map indicates the several aquifers of the country, connected with the potential for ground water yields and the Level 1 catchments.

Lake Kivu catchment: The catchment is characterized by granite rock in the north and south and by a fault zone with alternating schist and quartzite layers in the center.
The north is characterized by a unique basement aquifer consisting of granite, with a low storage capacity.
The center has more favorable conditions for groundwater storage. The west-eastern fault zone and alternations of quartzite, schist and green rock provide good conditions for groundwater flow and storage.
The south part can also be subdivided into a northern part and a southern part. The northern part is still affected by faulting and more permeable due to tectonic stress and the occurrence of more permeable rock (green rock). The southern part is dominated by intrusive rocks and fractured bedrock of lower permeability.

The Rusizi catchment: Is characterized by basalt, schist and quartzite. The west part is subdivided into a basalt aquifer and a schist aquifer (valley bottom). The basalt aquifer has high recharge and the highest yields found in Rwanda. Schist acts as an aquitard and stores only limited amount of water. The east party is sub-divided into a quartzite and a granite basement aquifers. The quartzite aquifer provides more favorable recharge and storage conditions, while the granite basement aquifer has lower recharge, faster recession and less storage.

Upper Nyabarongo Catchment: The upper Nyabarongo is sub-divided into the granite basement aquifer (Nile-Congo watershed in the West) and the quartzite and schist aquifer in the central part. Along the river Nyabarongo itself an alluvial aquifer is distinguished that is composed of the river sediments in the alluvial plain. The granite aquifer has low storage capacity. The quartzite and schist aquifer has intermediate storage and recharge conditions. The alluvial aquifer has excellent storage capacity (>25 %) and can be of local importance for groundwater storage and abstraction schemes.

Mukungwa Catchment: The Mukungwa basin (NMUK) is subdivided into 3 groundwater basins: a) the basalt and volcanic sediment province in the North and North West with excellent storage capacity and high recharge and base-flow rates, b) the granite and pegmatite basement aquifer in the West and South-West with low permeability and low storage, c) the quartzite and schist aquifer in the South-East and East. of variable quality.

Lower Nyabarongo Catchment: The lower Nyabarongo is dominated by quartzite and schist basement aquifers with neither really excellent neither really bad storage and transmission properties. In addition, as a separate aquifer, the alluvial aquifer is an important storage for infiltrating river water. It has considerable potential for drinking water supply, good storage and high flow rates.

Akanyaru Catchment: The Akanyaru River catchment is dominated by granite and pegmatite in the upper part, which in combination with high rainfall and steep slopes, high runoff rates and low recharge rates are typical. The lower part is characterized by alluvial aquifers, partly organic, partly mineral. The mineral aquifers are identified as a separate aquifer with good storage properties.

Upper Akagera River Catchment: The upper Akagera is sub-divided into the quartzite aquifers, the schist-aquifers and alluvial aquifers with an organic matrix. The quartzite aquifer has intermediate storage and provides access to groundwater. The central part of the basin is dominated by schist with low storage. The alluvial aquifers mainly have an organic matrix, so water quality issues for groundwater abstraction should be considered.

Lower Akagera River Catchment: The lower Akagera is subdivided into the upper schist-quartzite basement aquifer and the northern granite basement aquifer. In the upper part of the basin recharge is low due to the low rainfall amount and high evaporation, while the northern part has low storage and groundwater is mainly stored in the weathering and saprolite layer.

Muvumba River Catchment: The Muvumba basin consists of two adjacent units and basement aquifers: The western part of the basin, characterized by alternating schist and quartzite with average groundwater characteristics mainly for local supply, while the eastern part is dominated by granite as the dominant basement aquifer resulting in generally poor groundwater characteristics.

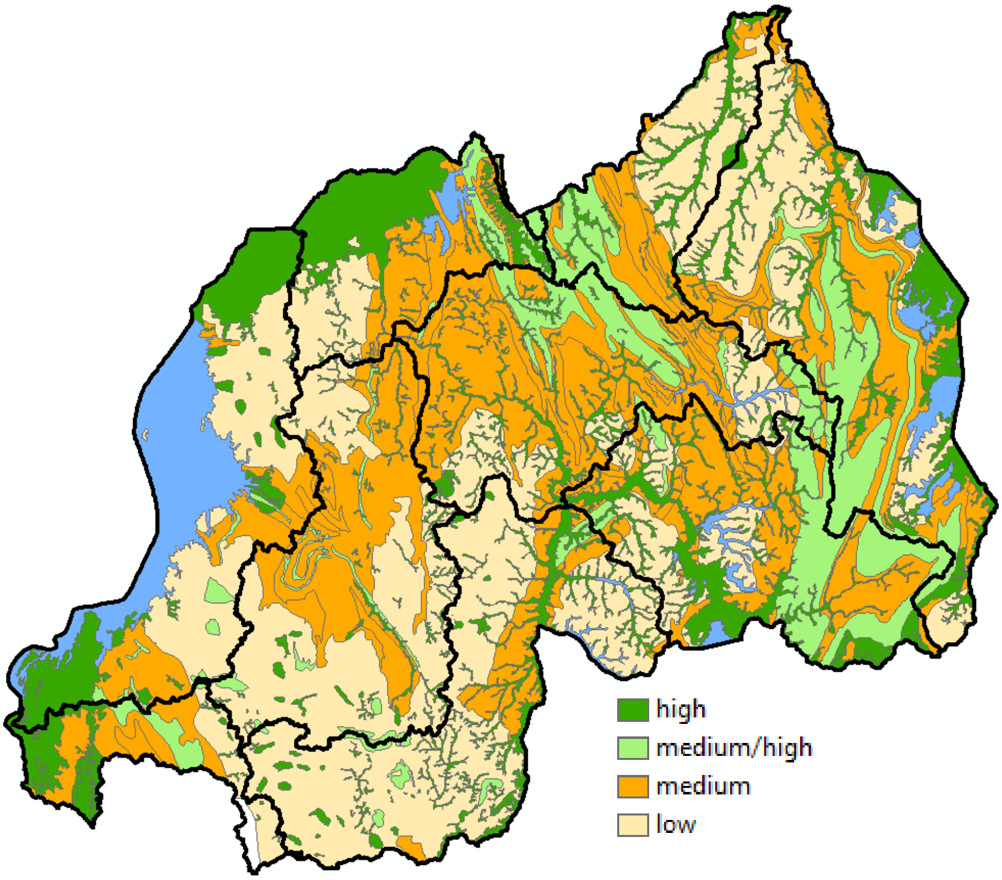


Figure 6-2: Areas with groundwater potential

6.2.6.3. Groundwater potential for irrigation areas

According to the above data, it is proved that the use of groundwater can not be one of the main domains for irrigation, but can be utilized as support to areas that surface water is not enough to support a development. It has to be noted once more, that the amount of water that can be abstracted has been already included in the renewable water used for the calculation of availability. The additional command areas that can be irrigated by groundwater per catchment, can be estimated as follows:

Table 6-2: Potential area for irrigation using groundwater

Catchment	Abstracted groundwater quantities (hm3)	Irrigation Area (ha)
CKIV	30.0	5,000
CRUS	18.0	3,000
NNYU	49.0	7,000
NMUK	31.0	5,000
NNYL	27.0	4,000
NAKN	39.0	5,500
NAKU	18.0	2,500
NAKL	27.0	3,000
NMUV	6.0	1,000
Total		**36,000**

6.3. Slopes

Slope gradient is one of the most important edaphic limitations to crop production in Rwanda together with soil depth. To evaluate the potential irrigation suitability in Rwanda, slopes were classified in four (4) categories (Class 1: 0-16%, Class 2:16-25%, Class 3:25-40%, Class 4: >40%) with lower values being more favorable as they reduce the risk of soil erosion. Irrigation schemes have been considered in locations with slopes up to 40% considering that irrigation in hillsides (Class 3) can be performed through terracing techniques. The results is based on GIS analysis by using the 2010 orthophoto maps (0.25mx0.25m) and the associated 10x10 grid DTM developed by the Rwanda National Land Use and Development Master Plan Project.

Table 6-3: Catchments' Average Slope

Catchment	0-16%	16-25%	25-40%	>40%	Mean Slope (%)	Class
CKIV	29,97%	10,44%	18,70%	40,89%	34.7	3
CRUS	11,99%	10,68%	20,59%	56,74%	49.2	4
NAKL	76,17%	10,19%	8,19%	5,44%	2.4	1
NAKN	42,70%	22,22%	18,57%	16,51%	12.7	1
NAKU	65,00%	18,07%	11,59%	5,34%	23.4	2
NKIR	9,81%	8,27%	21,86%	60,06%	14.7	1
NMUK	36,21%	9,38%	16,09%	38,32%	45.1	4
NMUV	56,18%	9,36%	11,69%	22,76%	33.0	3
NNYL	29,69%	17,27%	21,46%	31,59%	23.7	2
NNYU	15,90%	14,60%	24,92%	44,58%	31.3	3

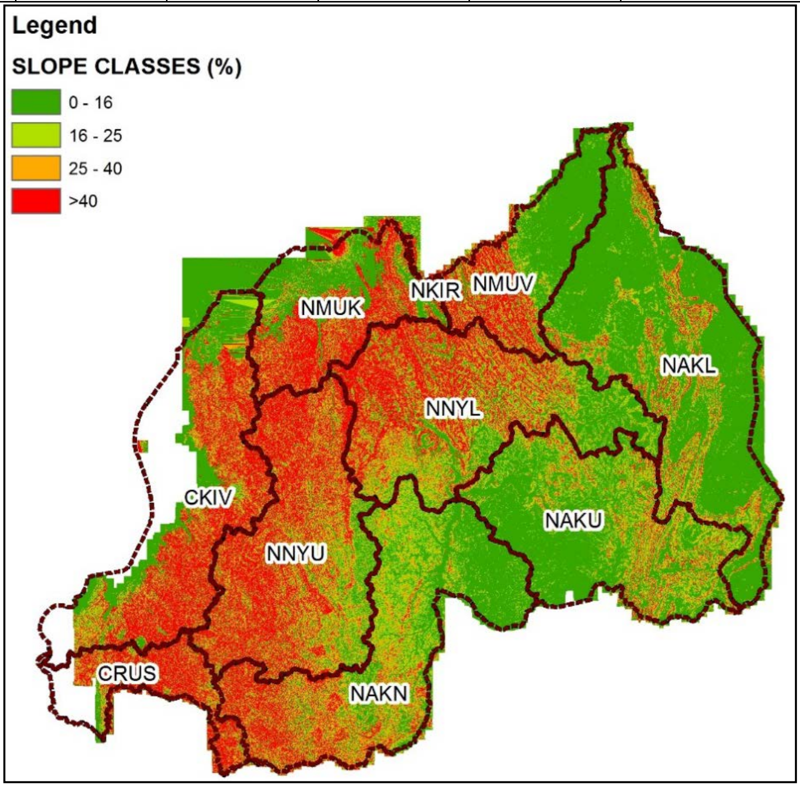


Figure 6-3: Rwanda Slopes Classification Map

6.4. Land Use

As previously mentioned, collected data from Rwanda Land Management and Use Authority (RLMUA) combined with orthophotos and Google Earth images were used to delineate the boundaries of the proposed Command Areas. The following figure illustrates an example of the correlation between existing and planned land use data and potential irrigable areas within the Bugesera district. The figure below, displays an index of planned and existing land uses (Agriculture, Parks, Industrial, Urban {including residential, administrational, infrastructure, mixed uses etc,}). The areas marked with brown color illustrate potential or existing command areas as shown in the legend. The example of the Bugesera District was chosen to be highlighted within the report, as the local development plans include numerous interventions, the construction of a regional airport, industrial zones and urban developments with the aim to increase access to socio-economic infrastructures for future development.

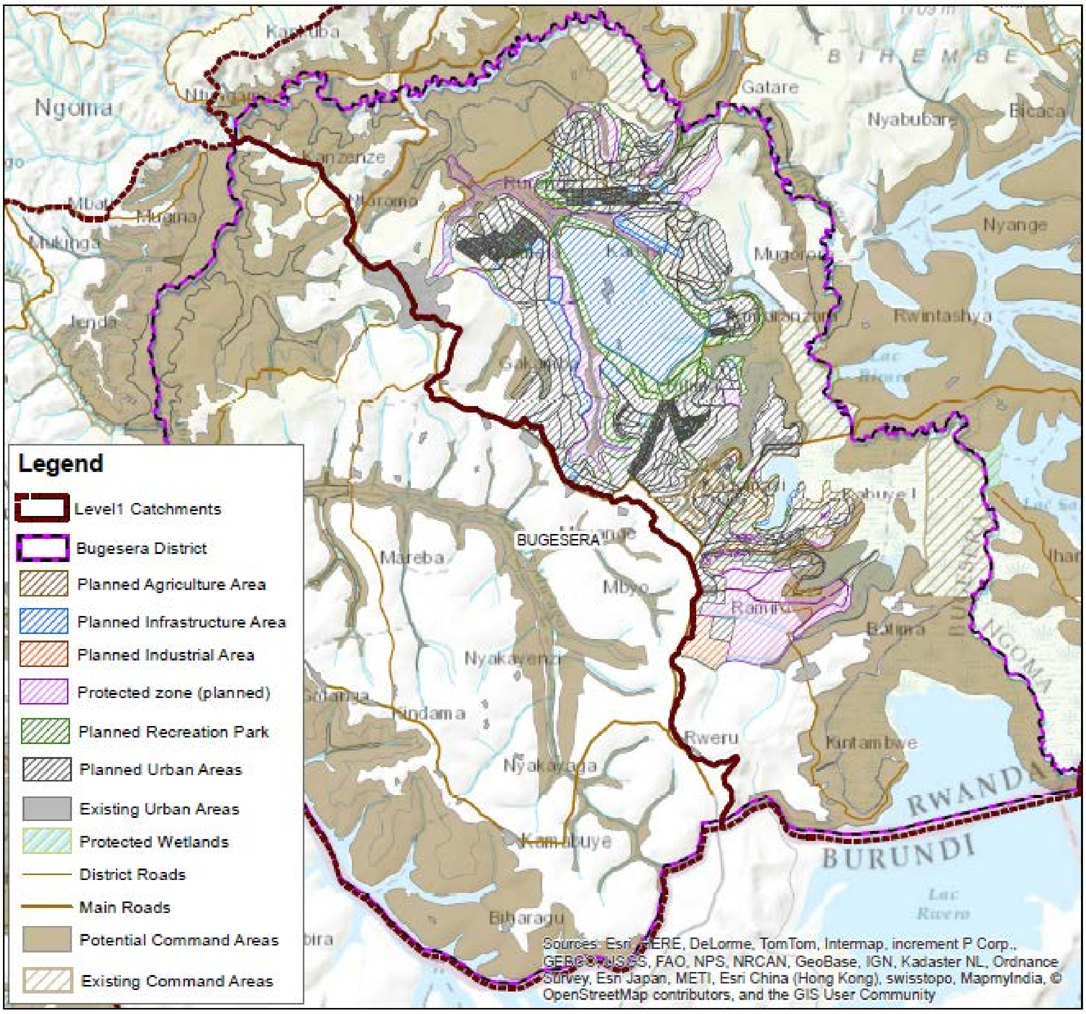


Figure 6-4: Bugesera District Land use data

6.5. Hydropower use

Water demand for hydropower should be considered in the analysis of the demands, however in most of the cases the consumptive water use for hydropower generation is negligible and sometimes the installation is supporting the water demand for irrigation downstream.

There are two types of hydropower installation:

The runoff river installation. This installation typically consists of a diversion of the surface flow with subsequent return of the diverted flow in the river bed at some downstream location. In this case there is no 'consumptive use' of water and the flow regime and water quality remains unaltered. In the same category falls the the hydropower plant installation at the outflow of a natural lake (for example Rusizi 1 and 2 powerplants).

The hydropower plant installation with an artificial storage. This type consists of a large facility i.e. dam, that will store the required water for the constant operation of the plant even in the dry periods. It is common that this type of plants is considered only at the main rivers where adequate quantities of water exist. Some of the issues for water resources downstream of the installation are:
o the newly created artificial lake will function as an evaporation plain thus reducing the annual flow downstream of the artificial lake;
o the newly created lake will absorb peak flows while energy demand may dictate increased flow during part of the day and year, hence the flow regime in the downstream river may alter in a significant manner;
Related to irrigation this type in most of the cases has a positive impact on the downstream potential command areas, since can provide constant water also during dry periods.

During planning of hydropower schemes the upstream water demands of the location of a hydropower, are always taken into consideration in order to estimate a secured power production. Furthermore, considering full utilization of the estimated demands for 2040, 50% of the available water in Nile basin main catchment still remains as river runoff, a quantity that can adequate support the operation of the hydropower schemes. Regarding the downstream uses, as indicated in several reports, including WRMP, hydropower installations are not characterized as consumptive water use, thus no impacts should be considered for the downstream water demands.

6.6. Results and Conclusions

The irrigation areas identified have been derived by checking and combining the above mentioned data in GIS format, producing the respective shape files with attribute tables, background information and all other useful data that needed to produce the maps include in Annex 2. The files are part of the submission. Specifically, for the irrigation areas, these are presented as closed polygons with the required information included in the attribute table that can be easily accessed by GIS software.

6.6.1. Rusizi Catchment (CRUS)

Basic Characteristics

The catchment is isolated by its remoteness from the center of Kigali. Accessibility of the catchment is very difficult especially as regards the eastern area on the fringes of the Nyungwe forest. Positive points are the navigation on Lake Kivu (Rusizi) and the accessibility of Bujumbura and Lake Tanganyika.

The area receives high rainfall (mean 1295mm/year) with a relatively short dry season. Rain fed agriculture shall remain the main activity of the catchment's agricultural production. The protection of the catchment's land resources with appropriate land-use (when needed by readjustment of land use), erosion protection by radical and bunch terraces and other protective measures must remain the focus for the future of the catchment.

The main surface flow is generated from two main tributaries Rubyiro (comprising Gishoma basin) and Ruhwa rivers. The Rusizi river forms the south border of the catchment and of Rwanda. Its sources are from Lake Kivu to the west side of the catchment and for that reason the quality of the water should be considered.

The outflow of the catchment is at the confluence of the Rusizi and Ruhwa Rivers where the three nations Rwanda, DRC and Burundi share their border.

Irrigation Potential Areas and Water Balance

Based on the WRMP the renewable resource of the catchment is 432Mm3 while the demand of all other uses except irrigation is taken to 36Mm3 annually (ref. chapter 2).

The irrigation demand of the catchment is estimated in the following table where the irrigation potential areas per category have been defined. The demand for the different categories is an average rate selected based on the Agronomy Assessment, considering irrigation demand and efficiency, of this report (chapter 3).

Table 6-4: CRUS-Irrigation Potential Areas

Categories	Area (ha)	Water demand (m3/ha/year)	Total water demand (Mm3/year)
SSIT Site	-	-	-
Dam Potential Site	167	5,000	0.84
Lake Potential Site (Zone 0 - 50 m)	-	-	-
Lake Potential Site (Zone 50 - 80 m)	-	-	-
Lake Potential Site (Zone 80 - 120 m)	-	-	-

Marshland Potential Site	-	-	-
Marshland Potential Site under Conditional use	260	8,000	2.08
River Potential Site (Zone 0 - 50 m)	-	-	-
River Potential Site (Zone 50 - 80 m)	-	-	-
River Potential Site (Zone 80 - 120 m)	-	-	-
Potential Sites under Design	-	-	-
Existing Schemes	2,840	8,000	22.72
Existing Schemes rainfed	600	2,500	1.50
Runoff for small reservoirs domain (4.13%)	2,143	3,000	6.43
Ground Water	3,000	6,000	18.00
Total:	**9,010**		**51.57**

The total demand estimated as 87.57Mm3 (51.57+36.00) per year is only a small percentage (20.3%) of the total available water, thus there is an excess water regarding the water balance on catchment level.

Irrigation characteristics

- The national Park of Nyungwe reserves a large part of the catchment, thus irrigation schemes can be developed only in the sub catchment of Rubyiro.
- The existing schemes are developed marshlands at the subcatchment of Rubyiro. Bugarama valley is the main area that agriculture activities are taking place. The catchment of the Bugarama valley is estimated to 1,756ha. According to WRMP the available water of this catchment is 4300m3/ha/year, resulting to 7.55Mm3/year, which cannot cover the demand of the existing scheme of 1840ha, in case of irrigating high water demanding crops. Water use from the Rusizi river, should be considered in order to enhance the area with the required water to cover all needs.
- The Gishoma marshland located at the southwest of the catchment, is currently under agriculture, even though the site has been characterized as full protected area by REMA, means that no activities are allowed.
- Rainfed organized schemes exist in this catchment. Due to high rainfall rates, rainfed schemes should be promoted further.
- A viable dam site in the upper reach of the Rubyiro river would be very valuable for irrigation development but also for flow regulation and sustaining dry season flow for irrigation in the Bugarama valley.
- The Rusizi river water alkalinity level, might be an obstacle while considering the utilization of it, since the source of the river is Lake Kivu. More information and details on alkalinity are given in the next paragraph 6.6.2.

Monthly Water Balance and irrigation potential

The above exercise is based on average annual values, but in order to estimate the scarcity of water during the dry period of Season C, an analysis on demand and water availability was conducted as it is presented in the following table.

Table 6-5: CRUS-Monthly Scarcity of water

Month	Available		Other Demands	Available for irrigation Mm3	Irrigation Demand		Scarcity of water
	432 Mm3		36 Mm3		51.57 Mm3		
Oct.	7.2%	31.0	3.0	28.0	4.08%	2.1	-
Nov.	8.9%	38.6	3.0	35.6	3.79%	2.0	-
Dec.	10.8%	46.4	3.0	43.4	8.10%	4.2	-
Jan.	8.0%	34.8	3.0	31.8	9.71%	5.0	-
Feb.	8.3%	35.7	3.0	32.7	8.54%	4.4	-
Mar.	9.6%	41.5	3.0	38.5	4.37%	2.3	-
Apr.	12.0%	51.7	3.0	48.7	1.75%	0.9	-
May	12.7%	55.0	3.0	52.0	6.99%	3.6	-
Jun.	7.4%	32.1	3.0	29.1	13.84%	7.1	-
Jul.	4.9%	21.2	3.0	18.2	15.50%	8.0	-
Aug.	4.9%	21.1	3.0	18.1	16.42%	8.5	-
Sep	5.3%	22.9	3.0	19.9	6.90%	3.6	-

6.6.2. Lake Kivu catchment (CKIV)

Basic Characteristics

The area, located at the west of the country, forms the border of Rwanda with the Republic of Kongo. The catchment is characterized by a numerous small catchment areas that drain into the lake Kivu.

The division with the next downstream catchment of CRUS is located at the first Rusizi Hydropower Plant (Rusizi I) which constitutes a clear separation between the lake and the Rusizi River.

There is an institutional framework for trans-boundary cooperation between Rwanda, Burundi and DRC for the protection and equitable and fair exploitation of the water resources based on the principles of Integrated Water Resources Management. The current analysis is based only on the amounts of water produced within the Rwanda territory.

A new catchment plan has been developed by Water for Growth Rwanda and RWFA for Sebeya subcatchment. The report presents updated information on demands while on irrigation is based on the proposed areas by the IMP. The results and recommendations for the subcatchment are considered for the below analysis, however, the contribution is small to the general results, due to the small size compare to the entire catchment (only 13.8%).

Irrigation Potential Areas and Water Balance

Based on the WRMP the renewable resource of the catchment is 898Mm3, while the demand of all other uses except irrigation, is estimated to 163Mm3 (ref. chapter 2).

The irrigation demand of the catchment is estimated in the following table where the irrigation potential areas per category have been defined. The demand for the different categories is an average rate selected based on the Agronomy Assessment, considering irrigation demand and efficiency, of this report (chapter 3).

Table 6-6: CKIV-Irrigation Potential Areas

Categories	**Area (ha)**	**Water demand (m3/ha/year)**	**Total water demand (Mm3/year)**
SSIT Site	-	-	-
Dam Potential Site	1,219	5,000	6.09
Lake Potential Site (Zone 0 - 50 m)	7,478	5,000	37.39
Lake Potential Site (Zone 50 - 80 m)	8,675	5,000	43.38
Lake Potential Site (Zone 80 - 120 m)	7,756	5,000	38.78
Marshland Potential Site	493	8,000	3.95
Marshland Potential Site under Conditional use	839	8,000	6.71
River Potential Site (Zone 0 - 50 m)	-	-	-
River Potential Site (Zone 50 - 80 m)	-	-	-
River Potential Site (Zone 80 - 120 m)	-	-	-
Potential Sites under Design	-	-	-
Existing Schemes	758	8,000	6.06
Existing Schemes rainfed	2,840	2,500	7.10
Runoff for small reservoirs domain (9.96%)	5,180	3,000	15.54
Ground Water	5,000	6,000	30.00
Total:	**40,238**		**195.00**

The total demand estimated as 358.00Mm3 per year is 39.9% of the total available water, thus there is an excess water regarding the water balance on catchment level.

Irrigation characteristics

- The main domain in this catchment that gives the larger irrigation potential is by using pumping from the Lake, 23,900ha. According to several previous reports, including WRMP, the salinity of water of Lake Kivu should be considered for suitability for irrigation. Further information on the salinity issue is given in the below paragraph.
- The area receives high rainfall (mean 1240mm/year) with a relatively short dry season. Rain fed agriculture shall remain the main activity of the catchment's agricultural production. The protection of the catchment's land resources with appropriate land-use (when needed by readjustment of land use), erosion protection by radical and bunch terraces and other protective measures must remain the focus for the future of the catchment.

Monthly Water Balance and irrigation potential

The above exercise is based on average annual values, but in order to estimate the scarcity of water during the dry period of Season C, an analysis on demand and water availability was conducted as it is presented in the following table.

Table 6-7: CKIV-Monthly Scarcity of water

Month	Available		Other Demands	Available for irrigation Mm3	Irrigation Demand		Scarcity of water
		898 Mm3	163 Mm3		195.00 Mm3		
Oct.	7.6%	68.2	13.6	54.6	4.08%	8.0	-
Nov.	7.8%	70.4	13.6	56.8	3.79%	7.4	-
Dec.	7.5%	67.2	13.6	53.6	8.10%	15.8	-
Jan.	7.1%	63.7	13.6	50.1	9.71%	18.9	-
Feb.	8.7%	77.7	13.6	64.1	8.54%	16.7	-
Mar.	8.6%	77.3	13.6	63.8	4.37%	8.5	-
Apr.	10.5%	94.1	13.6	80.5	1.75%	3.4	-
May	10.0%	89.4	13.6	75.8	6.99%	13.6	-
Jun.	8.2%	74.1	13.6	60.5	13.84%	27.0	-
Jul.	8.2%	73.6	13.6	60.0	15.50%	30.2	-
Aug.	8.3%	74.7	13.6	61.1	16.42%	32.0	-
Sep	7.5%	67.6	13.6	54.0	6.90%	13.5	-

Salinity of water

Identification of problem in irrigation

Water with high salinity is toxic to plants and poses a salinity hazard. Soils with high levels of total salinity are call saline soils. High concentrations of salt in the soil can result in a “physiological” drought condition. That is, even though the field appears to have plenty of moisture, the plants will be cause the roots are unable to absorb the water.

Sometimes even if the Irrigation water is only moderately saline, it might contains high concentrations of sodium ion levels which will cause symptoms similar to high salinity.

Measuring salinity

Water salinity is usually measured by the TDS (total dissolved solids) or the EC (electric conductivity). TDS is sometimes referred to as the total salinity and is measured or expressed in parts per million (ppm) or in the equivalent units of milligrams per liter (mg/L). Subscripts are used with the symbol EC to identify the source of the sample. EC_W is the electric conductivity of the irrigation water and EC_e the electric conductivity of the soil. The EC does not identify the dissolved salts, or the effects they have on crops and soil, but gives a fairly reliable measure of salinity problems.

EC is measured in milliSiemens per metre (mS/m). To convert mS/m to milliSiemens per centimetre (mS/cm), deciSiemens per metre (dS/m) or millimhos per centimetre (mmhos/cm), multiply by 0.01. To change mS/m to microSiemens per centimetre (µS/cm), multiply by 10.

To convert EC to TDS (milligrams per litre (mg/L) or parts per million (ppm)), multiply a measurement of EC by 640 if EC<5dS/m or by 800 if EC>5dS/m. These conversion figures are approximate and slightly different conversion figures may be used in some areas. The below table indicates a general classification of water regarding salinity.

Table 6-8: Classification of water regarding salinity and restriction to use

EC (dS/m)	Classification
< 0.8	Low salinity
0.8 – 2.7	Moderately Salty
2.7 – 5.0	Salty
> 5.0	Very Salty

EC (dS/m)	Restriction to use
< 1.0	None
1.0 – 2.7	Slight to Moderate
> 2.7	Severe

Levels of salinity

All plants do not respond to salinity in a similar manner; some crops can produce acceptable yields at much greater soil salinity than others. This is because some are better able to make the needed osmotic adjustments enabling them to extract more water from a saline soil. The ability of the crop to adjust to salinity is extremely useful. In areas where a build-up of soil salinity cannot be controlled at an acceptable concentration for the crop being grown, an alternative crop can be selected that is both more tolerant of the expected soil salinity and can produce economical yields. FAO - Water Quality for Agriculture Report, presents tables with a range of crops and how salinity affects yield production. The below figure indicates relative tolerance ratings. Based on this information can be derived that full yield potential should be obtainable for nearly all crops when using a water which has a salinity less than 0.7 dS/m.

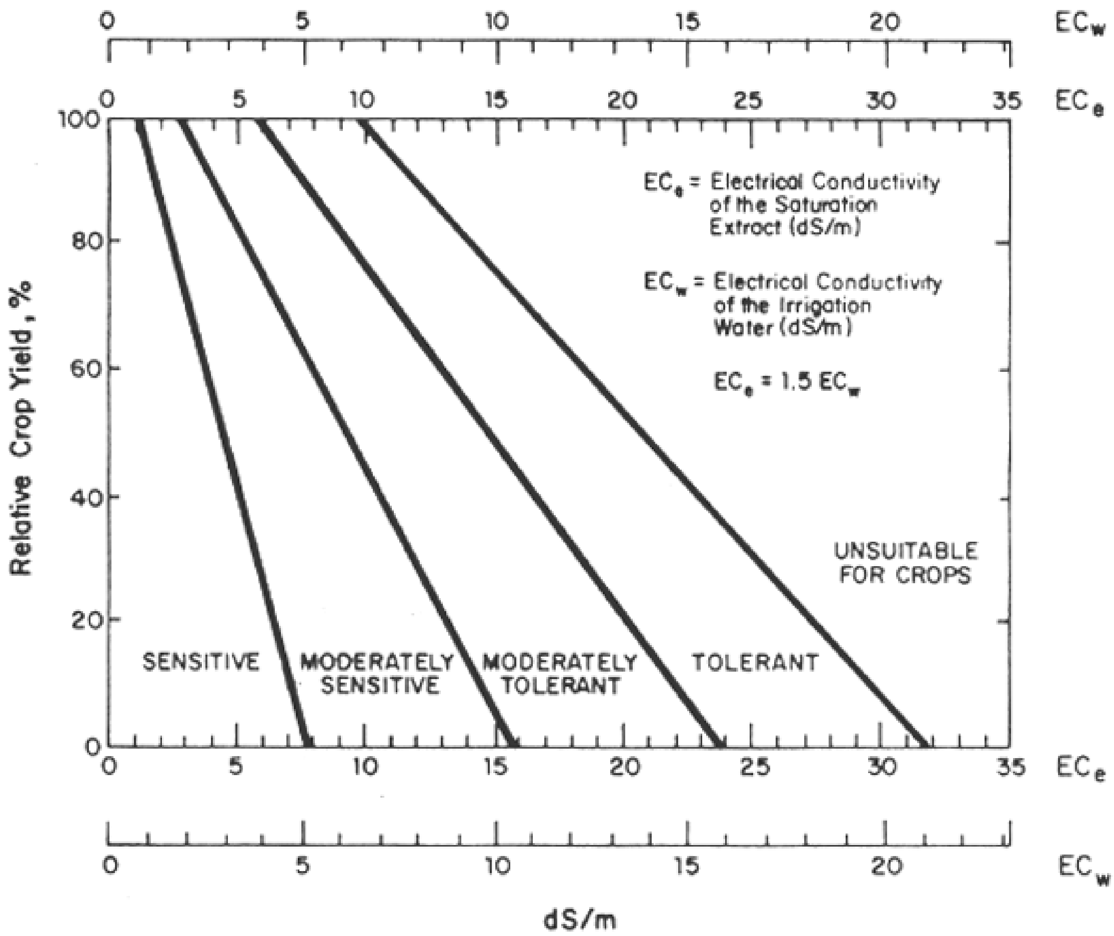


Figure 6-5: Divisions for relative salt tolerance ratings of agricultural crops

Water quality Data interpretation for 3 sampling sites around Kivu Lake

Available water quality measurements are in https://waterportal.rwfa.rw/data/water_quality. Two sites selected for Lake Kivu

a) Kivu Lake at 100m from Bralirwa, site WQ05

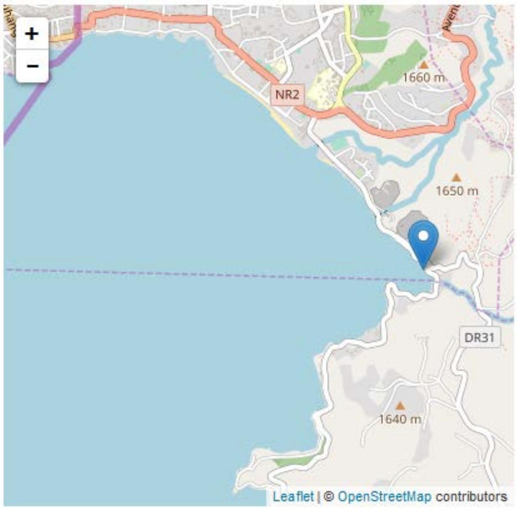
b) Kivu Lake at the beach (ex.Golf Hotel), site WQ20

This monitoring work is suggested to be done on regular basis (Annual) either dry or wet season.

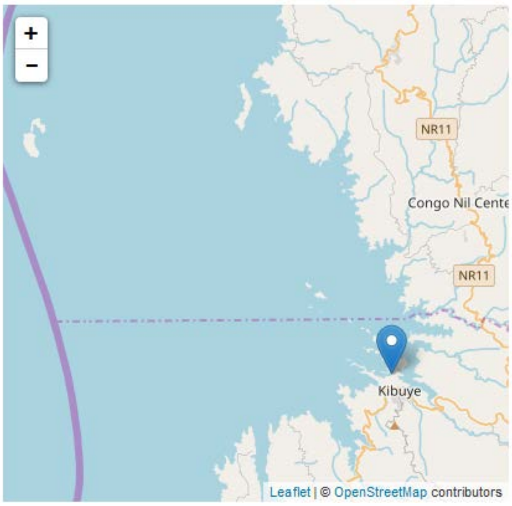
The following are the results

Table 6-9: Sampling for Salinity

Sampling Site	Date	TDS	Conductivity
WQ05	19-19-2016	745.00	1164.00
	04-05-2017	782.00	1221.00
WQ20	21-11-2016	740.00	1156.00
	28-05-2017	769.00	1201.00



at 100m from Bralirwa, site WQ05



at the beach (ex.Golf Hotel), site WQ20

The average value of conductivity for three sites is 1,185μs/cm. Based on the above, the water is characterized as moderately salty and can be used for irrigation, with very few or none restrictions, depending also on the selected crops.

In case is needed to reduce the affect of the salty water, the main management options are:

- Choose saline-resistant crops in new plantings
- A layer of mulch under the crop helps to reduce surface evaporation, maintains moisture near the soil surface and lessens the build-up of soil salinity.
- Apply extra water to leach salts below the rootzone
- All fertilizers have a salt index which indicates what the fertilizer contributes to soil salinity. Thus, in case of salty water, fertilizers with similar nutrients but with a lower salt index shall be selected.
- Desalinisation for saline waters is technically possible, but its use is limited by cost (initial capital cost of the equipment, and high operation and maintenance costs) and the problem of disposing of the residual saline concentrate. In this case of Lake Kivu, with the low levels of salinity, desalinization is not recommended in any case.

6.6.3. Mukungwa catchment (NMUK)

Basic Characteristics

This catchment contains the volcanic lava region in the North-West and drains in a southerly direction.

A large wetland (Rugezi marshland) draining subsequently in Lake Bulera and then into Lake Ruhondo from which outflow originates the Mukungwa River, that flows in a southern direction to its confluence with the Nyabarongo river.

There is substantial hydropower energy generation along this series (Ntaruka and Mukungwa hydropower stations) which was reduced during the mid-2000s presumably by climate factors and development works in the Rugezi marshland.

Rugezi marshland at the east of the catchment with a size of 6,376ha, is one of the major features of the catchment, characterized as fully protected area by the respective authorities.

Irrigation Potential Areas and Water Balance

Based on the WRMP the renewable resource of the catchment is 905Mm3, while the demand of all other uses except irrigation, is estimated to 139Mm3 (ref. chapter 2).

The irrigation demand of the catchment is estimated in the following table where the irrigation potential areas per category have been defined. The demand for the different categories is an average rate selected based on the Agronomy Assessment, considering irrigation demand and efficiency, of this report (chapter 3).

Table 6-10: NMUK-Irrigation Potential Areas

Categories	Area (ha)	Water demand (m3/ha/year)	Total water demand (Mm3/year)
SSIT Site	-	-	-
Dam Potential Site	172	5,000	0.86
Lake Potential Site (Zone 0 - 50 m)	-	-	-
Lake Potential Site (Zone 50 - 80 m)	-	-	-
Lake Potential Site (Zone 80 - 120 m)	-	-	-
Marshland Potential Site	1,367	8,000	10.94
Marshland Potential Site under Conditional use	1,908	8,000	15.26
River Potential Site (Zone 0 - 50 m)	-	-	-
River Potential Site (Zone 50 - 80 m)	-	-	-
River Potential Site (Zone 80 - 120 m)	-	-	-
Potential Sites under Design	-	-	-
Existing Schemes	1,711	8,000	13.69
Existing Schemes rainfed	1,412	2,500	3.53
Runoff for small reservoirs domain (8.01%)	3,877	3,000	11.63
Ground Water	5,000	6,200	31.00
Total:	**15,735**		**87.77**

The total demand estimated as 226.77Mm3 /per year is 25.1% of the total available water, thus there is an excess water regarding the water balance on catchment level.

Irrigation characteristics

- The total estimated water demand of the catchment is ~227Mm3, which is only a small part of the total renewable resource of the catchment. The remaining water (~700Mm3) it is transferred to Nyabarongo river through the main river of the catchment Mukungwa

River. This excess water can be considered for use at the downstream areas of Nyabarongo.

- Due to the location of the catchment the area receives high rainfall (mean 1315mm/year). Rain fed agriculture shall remain the main activity of the catchment's agricultural production. The protection of the catchment's land resources with appropriate land-use (when needed by readjustment of land use), erosion protection by radical and bunch terraces and other protective measures must remain the focus for the future of the catchment.

Monthly Water Balance and irrigation potential

The above exercise is based on average annual values, but in order to estimate the scarcity of water during the dry period of Season C, an analysis on demand and water availability was conducted as it is presented in the following table.

Table 6-11: NMUK-Monthly Scarcity of water

Month	Available		Other Demands	Available for irrigation Mm3	Irrigation Demand		Scarcity of water
		905 Mm3	139 Mm3			87.77 Mm3	
Oct.	7.9%	71.6	11.6	60.0	4.1%	3.6	-
Nov.	9.6%	87.1	11.6	75.5	3.8%	3.3	-
Dec.	9.0%	81.6	11.6	70.0	8.1%	7.1	-
Jan.	7.1%	64.6	11.6	53.0	9.7%	8.5	-
Feb.	7.5%	67.8	11.6	56.2	8.5%	7.5	-
Mar.	7.4%	67.2	11.6	55.6	4.4%	3.8	-
Apr.	10.3%	93.1	11.6	81.5	1.7%	1.5	-
May	11.5%	103.7	11.6	92.1	7.0%	6.1	-
Jun.	8.7%	78.8	11.6	67.2	13.8%	12.1	-
Jul.	7.0%	63.7	11.6	52.1	15.5%	13.6	-
Aug.	6.7%	60.9	11.6	49.4	16.4%	14.4	-
Sep	7.2%	64.9	11.6	53.3	6.9%	6.1	-

6.6.4. Nyabarongo Upper catchment (NNYU)

Basic Characteristics

This is an elongated catchment area sloping down from south to north with three main tributaries and the upper Nyabarongo River itself.

Mwogo River which originates in the south eastern corner of the catchment and becomes the Nyabarongo at its confluence with the Mbirurume River;

Rukarara River which originates in the south west in the Nyungwe forest reserve. It features substantial potential for micro hydropower development. It falls in the Mwogo River at its downstream end;

Mbirurume River which also originates at high altitude near the Nyungwe forest reserve north of the source of the Rukarara River. It also has good potential for micro hydropower development. At the confluence of the Mbirurume river with the Mwogo river the name of the river changes to Nyabarongo;

The discharge from the three tributaries then flows north through the Nyabarongo river.

The MoE produced a catchment management plan[121] for Upper Nyabarongo as a planning tool to prioritize and address the matters directly linked to water management such as catchment restoration, maximum water availability and equitable water allocation to all water users within the catchment. The plan has also updated the water demands and the availability of water, coming with new figures that should be used, instead of using figures from WRMP.

Irrigation Potential Areas and Water Balance

Based on the Upper Nyabarongo Plan (2018) the renewable resource of the catchment is 1,407Mm3, while the demand of all other uses except irrigation, is estimated to 287Mm3 annually.

The irrigation demand of the catchment is estimated in the following table where the irrigation potential areas per category have been defined. The demand for the different categories is an average rate selected based on the Agronomy Assessment, considering irrigation demand and efficiency, of this report (chapter 3).

Table 6-12: NNYU-Irrigation Potential Areas

Categories	Area (ha)	Water demand (m3/ha/year)	Total water demand (Mm3/year)
SSIT Site	3,636	5,000	18.18
Dam Potential Site	2,622	5,000	13.11
Lake Potential Site (Zone 0 - 50 m)	-	-	-
Lake Potential Site (Zone 50 - 80 m)	-	-	-
Lake Potential Site (Zone 80 - 120 m)	-	-	-
Marshland Potential Site	1,175	8,000	9.40
Marshland Potential Site under Conditional use	5,245	8,000	41.96
River Potential Site (Zone 0 – 50 m)	3,249	5,000	16.25
River Potential Site (Zone 50 - 80 m)	2,398	5,000	11.99
River Potential Site (Zone 80 - 120 m)	3,141	5,000	15.70

[121] *Upper Nyabarongo Catchment Management Plan 2018-2024, MoE, 2018*

Potential Sites under Design	3,466	5,000	17.34
Existing Schemes	3,417	7,000	23.92
Existing Schemes rainfed	190	2,500	0.47
Runoff for small reservoirs domain (13.76%)	7,155	3,000	21.47
Ground Water	7,000	7,000	49.00
Total:	**42,697**		**238.79**

The total demand estimated as 525.87Mm3 per year is 37.4% of the total available water, thus there is an excess water regarding the water balance on catchment level.

Irrigation characteristics

- Due to the morphology of the catchment there is a large potential of dam construction, but since the catchment receives adequate amount of water (1,365mm/year), the cost of implementing dam projects is considered high, however, storage of water in order to enhance the irrigation schemes and support the production during dry season, should also be considered.
- Most of the existing schemes are developed marshlands, resulting to a total existing irrigated area of 3,417ha. The additional marshland potential of this catchment is estimated to 6,420ha, while of that 5,245ha can be only developed under specific conditions.
- Another domain that should be considered to be explored further, is the irrigation development by pumping water from Nyabarongo river. The potential of this domain is estimated to reach approximately 9,000ha. The water quantities of the river can cover without any restrictions the available areas.
- The total estimated water demand of the catchment results to 525.87Mm3, which is only a small part of the total renewable resource of the catchment. The remaining water (~900Mm3) it is transferred to Nyabarongo river lower catchment.
- There is only a small organized scheme identified as rainfed irrigation scheme at the southwest part of the catchment. Most of the other existing schemes are developed marshlands.

Monthly Water Balance and irrigation potential

The above exercise is based on average annual values, but in order to estimate the scarcity of water during the dry period of Season C, an analysis on demand and water availability was conducted as it is presented in the following table.

Table 6-13: NNYU-Monthly Scarcity of water

Month	Available		Other Demands	Available for irrigation Mm3	Irrigation Demand		Scarcity of water
	1,290 Mm3		166 Mm3		237.31 Mm3		
Oct.	7.2%	101.6	20.8	80.8	0.0%	0.0	-
Nov.	7.8%	109.2	22.3	86.9	0.0%	0.0	-
Dec.	9.1%	128.0	26.1	101.9	20.5%	48.9	-
Jan.	8.8%	123.3	25.1	98.1	17.5%	41.8	-
Feb.	9.5%	134.0	27.2	106.7	2.6%	6.1	-
Mar.	9.8%	137.3	27.9	109.4	0.0%	0.1	-
Apr.	10.2%	144.1	29.3	114.8	0.0%	0.0	-
May	9.6%	134.4	27.4	107.1	0.5%	1.2	-
Jun.	7.8%	109.4	22.3	87.0	16.5%	39.4	-
Jul.	7.0%	98.1	20.1	78.0	25.3%	60.5	-
Aug.	6.6%	93.0	19.1	73.9	16.2%	38.7	-
Sep	6.8%	95.1	19.5	75.6	0.9%	2.2	-

6.6.5. Nyabarongo Lower catchment (NNYL)

Basic Characteristics

This catchment receives the inflow from the upper Nyabarongo and the Mukungwa and conveys it in a south easterly direction.

Nyabarongo River drains the entire western part of the catchment through a number of small and rather steep secondary valleys. The wide valley of the Nyabarongo is extensively used for agricultural production.

Nyabugogo River drains the entire eastern part of the catchment partly through the Muhazi Lake which functions as a flood buffer. The Nyabugogo valley is extensively used for agricultural production throughout the year.

In Muhazi Lake there is limited agricultural use of the water resource along the lake shores, due to the 50m lake band restrictions.

The urban centre of Kigali is located within this catchment, with substantial demand for domestic and industrial water supply mainly provided through groundwater abstraction at several locations in the Nyabarongo valley. The industrial activities and the high population density within the Kigali urban area are having an impact on surface and groundwater quality;

Notwithstanding the buffer function provided by Lake Muhazi, the Nyabugogo is very prone to flooding with frequent and major problems in the vicinity of Kigali where urban expansion and natural flooding of the valley bottom are difficult to reconcile.

The total surface area of the Nyabugogo catchment is 1,661 km² which represents almost 50% of the entire catchment. The Nyabugogo catchment is considered as the most densely populated catchment of Rwanda.

The MoE produced a catchment management plan[122] for Nyabugogo as a planning tool to prioritize and address the matters directly linked to water management such as catchment restoration, maximum water availability and equitable water allocation to all water users within the catchment. The plan has also updated the water demands of the respective catchment.

According to the plan's new analysis the demand can reach up to 378Mm3 for the catchment, figure that it is in line with the respective figures of WRMP, which is 607Mm3 for the entire NNYL catchment. The high demand in the sub catchment showa a clear need for sustainable land management, enhanced efficiency in water use in all sectors and that the total potential of irrigation schemes is feasible only under specific conditions. This is in line with the below analysis, which includes the entire catchment and the Nyabugogo sub catchment which forms the major part of it.

Irrigation Potential Areas and Water Balance

Based on the WRMP the renewable resource of the catchment is 899Mm3, while the demand of all other uses except irrigation, is estimated to 239Mm3 annually (ref chapter 2).

The irrigation demand of the catchment is estimated in the following table where the irrigation potential areas per category have been defined. The demand for the different categories is an average rate selected based on the Agronomy Assessment, considering irrigation demand and efficiency, of this report (chapter 3).

Table 6-14: NNYL-Irrigation Potential Areas

Categories	Area (ha)	Water demand (m3/ha/year)	Total water demand (Mm3/year)
SSIT Site	871	5,000	4.36
Dam Potential Site	1,283	6,000	7.70
Lake Potential Site (Zone 0 - 50 m)	13,029	6,000	78.17
Lake Potential Site (Zone 50 - 80 m)	8,421	6,000	50.53
Lake Potential Site (Zone 80 - 120 m)	6,922	6,000	41.53
Marshland Potential Site	1,374	8,000	11.00
Marshland Potential Site under Conditional use	5,292	8,000	42.34
River Potential Site (Zone 0 - 50 m)	1,536	6,000	9.22
River Potential Site (Zone 50 - 80 m)	1,280	6,000	7.68
River Potential Site (Zone 80 - 120 m)	1,023	6,000	6.14
Potential Sites under Design	11,448	6,000	68.69

[122] *Nyabugogo Catchment Management Plan 2018-2024, MoE, 2018*

Existing Schemes	5,211	7,000	36.48
Existing Schemes rainfed	-	-	-
Runoff for small reservoirs domain (13.57%)	7,056	3,000	21.17
Ground Water	4,000	6,750	27.00
Total:	**68,746**		**411.98**

The total demand for irrigation is estimated to 411.98Mm3 per year and the total water demand, considering other uses, is 650.98Mm3.

Irrigation characteristics

- The Nyabugogo catchment is part of the Nile basin and a tributary of the lower Nyabarongo River. It is rather centrally located with a wedge extending into the eastern and dryer part of Rwanda. The Nyabugogo River has a length of 46 km from the outflow of Lake Muhazi to its confluence with the Lower Nyabarongo River, in the vicinity of Kigali. A smaller part of the catchment forms the Muhazi lake catchment. The Lake Muhazi winds over a length of about 80 km from East to West, as a central feature of the catchment. It drains approximately 55% of the entire catchment and is spread out over five different districts. It is situated at 1,444m above mean average sea level (masl) and it is 37 km long with an average width of circa 0.6 km, and a maximum width of 2 km. It occupies the floor of a system of valleys, with 13 narrow branches. The lake water level varies between seasons by a magnitude of circa 50 to 70cm. The landscape of the catchment is characterized by small fragmented holdings on mountainous terrain in the high-altitude areas in the western highlands.

  The greater area has a great potential for irrigation, approximately 33,000ha, with 28,000ha calculated to be served by pumping from the lake. The estimated available sources from the lake are in the order of 248Mm3/year (2720m3/ha/year x 166,200ha x 55%), figure that is almost similar of the irrigation potential demand of 242Mm3/year. The lake is also operating as storage of water, which means that irrigation can also take place during dry season C.

Table 6-15: Lake Muhazi-Irrigation Potential Areas

Categories	Area (ha)	Water demand (m3/ha/year)	Total water demand (Mm3/year)
SSIT Site	458	5,000	2.29
Dam Potential Site	460	6,000	2.76
Lake Potential Site (Zone 0 - 50 m)	13,029	6,000	78.17
Lake Potential Site (Zone 50 - 80 m)	8,421	6,000	50.53
Lake Potential Site (Zone 80 - 120 m)	6,922	6,000	41.53
Marshland Potential Site	257	8,000	2.06
Marshland Potential Site under Conditional use	1,240	8,000	9.92
Potential Sites under Design	406	6,000	2.44
Existing Schemes	172	7,000	1.20
Runoff for small reservoirs domain (13.57%*28%)	1,839	3,000	5.52
Ground Water	2,000	6,750	13.50
Total:	**35,202**		**209.90**

In the calculation, the demands of other uses should also be added (estimated as 237Mcm x 3,304Km2/914Km2 = 65.56Mm3), which results to 275.46Mm3, more than the capacity of the Lake's catchment to cover the demands. In the case of development of the area, the agriculture of less water demanding crops and the use of more efficient technologies in order to reduce losses and the water demand per hectare, should be considered. This is in line with the new Plan of Nyabugogo catchment and the proposal for an efficient use of the water resources.

Table 6-16: Lake Muhazi-Irrigation Potential Areas with reduced IWR per hectare

Categories	**Area (ha)**	**Water demand (m3/ha/year)**	**Total water demand (Mm3/year)**
SSIT Site	458	4,000	1.83
Dam Potential Site	460	4,500	2.07
Lake Potential Site (Zone 0 - 80 m)	13,029	4,500	58.63
Lake Potential Site (Zone 0 - 80 m)	8,421	4,500	37.89
Lake Potential Site (Zone 80 - 120 m)	6,922	4,500	31.14
Marshland Potential Site	257	7,000	1.80
Marshland Potential Site under Conditional use	1,240	7,000	8.68
Potential Sites under Design	406	4,500	1.83
Existing Schemes	172	5,000	0.86
Runoff for small reservoirs domain (13.57%*28%)	1,839	4,000	5.52
Ground Water	2,000	6,750	13.50
Total:	**35,202**		**163.75**

A recent assessment of the availability of water of Muhazi Lake was completed, during the study of a new Muhazi dyke (study completed on March 2019). The result of the study is that the available water for irrigation is 109Mm3 for irrigation water, based on demand projections of 2040, which makes the use and implementation of efficient systems to reduce the demand of water, a necessity.

The above follows the proposals of Nyabugogo Catchment in which the analysis shows that based on demands, irrigations schemes can be developed in full in sub-catchments with abundant water resources. Conversely, in sub-catchments with lower overall resource, or more competing users, development of new irrigation schemes will have to be restricted. Optimum water-based economic development and food security can be combined with meeting the needs for domestic, livestock and industrial users, as well as the environment. In situations of extreme water scarcity, i.e. in dry years, the volume of water allocated to irrigation would have to be further reduced if all other users were also to still receive some allocation. Under such circumstances, RAB and WRMD would need to jointly adjust allocations to irrigation systems and promote uptake of extra water saving technologies and further adjust cropping patterns in each season, e.g. by shutting down compartments of irrigation schemes, or by planting crops with higher drought tolerance. Timely seasonal forecasts by RMA are needed to allow for timely preparations.

- Marshland irrigation is quite developed in the areas where Nyabarongo river lies. These areas are prone to flooding from the excess amount of water running through Nyabarongo, estimated as 200Mm3, which is the amount of water remaining after covering all projected demands of the NNYL catchment. In this amount the quantities from the upstream catchments of NMUK and NNYU should be added (~1,600Mm3), resulting to 1,800Mm3 unexploited water.
- Many projects have been already identified, as dam projects or river pumping projects. The total area of this category is 11,448ha. The existing organized schemes are 5,211ha, while the majority of them are marshland developments.
- The average rainfall of the catchment is 1,191mm/year, which brings this catchment to the second position of priority regarding irrigation, but due to proximity with Kigali town, market is available and transportation of production is easier, thus the development of the catchment to the extent possible should be considered.

Monthly Water Balance and irrigation potential

The above exercise is based on average annual values, but in order to estimate the scarcity of water during the dry period of Season C, an analysis on demand and water availability was conducted as it is presented in the following table.

Table 6-17: NNYL-Monthly Scarcity of water

Month	Available		Other Demands	Available for irrigation Mm3	Irrigation Demand		Scarcity of water
		899 Mm3	237 Mm3			411.98 Mm3	
Oct.	7.0%	63.3	19.8	43.5	5.4%	22.4	-
Nov.	8.9%	79.9	19.8	60.1	8.3%	34.0	-
Dec.	8.6%	77.2	19.8	57.5	6.6%	27.0	-
Jan.	7.7%	69.1	19.8	49.3	10.6%	43.8	-
Feb.	8.3%	74.3	19.8	54.5	1.6%	6.6	-
Mar.	8.7%	77.9	19.8	58.2	1.8%	7.4	-
Apr.	12.2%	109.7	19.8	89.9	0.1%	0.3	-
May	12.2%	110.1	19.8	90.3	1.9%	7.8	-
Jun.	7.9%	70.8	19.8	51.0	15.3%	63.1	12.1
Jul.	6.3%	57.1	19.8	37.3	24.0%	98.7	61.4
Aug.	5.8%	52.6	19.8	32.8	14.5%	59.8	26.9
Sep	6.4%	57.2	19.8	37.5	10.0%	41.2	3.7

The above table proves the scarcity of water during the dry period and the months from June to September. This scarcity can only be addressed by implementation of water storage infrastructures but also it is important to focus on the areas of Nyabarongo river, where the volume of water coming from the above catchments is sufficient.

6.6.6. Akanyaru catchment (NAKN)

Basic Characteristics

This catchment takes its source high in the Nyungwe Forest in south-western Rwanda from where it follows a steep slope along the Rwanda – Burundi border in an easterly direction. Upon reaching the south central area, the Akanyaru river changes dramatically from a rather steep mountain stream into a river meandering in a very flat and wide valley and turning north along the border to enter into Rwanda about 30 km prior to its confluence with the Nyabarongo.

The Akanyaru valley is wide and inundated for at least several months per year over its entire length of about 90 km. The entire valley is extensively used for mostly traditional agricultural production. The affluent valleys of the Akanyaru River (on either side of the border) are also typically flat and wide and are extensively used for traditional agriculture.

Another feature of the catchment is the Cyohoha south lake, with the larger part of the respective catchment to be located in Burundi.

The outflow of the catchment is at its confluence with the lower Nyabarongo from where the Nyabarongo and Akanyaru continue as the Akagera River.

Irrigation Potential Areas and Water Balance

Based on the WRMP the renewable resource of the catchment is 798Mm3, while the demand of all other uses except irrigation, is estimated to 171Mm3 annually (ref chapter 2).

The irrigation demand of the catchment is estimated in the following table where the irrigation potential areas per category have been defined. The demand for the different categories is an average rate selected based on the Agronomy Assessment, considering irrigation demand and efficiency, of this report (chapter 3).

Table 6-18: NAKN-Irrigation Potential Areas

Categories	Area (ha)	Water demand (m3/ha/year)	Total water demand (Mm3/year)
SSIT Site	11,165	5,000	55.82
Dam Potential Site	2,781	6,000	16.68
Lake Potential Site (Zone 0 - 50 m)	4,034	6,000	24.20
Lake Potential Site (Zone 50 - 80 m)	2,828	6,000	16.97
Lake Potential Site (Zone 80 - 120 m)	2,262	6,000	13.57
Marshland Potential Site	2,313	9,000	20.82
Marshland Potential Site under Conditional use	11,795	9,000	106.15
River Potential Site (Zone 0 - 50 m)	11,979	6,000	71.87
River Potential Site (Zone 50 - 80 m)	7,743	6,000	46.46
River Potential Site (Zone 80 - 120 m)	5,284	6,000	31.70
Potential Sites under Design	15,195	6,000	91.17
Existing Schemes	6,888	7,000	48.21
Existing Schemes rainfed	547	2,500	1.37
Runoff for small reservoirs domain (13.98%)	7,270	3,000	21.81
Ground Water	5,500	7,000	38.50
Total:	**97,584**		**605.32**

The total demand estimated is 605.32Mm3 per year, therefore with the additional demand of other uses, the total demand is 776.32Mm3, almost equal to the available of the catchment.

Irrigation characteristics

- The average rainfall of the catchment is 1,225mm/year, but it is evident that the catchment faces problems to secure the required flow and support the demand for irrigation.
- The existing organized schemes identified are 7,435ha, while the majority of them are marshland developments.
- Many projects have been already identified, as dam projects or river pumping projects. The total area is estimated to 15,195ha.
- The development of the area should consider the use of less water demanding crops, efficient technologies to reduce losses and construction of storage facilities to improve water scarcity during dry season.
- Effort should be given to explore and support the implementation of the SSIT technologies in the areas identified.
- The larger potential is by the use of pumping from Akanyaru river (25,006ha), which is the most secure source in this catchment
- An area of 9,125ha has been identified as a potential for irrigation by pumping from the Lake. The catchment's size of the lake within Rwanda is 39,534ha, providing 2350m3/ha/year. The total amount for exploitation is 92.90Mm3, while the demand 54.75Mcm, which proves that the lake can cover the irrigation demand of the area, even

considering that the catchment should also cover other demands. The capacity of storage of water of the lake should be investigated.

Monthly Water Balance and irrigation potential

The above exercise is based on average annual values, but in order to estimate the scarcity of water during the dry period of Season C, an analysis on demand and water availability was conducted as it is presented in the following table.

Table 6-19: NAKN-Monthly Scarcity of water

Month	Available		Other Demands	Available for irrigation Mm3	Irrigation Demand		Scarcity of water
	798 Mm3		171 Mm3		605.32 Mm3		
Oct.	7.0%	55.6	14.3	41.3	5.4%	33.0	-
Nov.	8.6%	68.9	14.3	54.7	8.3%	50.0	-
Dec.	9.0%	71.9	14.3	57.7	6.6%	39.7	-
Jan.	8.4%	67.1	14.3	52.9	10.6%	64.3	11.4
Feb.	8.2%	65.7	14.3	51.5	1.6%	9.7	-
Mar.	9.7%	77.2	14.3	62.9	1.8%	10.8	-
Apr.	13.2%	105.0	14.3	90.8	0.1%	0.5	-
May	12.6%	100.5	14.3	86.3	1.9%	11.4	-
Jun.	7.1%	56.5	14.3	42.3	15.3%	92.7	50.4
Jul.	5.4%	43.3	14.3	29.1	24.0%	145.0	115.9
Aug.	5.2%	41.6	14.3	27.4	14.5%	87.8	60.4
Sep	5.6%	44.6	14.3	30.3	10.0%	60.5	30.2

The above table proves the scarcity of water especially during the dry period and the months from June to September. This scarcity can only be addressed by implementation of water storage infrastructures but also it is important to focus on the areas of Akanyaru river, where the volume of water is sufficient.

6.6.7. Akagera Upper catchment (NAKU)

Basic Characteristics

This catchment is the continuation of the Nyabarongo and Akanyaru rivers. The upper Akagera River flows through a wide and extremely flat valley in a south easterly direction until it reaches the border between Rwanda and Burundi where it takes an easterly course until reaching the Rusumo falls.

The entire reach of the upper Akagera crosses a series of lakes (of which Lake Mugesera, Lake Sake, Lake Rweru are the largest) that function as buffer zones hence according to the WRMP flow may occur either in the direction from lake to the Akagera or vise versa;

Downstream of its confluence with Lake Rweru, the Akagera River forms the boundary between Rwanda and Burundi and then between Rwanda and Tanzania. The confluence with the Ruvubu River, at the end point of the catchment, entering from Tanzania just upstream of the

Rusumo Falls, of about equal importance as the Akagera, is almost doubling the discharge that continues in NAKL catchment. The Rusumo Falls mark the end of the catchment and the transition to the Lower Akagera River.

Irrigation Potential Areas and Water Balance

Based on the WRMP the renewable resource of the catchment is 504Mm3, while the demand of all other uses except irrigation, is estimated to 130Mm3 annually (ref chapter 2).

The irrigation demand of the catchment is estimated in the following table where the irrigation potential areas per category have been defined. The demand for the different categories is an average rate selected based on the Agronomy Assessment, considering irrigation demand and efficiency, of this report (chapter 3).

Table 6-20: NAKU-Irrigation Potential Areas

Categories	Area (ha)	Water demand (m3/ha/year)	Total water demand (Mm3/year)
SSIT Site	7,750	6,000	46.50
Dam Potential Site	894	6,000	5.36
Lake Potential Site (Zone 0 - 50 m)	14,402	6,000	86.41
Lake Potential Site (Zone 50 - 80 m)	8,457	6,000	50.74
Lake Potential Site (Zone 80 - 120 m)	1,254	6,000	7.52
Marshland Potential Site	7,517	8,500	63.90
Marshland Potential Site under Conditional use	12,914	8,500	109.77
River Potential Site (Zone 0 - 50 m)	8,159	6,000	48.95
River Potential Site (Zone 50 - 80 m)	5,843	6,000	35.06
River Potential Site (Zone 80 - 120 m)	2,139	6,000	12.83
Potential Sites under Design	9,553	6,000	57.32
Existing Schemes	7,880	7,000	55.16
Existing Schemes rainfed	-	-	-
Runoff for small reservoirs domain (12.54%)	6,521	3,000	19.56
Ground Water	2,500	7,200	18.00
Total:	**95,783**		**617.10**

The total demand estimated is 617.10Mm3 per year, therefore with the additional demand of other uses, the total demand is ~747Mm3, more than the available of the catchment.

Irrigation characteristics

- The average rainfall of the catchment is 925mm/year and it is evident that the catchment itself cannot secure the required amounts of water to cover the extensive demand, especially for irrigation with a total potential of ~95,000ha.
- The use of external sources should be explored in order to minimize the scarcity. As it was described in the above paragraphs, there is an excess amount of water from NNYU and NMUK catchments, in the order of 1,600Mm3, that flows through Nyabarongo river. This amount of water can be utilized to support the needs of this specific catchment, especially by supporting the schemes developed in the areas of the river and the connected lakes.

River, Lake and marshland (in the vicinity of Nyabarongo river) potential is approximately 50,000ha. These are the areas that should use the water from the river, in order the amount of water produced by the catchment to be used to cover the other needs.

- There is an urban development at the western part of the catchment, including the construction of the new airport, thus the area for irrigation in this part has been reduced.
- The lakes, especially Mugesera lake, are very swallow, but since they are connected with the river flow, the development of the area should consider the construction of adequate infrastructures, in order the river to support with flow the lakes whenever is needed.
- The area along the river, facing flooding problems frequently. There is a plan to construct two dams for hydropower production in the two main rivers of Nyabarongo and Akanyaru. The reservoirs of the dams and especially the reservoir at Nyabarongo which contains the larger flow, will protect the downstream areas from flooding, operating as regulating reservoirs. Without the construction of the dams or at least the dam at Nyabarongo, the development of the marshlands in the vicinity of the river shall be a challenge.

Monthly Water Balance and irrigation potential

The above exercise is based on average annual values, but in order to estimate the scarcity of water during the dry period of Season C, an analysis on demand and water availability was conducted as it is presented in the following table.

Table 6-21: NAKU-Monthly Scarcity of water

Month	Available		Other Demands	Available for irrigation Mm3	Irrigation Demand		Scarcity of water
	504 Mm3		199 Mm3		617.10 Mm3		
Oct.	7.2%	36.2	16.6	19.6	5.4%	33.6	14.0
Nov.	8.6%	43.4	16.6	26.8	8.3%	51.0	24.1
Dec.	9.0%	45.6	16.6	29.0	6.6%	40.4	11.4
Jan.	8.8%	44.3	16.6	27.7	10.6%	65.6	37.8
Feb.	8.9%	45.0	16.6	28.5	1.6%	9.9	-
Mar.	9.1%	45.6	16.6	29.0	1.8%	11.0	-
Apr.	10.1%	50.8	16.6	34.2	0.1%	0.5	-
May	10.7%	54.0	16.6	37.4	1.9%	11.7	-
Jun.	9.1%	46.1	16.6	29.5	15.3%	94.5	65.0
Jul.	6.8%	34.2	16.6	17.6	24.0%	147.8	130.2
Aug.	5.4%	27.3	16.6	10.7	14.5%	89.5	78.8
Sep	6.2%	31.4	16.6	14.9	10.0%	61.7	46.8

The above table proves the scarcity of water during the dry period C and period A and the months from June to September and October to January. This scarcity can only be addressed by implementation of water storage infrastructures but also it is important to focus on the areas of Nyabarongo river, where the volume of water is sufficient.

6.6.8. Akagera Lower catchment (NAKL)

Basic Characteristics

This catchment drains the flow from the Upper Akagera and the Ruvubu rivers. The Lower Akagera features the same hydro morphology of the upper part, flowing through a wide and extremely flat valley with numerous lakes that function as buffers during extreme flow or otherwise drain into the river. The river forms the boundary between Rwanda and Tanzania for its entire course to the North from where it takes a sharp turn East towards Lake Victoria. The river is a major feature of the Akagera National Park (1021Km2, 24% of the total catchment).

The Lake Nasho complex (the three lakes of Nasho, Cyambwe and Mpanga) is at the south part of the catchment and before Akagera river enters to the Akagera National park. The area of the Lakes is a great potential for irrigation by pumping. The lakes further downstream are within the domain of the national park and therefore entirely protected for purposes of wildlife.

This catchment is the driest part of Rwanda, receiving only 835mm/year on average, thus it is the first priority of the Government because of the less water but also due to the mild slopes of the catchment that make the development easier from the technical, economical and operational point of view.

Irrigation Potential Areas and Water Balance

Based on the WRMP the renewable resource of the catchment is 907Mm3, while the demand of all other uses except irrigation, is estimated to 67Mm3 annually (ref chapter 2).

The irrigation demand of the catchment is estimated in the following table where the irrigation potential areas per category have been defined. The demand for the different categories is an average rate selected based on the Agronomy Assessment, considering irrigation demand and efficiency, of this report (chapter 3).

Table 6-22: NAKL-Irrigation Potential Areas

Categories	Area (ha)	Water demand (m3/ha/year)	Total water demand (Mm3/year)
SSIT Site	2,949	7,000	20.64
Dam Potential Site	914	7,000	6.40
Lake Potential Site (Zone 0 - 50 m)	7,262	7,000	50.83
Lake Potential Site (Zone 50 - 80 m)	1,221	7,000	8.54
Lake Potential Site (Zone 80 - 120 m)	-	-	0.00
Marshland Potential Site	2,769	9,000	24.92
Marshland Potential Site under Conditional use	11,531	9,000	103.78
River Potential Site (Zone 0 - 50 m)	19,145	7,000	134.02
River Potential Site (Zone 50 - 80 m)	12,975	7,000	90.83
River Potential Site (Zone 80 - 120 m)	2,377	7,000	16.64
Potential Sites under Design	16,146	6,000	96.88
Existing Schemes	9,254	8,000	74.03
Existing Schemes rainfed	-	-	0.00
Runoff for small reservoirs domain (17.62%)	9,162	4,000	36.65
Ground Water	3,000	9,000	27.00
Total:	**98,962**		**691.16**

The total demand estimated is 691.16Mm3 per year, therefore with the additional demand of other uses, the total demand is ~758Mm3, less than the available of the catchment (83.6%), but during the dry season the catchment is facing a large scarcity of water, except the areas close to the river.

Irrigation characteristics

- With a large part of the catchment to drain to Akagera River and the dry season to affect all schemes that operating by using the catchment's source, the effort should be given to utilize the water of the Akagera River by pumping directly from the river or through the lakes that can be fitted by the river.
- The potential by pumping, existing and schedules schemes, is estimated to ~68,000ha, 66% of the total potential.
- The existing schemes cover an area of 9,254ha, based on schemes supported by small dams or supplied by pumping, while for 16,146ha designs of different levels have been already produced.
- An area of 31,000ha is served as military area. A design of exploring the alternative to develop an area of ~5,000ha within this area has been already completed, while more area is potential for irrigation in the restricted area.

Monthly Water Balance and irrigation potential

The above exercise is based on average annual values, but in order to estimate the scarcity of water during the dry period of Season C, an analysis on demand and water availability was conducted as it is presented in the following table.

Table 6-23: NAKL-Monthly Scarcity of water

Month	Available		Other Demands	Available for irrigation Mm3	Irrigation Demand		Scarcity of water
		907 Mm3	67 Mm3			691.16 Mm3	
Oct.	6.1%	55.7	5.6	50.1	5.4%	37.6	-
Nov.	6.8%	61.6	5.6	56.0	8.3%	57.1	1.1
Dec.	7.5%	68.4	5.6	62.8	6.6%	45.3	-
Jan.	8.1%	73.2	5.6	67.6	10.6%	73.4	5.8
Feb.	8.5%	77.2	5.6	71.6	1.6%	11.1	-
Mar.	9.1%	82.4	5.6	76.8	1.8%	12.4	-
Apr.	10.4%	94.5	5.6	88.9	0.1%	0.6	-
May	11.3%	102.1	5.6	96.6	1.9%	13.1	-
Jun.	10.0%	90.5	5.6	84.9	15.3%	105.8	20.9
Jul.	8.6%	77.8	5.6	72.2	24.0%	165.5	93.3
Aug.	7.4%	66.8	5.6	61.2	14.5%	100.3	39.0
Sep	6.3%	56.8	5.6	51.2	10.0%	69.0	17.9

The above table proves the scarcity of water during the dry period C and the months from June to September. This scarcity can only be addressed by implementation of water storage infrastructures but also it is important to focus on the areas of Akagera river, where the volume of water is sufficient.

6.6.9. Muvumba catchment (NMUV)

Basic Characteristics

The South Western part of this catchment is drained by the Mulindi River that drains towards the North to Kabala in Uganda where the river makes a U-turn and returns into Rwanda as the Muvumba which follows a north easterly course towards its confluence with the Akagera River.

Mulindi River is located along the main road from Kigali to Gatuna along the border with Uganda. This is a typical upland river draining relatively narrow and deep valleys and exits towards Uganda.

Muvumba river, enters from Uganda and drains a much more gentle sloping landscape before joining the Akagera river at the border point between Uganda, Tanzania and Rwanda. The Muvumba river is the only permanent water body of the region and its waters are required for water supply, irrigation, and livestock watering. Another main river, is Kaungeri river, which serves as a tributary of Muvumba, flowing completely within Rwanda, and discharges to Muvumba close to Nyagatare town.

The MoE produced a catchment management plan[123] for Muvunba as a planning tool to prioritize and address the matters directly linked to water management such as catchment restoration, maximum water availability and equitable water allocation to all water users within the catchment. The plan has also updated the water demands of the respective catchment.

According to the plan's new analysis the demand can reach up to 369Mm3 for the catchment, an increased figure compare with the respective figures of WRMP, which is 216Mm3 for the entire NMUV catchment. For that reason the highest demand shall be used for further analysis.

Irrigation Potential Areas and Water Balance

Based on the Muvumba Plan the demand of all other uses except irrigation, is estimated to 147Mm3.

The irrigation demand of the catchment is estimated in the following table where the irrigation potential areas per category have been defined. The demand for the different categories is an average rate selected based on the Agronomy Assessment, considering irrigation demand and efficiency, of this report (chapter 3).

Table 6-24: NMUV-Irrigation Potential Areas

Categories	Area (ha)	Water demand (m3/ha/year)	Total water demand (Mm3/year)
SSIT Site	2,931	7,000	20.52
Dam Potential Site	7,841	7,000	54.89
Lake Potential Site (Zone 0 - 50 m)	-	-	-
Lake Potential Site (Zone 50 - 80 m)	-	-	-
Lake Potential Site (Zone 80 - 120 m)	-	-	-
Marshland Potential Site	644	9,000	5.80
Marshland Potential Site under Conditional use	1,953	9,000	17.58
River Potential Site (Zone 0 - 50 m)	2,828	7,000	19.80
River Potential Site (Zone 50 - 80 m)	1,957	7,000	13.70
River Potential Site (Zone 80 - 120 m)	-	-	-
Potential Sites under Design	4,936	6,000	29.62
Existing Schemes	5,575	8,000	44.60
Existing Schemes rainfed	-	-	-
Runoff for small reservoirs domain (6.43%)	3,344	4,000	13.37
Ground Water	1,000	6,000	6.00
Total:	**33,009**		**225.86**

The total demand estimated is 225.86Mm3 per year, therefore with the additional demand of other uses, the total demand is 373Mm3, more than the available of the catchment.

[123] *Muvumba Catchment Management Plan 2018-2024, MoE, 2018*

Irrigation characteristics

- The main feature of the catchment is the Muvumba river. Several projects have been developed on this river as it is perennial. Marshlands on the Muvumba river and Karungeri river with an approximate size of 1820ha and 850ha respectively, have been developed by RSSP project and are under operation.
- Recently a study completed on Muvumba river, regarding the construction of a dam to store the water coming from Uganda and support all uses of the downstream areas, especially irrigation during the dry season. The proposal of the study is that a size of 6,200ha can be developed downstream of the dam, similar to the figures given on the maps.
- Another study, investigated the development of a dam and an irrigation project to exploit the water from Warufu river, an upstream tributary of Karungeri river. The result is to propose a scheme of 2,500ha to be developed in the downstream valley. The study also included a water balance of Muvumba river, investigating the capability of Muvumba river to cover the demands downstream without the use of water coming from Warufu river. The result of the study was that up to the confluence of Karungeri and Muvumba river, the irrigation demand for the developed and planned schemes shall be covered with their own sources from the above catchment (Ngome, Warufu and Karungeri)
- The catchment resources are very stressed in order to cover the entire demand. The water coming from Uganda, has not been included in the estimated availability of 193Mm3/year by WRMP, and it is evident that this additional resource is sufficient and required for this purpose.

  The above follows the proposals of Muvumba Catchment in which the analysis shows that based on demands, irrigations schemes can be developed (almost) in full. Conversely, in sub-catchments with lower overall resource, or more competing users, development of new irrigation schemes will have to be restricted. Optimum water-based economic development and food security can be combined with meeting the needs for domestic, livestock and industrial users, as well as the environment. In situations of extreme water scarcity, i.e. in dry years, the volume of water allocated to irrigation would have to be further reduced if all other users were also to still receive some allocation. Under such circumstances, RAB and WRMD would need to jointly adjust allocations to irrigation systems and promote uptake of extra water saving technologies and further adjust cropping patterns in each season, e.g. by shutting down compartments of irrigation schemes, or by planting crops with higher drought tolerance. Timely seasonal forecasts by RMA are needed to allow for timely preparations.

Monthly Water Balance and irrigation potential

The above exercise is based on average annual values, but in order to estimate the scarcity of water during the dry period of Season C, an analysis on demand and water availability was conducted as it is presented in the following table.

Table 6-25: NMUV-Monthly Scarcity of water

Month	Available		Other Demands	Available for irrigation Mm3	Irrigation Demand		Scarcity of water
		193 Mm3	147 Mm3			225.86 Mm3	
Oct.	8.1%	15.7	11.5	4.2	5.4%	12.3	8.1
Nov.	9.6%	18.5	11.4	7.1	8.3%	18.7	11.5
Dec.	8.9%	17.2	13.2	4.0	6.6%	14.8	10.8
Jan.	7.6%	14.7	17.1	-2.4	10.6%	24.0	26.4
Feb.	7.3%	14.2	19.4	-5.2	1.6%	3.6	8.9
Mar.	7.8%	15.0	11.4	3.5	1.8%	4.0	0.5
Apr.	10.6%	20.4	10.2	10.2	0.1%	0.2	-
May	10.5%	20.3	9.5	10.8	1.9%	4.3	-
Jun.	7.9%	15.3	8.3	7.0	15.3%	34.6	27.6
Jul.	7.0%	13.5	10.8	2.8	24.0%	54.1	51.3
Aug.	7.1%	13.7	12.1	1.6	14.5%	32.8	31.1
Sep	7.6%	14.6	12.2	2.4	10.0%	22.6	20.2

The above table proves the scarcity of water during the dry period C and period A, the months from June to September and October to January. This scarcity can only be addressed by implementation of water storage infrastructures but also it is important to focus on the areas of Muvumba river, where the volume of water is sufficient by utilizing the quantities coming from Uganda.

6.6.10. Summary of the irrigation potential

The data collection and the interpolation exercise on all available information regarding potential irrigable areas, existing schemes and information on protected areas resulted in the production of an Irrigation Potential Map for each one of the Level 1 Catchments. The delineation of the potential command areas boundaries follows the specific criteria set for each domain (e,g pumping lift zones etc.).

The irrigation potential was delineated per level 1 catchments in order to be in agreement and easily comparable to the WRMP, as this forms part of the scope of this study. The maps are included in Annex 2 of this report.

The following table summarizes the results of the above exercise with the total areas of land which apply to the different domains.

Table 6-26: Irrigation Potential of Rwanda (ha)

Domains	CRUS	CKIV	NMUK	NNYU	NNYL	NAKN	NAKU	NAKL	NMUV	All
Runoff for small reservoirs domain	2,148	5,179	4,165	7,155	7,056	7,270	6,521	9,162	3,344	52,000
Dam Potential	167	1,447	172	7,058	15,610	12,859	894	1,430	12,464	52,100
River Potential	-	-	-	12,424	4,710	36,171	25,868	48,241	8,466	135,880
Lake Potential	-	23,909	-	-	28,372	9,125	26,816	14,142	-	102,364
Marshland Potential	3,700	4,702	6,398	9,060	8,998	26,656	33,184	22,731	7,735	123,164
Groundwater	3,000	5,000	5,000	7,000	4,000	5,500	2,500	3,000	1,000	36,000
SUM	9,015	40,237	15,735	42,697	68,746	97,581	95,783	98,706	33,009	501,509

The following supplementary to the above information should be highlighted, based on the previous analysis and map data:

- ✓ The above domains can be separated to two major categories, to indicate the formal and informal developed areas under irrigation. The formal category includes the projects that can be implemented by the respective authorities with the help of Developing Partners (Minagri, RAB, WB, USAID etc). Under this category fall the dam, lakes, rivers and marshland domains that forms 82% of the total area.
  The informal includes the other two domains, runoff and groundwater, developed by small farmers without under any organized conditions. Part of this area is already irrigated, but it is very difficult to be measured.
- ✓ The total area that irrigation has been already implemented under formal conditions, is estimated to approximately 50,000ha in year 2019. It is under the responsibility of RAB to update the maps and the figures accordingly with the projects that will be implemented in the future.
- ✓ A number of projects have been already identified and designs have been conducted to different levels. This figure is up to 60,000ha, that can be utilized in order to achieve the next targets on a country scale.
- ✓ The river and lake domains refer to pumping from the water sources. Within these two domains SSIT technology as described above is also included. The total available area used by pumping is estimated as 238,000ha, which is the largest group and gives a great potential for implementation.
- ✓ Pumping from water source was divided into three categories, as explained previously. It is important for planning reasons to indicate that the total area available for pumping up to 50m high, is estimated at 122,403ha, since up to this level all small scale farmers that they are using small pumps are included.
- ✓ As it is described in detail in the above paragraphs, NAKU, NAKL and NMUV catchments are facing large scarcity of water to meet the respective demands,

especially during the dry months of the year. There is also some less scarcity of water during the dry period for catchments NAKN and NNYL, while the yearly demand/water availability is balanced. In order to enhance the amount of available water for these catchments the following proposals are given:

- In the case of full development of the areas, the agriculture of less water demanding crops by adjusting the cropping patterns and the use of more efficient technologies in order to reduce losses and the water demand per hectare, should be implemented. This is in line with the new Plans produced for the different catchments and the proposal for an efficient use of the water resources.
- In cases where the scarcity is allocated mainly during the dry period, implementation of water storage infrastructures should be considered.
- As it was described in the above paragraphs, there is an excess amount of water from NNYU and NMUK catchments, in the order of 1,600Mm3 per year, that flows through Nyabarongo river, and continues to Akagera river. This external source of water should be utilized to support the needs of catchments NAKU and NAKL, especially through schemes developed in the vicinity of the rivers and the connected lakes.
- The catchment resources of NMUV are very stressed in order to cover the entire demand. The water that flows from Uganda side, through Muvumba river, is sufficient to cover all needs and shall be utilized accordingly.

CHAPTER 7. TYPOLOGY & PRIORITIZATION

7.1. Prioritization of irrigation sites

7.1.1. Site Selection Criteria

The areas proposed as potential areas must be prioritized in order the most advantageous projects, from both technical and financial point of view, with the most benefits for the purpose to serve shall be developed in advance. Thus, a prioritization method is deemed necessary to be developed in order to group and classify the various opportunities.

This prioritization process involves the comparison on a sound basis of the various project characteristics and their impacts when the project implementation will proceed. For this reason, a list of selection criteria was developed; to allow for this comparison, by quantifying as much as possible the various project characteristics. The criteria are based on a project comparison under a Master Plan scale. In Annex 5, a detail procedure to compare projects is given as a reference and to be used when specific projects should be compared.

The prioritization is based on five (5) distinctive criteria categories. These categories are considered especially useful for an irrigation project site selection from a technical, social and environmental standpoint. These are:

1. Hydrology – Water Yield
2. Command Area
3. Environmental
4. Social
5. Investment

These categories shall be assigned a specific rating, defining the significance allocated in between them. Under each category several sub criteria shall be developed. The proposed rating is presented in table below.

Table 7-1: Rating of the main categories of the Site Selection Criteria

	Criteria Categories	Rating
1	Hydrology – Water Yield	40%
2	Command Area	30%
3	Environmental	10%
4	Social	10%
5	Investment	10%
	Total	**100%**

Under each category several criteria were developed as presented in the following table**Error! Reference source not found.**. In this table, a brief description is given for each criterion.

Table 7-2: Site Selection Criteria per category

Category	Criteria and Description
Hydrology – Water Yield	– *The location of site and rainfall* – *The main sources for irrigation water, namely dams, rivers, lakes, groundwater, marshlands. The constraints featured in different water sources indicate a more or less favorable site location* – *Potential for multipurpose applications of the project (e.g. irrigation, hydropower, livestock watering purposes, fisheries and aquaculture activities, flood control and general watershed management) will be evaluated*
Command Area	– *The shape and the mainly the slopes of the command area determine a more or less favorable command area.* – *The quality of the soils of the command area (depth of arable soil, texture, water content) from the agricultural potential point of view, based on the initial observations* – *The size of the potentially irrigable command area to the size of the available command area* – *The distance of the proposed project from access roads* – *The distance from any existing power transmission lines.*
Environmental	– *The presence of recognized, protected forests, wildlife zones and non gazetted zones and protected flora and fauna species shall be evaluated. Cultural or heritage resources that may be affected*
Social	– *Resettlement issues and the number of individuals or households requiring resettlement; affecting infrastructure (roads, electrical power transmission), municipal facilities, agriculture facilities* – *The proximity of the proposed project site to existing communities and settlements, as well as the size of the communities and people served (population density) are examined* – *Accessibility to markets, district centres, towns (distance and road conditions)*
Investment	– *Investment costs for dam construction, appurtenant structures, and conveyance canals and for irrigation scheme.* – *Operation cost*

7.1.2. Weighting of Criteria

Following all the above, a scoring system is defined, with specific reference to project conditions, to score each site against the site selection criteria. The proposed scoring system is divided in three (3) levels, having an equal point system. Criteria are evaluated with:

- High score – gaining 3 points
- Medium score – gaining 2 points
- Low score – gaining 1 point

During the evaluation process, the scoring against each criterion will be allocated following the criterion vs. project site evaluation. A weighting of 3 is assigned to criteria with highly positive significance, a weighting of 2 to those criteria with a moderate significance and a weighting of 1 to criteria with a significant negative impact on the site selection decision.

Criterion 1: Hydrology – Water Yield

Annual rainfall

A first prioritization was conducted by the Ministry and has to do with the location of site and annual rainfall in mm. The philosophy behind this prioritization is that in the areas that there is high rainfall, there is no need for infrastructures to support the irrigation, since rainfed irrigation is considered efficient to cover the needs. Thus, priority for development is wherever there is no rainfall and supporting infrastructures should be implemented to cover this gap.

On this regard the following table was derived:

Table 7-3: Priority based on the annual rainfall

Ranking	District name	Score
Priority 1 (up to 850mm)	Bugarama, Bugesera, Kirehe, Kayonza, Gatsibo (the east of the road Kayonza-Kagituma), Nyagatare (the east of the road Kayonza-Kagituma)	3
Priority 2 (850mm – 1100mm)	Gisagara, Huye, Nyarugugu (low land), Nyamagabe (low land), Nyanza, Ruhango, Muhanga, Kamonyi, Kigali, Rwamagana, Ngoma, Gatsibo (the west of the road Kayonza-Kagituma), Nyagatare (the west of the road Kayonza-Kagituma), Rubavu, Nyamasheke (marshland only)	2
Priority 3 (above 1100mm)	Nyaruguu, Nyamagabe, Rusizi, Nyamasheke, KarongiRutsiro, Ngororero, Gakenke, Rulindo, Gicumbi, Burera, Musanze, Myabihu, Rubavu.	1

In terms of location, from the above table can be extracted that the areas located at the eastern part of the country are first priority due to low rainfall, thus rainfed irrigation can be very limited. In terms of water catchments, catchments of NMUV, NAKL and NAKU are the catchments that should be prioritized.

Figure 7-1: Priority per District

<u>Availability of water</u>

The main source of supplying the water is one of the major parameters to be considered. As derived from the Irrigation Potential Report, the only sources that can provide adequate quantities of irrigation water covering all three irrigation periods, are the main rivers and lakes. Other sources like small rivers, marshlands and groundwater can be only act as supplementary irrigation and accompanied by infrastructures for storage.

The SSIT projects, is a technology that should be considered as high priority of the government. Since the technology is using both surface and swallow groundwater as supply source, is expected not to face any scarcity of water. The technology can be an efficient tool to the value chain systems, since the SSIT farmers have shown a preference for producing vegetables which have a short table life and high value and in parallel has the least cost development per hectare.

Regarding ranking of this category, the below tables presents the score accordingly.

Table 7-4: Priority based on the domain

Domain	Score
Projects related to large Rivers	3
Projects related to large Lakes	3
Projects related to Dams	2
Projects related to Marshlands	2
Projects related to Groundwater	1
Projects related to SSIT	3

Multipurpose projects

Most of the large projects can be operating as multipurpose projects and supporting the local communities with water for domestic use and livestock or hydropower. The amount of water for these uses is less than the need for irrigation water thus can not affect the size of the irrigation project but can be large benefit for the society and the greater development of the area. In cases of small projects, where the amount of water is less sufficient, the implementation of multipurpose project can be a challenge.

Criterion 2: Command area

Slopes

The slopes in the command area is a parameter that affect the decision of implementation of a project. The mild areas are easier to be developed since there is no need for extensive earthworks and minimize the ratio between the net and the gross area, which results to less lost area. According to the below figure, presenting the sloping categories of the country, the central and east parts have more gentle morphology. Again, the areas located into catchments NAKL, NAKU, NMUV (east part) and NAKN (east part) score 3, CRUS, NNYL and NNYU score 2 and finally CKIV and NMUK score 1.

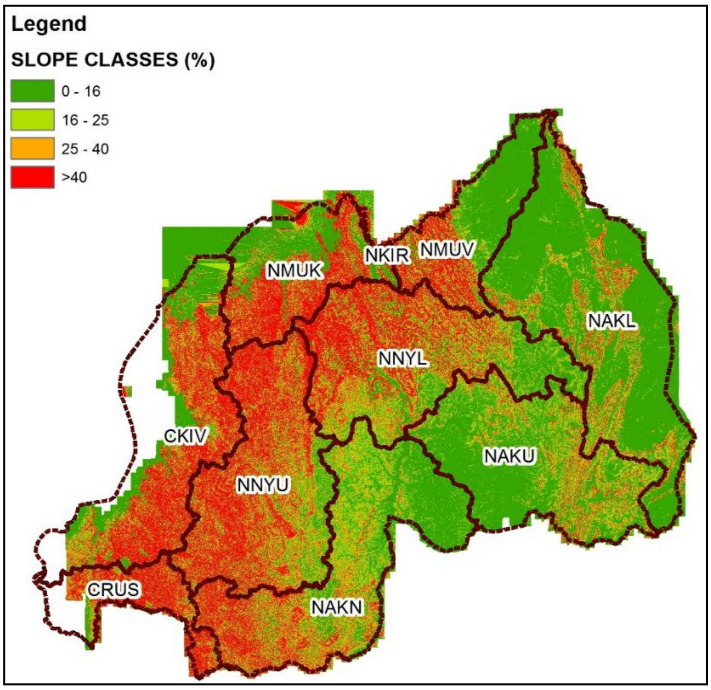


Figure 7-2: Priority per slope

Soils

The soils of a command area is another parameter that affect the decision of implementation of a project. As indicated in the below figure, the majority of the soils of Rwanda are indicated as suitable or highly suitable. The purpose of this masterplan does not allow to give detail assessment of the soils of each project, thus can not be considered in this prioritization. In other cases, while comparing specific projects, a detail soil assessment of the specific areas should be conducted.

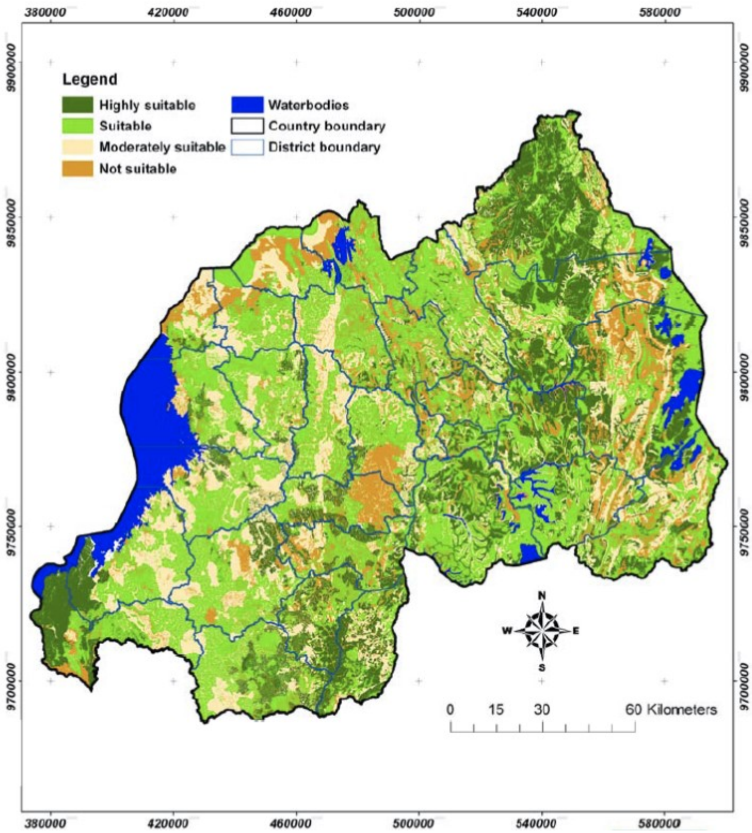


Figure 7-3: Rwanda Soil suitability map for irrigation (Source: Malesu et al., 2010)

Available area and access and other infrastructures

The availability of area is depending on the land use and land tenure conditions of each site resulting to a specific land free of any obstacles to be used for irrigation. Together with the availability of access and the existence of other infrastructures (ex: power lines) are parameters that are site specific and must be examined during evaluation of project but are beyond the scope of a masterplan.

Criterion 3: Environmental

The land that has already been reserved due to environmental reasons (ex: protected forests wildlife zones), has been also excluded from the potential for irrigation areas. For the areas proposed, the environmental issues which mainly refer to specific environmental rules that should be follow during construction and operation and site specific measures to mitigate the effect of the project to the environment, should be considered in each project. In general, if these rules are followed, there is no environmental obstacle for implementing an irrigation project. These rules can only be examined under a detail evaluation of a project, which is out of the scope of a masterplan.

Criterion 4: Social

This criterion examines the situation on the ground regarding the existence of communities and settlements in the area of the project, how these communities can be benefit, accessibility to markets and other infrastructures that help in this direction. On this regard, a project that is close to Kigali it is much more attractive and can score high, instead of a project at the east where the density of the area is low and access to markets is a challenge. However, a project far from the center can be of high benefit for the people of this area and can be the start for the entire area's development. Both views should be considered during evaluation.

Based on this analysis, the areas proposed in the central part of the country can score 3, while areas far from the center can score 2. On the issue of resettlement this depends on the specific ground conditions of each of the sites.

Criterion 5: Investment

This criterion refers to the cost of the investment of a project, but also the cost during operation and how these two costs affect the decision of the investors to proceed. There are several factors to be evaluated in order to rank the sites.

Cost of infrastructures

The cost for the construction of a project varies from 6,000$/ha to 30,000$/ha depending on the type of the infrastructures needed. The cost of the sites that involve the construction of storage facilities ranges from 16,000$/ha to 30,000$/ha, while the cost of other sites that they supply of water is simple intake structure or pumping stations ranges between 6,000$/ha to 10,000$/ha. More simple techniques such as SSIT, are in the range of 3,500$/ha to 6,000$/ha.

Cost of operation

The operation in all project is highly related with the investment cost, proportionally estimated to 1-2% of the capital cost for the annual operation and maintenance of the system. A big difference is on the projects which depend on energy consumption.

The high capital cost of projects with storage facilities is accompanied by a small cost of operation, while it is the exact opposite for the large projects that need the operation of a pumping station in order to secure the required quantities of water.

An economic analysis is needed per specific project in order order to quantify the figures and to evaluate what is the best for an investor to do. For the basis of this Master Plan, the project operation cost of the pumping stations can be estimated to 300-500/ha/year, depending on the various conditions of the area, the difference in elevations, the type of irrigation etc.

For these cases, should be also considered that the comparison of the new technology of using solar energy and energy from diesel for pumping water, solar has lower total costs and lower overall energy consumption despite the higher initial investment cost and greater energy consumption of depreciation of machinery and equipment.

Ranking

Based on the above, projects that can be relied on pumping water, including the SSIT projects with the very low investment cost, can score 3, while the other projects score lower.

7.1.3. Prioritization

The results of the above analysis can be summarized as follow:

- The high priority schemes are the large schemes at the east of the country which shall be supplied by the large rivers or lakes by pumping stations. The area provides large size command areas with good soils and gentle slopes, the water is secured since it is provided by pumping from the main larger rivers of the country and the need for the development the greater area and support the communities is very high.

- SSIT technology should also be prioritized as it is proved as a great benefit for the farmers.

- Due to the high capital cost, the projects that include storage facilities can be second priority unless specific projects have been identified with a cost in the order of 18,000$/ha or even less, and the capital cost has been secured from donors.

- Projects located within catchments NNYL, NAKU, part of NAKN also should be prioritize as medium priority. The sites have a potential to be attracted for investment due to easy access and proximity of Kigali. The existence of some difficulties like, less gentle slopes, high density areas, secured water etc should be considered but are not obstacle for the implementation of the respective projects.

- Low priority can be considered the areas at the west and north of the country. These areas have already developed rainfed schemes due to the high rainfall amounts, however potential exists for supplementary irrigation and support the schemes during Season C and the dry period.

Table 7-5: Scoring Table

Catchment	Location	Command area	Social
CKIV	1	1	1
CRUS	1	2	2
NNYU	1	2	1
NMUK	1	1	1
NNYL	2	2	3
NAKN	2	2	2
NAKU	3	3	3
NAKL	3	3	2
NMUV	3	3	2

Domain	Water Yield	Investment
Rivers	3	3
Lakes	3	3
Dams	2	2
Marshlands	2	2
Groundwater	1	1
SSIT	3	3

Multipurpose use	
Large projects	3
Medium projects	2
Small projects	1

It has to be noted that prior to the any comparison process, there are identified certain factors that are the first priority for the actual further assessment or not of a project, addressing the actual viability and feasibility of such development. These are named “Discarding Criteria”. These criteria define whether any project shall be further assessed or not. The discarding criteria fall under the following six categories and are defined as presented in the Table that follows:

Table 7-6: Discarding Criteria

Criteria	Description Aspects
Site conflict related to alternative water usage	In conflict with: hydropower plant projects, existing irrigation schemes, existing or future water wells may be inundated, evident shortcomings of water use d/s
Site conflict due to environmental protected areas	Gazetted or protected areas that are part or located in the reservoir area
Serious resettlement actions or problems with land ownership	The presence of houses / communities, other important infrastructure, municipal facilities, that prevents development of sub-project
Very unfavorable geological conditions	Dam foundation conditions that are considered unfavorable (such as weak overburden soils, active faults at dam foundation area, highly tissured bedrock)
Water quality unsuitable for irrigation	Water quality not acceptable for most of the crops
Administrative obstacles, no acceptance of sub-project	No acceptance by district authorities / concerned farmers

7.2. Site Classification

Site classification and categorization will be based on

- The geographic location of the potential site classified as per the 9-catchment division of the Water Resources Master plan. This creates a total of nine classes symbolized as shown in the following table:

Table 7-7: Catchments' symbolology

a/a	Catchment
1	Lake Kivu (CKIV)
2	Rusizi (CRUS)
3	Nyabarongo upper (NNYU)
4	Mukungwa (NMUK)
5	Nyabarongo lower (NNYL)
6	Akanyaru (NAKN)
7	Akagera upper (NAKU)
8	Akagera lower (NAKL)
9	Muvumba (NMUV)

- Site classification based on the domain, which refers to the supply source and the technology for the supply system. This creates a total of nine classes symbolized as shown in the following table:

Table 7-8: Domain symbolology

a/a	Domain
R	Rivers
L	Lakes
D	Dams
M	Marshlands
G	Groundwater
S	SSIT

- Site classification based on the size of the project. The classification according to each potential site's can be:

  Small (S): size < 200ha

  Medium (M): 200ha ≤ size < 1,000ha

  Large (L): size ≥ 1,000ha

- Site classification based on the scoring generated for each site as described in the previous section. The classification according to each potential site's priority can be:

  Class l (low): for a scoring < 1.5

  Class m (medium): for a scoring 1.5 ≤ Pr < 2.4

  Class h (high): for a scoring ≥ 2.4

As an example, a potential site of 1,200ha, which has scored 2.80, is located within the Lake Kivu catchment and supplied by the lake water through pumping, lies within the CKIV/L/L/h class.

A potential site of 500ha, which has scored 2.2, is located within the Lower Nyabarongo catchment and supplied by dam, lies within the NNYL/D/M/m class.

7.2.1. List of Specific proposed schemes by priority

The below indicative priority list of sites includes projects that have been already identified and projects that should be examined in the future.

Sites with Feasibility or Detail Design Studies					
Catchment	**District**	**Name**	**Status**	**Domain**	**Ha**
Lower Nyabarongo (NNYL)	Rulindo, Kamonyi, Nyarugenge, Bugesera, Ngoma	Nyabarongo-2	Detail Design of Dam, Feasibility of Irrigation	D	15,000
Lower Akagera (NAKL)	Nyagatare, Gatsibo	Gabiro NETAFIM	Under Design	R	14,000
Muvumba (NMUV)	Nyagatare	Muvumba	Detail Design of Dam, Feasibility of Irrigation	D	5,880 Design 12,000 Potential
Muvumba (NMUV)	Nyagatare, Gatsibo	Warufu	Tender Documents	D	3,000
Upper Akagera (NAKU)	Bugesera	Gashora	Under Design	L	2,850
Akanyaru (NAKN)	Bugesera	Cyohoha N.	Under Design	R/L	2,650
Upper Akagera (NAKU)	Bugesera	Rweru	Under Design	L	2,500
Rusizi (CRUS)	Rusizi	Bugarama	Detail Design	R	2,000
Lower Akagera (NAKL)	Kayonza	Ndego	Under Feasibility	L	2,000
Upper Akagera (NAKU)	Ngoma	Mugesera	Procurement for Design	L	1,200
Lower Nyabarongo (NNYL)	Muhanga	Bakokwe	Detail Design	R	400
Lower Nyabarongo (NNYL)	Gicumbi	Bwanya	Feasibility – RSSP/Minagri	M	200
				Total	51,680

Sites with Prefeasibility Studies					
Catchment	**District**	**Name**	**Status**	**Domain**	**Ha**
Akanyaru (NAKN)	Gisagara, Nyanza, Ruhango, Kamonyi, Bugesera	Akanyaru	Prefeasibility - NELSAP	D	12,300
Lower Akagera (NAKL)	Nyagatare	Karangazi	Under Feasibility	R	8,000
Upper Nyabarongo (NNYU)	Nyaruguru	Agatobwe	Prefeasibility - LWH	D/M	1,340 with Dam, 365 marshland
Akanyaru (NAKN)	Nyanza	Budubi	Prefeasibility - LWH	D/M	646 with Dam, 135 marshland
Lower Nyabarongo (NNYL)	Gakenke	Banga	Prefeasibility - LWH	D/M	350 with Dam, 101 marshland
Lower Nyabarongo (NNYL)	Rulindo	Nyamuziga	Prefeasibility - LWH	D	300
Lower Nyabarongo (NNYL)	Rulindo	Rugabano	Prefeasibility - LWH	D	100
Upper Nyabarongo (NNYU)	Nyamagabe	Kabiri	Prefeasibility - LWH	D	390
Akanyaru (NAKN)	Ruhango	Muhanga	Prefeasibility - LWH	D	980
Lower Nyabarongo (NNYL)	Muhanga & Kamonyi	Bakokwe	Prefeasibility	D	30
				Total	24,440

Sites without Study					
Catchment	**District**	**Name**	**Status**	**Domain**	**Ha**
Upper Akagera (NAKU)	Kayonza, Gatsibo	Nyamashuri	Identified in IMP	R	8,000
Upper Akagera (NAKU)	Kayonza	Karambi	Identified in IMP	L	6,000
Upper Akagera (NAKU)	Kirehe	Rwampanga	Identified in IMP	L	2,000
Upper Akagera (NAKU)	Kirehe	Nasho	Identified in IMP	R	3,500
Upper Akagera (NAKU)	Kirehe	Kagasa	Identified in IMP	R	4,000
Nyabarongo Lower (NNYL)	Rwamagana, Kayonza	Muhazi	Identified in IMP	L	8,000
Upper Akagera (NAKU)	Ngoma	Jarama	Identified in IMP	L	2,700
Akanyaru (NAKN)	Gisagara	Rutobo	Identified by IMP and Marshland Study	M	56
Akanyaru (NAKN)	Gisagara	Nili	Identified by IMP and Marshland Study	M	109
Akanyaru (NAKN)	Gisagara	Duwane	Identified by IMP and Marshland Study	M	134
Akanyaru (NAKN)	Gisagara	Umusizi	Identified by IMP and Marshland Study	M	136
Akanyaru (NAKN)	Nyaruguru	Gipfuna	Identified by IMP and Marshland Study	M	95
Akanyaru (NAKN)	Nyaruguru	Agatorove (upstream)	Identified by IMP and Marshland Study	M	99

Akanyaru (NAKN)	Nyaruguru	Akavuguto	Identified by IMP and Marshland Study	M	217
Upper Nyabarongo (NNYU)	Nyamagabe	Mwogo	Identified by IMP and Marshland Study	M	262
Upper Nyabarongo (NNYU)	Huye	Bishyimbo	Identified by IMP and Marshland Study	M	125
Upper Nyabarongo (NNYU)	Huye	Birambo	Identified by IMP and Marshland Study	M	128
Akanyaru (NAKN)	Huye	Munyazi	Identified by IMP and Marshland Study	M	139
Akanyaru (NAKN)	Huye	Ndobogo	Identified by IMP and Marshland Study	M	106
Upper Nyabarongo (NNYU)	Huye	Runukangoma	Identified by IMP and Marshland Study	M	96
Upper Nyabarongo (NNYU)	Huye	Umwaro	Identified by IMP and Marshland Study	M	45
Akanyaru (NAKN)	Kamonyi	Kavunja	Identified by IMP and Marshland Study	M	104
Upper Nyabarongo (NNYU)	Nyanza	Mwogo	Identified by IMP and Marshland Study	M	405
Akanyaru (NAKN)	Nyanza	Rubuyenge - Burakari	Identified by IMP and Marshland Study	M	244
Upper Nyabarongo (NNYU)	Ruhango	Nyirakiyange	Identified by IMP and Marshland Study	M	98
Upper Nyabarongo (NNYU)	Ruhango	Kibingo	Identified by IMP and Marshland Study	M	189
Upper Nyabarongo (NNYU)	Ruhango	Nyagafunzo	Identified by IMP and Marshland Study	M	91
Upper Nyabarongo (NNYU)	Ruhango	Base	Identified by IMP and Marshland Study	M	133
Upper Nyabarongo (NNYU)	Ruhango	Kana	Identified by IMP and Marshland Study	M	134
Upper Nyabarongo (NNYU)	Ruhango	Kiryango	Identified by IMP and Marshland Study	M	108
Upper Nyabarongo (NNYU)	Ruhango	Nyamuko	Identified by IMP and Marshland Study	M	101
Akanyaru (NAKN)	Ruhango	Rugondo	Identified by IMP and Marshland Study	M	153
Akanyaru (NAKN)	Ruhango	Akabebya	Identified by IMP and Marshland Study	M	124
Lower Nyabarongo (NNYL)	Muhanga	Takwe	Identified by IMP and Marshland Study	M	143
Lower Nyabarongo (NNYL)	Rwamagana	Kavura	Identified by IMP and Marshland Study	M	140

Muvumba (NMUV)	Nyagatare	Ngoma	Identified by IMP and Marshland Study	M	708
Lower Akagera (NAKL)	Gatsibo	Gahama	Identified by IMP and Marshland Study	M	115
Lower Akagera (NAKL)	Gatsibo	Minago	Identified by IMP and Marshland Study	M	60
Muvumba (NMUV)	Gatsibo	Cyamuganga	Identified by IMP and Marshland Study	M	200
Upper Akagera (NAKU)	Bugesera	Rwansoro	Identified by IMP and Marshland Study	M	300
Mukungwa (NMUK)	Burera	Cyeru-Nyamusanze	Identified by IMP and Marshland Study	M	95
Mukungwa (NMUK)	Burera	Gana-Ntaruka	Identified by IMP and Marshland Study	M	94
Mukungwa (NMUK)	Burera	Gatsibo-Kamiranzovu	Identified by IMP and Marshland Study	M	463
Mukungwa (NMUK)	Gakenke & Nyanihu	Mukungwa	Identified by IMP and Marshland Study	M	170
Mukungwa (NMUK)	Gakenke	Gaseke-Karangara	Identified by IMP and Marshland Study	M	98
Lower Nyabarongo (NNYL)	Gakenke	Banga	Identified by IMP and Marshland Study	M	101
Lower Nyabarongo (NNYL)	Rulindo & Gicumbi	Mwange	Identified by IMP and Marshland Study	M	78
Lower Nyabarongo (NNYL)	Rulindo	Yanze	Identified by IMP and Marshland Study	M	152
Muvumba (NMUV)	Gicumbi	Gatuna	Identified by IMP and Marshland Study	M	297
Lower Nyabarongo (NNYL)	Gicumbi	Mwange-Kaguhu	Identified by IMP and Marshland Study	M	124
Kivu (CKIV)	Rutsiro	Koko	Prefeasibility	M	98
Rusizi (CRUS)	Rusizi	Gihitasi	Identified by IMP and Marshland Study	M	95
Kivu (CKIV)	Rusizi	Cyunyu (upstream)	Identified by IMP and Marshland Study	M	103
Kivu (CKIV)	Nyamasheke	Kigoya (downstream)	Identified by IMP and Marshland Study	M	148
			Total River/Lakes		34,200
			Total Marshlands		7,413

CHAPTER 8. INSTITUTIONAL

8.1. Stakeholder Engagement

8.1.1. Stakeholder Support

Successful establishment, management and rehabilitation of irrigation schemes require support from a quite number of multiple stakeholders. This is because, irrigation schemes in most developing countries including Rwanda have proved to be unsustainable after withdrawal of external assistance due to financial, technical and managerial constraints. Therefore, there is a need to gain a strong buy-in and ownership from all the important stakeholders of irrigation projects throughout the whole process.

Stakeholders in irrigation projects are individuals or groups who can affect or be affected by irrigation project's activities depending on the degree of their interest, influence/power or expertise in irrigation projects. Worldwide, one of the key challenges for the sustainability of any development projects/program is inadequate cooperation and collaboration among the projects' stakeholders. A stakeholder analysis in irrigation projects is necessary to capture the opinions, interests and concerns of different stakeholders that will likely affect or be affected by the project in order to identify the type of support that will be needed from them for successful implementation of the project.

Irrigation project in Rwandan context is complex in nature because it involves many stakeholders with different interest and power. Key among them include government institutions at central and district levels, farmers and farmers' organization, local communities, private operators, Development Partners, Non-Governmental Organizations, Civil Society Organization, Community-Based Organization, Faith-Based Organization, financial institutions, academia, etc. All these stakeholders provide various supports in irrigation projects. Key among these supports include establishing an enabling policy and institutional environment for an effective irrigation development, proximity extension services and farmers and institutional capacity building services, affordable financial services, post-harvest and storage solutions, market services, infrastructural services, etc.

This entails that irrigation projects should encourage activate participation of these stakeholders to ensure their full support and engagement for the successful irrigation projects' implementation.

8.1.2. Engagement with beneficiaries

The importance of engaging beneficiaries at an earlier stage is undoubtedly a strong and effective pathway to successful implementation of irrigation projects because it results into faster, less contested implementation, ownership and sustainability. Engaging stakeholders during and especially at the beginning of irrigation project helps to reduce and uncover risks and increase the stakeholders' buy-in. It is well documented that when key stakeholders, especially beneficiaries are adequately engaged in irrigation projects, their influence spreads far and wide.

The GoR through the Ministry of Agriculture and Animal Resources (MINAGRI) has institutionalized different mechanisms to engage agriculture sector stakeholders at both national and decentralized levels. At national level, functional Agriculture Sector Working Group (SWG) has been institutionalized as an essential forum for policy dialogue and coordination around key agricultural development issues. Members include Ministries and Development Agencies (MDAs), Development Partners, NGOs, private sector, civil society, farmers' organizations representatives, financial institutions and. ASWG is made up of four clustered Sub-Sector Working Groups (SSWGs) or Technical Working Groups for policy development, implementation and agricultural services delivery. These SSWGs include: (i) SSWG Cluster 1- Planning and Budgeting focusing on planning, budgeting, M&E and other cross-cutting issues such as, gender, environment, nutrition and capacity building; (ii) SSWG Cluster 2- Crop Development focusing on agricultural inputs, research, extension services, soil conservation, irrigation, mechanization and post-harvest; (iii) SSWG Cluster 3- Agribusiness, Markets and Export Development focusing on agribusiness development, agricultural export promotion, agri-finance, rural feeder roads; and (iv) SSWG Cluster 4- Livestock Development focusing on animal nutrition, genetic improvement, extension service in livestock, dairy, meat and small livestock promotion.

At District level, a functional Joint Action Development Forum (JADF) has been established as platform that ensures full participation of citizens in the local development process, promotes the culture of dialogue and accountability and enhances efficiency of development efforts and avoids duplication or redundant efforts. JADF members come from distinctly different backgrounds including local government, civil society organizations, private sector, and other local development partners. JADF meetings are a key platform facilitating the implementation of effective decentralization by providing a forum for agricultural service provision and development planning accountability.

In addition, a Development Partners Coordination Group (DPCG) has been established as the highest level coordination forum in the country under the leadership of MINECOFIN with the main responsibility of overseeing the entire aid coordination. Through this forum, agriculture sector partners' interventions are coordinated to ensure that they are aligned to the agricultural sector strategic and action plans and reinforce the planning, budgeting and implementation of the budget, program and projects. This forum is also another key forum of engaging different irrigation sector stakeholders.

Despite the presence of these platforms at national and district levels to support implementation of irrigation projects' interventions, inadequate institutional arrangement to engage stakeholders in irrigation projects has been highlighted among the key bottlenecks to ensure proper coordination of all the actors' interventions in irrigation projects in Rwanda. Based on the theory of stakeholders' engagement, it is essential that stakeholders participate fully in planning, decision-making, and implementation to integrate their knowledge, resources, and values in any particular irrigation projects.

Given the importance of irrigation in supporting Rwanda's agricultural transformation and resilience to climate change to support the country's economic growth, food security and nutrition as well as poverty reduction, it is an imperative for the GoR to establish a specific effective and functional irrigation platform that ensures engagement of all the stakeholders in irrigation projects for policy dialogue, information sharing, consensus-building, decision-making and implementation of practical solutions.

Particular frameworks should be given to an engagement model/institutional arrangement that facilitates active participation of private sector in irrigation. One of these is the Public Private Partnership (PPP) model which has the potential to facilitate an expanded role for the private sector in irrigation, mobilize expertise in the sector, and ensure medium- to long- term sustainability.

Key actions to be undertaken should first of all focus on identifying or mapping all the beneficiaries as primary stakeholders in irrigation projects in each specific irrigation site; determine their level of interest and power through a stakeholder analysis approach; assess the right approach or stakeholders' engagement model to support the project's implementation; clearly define each one's roles and responsibilities; establish a clear coordination mechanisms as well as institutionalize a clear M&E and accountability, learning and reporting systems.

8.1.3. Engagement of other stakeholders

Stakeholders' engagement in irrigation projects is the process of bringing in and involving individuals, groups and institutions that affect or are affected by irrigation projects directly or indirectly. These stakeholders are classified into two broad categories: core stakeholder (government, farmers, non-governmental organizations, private sector/services providers, development partners, trade unions, CBOs, FBOs, etc.) and other stakeholders (property developers, long-term institutional investors and under-represented groups such as women, youth, poor and other vulnerable groups).

Once these other stakeholders are identified and mapped, it is also important to determine their levels of interest and power (high or low), justifying why they should support irrigation development projects as well as how to engage them and manage their expectations. Literature suggests that stakeholders are engaged because of a number of reasons. Some of these reasons are related to (i) investment (they perceive that there would be return to investment); (ii) potential social, economic and environmental benefits (they expect that potential benefits for engaging are greater than not engaging); (iii) compulsion (they engage because they have been asked to do) and (iv) altruism (they engage because they believe it is right to do so).

The necessity to improve agriculture sector coordination and stakeholders' engagement is recognized in the current National Strategic Plan for Agriculture Transformation (PSTA4). Recent years have seen the emergence of joint planning, implementation, M&E and accountability, commonly known as Imihigo to enhance intra-and inter sectoral coordination systems.

PSTA4 highlights that there are clear strategic overlaps between the agriculture sector and other sectors. Some of these overlaps are observed between agriculture sector with the private sector development and youth employment sector for investments, commercialization, value addition, and trade; with environment, land and forestry sectors in land and water management and agroforestry; with the health, nutrition and food security sectors and with infrastructure, especially for feeder roads, irrigations, and market infrastructure. In addition, collaboration between agriculture sector with local governments is essential for the successful implementation of various activities since all the sectors' interventions are executed at decentralized entities. One of the key interventions of PSTA 4 is to increase the capacity of MINAGRI to cooperate and coordinate with these institutions, moving towards joint planning (and budgeting), as well as better information on implementation and impact through enhanced data collection. Furthermore, the GoR encourages strengthening dialogue with relevant civil society organisations, especially representatives of farmers, youth, consumers, and private sector organisations as a way of engaging them in agriculture sector development

8.2. Institutional Responsibilities

Rwanda relies heavily on agriculture for its economic growth. The Government of Rwanda's (GoR's) commitment for irrigation development is well articulated into the national development policies and plans. Irrigation is given ample considerations in Rwanda's ambitious national transformation agenda as an essential component and strategy for poverty reduction, food security and nutrition as well as climate change induced droughts mitigation.

Currently, there are about 148 irrigation schemes established in Rwanda covering an area estimated above 50,000 ha of Hillside, Marshland and Small Scale Irrigation. A quite number of these established irrigation schemes have been characterized by low performance where low water use efficiencies are prevalent and production levels are low resulting in low productivity and low incomes for farmers. Some built irrigation infrastructures including dams and field networks are lying idle or underutilized.

Irrigation systems cannot themselves ensure equitable distribution of water among water users and sustainable operation and maintenance of the systems without capable institutions to support them. A well functional institutional framework helps to clearly assign roles and responsibilities to different stakeholders to address some of the key constraints facing the irrigation sector in Rwanda such as, high cost of irrigation development; poor organization in schemes resulting into poor scheme management; inadequate technical capacities in both private and public sectors leading to poor performance in managing water distribution in terms of adequacy, reliability and equity in water distribution; inadequate functioning of market systems resulting into low and unpredictable market prices; inadequate transport facilities, lack of sufficient storage facilities and inadequate access to financial and extension services.

At policy level, the Ministry in charge of water resources management has defined clear enabling policy and regulatory frameworks to support sustainable investments in water resources for irrigation as well as other usages. Key principles and priorities within the national water policy framework include protection of the resource; regulation of appropriate use; precautionary of water resources management aiming at the prevention of irreversible risks, prevention of pollution; application of the principles of user-payer and polluter- payer and creation of user's associations for administrative management of resources use after consultation with other ministries and institutions concerned.

In line with the above framework, other ministries including the ministry in charge of irrigation have developed their sector strategies with respect to the use of water resources for their respective interventions.

Under its pillar 3 relating to productivity and sustainability, the National Agriculture Policy (2018) recognizes the need to build resilience against adverse events in farming communities through provision of irrigation and other agricultural inputs (improved seeds, quality fertilizers, etc.) to sustain crop yields. Promoting irrigation and sustainable water management systems is given great considerations in national agricultural policy and planning frameworks as it allows farmers to move from rain-fed to diversified, high value crops, thus increasing cropping intensity and land productivity. The policy recognizes that much as developing irrigation is a priority, the irrigation systems need to be efficient and sustainable, both in terms of its provision of water resources for sustainable agricultural productivity as well as the development and management of the irrigation systems.

With regards to institutional responsibilities, the ministry in charge of water resources management in its Water Resources Master Plan (WRMP), has established an institutional framework for water resources management at different levels including the central, catchment, and district as well as user levels. This institutional framework clearly defines the roles and responsibilities of each stakeholders in water resources management and development sector. The institutional framework established under WRMP involves a number of ministries (and affiliated agencies) including MoE, MINAGRI, MINECOFIN, MININFRA, MoH, MINALOC, MINICOM, MINEDUC, MIGEPROF, MoD, RDB, etc. having roles and responsibilities in water resources management. However, the coordination framework of these institutions remains inadequate.

In line with the above institutional framework, MINAGRI in collaboration with other institutions relevant to irrigation sector development has established different irrigation scheme operation and management models including Irrigation Water Users' Organizations (IWUOs), producers' cooperatives, District Irrigation Steering Committees (DISCs), District Irrigation Technical Committees, service providers. These institutional arrangements have been adopted as a way of promoting a coordinated, integrated and participatory approach at all stages of planning, implementation, monitoring and evaluation of irrigation interventions across all irrigation schemes. However, there still is insufficient coordination across all the above institutional arrangements and at all levels, there still exists low institutional capacities (human, technical and financial) which are critical to enhance development of irrigation with respect to irrigation project planning, design, implementation, and operation and maintenance as well as advisory services.

In addition, inadequate communication and collaboration among irrigation sector stakeholders (especially between central and District and/or decentralized levels) constitutes another challenge that limits most of irrigation schemes to be productive. In practice, the existing institutional framework does not support irrigation sector stakeholders to productively perform their roles and responsibilities. Due to inadequate coordination of these institutions, there is duplication of efforts during the implementation of some policy activities. Issues related to water use permit, especially for small holder farmers are also observed and this raises conflict between the agency in charge of water and the agency in charge of agricultural irrigation, smallholder farmers claim that water use permit is costly. Other policy issues arise where for instance, MINALOC/Districts and RAB advocate for the cultivation of food crops in irrigation schemes to meet food security targets while NAEB advocates for expansion of cash crops in irrigation schemes to meet export targets. This situation brings high competition over scarce irrigated lands between staple and cash crops. Furthermore, issue of registering IWUAs by RGB as legal entities has been also raised among the key challenges these organizations are facing.

The lack of functional M&E and mutual accountability systems also contribute to poor performance of established irrigation sector institutional framework in most irrigation schemes. The role of private sector within this institutional framework is still insignificant. Interventions towards promoting pure private sector-led or PPP models for irrigation schemes development, management and maintenance need to be given high priority within the new updated Irrigation Master Plan. For this to be possible, there is a need to come up with irrigation business cases that clearly presents commercial viability of a pure private –led or PPP irrigation project defining the extent to which the project has the potential to offer a private firm a sufficient financial return to enable it to recover any capital and operational costs as well as a suitable financial return on any investment given the opportunity cost involved.

Considering the GoR's plan to increase the areas under irrigation up to 102,284 ha by 2024 (PSTA4), there is a need to raise significant investments in irrigation, reinforce institutional capacities as well as strengthening the policy and institutional enabling policy environments to ensure that the established irrigation schemes are effective and efficient under the current IWRM frameworks. Key priorities to accelerate efficient and sustainable implementation of the new updated Irrigation Master Plan include the following:

1. Institutional, policy and regulatory reforms

For the new updated Irrigation Master Plan to be effectively implemented, there is a need to advance some micro policy, institutional and regulatory reforms. The government and other stakeholders have to consider all farmers as investors and not thinking that only big capital owners are investors. As it is difficult to have one voice for big number of small holders' farmers, there is a need to streamline enabling policy and regulation environments regarding the marketing of the agriculture produces for both domestic and external markets. This will protect small farmers against middle men leading to poor pricing and failures of farmers in their business. Prices for agriculture commodities especially for local market should be set based on real costs incurred by farmers including famers owned supplied labor, hired labor and other inputs. In case the production cost is higher than local prices, there should be subsidized prices. Therefore, there is a need to undertake some micro policy reforms such as review of the existing subsidy program or introduce subsidy policy on agriculture output to encourage people to farm and invest in agriculture easily, review the taxes policy on agricultural profits and reinforcement of agriculture insurance enforcement. Convenient infrastructures (Post-harvest infrastructure, industries…) have also to be availed to farmers to strengthen the market linkages.

2. Capacity building

Advancing adequate technical capacities in irrigation sector is critical to enhancing development of irrigation in terms of planning, design, implementation, and operation and maintenance as well as providing irrigation advisory services. Key practical strategic interventions include establishing continuous in-house training programs for irrigation personnel in both public and private sectors including farmers/irrigators; establishing continuous in-house training programs for value chains actors across all the irrigation schemes; promoting research and innovation on efficient, cost-effective, affordable and sustainable irrigation technologies, especially for hillside irrigation; institutionalizing in-house training programs for irrigation farmers' cooperatives/associations on cooperative management and promoting sustainable uptake of irrigation schemes from the point of view of end-users and adopters through strategic and systematic learning by all stakeholders and provision of incentives and subsidies.

3. Irrigation investment and financing

Inadequate financial capacities is highlighted among the key constraints in irrigation sector and the role of private sector to finance irrigation development and management remains insignificant. Some of the key strategic interventions to address this constraint focus on promoting Public Private Partnership sector- led models of irrigation development and management as a sustainable and quick win strategy to increase the areas under irrigation but also improve efficiency in management and maintenance of developed irrigation infrastructures. Other strategic interventions envision to attract private sector and external finance/investment for irrigation development including small scale irrigation through introduction of high-value horticultural crops with good productivity and strong marketing potential in irrigation schemes and establish an Irrigation Revolving Fund (IRF) or create a special irrigation fund window within existing funding schemes or initiate the creation of agriculture development banks (specialized for agriculture reality at low interest rates) to facilitate farmer's access to finance.

4. Monitoring and evaluation and accountability system

Irrigation projects involves a number of policies, programs and projects that touch upon distinct sectors such as environment, water, health, infrastructure, education, land, financial systems, and so forth. The implementation of irrigation projects not only increases the food production of an area when compared to rain-fed agriculture but also significantly improves the reliability of the production process by ensuring proper water control. However, irrigation projects may also cause adverse environmental and health hazards. Establishing a strong and functional M&E and accountability systems for irrigation projects is very critical as it clearly and unambiguously helps to identify the impacts of the projects. M&E supports to appraise irrigation projects' performance objectively, reflect on what has been learned for future use, and adjust policies whenever necessary. Key strategic interventions to support M&E and accountability systems under the new updated Irrigation Master Plan should focus on establishing an Irrigation Management Information System (IMIS) for timely and reliable data collection at central and decentralized levels; setting-up both environmental protection and management indicator standards and public health and safety indicator standards to be monitored.

Based on the above priorities, the following table presents key institutions identified and their roles and responsibilities in the implementation of the new updated Irrigation Master Plan:

Table 8-1: Institutional roles and responsibilities

N/S	Institution	Roles and responsibilities
	MINAGRI (with affiliated agencies-RAB and NAEB)	Lead the overall coordination of the policy, institutional and legal reforms needed for efficient implementation of new Irrigation Master Plan and ensure their implementation. These reforms include the review of the current irrigation schemes operation and management models, irrigation projects planning, operation and management, promotion of delivery of GoR irrigation services via a private-led entrepreneurial model,

		improvement of farmers' access to irrigation equipment/materials, proximity extension services, inputs, training of irrigation personnel in public and private sectors, establishment of a professional irrigation association in Rwanda to further irrigation profession, and ensure a robust and functional M&E and accountability mechanisms is in place through establishment of an Irrigation Management Information System (IMIS) for timely and reliable data collection at central and decentralized levels
	MINECOFIN	Mobilize domestic and external funds/finances for investments in irrigation projects, provision of fiscal incentives to promote private sector investment in irrigation and establish an Irrigation Revolving Fund (IRF) or create a special irrigation fund window within existing funding schemes to ensure adequate financial capacities are available to implement irrigation projects projects or initiate the creation of agriculture development banks (specialized for agriculture reality at low interest rates) to ensure famers's access to finance.
	MINALOC/District (with affiliated agency RGB)	Mobilize farmers and support in strengthening governance in farmers' irrigation cooperatives and/or associations and community-based irrigation schemes through capacity building programs in cooperatives management, entrepreneurship and business development and ensure decentralized proximity extension services and capacity building to farmers
	MININFRA (with affiliated agencies-WASAC, RTDA, EDCL, EUCL)	Ensure provision of utility services (electricity/energy), access roads and other agricultural and livestock infrastructures to support irrigation development projects
	MoE (with affiliated agencies-REMA, RWFA, RLUMA)	Ensure proper and sustainable conservation, protection and development of water resources to support efficient irrigation and ensure the safeguard of green and climate resilience for growth of the economy and ensure proper use of land resources in irrigation projects
	MINICOM (with affiliated agencies-RCA, NIRDA, RSB)	Support agricultural value chain development in irrigation schemes, regulations for commodity pricing, agro-industry development, linking farmers to local, regional and international markets and famers' cooperative registration, training in farmers' cooperatives and/or associations management
	MoH (with affiliated agency-RBC)	Support in setting-up public health indicator standards in irrigation schemes and promotion of agricultural innovations that respond to nutritious food requirements
	MINEDUC (with affiliated agencies-WDA, REB, UR)	Support in provision of technical and specialized human skills required in irrigation development, operation and management
	MICT&I (with affiliated agency-RISA)	Promote technologies and innovations in irrigation to improve crop productivity
	MIGEPROF	Promote gender mainstreaming in irrigation policies, programs and projects
	RDB	Attract private sector investments through PPP or purely private sector-led investment in irrigation development projects, management and maintenance by establishing irrigation business cases

	Development Partners namely, FAO, EU, WB, DFID, IFAD, USAID, Enabel (BTC), GIZ, Netherlands, JICA, Swiss, etc.	Provide funding, capital investment and technical support for the development of irrigation projects
	Private Sector including individual farmers, farmers' organizations/ cooperatives, inputs dealers, agro-processing industries, traders, consumers, agri-business enterprises, private Higher Learning Institutions, financial institutions (including commercial banks, MFIs, SACCOs, insurances, etc.)	Support in provision of extension and advisory services, financial services, technical support, information for agricultural markets, linking farmers to markets, capacity building, and provision of services for the operation and maintenance of irrigation schemes infrastructures
	Community-Based Organizations, Civil Society Organizations including Local and International NGOs and Faith-Based Organizations	Support in providing training to farmers in good and innovative agronomic practices, assist farmers with new agricultural technologies. linking farmers with viable markets

CHAPTER 9. MARKET LINKAGES & INVESTMENT REQUIREMENTS

9.1. Introduction

Robust supply chains are essential for the long-term viability of irrigation projects, both upstream and downstream of the irrigated crop production. The upstream supply of inputs, equipment and mechanization services is established through the demand from farmers, which spurs the development of commercial suppliers, provided that affordable transport links and finance are available. The downstream marketing of irrigated produce requires the establishment of trust between the farmer and the buyer and is influenced by the reliability of quantity and quality, and economic factors such as transport cost and seasonal price fluctuations. An effective market system which is profitable for both the grower and the buyer is critical to the success of an irrigation project and can simultaneously solve the challenge of financing inputs.

9.2. Complementary on-farm work and inputs

For the purposes of the IMP, on-farm work refers to developments that would not normally be included in the construction contract of an irrigation scheme. The work should contribute to improved operation or productivity and can include hardware such as in-field irrigation equipment and machinery, or “soft” interventions such as training and capacity-building. Inputs are materials required for crop production, and include seed or seedlings, lime, compost, fertilizers, agrochemicals and packaging. While some work can be achieved by farmers’ labour, like making tertiary canals, drains, furrows and compost, the provision of services is required for the most part. Some of the most beneficial services and innovations are described below.

9.2.1. Irrigation equipment

The water-use efficiency (volume of water used per unit of crop produced) and labour efficiency of existing surface irrigation schemes can be improved by farmers converting to overhead or drip irrigation. Some hillside schemes offer the chance to use pressurized water without pumping, otherwise energy in the form of fuel or electricity is required. There is increasing interest in MINAGRI in developing pumped schemes from rivers and lakes without storage dams, which lend themselves to more efficient irrigation and better flow control. The inherent labour-savings and flexibility of application make it worthwhile for commercial farmers to invest in and maintain their own on-farm equipment.

Centre-pivot irrigation is often the preferred choice for large-scale farmers, but requires a relatively high initial investment, and large, flat expanses of land, and can be wasteful of limited command areas. For small individually-owned irrigation plots, sprinklers or drip are more economically attractive.

9.2.2. Farm machinery

Although the small plot sizes on marshland and steep hillside schemes preclude the use of 4-wheel tractors, 2-wheeled power-tillers are suitable for tilling small plots, including wet paddy fields. Their capacity is often larger than a single smallholding so owners can provide tillage services for other farmers. Irrigation allows farmers to control soil moisture levels which widens the window for tillage operations and can make mechanization more effective than under rain-fed conditions.

Access to finance is often a constraint to investing in farm machinery, and facilities for repairs and supplies of spare parts are lacking in many rural areas. MINAGRI continues to promote the adoption of farm machinery through RAB's Agriculture Mechanization Unit, subsidizing the landed cost of imported equipment, and facilitating lease finance arrangements between banks, suppliers and cooperatives. Progress has also been made in training operators and establishing mobile workshops. Ultimately, the private sector should be the driver of expanded mechanization, comprising dealers, manufacturers, workshops, contractors and individual farmers. This is recognized in the PSTA4 (2019-2024) program, which intends to establish the Agricultural Development Fund to provide competitive funding and matching grants that can be used for acquiring machinery, and to promote PPPs through financial incentives.

In order to facilitate mechanization in existing and planned irrigation schemes, the provision the basic infrastructure for a central workshop with electricity should be considered, for leasing to a private company. Contractors or workshop operators will then have a secure base and ready market for services within the scheme. Provided that the type of machinery and pricing is appropriate, and with competitive finance, viable businesses can be established. The types of equipment that would be appropriate include:

- Power-tillers for schemes with small plots hillside and marshland (with steel lugged wheels for puddling in paddy)
- Tractors (60-100hp) for larger areas with good access and without steep slopes;
- Tillage implements – ploughs, cultivators, rippers, etc.
- Planters for maize, beans, etc.
- Sprayers - mounted boom-sprayers, knapsack sprayers
- Threshers for rice, beans, and shellers for maize
- Light trucks for transport

9.2.3. Crop protection structures

Certain high-value crops such as flowers, some vegetables and nurseries, justify the use of greenhouses or poly-tunnels to create a favourable micro-climate, fitted with drip, hydroponic or simply with hand-operated hose irrigation. The area will always be a small fraction of the total irrigated area. Other simpler methods are fleece or nets for protection from pests, useful for susceptible high-value vegetables. Trellises are commonly used for tomatoes and climbing beans to improve production and quality, and reduce wind-damage.

Recommended interventions to promote the adoption of structures include:

- Facilitating the supply of trellising wire, hooks, twine, and poles
- Establishing fast-growing agro-forestry species in uncultivated areas to produce poles for trellising
- Matching-grants or subsidies for poly-tunnels with micro or drip irrigation kits
- Facilitating the supply of crop netting, fleece and polythene sheeting
- Exemption for import duties for selected items if local manufacturing capacity does not exist

9.2.4. Training

MINAGRI and its agencies (RAB, NAEB), with help from development partners and localized NGO programs, put a lot of effort into extension and training. Irrigation requires specific training in water control, scheduling, improved application techniques, and maintenance. To improve the output from existing schemes, and ensure that new projects become commercially-viable, there will be an increased need for training in irrigation.

9.2.5. Market information systems

The revival of the useful eSoko system (eSoko+) will contribute to improved awareness of local market prices amongst growers. The high penetration rate of mobile telephones (76.6% as at March 2018[124]) and almost complete 4G LTE geographic coverage (92.5%[125]) makes Rwanda well-placed to benefit from mobile and internet based information systems. The platform can not only assist with marketing and inputs, but also with financial services. The current eSoko platform is somewhat cumbersome to access and navigate, and improvements are necessary. Maintaining and updating a market information system in the fast-changing IT environment can be difficult for a government ministry. A successful model for a sustainable service is the privately owned eSoko in Ghana (https://esoko.com/), which is more user-friendly, and has extended its operations to several other countries. This company derives its income from larger agribusinesses and projects, but still relies on Ministry of Agriculture's market data collection, and in return provides free access to information to farmers and traders.

9.2.6. Transport

Commercial irrigated farming is dependent on transport services, both for inputs and delivering produce. While only larger-scale farmers or cooperatives can justify the investment in trucks,

[124] *Rwanda Utilities Regulatory Authority (RURA), Active Mobile Subscriptions report, April 2018*
[125] *https://africabusinesscommunities.com/tech/tech-news/rwanda-almost-achieves-nationwide-4g-lte-network-coverage/, accessed 20 May 2019*

small-scale farmers often used hired transport, motorcycles or animal-drawn carts to move their goods. Public investment in the feeder road network will improve access to irrigation schemes, and should bring down transport costs and delivery times. Refrigerated transport is desirable for fresh produce to preserve quality and reduce wastage, and there will be increasing need for investment in this type of equipment if high-value crops are to become more widely grown on irrigation schemes.

9.2.7. Inputs

There is a well-established system of supplying common fertilizers and seeds to the farming community, supported by MINAGRI’s national Crop Intensification Program. However, irrigated high-value crops require specialized seeds, fertilizers and agrochemicals which are often difficult to find outside major centers. Due to the low demand, agro-dealers are unwilling to stock specialized inputs without firm orders. Cooperatives and out-grower schemes can overcome this hurdle by ordering in bulk and distributing to their members.

Lime is required on many of Rwanda’s soil types, and is essential to make best use of applied fertilizer and achieve optimum yields, but usage is generally low except where projects specifically supply it to beneficiaries. The scarcity of supply and cost of transport can make small-scale farmers unwilling to purchase and apply lime regularly, so there is a need to improve availability and affordability.

9.3. Market-orientation

Irrigation schemes implemented by GoR have been generally categorized as being intended for food crops or high-value crops. Food crops include cereals such as rice and maize, pulses such as beans and soya, or root crops such as cassava or potatoes. Fruits, vegetables and cut-flowers are regarded as high value crops. Due to the high cost of construction, hillside schemes have been encouraged to produce high-value crops, which offer a higher return on investment. It has transpired, however, that high-value crops normally occupy only a minor part of existing hillside schemes, with the balance being food crops or fallow. Marshland schemes, being cheaper to build, are expected to be planted to food crops, especially rice.

9.3.1. Food crops versus high value crops

At plot- or farm-level it is possible to have the entire irrigated area devoted to high-value crops throughout the year, although there would normally be some food crops such as maize for rotational purposes, unless the area was planted to perennial fruit crops like avocado or passion-fruit. However, on an irrigation scheme with many farmers, it is very unlikely to have full-utilization with high-value crops, and food crops would occupy a significant share of the land, especially in seasons A and B. The estimated returns from different cropping patterns were presented in the earlier Irrigation Potential Report, and the results have been reproduced in the following table:

Table 9-1: Expected annual gross margins from irrigated cropping

Stratum	Crop pattern	Gross margin RWF/ha/yr
Marshland	Rice, 2 crops p.a. (100%)	1,385,950
	Food + horticulture (20-50%)[1]	2,866,292
	Sugarcane (100%)	802,307
Hillside	Food + horticulture (20-50%)[1]	2,866,292
	Fruit trees (55%) + food + horticulture (5-15%)[1]	1,844,976
	Irish potatoes + food + horticulture (25-50%)[1]	3,411,516

Note: [1] Lower % for horticulture in seasons A and B, and higher % in season C.

While the share of horticulture in the proposed mixed cropping patterns during seasons A and B may be regarded as conservative, it is not considered to be so when looking ahead to future irrigation development in Rwanda. Furthermore, a significant share of horticultural crops produced for the local market in seasons A and B will continue to be rain-fed. Therefore, market demand will limit the area that can be planted to horticultural crops.

Marshland irrigation schemes are dominated by flood-irrigated paddy, but can equally be used for upland crops by using basin or furrow irrigation. In fact, the build-up of persistent grass weeds in some mono-cropped paddy schemes signals the need to occasionally change crops and irrigation methods, and allow better weeding by hand or herbicides. Sugarcane is suited to marshland irrigation, but the farm-gate price for cane is unfavourable for out-growers. It is only considered commercially viable for large-scale production (>5,000 ha) in an integrated model including crushing and refining.

9.3.2. Export *versus* local high value crops

According to NAEB, the volume of horticultural exports in the year 2016/17 was 19,227 T of vegetables and 5,918 T of fruit. When compared to the total production of fruit and vegetables, horticultural exports represent only a small fraction, less than 5%, as shown in the following table.

Table 9-2: Horticultural production in Rwanda, 2017

Product	Area harvested, FAO 2017,ha	Total production, FAO 2017, T	Exports, NAEB 2016/17, T	Export %
Vegetables	111,130	604,921	19,227	3.2%
Fruit	22,910	142,240	5,918	4.2%
Total	**134,040**	**747,161**	**25,145**	**3.4%**

The area of irrigated land dedicated to export horticulture is currently estimated at around 2,000 ha[126], and production is expanding rapidly. In 2015, NAEB announced a target for horticultural export earnings of USD140m by 2020, which they estimated would require 10-20 export companies on 2,000 ha of nucleus farms and 6,000 ha under out-growers. Although, the target will not be achieved by 2020, it is still achievable and gives an indication of the area of irrigated land that will be required by the sector. Therefore, although export horticulture will play an important role in future irrigated production, at 8,000 ha of the targeted 100,000 ha, it will occupy a relatively small part of the total irrigated area in Rwanda.

Land used for export horticulture must be certified to meet strict standards, as specified by importing countries. This is not to say that crops for the local market cannot be grown on certified land, but there should be minimal risk of contamination of soil or water supply with chemicals that are prohibited under certified agricultural practices. For practical reasons, certified land in an irrigation scheme should be in a discrete zone, preferably upstream in the water supply system, and at a higher elevation in relation to non-certified land, so that the risk of contamination through irrigation water and runoff is minimized.

9.3.3. Conclusions on market orientation

According to MINAGRI, a total of ~50,000 ha have been developed for irrigation by June 2018, and Rwanda is targeting to achieve 100,000 ha of land under irrigation by 2024. How the land is used will depend on a number of factors, not least of which is its geophysical characteristics, including elevation, climate, soil type, drainage, and proximity to markets. However, the wishes of the farmers and market-demand will ultimately determine what crops are produced, and it must be noted that these can change over time. This is entirely in line with the current policies of government and development partners, as stated in the National Irrigation Policy and PSTA-4, which both envisage demand-driven irrigation development with a much increased involvement of the private sector. While it is useful for planning purposes to allocate specific irrigation developments to specific markets, i.e. food crops, high-value local crops, or high-value export crops, it is necessary that market-orientation remains flexible throughout the planning, implementation and operation phases of an irrigation project.

9.4. Market linkages

The very purpose of irrigation development is to increase the productivity of farming and raise the incomes of farmers, which requires that the produce be profitably sold at market. Therefore, the measure of success of an irrigation project is not the increase in irrigated area, or even the volume of production, but the increase in disposable income earned by farmers through the production of irrigated crops. Transport systems form the essential backbone of market

[126] *Personal communications, NAEB and Garden Fresh Ltd, 10 May 2019*

linkages, and information technology will play an increasingly important role. The necessary linkages between farmers and markets include both the supply of farm inputs and equipment (upstream/backward), and the disposal of surplus production to processors, wholesalers, aggregators or retail markets (downstream/forward).

9.4.1. On going interventions supporting market linkages

The Government of Rwanda (GoR) and its development partners are well aware of the importance of improving market linkages, as evidenced by the number and coverage of projects and activities aimed at this area. Those with impact on the irrigation sector include:

- MINAGRI – Rwanda Agriculture Board's (RAB) Post-harvest and Biotechnology Department; National Agricultural Export Board's (NAEB) Horticulture Division
- MINICOM - Market access for sustainable business development; Great Lakes Trade Facilitation Project (GLTF) 2016-2020
- World Bank (WB) – Program for Results (PforR), a comprehensive multi-donor project managed by WB, 2018-2021, which supports the first three years of PSTA4 ; Sustainable Agricultural Intensification and Food Security Project (SAIFSP) - The business and market development pathway focuses on building inclusive and durable market linkages through which strong and self-reliant cooperatives are able to sell increased volumes of produce.[127]
- DfID - Improving Market Systems in Rwanda for Agriculture (IMSAR) project, 2018-2023
- USAID - The Feed the Future Rwanda Hinga Weze Activity/ Private Sector Driven Agricultural Growth (PSDAG) project, 2017-2022. Hinga Weze intends to increase access to post-harvest equipment and facilities, market information, and credit and financial services. It also aims to equip over 600 new hectares of farmland with new irrigation infrastructure.
- Agriculture Private Sector Leverage Strategy
- AgriProFocus –a platform for building market linkages, supported by Dutch charitable foundations and companies

9.4.2. Logistics

Road – Rwanda is relatively well-connected by roads, despite the hilly terrain, with a density of classified roads of 0.62km/sq.km. Including unclassified roads, the density is 1.42 km/sq.km. The following table shows the composition of the road network as of June 2018.

[127] World Bank Group: Project Information Document Sustainable Agricultural Intensification and Food Security Project (SAIFSP), Concept Stage, 01-May-2018

Table 9-3: Distances of existing road network

Class	Distance, km
National roads	2,749
District roads, class 1	3,906
District roads, class 2	9,706
Unclassified roads	21,145
Total	**37,506**

Source: RTDA, 2019

All roads which are not National roads are regarded as feeder roads, which are important connections to agricultural production areas and markets. The Ministry of Infrastructure (MININFRA), through its Road Transport Development Agency (RTDA) has placed a lot of emphasis on improving feeder roads. During the period 2013-2018, a total of 2,486km of feeder roads were rehabilitated, and under the National Strategy for Transformation (NST) which extends until 2024, a further 3,085km of feeder roads are planned for upgrading or rehabilitation. These works will be distributed over all districts on roads classified as below:

Table 9-4: Planned feeder road rehabilitation and upgrading

Classification	Distance, km
District class 1	300
District class 2	585
Unclassified – primary 4 (P4)	1,100
Unclassified – primary 5 (P5)	1,100

Source: RTDA, 2019

Only 22% of feeder roads are paved, which means that there is a heavy demand for periodic maintenance to keep them in good condition, which is an area where RTDA has under-performed[128]. Upgrading and rehabilitation projects are normally funded by development partners or DFIs, whereas routine maintenance is usually funded from Government finances.

When identifying roads for rehabilitation, RTDA takes due consideration of agricultural potential, and gives a weighting of 35% to this aspect in its selection process. A Roads Master Plan for Rwanda is expected to be completed by 2020, and it is recommended that the plan considers the priority irrigation sites identified in the updated Irrigation Master Plan so that the development of production and transport links are aligned.

[128] *RTDA Annual Report, 2017/2018*

One-Stop Border Posts (OSBPs) – Rwanda has established OSBPs at 5 key border crossings, namely Kagitumba on the Ugandan border, Rusumo on the border with Tanzania, Nemba and Ruhwa with access to Burundi, and Rabavu on the border with DRC. Also, a new OSBP is being built at Gatuna, bordering Uganda. These OSBPs speed up the clearing and transit of goods.

Rail – Rwanda currently has no rail system but a standard guage railway link from Isaka in Tanzania to Kigali is planned, which will connect Rwanda to the port in Dar es Salaam. When operational, this should lower the costs of importing farm inputs such as fertilizer, and exporting commodities to regional and world markets. In 2017 World Bank reported that, compared to its neighbors, Rwanda has the highest transport costs estimated at 40% of value of imports or exports; these costs are about 12% and 36% in Kenya and Uganda respectively[129] There are also preliminary plans for a rail link between Kigali and Kampala in Uganda, which would further connect to Nairobi and Mombasa in Kenya.

Air – Air-freight is required for the export of some perishable high-value crops, such as cut flowers and vegetables for the European and Gulf markets. Kigali International Airport provides access for cargo on international flights, and NAEB has been instrumental in building cold-room facilities and negotiating competitive air-freight rates with carriers. A new international airport is under construction in Bugesera, a 40km drive south-east of Kigali. When complete, it will offer increased freight opportunities for exporters.

9.4.3. Information technology

Most modern trade is reliant on mobile telephone or internet connectivity, even for small scale farmers. Fortunately, Rwanda ranks very highly in Africa, with coverage by 4G network claimed to be 95% of the population (market information, finance, growing advice, new apps etc)

9.4.4. Electricity

Most existing irrigation schemes have been sited and designed to deliver water by gravity in order to reduce operating costs and avoid costly transmission investments. However, Rwanda has begun to exploit new sources of energy, including methane from Lake Kivu, and peat deposits, and is in the process of strengthening its transmission network. Rwanda currently only has 218 MW of installed generation capacity. According to the International Energy Agency (IEA), Rwanda's national electrification rate is estimated at 30% (12% in rural areas, 72% in urban areas[130].

[129] World Bank: Lake Victoria Transport Program - SOP1, RWANDA, Project Information Documents, 03-Apr-2017
[130] USAID Power Africa Factsheet, Rwanda, https://www.usaid.gov/powerafrica/rwanda

9.4.5. Backward market linkages

All irrigated cropping requires a supply of basic inputs, such as seed or seedlings, fertilizers and usually agrochemicals. The Government has been at the forefront of providing inputs for staple crops, usually with subsidies, and it may be possible for growers of irrigated food crops to continue to access these in the future. Subsidized inputs can be justified on the grounds of food-security, or even social welfare, but it should not be necessary to subsidize inputs for irrigated cropping where the yield potential is much higher than for rain-fed crops. Furthermore, irrigated crops will often require specialized inputs which are not provided under government programs. It is desirable that private sector is the sole supplier of inputs and finance to irrigation farmers, and that they offer the full range of inputs at competitive prices. However, it is often a question of volume, and hence profit, which determines whether a company will invest in additional outlets, stock or financial products. Until irrigation schemes become fully utilized and farmers are making profits there will be a need for targeted interventions to incentivize private sector companies to provide the products that farmers need. This could be in the form of results-based incentives based on uptake in certain locations, or direct investment in agri-businesses to expand their impact, such as the investments by AgDevCo under DfID's IMSAR program (see following box).

Box 9-1: AgDevCo

AgDevCo invests funds from government and non-governmental donors on a commercial basis in viable and compliant agribusinesses. Its objective is to commercialize agriculture in Africa and have a positive impact on smallholder farmers, job creation and productivity. Since 2016, AgDevCo has invested $6.45m in 3 agri-businesses in Rwanda in the form of debt and equity, namely Kigali Farms Ltd (mushrooms), Uzima Chicken (day-old broiler chicks), and Minimex Milling (maize milling).

Source: https://www.agdevco.com*; accessed 23/05/2019*

Contract farming arrangements can provide some of the input requirements for farmers, for example seeds or seedlings for horticultural crops, and hence reduce the need for farmers to finance their inputs (see box 9-2 below). Companies offering out-grower contracts tend to limit their exposure by excluding fertilizers which can be used on other crops. For contract farming to work well there has to be a high degree of trust between the parties, and limited opportunities for growers to sell their produce to other buyers, for example with specialized horticultural crops.

9.4.6. Forward market linkages

Successful crop marketing arrangements for fresh produce will minimize the amount of wastage *en route* from field to market, therefore satisfying the buyers' quality requirements, and provide the producers with an acceptable return. Below are two examples of efforts to improve market linkages for fresh produce.

Box 9-2: Garden Fresh Ltd

Garden Fresh is a private company engaged in the production and export of vegetables with markets in the UK and Europe. It has its main 20 ha production site at Kagitumba in the Eastern Province, where it grows export crops under centre-pivot and sprinkler irrigation. It also has out-growers on a further 20 ha, and is continuing to expand. It offers inputs, growing programs and technical advice to its out-growers.

Source: Garden Fresh Ltd, Kigali, 8 May 2019

Box 9-3: Kigali Wholesale Market

Kigali Wholesale Market is an initiative by NAEB to relocate and establish a modern fresh produce market in Kigali. Phase 1 will have a capacity of 50,000 t at a cost of $16.1m, while phase 2 will add a further 150,000 t at a cost of $10.5m. It is intended to be a PPP with a private operator. The investment intends to replace the informal market system which is overcrowded, unhygienic, and does not offer transparent pricing or traceability.

Source: Rwanda Development Board, May 2019

Non-perishable produce is less demanding on logistics, but small-scale growers still require support to get full value for their produce. Cooperatives are a useful vehicle for aggregating crops and negotiating better prices with buyers.

9.4.7. Recommended interventions for the public sector

While there are a multitude of NGO and donor agency projects helping to establish and strengthen linkages between small-scale farmers and markets, the government and its agencies have an important role to play. In a review of market linkage interventions in developing countries, FAO have developed guidelines to improve the success rate of these activities[131] Among their recommendations are several that are relevant to the public sector that oversees activities at a national level:

[131] *Approaches to linking producers to markets; Food and Agriculture Organization of the United Nations Rome, 2007*
[13] *by Andrew W. Shepherd Agricultural Management, Marketing and Finance Service FAO Rural Infrastructure and Agro-Industries Division*

- Fostering **coordination, communication and collaboration** between linking organisations. This should also entail mapping the various on-going and planned activities. This should include the **private sector** to learn of their direct efforts to establish linkages and understand their requirements.
- Address the **financing requirements,** which are essential for farmers to obtain inputs and equipment. This can include facilitating arrangements between banks, farmers, suppliers and marketing companies so that ensure credit is recovered by the lending institution.
- **Develop appropriate institutions**. Government should address the need for institutions that can support agribusiness development. These include market information systems, agricultural extension, quality certification quality control measures, agricultural research support and farm management and agribusiness training.

Some guiding principles offered by FAO for market linkage interventions include:

- Be realistic about markets – export markets, particularly for fresh produce, have demanding standards which smallholders find difficult to achieve, and the growing domestic market deserves due attention.
- Avoid interventions that benefit some farmers at the expense of others. For example, building linkages between a particular irrigation project and a marketing company may result in existing suppliers being dropped.
- Always consider the sustainability and scope for scaling up of intended interventions, and avoid the temptation to subsidise unduly. The objective should be to develop market linkages that are self-sustaining and can be replicated, without the need for recurrent subsidies.

9.5. Probable costs, financing and cost recovery

9.5.1. Investment and operating costs

The table below shows the probable range of investment and operating costs expressed in USD per irrigated hectare.

Table 9-5: Probable investment and operating costs by domain, USD/ha

Domain	Investment costs $/ha	O&M costs $/ha
Marshland, diversion, gravity	1,500-4000	50-100
Marshland, dam, gravity	16,000-20,000	150-200
Hillside, dam, gravity	20,000-30,000	200-300
River/lake, pumped	6,000-10,000	300-500
Groundwater, pumped	4,000-10,000	400-600
SSIT	3,500-6,000	600-800

The investment costs can vary widely within a given domain, due to topography, distance from the water source to the irrigated area, complexity of the irrigation network, among many other factors. O&M costs are generally related to investment costs, except in the case of pumped systems where energy is the main cost. Some examples of investment and O&M costs for various types of schemes in Rwanda and elsewhere in Africa are provided in Annex 6, together with estimated costs for new schemes, and the scope for private investment.

The construction of dams for storage greatly increases the cost per irrigated hectare, but can bring added benefits of flood control and multi-purpose opportunities. Projects which pump directly from rivers and lakes avoid expensive dams but incur higher operation costs due mainly to energy consumption. From a financial perspective, the river/lake projects are more attractive as the impact of higher future operating costs is outweighed by savings in the initial investment, as shown in the following simplified example.

Table 9-6: Cost implications of marshland v. pumped river/lake irrigation schemes

Project type	Investment cost, $	Future operating costs 25yrs, $	NPV @ 10% ¹
Marshland/dam, gravity, 500 ha @ $20,000/ha and $200/ha O&M	- 10,000,000	- 2,500,000	- 9,916,095
River/lake, pumped, 500 ha @ $8,000/ha and $400/ha O&M	- 4,000,000	- 5,000,000	- 5,286,735

¹ NPV = net present value at a discount rate of 10% p.a. over 26 years

Most publicly-funded irrigation schemes in Rwanda have been designed to be gravity-fed in order to eliminate energy consumption and reduce operational costs. While this has been a deliberate policy by GoR, the need to reduce investment costs and encourage private-sector involvement makes pumped schemes without storage a priority for future irrigation development.

While diversion weirs are cheaper than dams, their application is limited by their particular hydrological requirements (perennial flow, low risk of flooding). They can be a cost-effective method of developing irrigation downstream of a dam constructed primarily for other uses (e.g. hydro-power) which provides flood control and a steady flow of water.

9.5.2. Rehabilitation and modernization of existing schemes

Historically, the cost of rehabilitation in Sub-Saharan Africa has varied widely, from below $1,000/ha to over $10,000/ha, with a reported average of $8,233/ha[132]. However, projects which were deemed to be successful (with economic internal rates of return of 10% or higher at project completion), had an average cost of $3,488/ha, of which $2,303/ha was spent on

[132] A. Inocencio et al; Lessons from Irrigation Investment Experiences: Cost-reducing and Performance-enhancing Options for sub-Saharan Africa, y International Water Management Institute, August 2005

works, and the balance on “soft” interventions, such as building the capacity of organizations. MINAGRI budgeted for expenditure of RWF7.44m for 2,000ha of rehabilitation for the period 2013-17, approximately $6,000/ha[133].

It is necessary that investment in rehabilitation should not simply represent deferred maintenance, but should make the scheme work better and improve O&M[134]. The benefits of a successful rehabilitation and modernization project should include:

- Improved quality of service and greater satisfaction among water users, leading to higher cost recovery (increased recovery rates or higher user fees).
- More efficient operations (and possibly easier maintenance), leading to savings in O&M costs.
- Possibly increased productive area by supplying previously abandoned areas (e.g. tail reaches of gravity schemes).
- Possibly higher average yields due to timely supply of water at critical times, or increased cropping intensity.

Increased fee collection alone will not justify the cost of rehabilitation works, but it should be an additional benefit. To be economically viable, the investment must lead to increased production, either through a larger irrigated area, higher productivity, or both. Taking a theoretical 200 ha marshland rice scheme producing 9 t/ha per year, a 10% increase in production would justify an investment of $1,500/ha (EIRR 15%) but spending $2,000/ha would be marginal (EIRR 9%). On the other hand, it would take a 50% increase in irrigated area to justify an investment of $1,500/ha with no increase in average yield. An analysis of rehabilitation and modernization costs and benefits is provided in Annex 7.

It is proposed that an average cost of $1,500/ha is provided for rehabilitation and/or modernization of schemes which warrant it. Technical assessments and full consultation with users and WUOs are required to assess the expected costs and realistic benefits. Works should lead to improved service delivery and efficiencies. Lining of canals would only be justified if it significantly increased productive area or average yields (through increased water availability). Part of the cost would be applied to training (O&M and farming), and building the capacity of WUOs so they can ensure that regular maintenance is done on time, and to introduce cost-reflective tariffs.

[133] *National Irrigation Policy & Action Plan 2013, MINAGRI*
[134] *FAO. 2018. Guidelines on irrigation investment projects. Rome.122 pp. Licence: CC BY-NC-SA 3.0 IGO; Ch.3: Intensification of Existing Irrigation Systems*

9.5.3. Financing

In terms of financing, it is the stated objective of government and its development partners that there should be greater private-sector participation in investment and operation of irrigation projects. In Africa it has proved to be difficult to attract private investment in irrigation infrastructure which serves multiple users, especially where smallholder farmers make up a significant portion of the users[135]. It is easier in economies with well-developed commercial farming sectors, where demand is more certain and the willingness to pay cost-reflective tariffs is higher. Rwanda, which has a nascent commercial farming sector and is usually unable to offer large areas of land to agricultural investors, must find innovative ways to attract private investment in irrigation. One solution has been the Small-Scale Irrigation Technology (SSIT) program where government subsidizes up to 50% of equipment costs and private-sector farmers cover the balance of the investment cost and are responsible for all O&M costs (see Box 4-6 below). Another example is the Gabiro Agri-Business Hub project in Eastern Province where government provides the bulk water system and investors are offered blocks of land on along-lease on which to develop their own irrigation systems (see Box 4-5 below).

Public investment in irrigation has been a very significant part of MINAGRI's budget averaging $36.5m over the 5 years from 2011/12 to 2015/16[136], and cost per hectare developed as become unacceptably high. Therefore, there is a need to prioritize developments with lower per-hectare investment costs in order to achieve the Governments targets for new irrigated area.

Scope for private investment

Private investment can take several forms, including contributions to common infrastructure, development of on-farm infrastructure within a scheme, or even unskilled labour for excavation or building terraces. It is implicit in demand-driven irrigation projects that the beneficiaries of public investment must be willing to contribute within their means to the construction of irrigation infrastructure. The scope for private participation in a project will depend on the intended water users, the design of the scheme, and the potential for large-scale farming. Broad estimates of the share of private investment can be made for each irrigation domain, based on the analysis of different components that make up an irrigation project (see Annex 6). The results are given in the following table.

Table 9-7: Scope for private investment in irrigation projects

Domain	Small-scale	Large-scale	Private share %

[135] *FAO. 2018. Guidelines on irrigation investment projects. Rome.122 pp. Licence: CC BY-NC-SA 3.0 IGO.*
[136] *Analysis of public expenditures in support of food and agriculture in Rwanda, 2011/12–2015/16, FAO, Rome, 2017*

Marshland, diversion, gravity	excavation of canals and drains, land preparation	N/A	20 - 30%
Marshland, dam, gravity	excavation of canals and drains, land preparation	N/A	5 - 10%
Hillside, dam, gravity	excavation of canals, pipe trenches and drains, land husbandry, field equipment (e.g.hoses)	all on-farm infrastructure, contribution to conveyance network	5 - 15%
River/lake, pumped	excavation of pipe trenches, field equipment (e.g. hoses, sprinklers)	all on-farm infrastructure, contribution to conveyance network	30 - 50%
Groundwater, pumped	excavation of pipe trenches, field equipment (e.g. boosters, hoses, sprinklers)	all on-farm infrastructure, contribution to conveyance network	50 - 70%
SSIT	cash contribution to equipment	N/A	50 - 100%

The value of private investment, particularly in irrigation equipment, can be greatly enhanced by access to finance. While smallholders can make in-kind contributions to construction works, they are unlikely to be able to equip their plots without seasonal loans or micro-finance. Large-scale farmers will be more willing to participate in irrigation projects if they can access concessional loans below the commercial lending rate, such as through the Development Bank of Rwanda.

9.5.4. Cost recovery

Cost recovery of O&M costs is achievable, whereas the recovery of investment costs in public irrigation schemes has proved to be very challenging, even in developed economies. In Rwanda, the level of water fees is still very low, such that even O&M costs are not adequately covered. Normal water fees amount to only RWF40,000 - 45,000 per hectare per annum ($46-$52/ha), with O&M costs running at over $150/ha for gravity schemes. Higher fees are charged on pumped schemes such as Kagitumba in Eastern Province, but even here the annual fee for full utilization in all seasons is only RWF84,000/ha/p.a.($97/ha), against expected O&M costs of over $300/ha. Public investment in irrigation infrastructure is usually regarded as a “public good”, as the cost of storage and conveyance is beyond the means of the beneficiaries.

Purely private irrigation development must be able to recover both investment and O&M costs, as well as their other operational costs and investments in farm machinery and buildings. There are relatively few examples of this type of investment in Rwanda, but there are many successful operations in the region, which demonstrates that the model is feasible, and can be replicated in Rwanda. Such investors must achieve high levels of efficiency and control over their investment and operational costs, usually focus on high-value crops, and often depend on access to affordable finance. In public irrigation schemes with large numbers of small-scale farmers, the same levels of efficiency and control cannot be achieved, so a lower level of cost recovery is to be expected.

The recovery rates for O&M costs for public schemes will be determined by the "willingness to pay", which in turn depends on the net returns that farmers make from their crop production. Willingness to pay has been defined as *the largest amount of money an individual can pay for a service, or good, without being made worse off* [137], but in practice it is a behavioural concept, while ability to pay, which relates to farmers' income and level of public subsidies is more quantifiable[138]. The estimates of gross margins from proposed cropping patterns were presented in the Agronomy section of the earlier Irrigation Potential Report, and are compared with expected O&M costs in the following table.

Table 9-8: Analysis of ability to pay for water according to domain and cropping pattern

Domain	Cropping pattern	Annual gross margin $/ha	O&M cost est. $/ha	O&M as % of GM
Marshland, gravity	M1 Paddy	1,600	150	9%
	M2 Food + horticulture	3,300	150	5%
Hillside, gravity	H1 Food + horticulture	3,300	250	8%
	H2 Fruit trees + food + horticulture	2,100	250	12%
	H3 Irish potatoes + food + horticulture	3,900	250	6%
Pumped, river/lake	H1 Food + horticulture	3,300	400	12%
	H2 Fruit trees + food + horticulture	2,100	400	19%
	H3 Irish potatoes + food + horticulture	3,900	400	10%

The comparison shows that farmers have the ability to pay full O&M costs provided they achieve target yields and good utilization of their plots throughout the year. O&M requires around 10% of annual gross margin for gravity schemes, and around 15-20% for pumped schemes. With prevailing water fees being so low, it will be difficult to raise fees to cost reflective levels, especially on existing schemes, without impacting the uptake of and utilization of plots.

The level of water fees on a public scheme is ultimately a political decision, determined by government's priorities and objectives, and ability to offer subsidies. Existing schemes may be viewed differently from new projects with regards to cost recovery, as prior investment can be regarded as a sunk cost, although government may still have debt obligations incurred at construction. The following table lists the necessary steps to achieving full recovery of O&M costs on public schemes.

[137] *Cledan Mandri-Perrott and Jyoti Bisbey, 2016: How to implement Sustainable Irrigation Projects with private sector participation, PPIAF, World Bank Group, Washington*
[138] *Irrigation Water Pricing: The Gap Between Theory and Practice, edited by François Molle, Jeremy Berkoff, CABI, 2008*

Table 9-9: Guidelines on achieving cost-reflective water user fees

Existing schemes	New schemes
Ensure full utilization, including season C if applicable	Conduct willingness to pay survey before project implementation
Improve crop productivity, cropping patterns, and market linkages	Decide on level of investment recovery required, O&M model, and design tariff structure (and escalation)
Ensure full fee collection	Agree tariffs with all stakeholders prior to implementation
Review O&M and improve efficiency; consider private-sector operator if applicable; agree annual budgets	Give due attention to market-linkages, training and support services to ensure high productivity
Agree fee escalation formula with users	Ensure full utilization, including season C if applicable, and full fee collection

Larger-scale commercial farmers generally have a higher ability to pay than smallholders, due to economies of scale, higher yields, and access to finance. They would be expected to be able to cover 100% of their share of O&M costs in a scheme, and make a contribution to investment costs. The degree to which investment costs are recoverable will depend mainly on the proportion of the scheme allocated to larger farms, and the investment cost per hectare, which may also include the significant cost of expropriation in order to make large blocks available.

9.5.5. Commercial feasibility

As the objective of Rwanda's irrigation development moves from the imperative for food security to one of commercialization, there is increasing pressure to ensure that future schemes are commercially feasible. Many earlier projects have been characterized by very high development costs and levels of farm incomes which cannot justify the investment in a commercial sense. The feasible level of investment for a commercial farming business can be estimated by calculating the net present value of future profits at the terms obtainable for commercial loans (i.e. what the business could afford to borrow). The following table gives some simplified examples.

Table 9-10: Estimated investment capacity of commercial irrigated farming, USD/ha

	Commercial farming models			
Cropping pattern	Paddy	Maize & soya	Mixed food crops & horticulture	Horticulture
Revenue $/ha p.a.	4,000	4,100	6,500	12,500
Gross margin $/ha p.a.	2,000	1,845	3,250	6,250
- Overheads (20% of revenue)	- 800	- 820	- 1,300	- 2,500
Profit, $/ha p.a.	1,200	1,025	1,950	3,750
NPV at 18% interest, 10 yrs	5,393	4,606	8,763	16,853

It should be noted that farming businesses also need to invest in machinery and buildings, so not all the indicated investment levels will be available for irrigation. The results show that schemes with dams cannot be commercially feasible on the basis of irrigation alone, and that multipurpose use and some degree of public subsidy is required. Pumped schemes from rivers, lakes and groundwater can be commercially feasible if the investment cost is below $8,000/ha and the cropping pattern includes high-value crops. With concessional finance, private investment levels can be considerably enhanced, for example at an interest rate of 5%, the affordable borrowing for a maize/soya model is around $8,000/ha. A more detailed analysis of some typical commercial farming business models is provided in Annex 8.

9.6. Prioritized investment opportunities

9.6.1. Scorecard results

The rationale and methodology for prioritizing irrigation developments is presented in section 2.4 above. This is a high-level approach suited to a master-plan, and the scorecard system used in conjunction with discarding criteria, provides a transparent and effective method to classify and rank identified irrigation projects. The generalized results of the scorecard system for the different catchments, domains and scales of project are displayed in the following table, assuming the project is not discarded for other reasons. The overall score for a specific potential irrigation site should be calculated by entering values for all the sub-criteria in the proposed scorecard system.

SSIT is treated separately from the other domains in the table above as “scale” or multi-purpose utility is not relevant and is excluded from the average score. Although it is currently a national program, SSIT is expected to be more relevant in catchments with lower rainfall and better access to markets.

Table 9-11: Generalized scorecard result by catchment and domain

Catchment	Domain	Scale			SSIT
		Large	Medium	Small	
Upper Akagera (NAKU)	R / L	3.0	2.7	2.7	3.0
	D / M	2.9	2.7	2.6	
	G	2.8	2.6	2.6	
Lower Akagera (NAKL) & Muvumba (NMUV)	R / L	2.8	2.5	2.3	2.8
	D / M	2.7	2.4	2.2	
	G	2.6	2.4	2.2	
Lower Nyaborongo (NNYL)	R / L	2.3	2.1	2.0	2.3
	D / M	2.2	2.0	2.0	
	G	2.1	2.0	2.0	
Akanyaru (NAKN)	R / L	2.2	1.9	1.8	2.2
	D / M	2.1	1.9	1.8	
	G	2.0	1.8	1.8	
Rusizi (CRUS)	R / L	1.9	1.6	1.6	1.9
	D / M	1.8	1.6	1.6	
	G	1.7	1.5	1.5	
Upper Nyaborongo (NNYU)	R / L	1.8	1.4	1.4	1.8
	D / M	1.7	1.4	1.4	
	G	1.6	1.3	1.4	
Lake Kivu (CKIV) & Mukungwa (NMUK)	R / L	1.5	1.1	1.0	1.5
	D / M	1.4	1.1	1.0	
	G	1.3	1.0	1.0	
Colour key for priority:		≥ 2.4	1.5 ≤ Pr < 2.4	< 1.5	
Domain key: R = river, L = lake, D = dam, M = marshland, G = groundwater					

9.6.2. Relevance for investment priorities

Investment costs and potential returns are integral to the design of the scorecard, as explained in the following summary of the prioritization from chapter 7:

Table 9-12: Investment implications of scorecard criteria

Prioritization	Investment implications
Annual rainfall: < 850mm (catchments NMUV, NAKL and NAKU)	Lower rainfall implies higher demand for irrigation, and greater economic returns, provided that hydrology supports irrigation demand
Scale: Large schemes which offer multi-purpose opportunities	Multiple revenue streams, especially those with more reliable demand and tariffs than irrigation (e.g. hydro-power, urban water); larger schemes can offer economies of scale
Domain: Pumping from lakes/rivers v. gravity feed from dams	Lower investment costs and demand-driven operation costs; lower resettlement costs (no reservoir); pressurized supply allows use of more efficient irrigation techniques
Slope: central and eastern areas with more gentle morphology	More efficient use of command area (higher ratio of net: gross irrigated area)
Social/location: proximity to markets and areas of higher population density	Higher farm-gate returns due to higher demand for produce, lower transport costs, less wastage of perishable produce; higher interest from private-sector
Small-scale irrigation technology (SSIT)	Low investment cost; demand-driven; zero resettlement costs

Higher scoring of particular irrigation opportunities therefore implies better investment prospects, and increases the chances for private-sector involvement. However, when detailed analysis is conducted on competing projects, specific opportunities for private investment and operation must be considered, with preference given to projects that will attract long-term private involvement, and lower recurrent public expenditure. Based on the results of the scorecard system a prioritized list of investment areas can be drawn up.

Table 9-13: Prioritization of catchments and irrigation domains

Priority		Investment area
1	a	SSIT in NAKU, NAKL and NMUV
	b	River/lake projects in NAKU, NAKL (all scales) and NMUV (medium-large)
	c	Dam/marshland projects in NAKU, NAKL (all scales) and NMUV (medium-large)
	d	Groundwater projects in NAKU, NAKL (all scales) and NMUV (medium-large)
2	a	SSIT in NNYL, CRUS, and NNYU
	b	River/lake projects in NAKL, NMUV (small) and NNYL, CRUS (all scales)
	c	Dam marshland projects in NAKL, NMUV (small) and NNYL, CRUS (all scales)
	d	Groundwater projects in NAKL, NMUV (small) and NNYL, CRUS (all scales)
	e	Large projects in NNYU (all domains)
3	a	Small to medium projects in NNYU (all domains)
	b	All projects in CKIV and NMUK

9.6.3. Potential irrigable areas

The updating of the IMP and reconciliation with WRMP has produced a dataset of potential irrigable command areas by Level 1 catchment and by domain (see table 8-25 of the final Irrigation Potential Report). Using these results, the potential area for new irrigation development (excluding existing schemes) can be identified for each level of investment priority, as shown in the following table. The command areas of potential river and lake command areas that lie between 80 and 120m above the water source have been excluded, as the energy requirement would make them unfeasible. The area identified for the "runoff for small reservoirs" domain (48,000 ha) has also been excluded as this is a provision for the water demand for small kitchen gardens (0.04ha per rural household) and not relevant to investment planning.

Table 9-14: Potential irrigated area by catchment and domain

	Potential new irrigable area, ha		
Priority	**1**	**2**	**3**
Domain / catchment	**NAKU NAKL NMUV**	**NNYL NAKN CRUS**	**CKIV NMUK NNYU**
River / Lake (<80m lift)	97,829	64,507	23,534
Dam / Marshland	62,295	38,586	16,774
Groundwater	6,500	12,500	17,000
SSIT	13,630	12,036	3,636
TOTAL	**180,254**	**127,630**	**60,945**

The results indicate that there are about 180,000 ha available for irrigation development in the high priority catchments, and about 130,000 ha under medium priority. The river and lake domains offer the largest potential, approximately 50% of the total area. Within this domain, projects with the lower pump lift requirements will be preferred, provided that other features of the command area (e.g. soil, slope, population density) do not disqualify them during project identification.

9.7. Investment framework

According to FAO, an investment framework is necessary to make a sound quantification of overall finance needs in relation to specific policy targets, and to be effective, it must generally define what needs to be done to achieve the objective in question[139]. For the purposes of the Rwanda's revised IMP, the overall objective is to expand the irrigated area in a sustainable

[139] *P. Koohafkan, M. Salman and C. Casarotto; Investments in land and water, SOLAW Background Thematic Report – TR17, FAO, Rome, 2010*

manner so as to improve food security and increase exports. In the short term, the target is to reach 102,284 ha under irrigation by 2024, an increase of 49,348 ha on the developed area as at June 2018. Beyond that, the target is unspecified, but it is necessary that it be demand-driven and commercially feasible. There are a total of 60,747 ha of irrigation schemes judged to be feasible and currently under design, and although not all of these may proceed to construction by 2024, with the addition of expansion through SSIT, it is considered that the short-term objective can be achieved provided that finance is available.

Another short-term objective must be to ensure that existing schemes are fully utilized and that a greater share of O&M costs are covered by collected water usage fees or other means. MINAGRI is actively seeking private investor participation in selected hillside and marshland schemes to achieve this end by offering to offset agreed O&M costs against lease payments (see Box 9-4).

Box 9-4: Potential private investment in existing schemes

In 2016 MINAGRI began seeking private investors to participate in existing schemes that were under-utilized, and to take on O&M services. A total of 2,053 ha was offered, representing between 19% and 100% of the selected schemes.

Scheme	Province	Irrigated Ha	Available Ha	% offered
Nasho Phase 1	Eastern	503	400	80%
Rurambi	Eastern	850	400	47%
Nyanza 23	Southern	301	301	100%
Mukunguri	Southern	400	250	63%
Matimba	Eastern	398	200	50%
Cyili	Southern	272	150	55%
Rwagitima-Ntende	Eastern	525	100	19%
Muvumba 4	Eastern	254	86	34%
Rusuli-Rwamuginga	Southern	141	86	61%
Karongi 12	Western	94	80	85%
TOTAL		**3,737**	**2,053**	**55%**

These can be attractive opportunities for investors, avoiding the need to invest in bulk-water supply. MINAGRI mitigates the risks to investor/operators by agreeing on operating costs, which would then be subtracted from the investor's periodic lease payments. This mechanism effectively guarantees payment for such operating cost to the investor by MINAGRI and shift the responsibility of collection from the other farmer/landowners to MINAGRI.

Source: MINAGRI, Information Booklets for Nine Irrigation Sites, March 2016

This investment framework will outline the processes that need to be followed to ensure that the short-term targets are achieved and that further expansion is commercially viable and justified by demand. Of prime importance will be adopting models of investment and operation which attract private-sector participation. As explained under 4.1.3 (Cost Recovery) above, it is not possible to recoup investment costs from small-scale irrigators on communal schemes, and the priority here should be to recover the full O&M costs. Commercial farmers, however, have the ability to cover O&M and contribute to investment costs, although concessional finance and some degree of public subsidy should be expected. Firstly, the issue of existing schemes will be addressed, due to the importance of ensuring their sustainability before investing in new schemes.

9.7.1. Existing schemes

Objective – to boost productivity and fee collection to ensure that income fully covers the necessary operation and maintenance costs.

Potential business models

(a) **Cooperatives / Water User Associations** – well-organized cooperatives or WUAs can employ workers for O&M and ensure that some maintenance jobs are carried out by members in a fair and effective manner. Government and its development partners have already provided training to many WUAs and farmers on the routine maintenance of irrigation schemes.

(b) **Private commercial farmer/operators** - on certain schemes there is available space to attract investors with a land lease and operating agreement whereby they take on responsibility for O&M of the whole scheme at an agreed cost, which is offset against lease payments (see Box 9-4). There may be a requirement for publicly-funded rehabilitation or modernization of some infrastructure before such an agreement can be made.

(c) **Specialized operator companies** - this business model is only viable if the command area and revenue stream is sufficient to justify a profitable commercial operator. The major risks are fluctuating demand, revenue collection and unforeseen maintenance/replacement costs. A degree of public subsidy may be required to mitigate the risks. Several schemes could be bundled under a single operator to improve economies of scale and simplify management. RAB has contracted a private company, Horeco, (see Box 9-5) to provide OMM services on various irrigation schemes. There is a high degree of public subsidy in this arrangement, and a need for a review of water user fees to increase revenue.

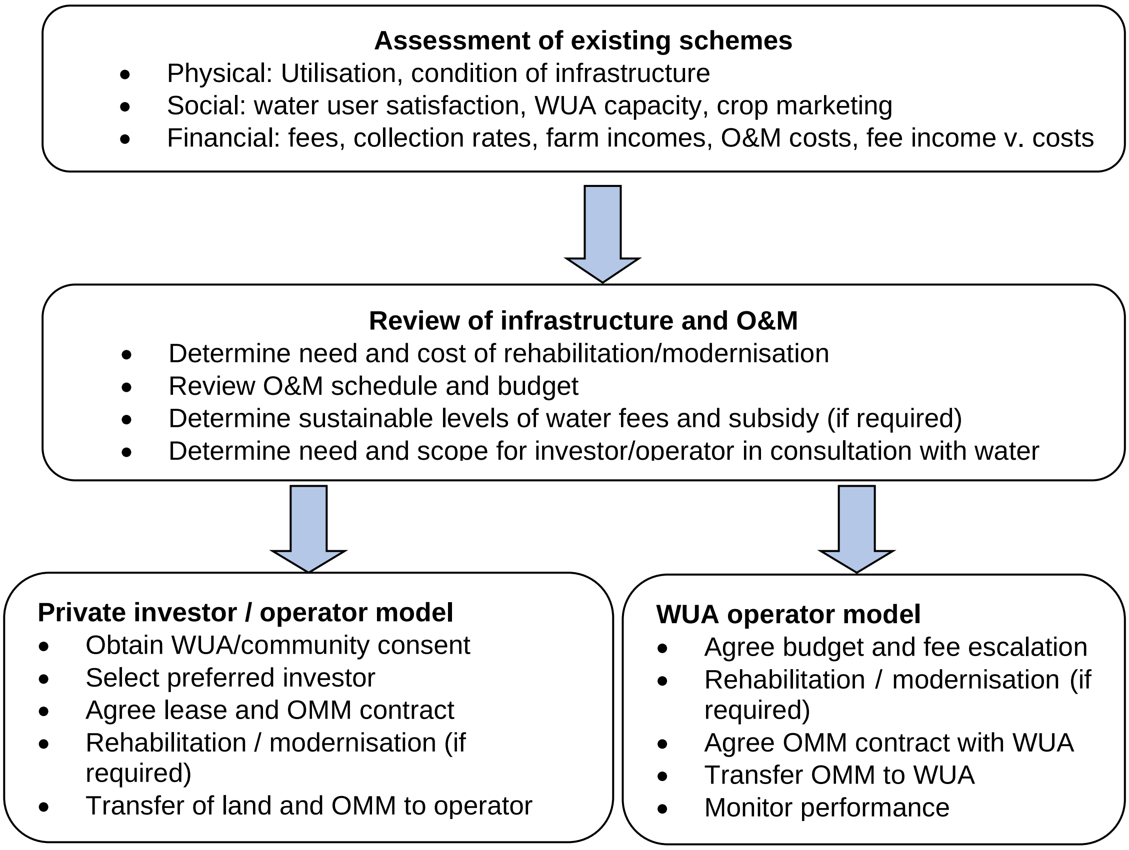
(d) **Direct public management** – this is a common arrangement on public schemes, but places a considerable drain on financial and human resources in MINAGRI. Income from water user fees is generally too low to cover expenditure. In order to relieve MINAGRI of these demands and allow them to focus on their core functions and capacity, it is necessary that OMM of irrigation schemes is transferred to third parties, unless special circumstances demand otherwise.

Box 9-5: Horeco

Horeco (Horticulture in Reality Cooperative) is a cooperative established in 2016 by several well-trained professionals in irrigated agriculture to facilitate Rwandan farmers to increase their productivity, and apply the latest technology. Horeco has been contracted by RAB to provide OMM services to 48 irrigation schemes in 16 districts, covering a total of 7,748 ha. The schemes produce a range of crops, including paddy, maize and vegetables. Horeco works closely with cooperatives, providing crop and irrigation technicians, and also manages contracts with buyers of both export and local crops.

Source: Personal communication Emmanuel Ndayizigye.President, Horeco, 6 May 2019, and www. http://horecorwanda.com/674-2/ accessed 25 May 2019

Figure 9-1: Investment framework for existing schemes



9.7.2. New projects

Objective - to develop commercially feasible, and sustainable irrigation projects with enhanced private-sector participation.

Private-sector participation in this sense extends beyond merely the production of irrigated crops by private farmers, and refers also to the operation, maintenance and management (OMM) of schemes, and investment by private investors in irrigation infrastructure. There are a range of existing and potential business models which are described below, with some examples illustrated in the accompanying boxes.

(a) **Cooperative-run schemes** – these are projects implemented by government and operated, maintained and managed by cooperatives (see Box 9-6) or Water User Associations (WUAs). They can be sustainable if there is sufficient income and capacity, but current levels of water user fees are too low to carry out proper maintenance and occasional replacement or rehabilitation. As a result, government still carries the burden of ensuring that these schemes remain in good working order and fully utilized.

Box 9-6: Ntende Irrigation Scheme / Corporiz

Ntende is a marshland dam project established in Gatsibo District, Eastern Province in 2003, and subsequently expanded to 900 ha in 2013. Currently, only 600 ha is utilized, exclusively for paddy, due to various reasons, including insufficient flow to tail-end, and parts of the command area at too high an elevation, susceptible to flooding in rains, or light soil texture. A strong and successful cooperative has emerged, Corporiz Ntende, with diversified interests in rice milling and a hotel. Corporiz handles the marketing of the entire rice output, and procures inputs for its members. Water fees are billed at RWF4/kg paddy which equates to only RWF40,000/ha ($46/ha) at normal yields of 10t/ha p.a., which is insufficient to cover O&M costs or undertake remedial works. While Corporiz is a good example of the potential of cooperatives to manage irrigation schemes, it also shows that there is still dependence on external parties to undertake anything more than routine maintenance.

Source: personal communication, Etienne Isabane, Agricultural Dept Manager, 14 August 2018.

9.7.3. Joint ventures and PPPs

PPPs in irrigation can take on several forms, ranging from operation and maintenance (O&M) contracts to full private investment in infrastructure. Although there are relatively few examples of fully-implemented irrigation PPPs in Africa, there are several innovative projects underway which aim to increase private sector involvement in a domain that has been dominated by public investment. A review of irrigation PPPs was produced by Public-Private Infrastructure Advisory Facility (PPIAF) of the World Bank in 2016, together with an essential toolkit for preparing and implementing sustainable PPPs [140].

In economies with well-established commercial farming sectors the willingness to pay for irrigation services is usually high enough to cover O&M and contribute to capital investment,

[140] Cledan Mandri-Perrott and Jyoti Bisbey, 2016: How to implement Sustainable Irrigation Projects with private sector participation, PPIAF, World Bank Group, Washington

but even in these situations, the procurement of suitable private partners, financing and implementation can be difficult. For example, the Guerdane scheme in Morocco and the West Nile Delta project in Egypt.

There is an increasing focus among the public-sector funders of irrigation on private participation in investment and OM. The PSTA-4/PforR program includes funding for new irrigation development and PPPs in agricultural infrastructure which is tied to the achievement of certain Disbursement-Linked Indicators (DLI 5: 2,940 ha of new irrigation under recognized PPP arrangement and DLI 7: $11.5m of matching private investment).

Government has a made a start towards increasing the contribution from the private sector in new irrigation projects with the design of the Gabiro Agri Hub project (see Box 9-7).

Box 9-7: Gabiro Agri-Business Hub (GABH)

The proposed Gabiro project is a large scheme in the pumped-river domain in the lower Akagera catchment (NAKL) in Eastern Province, with the first phase of 5,600 ha to be implemented by 2020, and a further 10,000 ha later in phase 2. Government has entered into a $66.5m joint-venture with Israeli irrigation specialist Netafim to develop phase 1. Netafim's 10% share will be provided mainly in the form of discounts on its irrigation equipment and technology. The government will fund 90% of the JV, which will construct the bulk water system and expropriate 3,900 ha for commercial farm investors, which will be made available in 200-300 ha blocks on long lease. The commercial farmers will need to invest $3,500 - $6,500/ha. Overall, private investment should reach 30% of the total investment, assuming $5,000/ha on-farm, and Netafim's 10% share of the JV company, with government funding 70%. Lease payments will accrue to the expropriated landowners and the JV, while water user fees will cover the JV's O&M costs.

Source: Rwanda Development Board, May 2019

9.7.4. Private investments

Purely private irrigation schemes are rare in Rwanda, and with emerging opportunities for leasing blocks on existing or new schemes, the development of private green-field projects is not expected to be very significant. It is however an important part of the irrigation sectors in other countries in the region, where land is more available. The attractiveness of full control over investment and O&M costs is expected to lead to a gradual growth in the area developed in this manner (see Box 9-8).

Box 9-8: Bramin Farm

Bramin is a 650 ha irrigated farm near Kayonza, Eastern Province on land under a 50 year lease from Government. The company is a joint venture between Minimex, Rwanda's largest milling company and brewer Bralirwa Ltd, a subsidiary of Heineken of the Netherlands. The farm is mechanized and professionally managed. The main crops have been maize and soyabeans, and yields have been lower than expected, due to soil-related problems, pest attacks and operational problems. This example demonstrates that despite high investment in irrigation and machinery, farming with irrigation still faces risks, and must be regarded as a long-term investment.

Source: Braliwa Ltd Annual Report, 2017

9.7.5. Subsidies

The provision of subsidies for farmer-owned irrigation development can be a cost-effective and demand-driven way for government to increase Rwanda's irrigation capacity while reducing the risk to public funds. The Small Scale Irrigation Technology program is an example of this approach (see following box), where subsidies are offered on irrigation equipment. Subsidies can also be used to increase the use of improved farm inputs, which is necessary to get good returns on irrigated farming. Subsidies on seed and fertilizer for staple crops, including irrigated rice, have been provided under MINAGRI's Crop Intensification Program (CIP).

Box 9-9: Small Scale Irrigation Technology (SSIT)

Small scale irrigation technology (SSIT) includes ready to use 1ha, 5ha, and 10ha complete sprinkler kits with portable diesel/petrol pump-units and pipes as well as the treadle pump and dam sheet technology. MINAGRI facilitates subsidy through financial institutions to the SSIT provider. Rwanda Agricultural Board (RAB) implements and Coordinates SSIT countrywide where a subsidy of 50% is given to farmers and funds are earmarked to selected Districts while MINAGRI and RAB mobilize farmers to adopt climate resilient methods which include irrigation equipment.

Support to SSIT is a component of World Bank's SAIFSP project. The proposed project will support the establishment of around 2,500 ha under small-scale irrigation through rainwater harvesting and rehabilitation of existing schemes. The project will support famers in assessing suitable options for irrigation and crop selection on their land (including relevant land-husbandry techniques), to form groups and develop business proposals for submission to MINAGRI/RAB. The project will support farmers to get access to finance through linking them with project supported SACCOs or other financial institutions.

The project will also finance operation and maintenance for a two years' period, to enable the farmer to start reaping the financial return on their investment allowing them to make provisions for regular operation and maintenance costs.

Sources: Rwanda Water Portal https://waterportal.rwfa.rw/toolbox/471; World Bank Group, PIN, SAIFSP, May 2018

With careful targeting, subsidies can boost the adoption of irrigation and productivity, and they can also encourage the formation of farmer groups which can bring with it benefits of better organization amongst farmers. However, there are a number of concerns that have arisen with subsidies, namely:

- Sustainability – subsidies can be become a recurrent drain on public funds.
- Un-focused – subsidized inputs cannot be specific to irrigated crops e.g. fertilizer can be used on any crop, and seeds may be used on rain-fed or irrigated crops.
- Maintenance and replacement costs – beneficiaries of subsidized equipment with a limited lifespan and high maintenance requirements, such as petrol or diesel pumps, and drip-line, may find they have limited resources to repair or replace equipment when required, leading to the abandonment of the equipment.
- Farmers' capacity – farmers or farmer groups may lack the capacity to apply for subsidized equipment, or make best use of subsidized inputs and equipment.
- Evaluation of impact – it is difficult to evaluate the impact of subsidized inputs or SSIT on production and farm incomes, due to many other factors at play in farming, and the large scale of the programs.

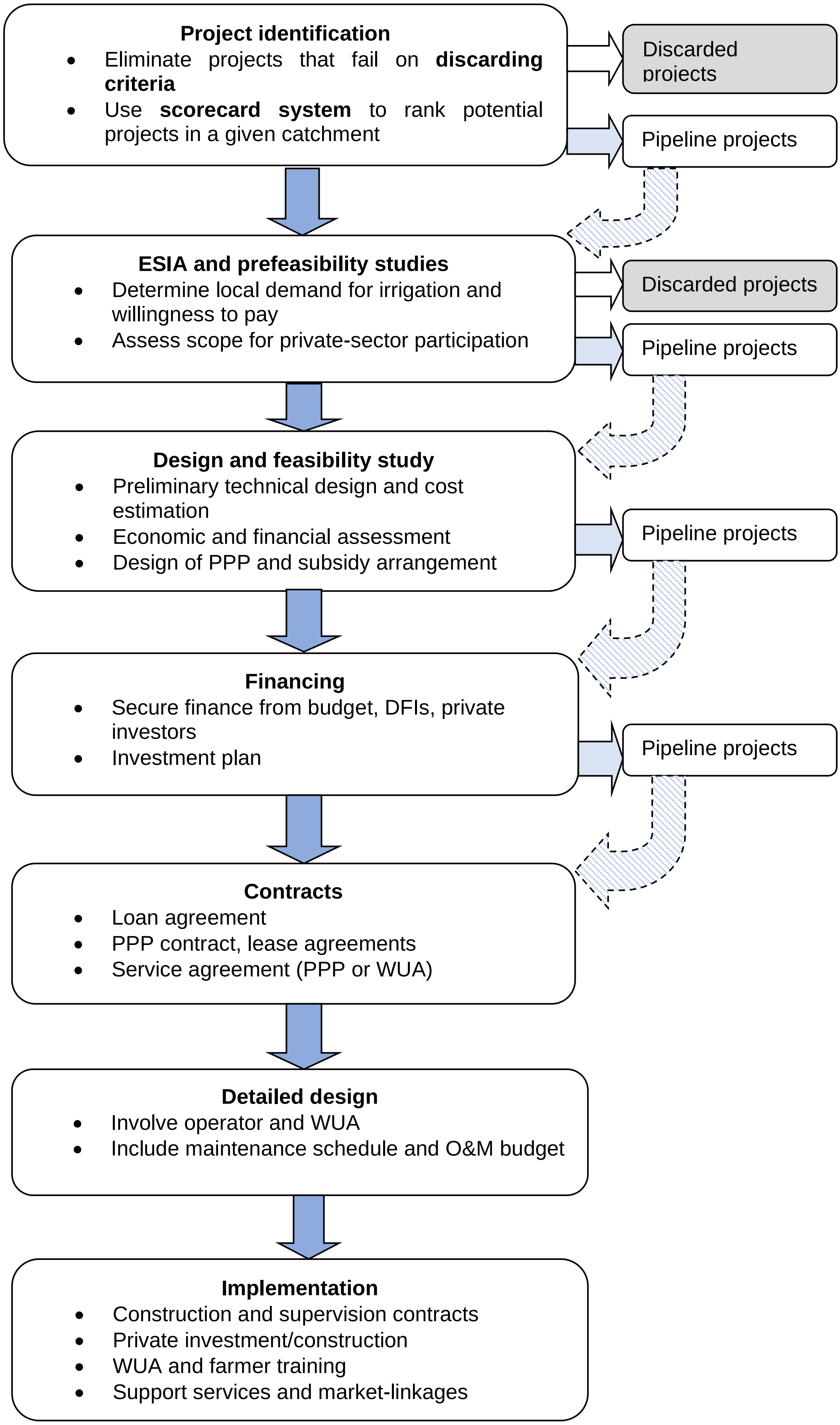
The investment framework for SSIT and similar subsidy programs without specific command areas differs from that for new irrigation schemes which require detailed site studies and designs.

Another approach to supporting farmers is **output subsidies**, which have often been used in developed countries including China, Japan, USA and the EU. These subsidies have usually represented the difference between a "protected" price and the market price, providing farmers with extra income and encouraging more production. Output subsidies can however lead to over-production of certain commodities, or price-distortion. In China, maize subsidies were reduced in 2017 due to reduce a growing stockpile of grain, while soya subsidies were increased to redress an imbalance. In the EU, output subsidies were prevalent until the early 2000's but have since been replaced by area-based subsidies[141].

The government of Rwanda is planning to introduce output subsidies on a limited scale in order to promote the aggregation of farmers into producer groups and cooperatives, and boost farm incomes. Such interventions should be made with care to avoid distorting markets or disadvantaging certain sectors of the farming community. It could be argued that rainfed farmers are more deserving of output subsidies, as irrigators have, in most cases, benefitted from subsidized infrastructure or equipment and are able to achieve higher yields than those who rely on rainfall alone.

[141] https://en.wikipedia.org/wiki/Agricultural_subsidy, accessed 24/10/19

9.7.6. Investment process for new irrigation project developments



9.8. Case studies of business models

Experience from other comparable countries in the development of successful irrigation projects can be instructive for policy-makers and planners in Rwanda. Three case studies can be found in Annex 9, documenting small, medium and large irrigation schemes in Sub-Saharan Africa which have achieved increased incomes for farmers in a sustainable manner.

CHAPTER 10. INVESTMENT PLAN

10.1. Introduction

The investment plan is guided by the prioritization developed in the previous section, and aims to take account of requirements of GoR, its development partners and private investors. These requirements with regards to irrigation developments can be briefly summarized as follows:

Government of Rwanda:

- Consolidate progress made in food security, and commercialize agriculture
- Increase exports of Rwandan produce to regional and world markets
- Reduce the cost to the treasury of operating and maintaining irrigation schemes
- Increase private investor participation in development and operation new irrigation schemes
- Transfer OMM services to private sector (WUAs, operator companies, or commercial farmer/operators in under-utilized existing schemes)
- Increase the irrigated area to over 100,000 ha in the short-term (MINAGRI target of 102,000 ha by 2024)
- Further expand irrigation in priority catchments in a demand-driven and sustainable manner

Development partners:

- Reduce capital investment in irrigation schemes compared to the past 20-30 years
- Ensure greater private-sector involvement in irrigation
- Irrigation development to be demand-driven and commercially feasible
- Focus on sector support, such as value-chain development and market linkages

Private sector investors:

- Secure environment for long-term investment
- Control risks to the extent possible
- Earn satisfactory returns from irrigated farming
- Access to affordable finance

10.2. Relevant assumptions

10.2.1. Capital costs

The following table shows the cost range of existing or designed irrigation schemes in Rwanda, and the assumed average cost per hectare for future developments.

Table 10-1: Investment cost, $ per hectare

Domain	Investment cost, $/ha	Assumed cost, $/ha
Marshland/dam, gravity	16,000-20,000	16,000 (only low cost sites)
Hillside/dam, gravity	20,000-30,000	no projects planned
River/lake, pumped	6,000-10,000	8,000
Groundwater, pumped	4,000-8,000	6,000
SSIT	3,500-6,000	4,500

Due to the very high cost of hillside/dam projects, they are unlikely to meet the requirement for commercial feasibility, even with multi-purpose use. Certain marshland/dam projects may qualify for development if there are multi-use opportunities and specific social or development priorities that justify them. The investment cost attributable to irrigation for marshland/dam projects has been assumed to be $16,000/ha.

10.2.2. Cost recovery

Existing schemes – the aim should be maximize recovery of O&M costs through improved efficiency and more cost-reflective water user fees.

New projects - Full recovery of O&M costs from water users is to be embedded in the design of new projects, with sharing of investment costs wherever feasible. Private investors should be in a position to provide up-front capital for their own on-farm investments including irrigation equipment, and contribute to investment in bulk-water infrastructure through connection fees and periodic water user fees. The potential for private investment is discussed in more detail in the following section.

10.2.3. Levels of private investment

It is a requirement that there is greater private investment in future irrigation developments. The potential for private investment varies by domain, as explained below:

SSIT already requires a 50% contribution from beneficiaries and this is assumed to continue for identified SSIT sites (approx. 28,000 ha).

Groundwater projects are well-suited to private co-investment as they can be broken down into small self-sufficient units, with public sector providing boreholes and conveyance infrastructure (approx. 30-40% of total cost), and users investing in-field conveyance and equipment.

Pumped schemes from the river/lake domain – on-farm conveyance and equipment costs make up a significant share of total investment (30-50%), for which commercial farmers will be responsible. Public expenditure on expropriation and resettlement costs can be significant, and the proportion of schemes that can be occupied by private investors will depend on demand from both local communities and potential investors. It is anticipated that the contribution to total investment costs from the private sector will increase from 20% in the short-term to 40% in the long-term.

Dam / marshland schemes with storage – the cost of dams and the main conveyance infrastructure will inevitably be borne by government, and as the majority of these command areas will be occupied by small-scale farmers, there is little scope to recover investment costs. Farmers and WUAs can contribute to a part of development costs, such as land development, tertiary canals and drains, which should be a pre-condition of future dam/marshland projects. Farmers' in-kind contribution is assumed to increase from 10% of total cost in the short-term to 20% in the long-term.

The assumed public share of investment in irrigation by domain is summarized in the following table.

Table 10-2: Estimated public share of future irrigation investment, %

Domain	2020-2024	2025-2034	2035-2050
Rehabilitation/modernisation	100%	100%	100%
SSIT	50%	50%	50%
River/lake projects	80%	70%	60%
Dam/diversion marshland projects	90%	85%	80%
Groundwater projects	35%	35%	35%
Private irrigation schemes	0%	0%	0%

10.2.4. Rehabilitation and modernization of existing schemes

The assessment of existing irrigation schemes will reveal the immediate need for rehabilitation or modernization, and a provision should be made for such works on an ongoing basis. It is anticipated that in future, the requirement for rehabilitation will be lower as O&M practices are improved, and modern pressurized irrigation becomes more common in new schemes. The investment plan provides for the rehabilitation or modernization of 40,000 ha over the period 2020-2050 at an average cost of $1,500/ha, as justified in section 4.1.1. above. This covers the majority of the existing irrigation infrastructure, which is mainly gravity-fed with open canals and drains.

10.2.5. Expansion of irrigated area

In line with Government's target, the developed irrigated area should reach ~100,000 ha by the end of 2024. The investment plan covers the period 2020 to 2050 (30 years) with the objective of achieving 220,000 ha under irrigation by 2050, or roughly 50% of the country's potential based on projected renewable resources. It is assumed that the total irrigated area at the end of 2019 will stand at around 54,000 ha, approximately 4,700 ha higher than at June 2018. While rapid expansion of around 10,000 ha p.a. is required to meet the short-term target, further expansion will need to be more measured and dependent on the emergence of a vibrant commercial farming sector.

Table 10-3: Planned command area development, ha

Domain	2020-2024	2025-2034	2035-2050	Total
Rehabilitation / modernisation	*8,000*	*12,000*	*20,000*	*40,000*
SSIT	13,000	12,000	3,000	28,000
River/lake projects	22,000	20,000	30,000	71,000
Dam/marshland projects	6,000	10,000	10,000	26,000
Groundwater projects	6,000	10,000	8,000	24,000
Private irrigation schemes	2,000	5,000	10,000	17,000
Total new area, ha [2]	**48,000**	**57,000**	**61,000**	**166,000**
Total area under irrigation, ha	102,000[1]	159,000	220,000	
New ha p.a.	9,600	5,700	4,067	5,533 (avg.)

Note: [1] assuming 54,000 ha as at end of 2019; [2] excluding rehabilitation / modernization

10.3. Investment plan

The plan is divided into short, medium and long term requirements covering the period 2020 to 2050. Increasing levels of private investment are anticipated, primarily in the form of on-farm irrigation and development, but also in a proportionate share of the bulk water system on larger schemes through up-front contributions (e.g. connection fees) and periodic water usage fees. For the purposes of this plan, it has been assumed that private contribution is made during the forecast period, although in practice cost recovery may be prolonged over many years of operation. The investment plan is laid out in full on the following page, but is summarized in the tables below.

Table 10-4: Proposed investment by domain, 2020-2050, $m

Domain	2020-2024	2025-2034	2035-2050	Total
Rehabilitation/modernisation of existing schemes	*12*	*18*	*30*	*60*
SSIT	59	54	14	126
River/lake projects	168	160	240	568
Dam/marshland projects	96	160	160	416
Groundwater projects	36	60	48	144
Private irrigation schemes	12	30	60	102
Total investment, $m	**383**	**482**	**552**	**1,416**
Average investment cost, $ per ha, new[1]	7,719	8,140	8,549	8,169

Note: [1] Excludes rehabilitation and modernization

By prioritizing lower-cost developments (river/lake, SSIT and groundwater), the average investment cost per hectare has been maintained at around $8,000/ha.

Table 10-5: Investment plan, 2020-2050

Short-term **2020-2024** **5 yrs**

Domain	Priority catchments	Area, ha	Capital cost $/ha	Capital cost, $m	Public %	Private %	Public $m	Private $m
					Source of funding - capital			
Rehabilitation/modernisation of existing schemes		*8,000*	*1,500*	*12.0*	*100%*	*0%*	*12.0*	*-*
SSIT	NAKU, NAKL and NMUV	13,000	4,500	58.5	50%	50%	29.3	29.3
River/lake projects	NAKU, NAKL and NMUV	21,000	8,000	168.0	80%	20%	134.4	33.6
Dam/marshland projects	NAKU, NAKL and NMUV	6,000	16,000	96.0	90%	10%	86.4	9.6
Groundwater projects	NAKU, NAKL and NMUV	6,000	6,000	36.0	35%	65%	12.6	23.4
Private irrigation schemes		2,000	6,000	12.0	0%	100%	-	12.0
Total		**48,000**		**382.5**			**274.7**	**107.9**
				Average public investment /yr			54.9	$m p.a.
				Public investment / new ha			5,472	$/ha

Medium term **2025-2034** **10 yrs**

Domain	Priority catchments	Area, ha	Capital cost $/ha	Capital cost, $m	Public %	Private %	Public $m	Private $m
					Source of funding - capital			
Rehabilitation/modernisation of existing schemes		*12,000*	*1,500*	*18.0*	*100%*	*0%*	*18.0*	*-*
SSIT	NNYL, NAKN, CRUS	12,000	4,500	54.0	50%	50%	27.0	27.0
River/lake projects	NAKU, NAKL and NMUV	20,000	8,000	160.0	70%	30%	112.0	48.0
Dam/marshland projects in	NAKU, NAKL and NMUV	10,000	16,000	160.0	85%	15%	136.0	24.0
Groundwater projects	NNYL, NAKN, CRUS	10,000	6,000	60.0	35%	65%	21.0	39.0
Private irrigation schemes		5,000	6,000	30.0	0%	100%	-	30.0
Total		**57,000**		**482.0**			**314.0**	**168.0**
				Average public investment /yr			31.4	$m p.a.
				Public investment / new ha			5,193	$/ha

Long-term	2035-2050	15 yrs			Source of funding - capital			
Domain	**Priority catchments**	**Area, ha**	**Capital cost $/ha**	**Capital cost, $m**	**Public**	**Private**	**Public, $m**	**Private, $m**
Rehabilitation/modernisation of existing schemes		*20,000*	*1,500*	*30.0*	*100%*	*0%*	*30.0*	-
SSIT	CKIV, NMUK and NNYU	3,000	4,500	13.5	50%	50%	6.8	6.8
River/lake projects	NAKU, NAKL and NMUV	30,000	8,000	240.0	60%	40%	144.0	96.0
Dam/marshland projects	NAKU, NAKL and NMUV	10,000	16,000	160.0	80%	20%	128.0	32.0
Groundwater projects	CKIV, NMUK and NNYU	8,000	6,000	48.0	35%	65%	16.8	31.2
Private irrigation schemes		10,000	6,000	60.0	0%	100%	-	60.0
		61,000		**551.5**			**325.6**	**226.0**
				Average public investment /yr			21.70	$m p.a.
				Public investment / new ha			4,845	$/ha

Table 10-6: Proposed public and private investment in irrigation development 2020-2050, $m

Source	2020-2024	2025-2034	2035-2050	Total
Public investment, $m	275	314	326	914
Private investment, $m	108	168	226	502
Total investment, $m	**383**	**482**	**552**	**1,416**
Public as % of total	72%	65%	59%	65%

10.4. Financing

The financing plan assumes that there will not be budget surpluses to channel into irrigation development. The requirement to achieve 102,000 ha under irrigation by 2024 is a substantial acceleration of irrigation development, and therefore requires substantial borrowing over a relatively short timeframe. The PforR program under PSTA-4, which runs until 2024, commits $30m on the achievement of a) 2,940 ha of new irrigation development under recognized PPP arrangement (DLI 5), and b) $11.5m of matching private investment in agricultural infrastructure projects (DLI 7) [142].

Continued support for SSIT from development partners is anticipated as it is a cost effective way to expand irrigated area with substantial private sector participation. In the medium to long term GoR will need to finance rehabilitation or modernization works from internal resources or borrowing, but in the short term, support from development partners is envisaged.

[142] *World Bank Group, Transformation of Agriculture Sector Program 4 Phase 2, Technical Assessment, April 17, 2018*

ANNEX 1: AGRONOMIC ASSESSMENT

ANNEX 2: MAPS

ANNEX 3: FULL PROTECTED AREAS

ANNEX 4: MARSHLANDS – OFFICIAL GAZETTE N.07 OF 13/02/2017

ANNEX 5: CLASSIFICATION SYSTEM FOR IRRIGATION POTENTIAL

ANNEX 6: ANALYSIS OF INVESTMENT AND OPERATING COSTS

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ANNEX 9: CASE STUDIES OF IRRIGATION BUSINESS MODELS

ANNEX 10: IRRIGATION SITES TABLE

ANNEX 11: PRIORITY OF MARSHLAND SCHEMES