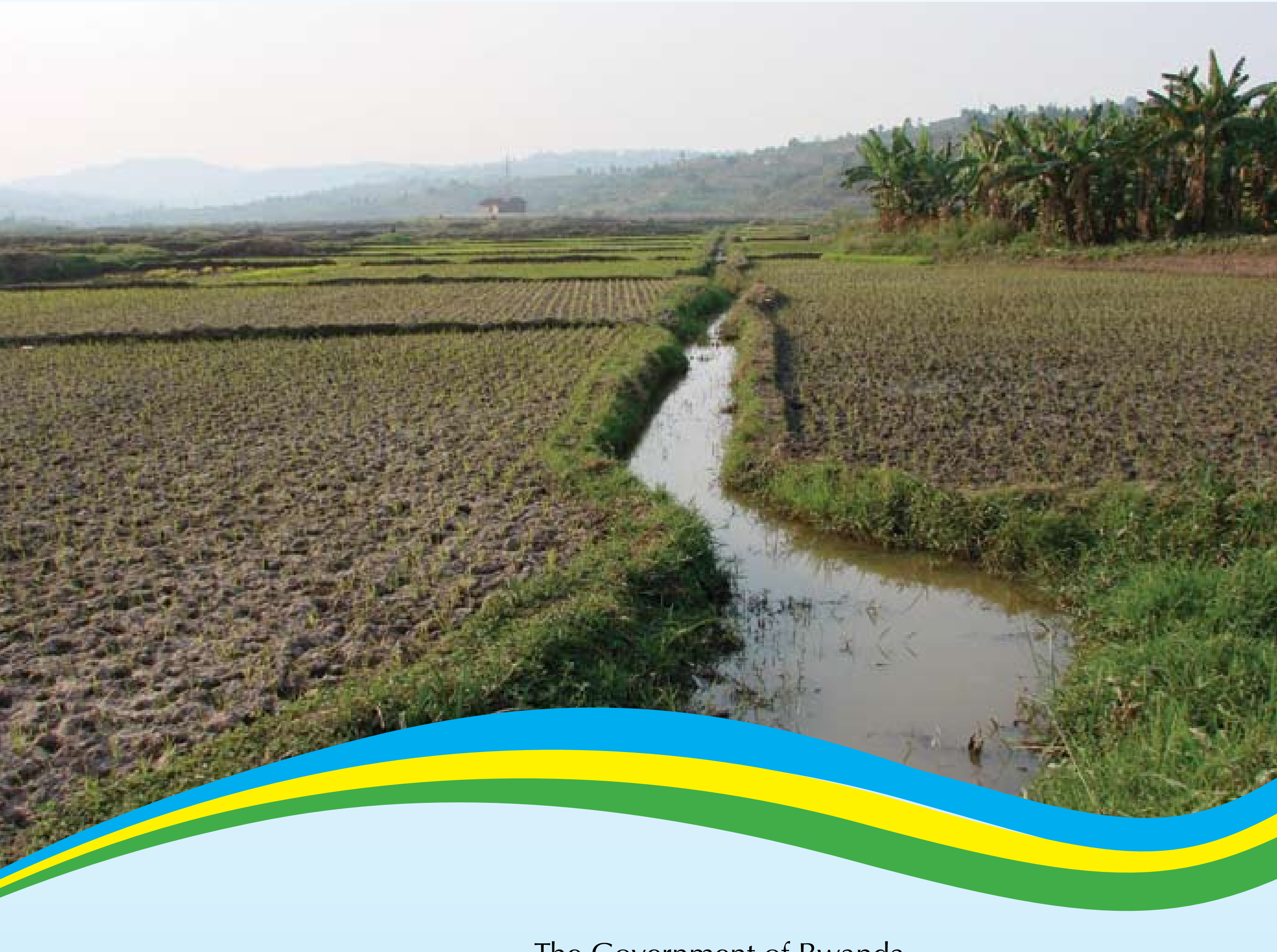
Rwanda Irrigation Master Plan



The Government of Rwanda,
Ministry of Agriculture & Animal Resources
Ebony Enterprises Ltd
The World Agroforestry Centre (ICRAF)

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Acronyms and Abbreviations

ACZ	Agroclimatic zone
AEZ	Agro-ecological zone
ADF	African Development Fund
APSP	Agricultural Processing Strategy Plan
ASTC	Agricultural Services and Training Centre
BCR	Benefit cost ratio
BS	Base saturation
CEC	Cation Exchange Capacity
CEPGL	Big Lakes Economic Community
CIDA	Canadian International Development Agency
COMESA	Common Market for Eastern and Southern Africa
DEM	Digital elevation model
EC	Electrical conductivity
EDPRS	Economic Development and Poverty Reduction Strategy
ESMF	Environment and Social Management Framework
ETc	Crop evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GIS	Geographic information systems
ICRAF	International Center for Research in Agroforestry
IDA	International Development Association
IFAD	International Fund for Agricultural Development
IMF	International Monetary Fund
IMP	Irrigation Master Plan
IMT	Irrigation management transfer
IPPF	Indigenous people's planning framework
IRR	Internal rate of return
IrrReq	Irrigation requirement
ISIA	Initial social impact analysis
JICA	Japan International Cooperation Agency
Kc	Crop coefficient
M&E	Monitoring and evaluation
MCA	Multi-criteria analysis
MDG	Millennium Development Goals
MINAGRI	Ministry of Agriculture and Animal Resources
MINECOFIN	Ministry of Finance and Economic Planning
MINICOM	Ministry of Commerce, Industry, Investment Promotion, Tourism and Cooperatives

MININFRA	Ministry of Infrastructure
MINIRENA	Ministry of Lands, Environment, Forestry, Water and Mines
MINITERE	Ministry of Lands, Environment, Forestry, Water and Mines (now MINIRENA)
NASA	National Space Agency
NBI	Nile Basin Initiative
NGO	Non-Governmental Organization
NPV	Net present value
OBK	Organization for Development of the Kagera River
O&M	Organization and management
P	Precipitation
PAIGELAC	Integrated Installation and Interior Lakes Management Support Project
PASNVA	Le Projet d'Appui au Système National de Vulgarisation Agricole
PBP	Payback period
PDRCIU	Projet de développement des ressources communautaires et des infrastructures de l'Umutara
PET	Potential evapotranspiration
PEARL	Partnership for Enhancing Agriculture in Rwanda through Linkages
Peff	Effective precipitation
PIA	Potential irrigation area
PIM	Participatory irrigation management
PGNRE	National Management of the Water Resources Project
PNUD	Progra mme des Nations Unies pour le Développement
P/PET	Precipitation and potential evapotranspiration
ppm	Parts per million
PRSP	Poverty Reduction Strategy Paper
PSTA	Programme Stratégique pour la Transformation de l'Agriculture
RADA	Rwanda Agricultural Development Authority
REMA	Rwanda Environmental Management Agency
RPSF	Rwanda Private Sector Federation
RSSP	Rural Sector Support Project
SPAT	Strategic Programme for Agricultural Transformation
SWOT	Strengths, weaknesses, opportunities and threats
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
WMO	World Meteorological Organization
WSU	Water and Sanitation Unit
WUA	Water user association

Foreword

The Government of Rwanda, through the Ministry of Agriculture and Animal Resources (MINAGRI), is keen to transform the promise offered by modern irrigation technology from potential into reality in its pursuit of food security. This Irrigation Master Plan (IMP) thus aims for a full, efficient and sustainable exploitation of both surface (runoff, rivers and lakes) and underground water resources by promoting irrigation in its various forms. In so doing, the IMP targets Rwanda's various practitioners and stakeholders to ensure sustainable production of food, cash, export and industrial crops.

Macro-economic management in Rwanda has been exemplary. Efforts to put in place a sound governance framework have been characterised by the establishment of independent regulatory and audit agencies and a strong focus on anti-corruption.

Although agriculture provides employment to 90% of the population, it accounts for less than 40% of gross domestic product (GDP). Production remains low, resulting in poor rural infrastructure and depressed prices for the two principal export commodities, coffee and tea. The contribution of the private sector to the economy and poverty alleviation remains limited. Only about 400 enterprises operate in Rwanda, half of which have less than 50 employees.

However, Rwanda is making good progress. Upon joining the Common Market for Eastern and Southern Africa (COMESA) and the East African Community on 1 July 2007, the country initiated the development of a strategy to fight poverty focused on six broad priorities: Rural development and agricultural transformation; Human development; Economic infrastructure; Good governance; Private sector development and Institutional capacity building.

Acknowledging the need to confront these challenges, the Government prepared a Vision 2020 document to identify appropriate policies and strategic objectives. Recognising the modernisation of agriculture as an essential part of Vision 2020, Rwanda is adopting strategies to intensify both food and cash crop production and to increase investment in support infrastructure. Importantly, irrigation has been identified as a key strategic activity.

Although Rwanda possesses considerable water resources, they are not evenly distributed. For example, while water is abundant in the marshlands, facilities for storing it elsewhere are lacking. This explains why farming during dry seasons is limited. Agriculture in the eastern parts of Rwanda, where rainfall is lowest, is especially affected.

To address these issues, the government of Rwanda commissioned Ebony Logistics Services and Trade Limited, an Israeli firm, to develop an IMP to manage water resources, promote irrigation and improve food security. Ebony subsequently subcontracted the World Agroforestry Centre (ICRAF) to undertake this task.

MINAGRI is proud to announce the successful completion of Phase 1 of the IMP that culminated in the national identification of the Potential Irrigation Areas. The findings in this document will provide good reference for policy and decision makers at national, provincial and district level which I welcome you to read meticulously.

Phase II employs detailed design aspects of individual selected irrigation schemes taking into account socio-economic, engineering, agronomic and environmental issues and will focus on the validation of the findings of Phase I through showcasing examples of how a dam, river and lake domain can be developed.

Dr. Agnes Kalibata
Honourable Minister
Ministry of Agriculture and Animal Resources

Executive Summary

The IMP provides Rwanda with a planning tool for rational exploitation of its soil and water resources. Intended to trigger an increase in crop production of both staple foods for local consumption and high-value products for export, the IMP will support decision making by:

- identifying the most favourable areas to establish irrigation water infrastructure;
- estimating the water stock that can be used for irrigation;
- prioritising distribution of irrigation water;
- identifying means of transporting water to selected sites;
- recommending means of abstraction for the chosen type of water source;
- establishing irrigated agriculture in small-, medium- and large-scale projects on hillsides, marshlands and other topographically suitable areas;
- identifying options for upgrading the agricultural value chain through appropriate training and extension (especially promoting the use of inputs, introducing mechanisation, training in postharvest management and marketing and sales);
- recommending options for water harvesting and storage;
- proposing solutions for drainage and flood mitigation;
- recommending locations and management for water storage and hydroelectric purposes;
- producing a plan map for the potential irrigation areas (PIAs) that could be irrigated by the different kinds of water resources by agroclimatic zone (ACZ) or even province level; and
- articulating the national policy options concerning the distribution of irrigation water.

Collecting the data

The success of any planning tool depends on the amount and type of data collected and the full utilisation of the data. In this study, we chose geographic information systems (GIS) as the central tool for conducting the data handling process.

In addition to collecting physical data, the study gathered administrative, social and economic information. The data were then categorised into four groups.

- Administrative and infrastructural: political subdivisions, roads, electricity

- Land and soils: land use, land cover, geology, lithology, geomorphology, detail of soil layers, topographic data, elevation, slope
- Climate: temperature, precipitation, potential evapotranspiration, agroclimatic zones
- Water resources: hydrography, hydrometric stations, hydrogeology

Water availability for PIAs

In order to produce the IMP, ICRAF developed a flow chart matrix that identifies potential irrigation areas and water sources by mapping biophysical and socioeconomic parameters. The matrix is a sequential tool that utilises scientific principles to determine and prioritise individual or combinations of sustainable irrigation water sources—dams, rivers, lakes and groundwater—using multi-criteria analysis (MCA). The matrix also assesses the financial and economic issues involved in the implementation of each irrigation scenario.

The disciplines applied in the flow chart include irrigation engineering, pedology, agronomy, socioeconomics, environmental and social impact assessment, livestock husbandry, agroforestry and GIS. As a tool, it enables the decision maker to choose from among relevant options, rank areas in order of suitability, and support priority settings for scheduling the development and allocation of irrigation resources.

Phase one assessment of Rwanda irrigation potential indicates that the country has a national irrigation potential of nearly 600 000 ha, taking into consideration the following domains:

- Runoff for small reservoirs (125 627 ha)
- Runoff for dams (31 204 ha)
- Direct river and flood water (80 974 ha)
- Lake water resources (100 153 ha)
- Groundwater resources (36 434 ha)
- Marshlands (222 418 ha)

Criteria for crop selection and estimated water requirements

A 2003 study by Vandoodt and Van Ranst entitled Large-scale land suitability classification for Rwanda culminated in the production of 53 maps that facilitated the selection of potential crops for various areas by policy and decision makers. The study utilised MCA of parameters such as food security, market access, socioeconomics and finance.

Once appropriate crops were identified, a software package called CropWat 8.0 was used to determine irrigation requirements, crop irrigation schedules, cropping patterns and water supply schemes. Inputs included evapotranspiration, rainfall, soil and crop characteristics. Long-term climatic data were analysed in a GIS environment to determine rainfall-to-potential evapotranspiration ratio. This information was useful in demarcating the country according to irrigation needs.

Organization and management of irrigation supply

The suggested framework for the organization and management (O&M) of Rwanda's irrigation supply relies on a logical flowchart that defines the criteria and objectives of the IMP. The specific organizational structure recommended for managing water supply is integral to the plan and critical to its implementation and success.

The various aspects used to test for the most appropriate structures include planning, monitoring, operations, process of water supply, outlet management and socioeconomic considerations such as demography and skilled vs non-skilled worker availability. Other parameters are the scope, size and level of economic development of the project (country-wide, regional or local).

Policy and legal considerations

There are pertinent policy and legal issues for the Government of Rwanda to tackle in order to set the right environment for implementation of irrigation schemes. Quite often, the lack of incentives has resulted in the collapse of many an irrigation project. The government will have to develop policies geared towards the reduction of energy tariffs and cost of irrigation equipment. The government should also offer tax rebates for the importation of irrigation equipment.

Institutional arrangements

An inter-ministerial committee charged with the responsibilities of guiding and monitoring irrigation implementation should be established to look into the following issues:

- Review and improvement of all irrigation projects
- institutional linkages in a view to reduce duplication;
- implementation of acts and by-laws developed by Government or local support agencies; and
- training and capacity building of various actors and support to irrigation research.

Socioeconomic considerations

Socioeconomic considerations include gender balance, food security, family income and national wealth creation through enhancement of GDP. Since women contribute the majority of labour for both cash and food crop production, user-friendly and affordable technologies should be identified to encourage their participation and boost the livelihoods of the poor. Labour-saving capacity can contribute to the mitigation of HIV/AIDS impacts through enhanced production of nutritious foods for improved diets and enhanced generation of family income.

Marketing chain

Owing to the high investments required for irrigation, strong market surveys, support and linkages are required. A committee mandated by MINAGRI should establish a marketing task force to develop the framework for the marketing of agricultural commodities produced by irrigation. The task force could look into issues such as:

- targeting of high potential areas for intensive production;
- identification of appropriate irrigation enterprises;
- setting up and mobilising farmer organizations such as local cooperatives;
- monitoring and supporting large-scale commercial producers with respect to export orientation;
- awareness creation and training of farmer organizations on agricultural marketing; and
- enhancing access to local, regional and international markets.

These initiatives will facilitate the considerations of market factors during project appraisals. The National Irrigation Strategic Plan should therefore be linked to the Agricultural Marketing Plan for Rwanda, which may be handled by a consortium involving the Trade Ministry, MINAGRI and private marketing firms.

Environmental considerations

A two-tier social and environmental impact assessment has been proposed to look into the negative externalities that irrigation works might impose downstream. The first tier is general assessment based on the national irrigation plans, while the second tier should be conducted after the actual irrigation sites have been identified.

Conclusion

Agricultural development based on modern irrigation techniques requires proper utilisation of water resources in an environmentally sensitive way. This can only be done by a central authority with the capacity to control quantity and to monitor environmental impact by providing a regulatory framework for fertilizer and pesticide use.

This analysis therefore concludes that a regionally managed, state-controlled water management structure is the most suitable for Rwanda. Importantly, it also concludes that the central government must work with its regional and local counterparts to ensure active dissemination of irrigation technology to small-scale farmers.

There is need to commission a study on groundwater potential for Rwanda for incorporation into the IMP. This will close the gap and provide a holistic assessment of irrigation water needs for the PIAs.

Chapter 1

Introduction

1.1 Overview

Rwanda covers an area of 26 338 km^2 with an estimated population of 9.9 million. This translates into an average density of 376 inhabitants per km^2, making it Africa's most densely populated country. Rwanda became independent in 1962 after colonization by Germany (1899) and Belgium (1919). In 1961 its monarchical government was formally abolished by referendum and the first parliamentary elections were held.

Although the country is currently at peace, Rwandans continue to struggle with the aftermath of the genocide that occurred in 1994. National reconciliation is a long-term endeavour that has the full commitment of the government as well as the support of the international community. The Rwandan government has undertaken significant measures to consolidate reconciliation, including the demobilization and re-integration of ex-combatants and the adoption of a model of democracy that features a decentralized administration. Efforts to promote peace and reconciliation continue through the International Criminal Tribunal for Rwanda and the Gacaca (Rwanda's community-based conflict resolution system).

Rwanda has made significant strides, enacting a new constitution in June 2003 and conducting multi-party presidential and parliamentary elections, resulting in the election of President Paul Kagame to a 7-year term.

1.2 Economy

Since 1994, the government of Rwanda has been able to maintain overall macro stability by implementing extensive reforms. These reforms have contributed significantly to the country's strong growth performance. As a result of the reforms enacted between 1995 and 2005, gross domestic product (GDP) growth rates averaged 7.4% per annum. Inflation has been contained at less than 10% since 1997, with the exception of 2004 when it reached 12%. By 1998, GDP had recovered to its pre-1994 level. Economic growth has been driven by the recovery in subsistence agriculture and a construction boom during the country's reconstruction phase.

Macro-economic management has been satisfactory. A 3-year Poverty Reduction Growth Facility arrangement was approved by the Board of the International Monetary Fund on 5 June 2006. Strong implementation of macroeconomic policies enabled Rwanda to reach the highly indebted poor country completion point in April 2005, thus qualifying for the multilateral debt relief initiative in June of the same year. Parallel efforts have put in place a sound economic governance framework, including independent regulatory agencies, stronger public expenditure management systems with independent audit agencies, and a strong anti-corruption focus, energetically supported by the President.

Agriculture and rural development form the current base of the economy and are key sources of growth, employment and poverty reduction in the short to medium term.

Agriculture currently accounts for less than 40% of GDP but provides employment to 90% of the population. Most Rwandans rely on subsistence agriculture and have limited participation in the market economy. Between 30 and 50% of the rural population do not produce a marketable surplus in any given year. Production remains low and constraints to agricultural growth are severe, resulting in scarcity of rural infrastructure and depressed prices for the two main export commodities, coffee and tea.

The contribution of the private sector to the economy and poverty alleviation remains limited—only about 400 enterprises exist in Rwanda, of which half have fewer than 50 employees. Private sector development remains hampered mainly by the perception of high political risks and the high cost of infrastructure services (to a lesser extent) by the weakness of the financial sector.

The outlook for the Rwandan economy depends on the maintenance of peace and stability in the Great Lakes region as well as Rwanda's reform programme. In the absence of peace in the region or a significant reform programme, growth, even under positive conditions, would remain below 6% per annum (the minimum needed to reach the 1990 poverty level by 2020). If the situation were to deteriorate, growth could be reduced to 2–3% percent (the current level of demographic growth). Regional cooperation, especially in the infrastructure sectors, is therefore prerequisite to economic growth. But Rwanda is making good progress. The country joined both the Common Market of Eastern and Southern Africa (COMESA) and the East African Community in 2007. In addition, Rwanda has made progress towards meeting the Millennium Development Goal (MDG) targets with regard to:

- gender parity in primary education,
- immunization of infants against measles, and
- the prevention of HIV/AIDS.

The government has developed a six-tier strategy to fight poverty. The strategy, resulting from a series of consultations on development challenges, is an integral part of Rwanda's Vision 2020, which spells out a medium-term development strategy for the country. As a first phase of this strategy, the government prepared a Poverty Reduction Strategy Paper (PRSP) which focuses on six broad priority areas:

1. Rural development and agricultural transformation
2. Human development
3. Economic infrastructure
4. Good governance
5. Private sector development
6. Institutional capacity building

The PRSP was discussed by the World Bank's Board of Directors in 2002, since then its implementation has been monitored through annual progress reports. Success has been significant in some areas, including private sector development and export promotion, successful re-allocation of funds from military spending to priority development areas, social services (primary education, immunization, health sector reform), peace and reconciliation and economic governance. Areas where further improvement is needed include rural development, decentralization and continuance of fiscal reform.

The government recently completed and adopted its second PRSP, now called the Economic Development and Poverty Reduction Strategy (EDPRS). In order to achieve the government's long-term development goals, the EDPRS has a strong focus on growth through improved economic infrastructure and greater agricultural productivity. The EDPRS also pays particular attention to programme implementation (World Bank 2007).

1.3 History of irrigation and drainage in Rwanda

Irrigation in Rwanda began during the Belgian colonial rule in 1945 at Karongi (Kibuye), after the famine known as Ruzagayura (1943–44). An 8-km water channel was dug from Ntaruka towards Rubengera with its tributaries irrigating local people's farms.

In 1964, the Taiwanese prepared 50 ha of the Mukunguli Swamp for rice cultivation. Three years later, they prepared an additional 250 ha of Kabuye Swamp, and in 1968 they developed a further 100 ha of Chili Swamp.

When people tried to stop irrigation after independence, irrigation infrastructure was destroyed. In 1968, the Chinese started working on irrigation in Rwanda. Before 1980, most swamp reclamation projects concentrated on drainage without planning for irrigation. Irrigation was also addressed in Rugeramigozi Swamp by a French project called Operation Petit Marias, which drained the swamp.

By 1980, the Canadians, Chinese and Koreans were already working in Eastern Province, while the French worked in Southern Province. From 1980 to 1986, the Canadian International Development Agency (CIDA) reclaimed 200 ha in the valley of Kagitumba-Muvumba in Nyagatare District. From 1984 to 1986, Rwanda reclaimed 3 peri metres (30 ha) for rice production. The Belgians came in from 1986 and worked on reclamation projects till 1987.

In 2003, the government of Rwanda embarked on swamp reclamation under the Rural Sector Support Project (RSSP, World Bank/IDA) with major focus on large-scale rice production. In 2004, The Marshland Master Plan was initiated. Marshes were drained and water tanks built to store water for irrigation, especially for rice production. By the end of 2006, almost 11 000 ha of swampland had been reclaimed and used for rice production. By the end of 2020, 40 000 ha of swampland will have been reclaimed. However, most farmers have been unable to exploit the swamps in their natural form because they are often completely flooded and the expense of installing drainage systems is unaffordable.

The rehabilitation and construction of irrigation infrastructure in Rwanda is of paramount importance. The following section lists works that have been completed, works being implemented and projected works. It also includes information on studies, training, extension and maintenance of works.

1.3.1 Hillside irrigation

Irrigation on hills is located in the following places.

- 12 ha in Gashora for cassava production (sprinkler irrigation)
- 50 ha of coffee farms in Ngugu near lake Rwampanga in Kirehe district (sprinkler irrigation)
- 100 ha of different crops along a stretch of 8 km from Ntaruko, Ndaba, to Rubengera in Karongi District (gravity-fed irrigation)

In order to use rainwater on hills, over 400 storage facilities with a capacity of 120 m3 have been constructed in Bugesera, Ruhango and Nyanza. The water is used to irrigate tree seedlings on farms and in vegetable gardens. For more details on irrigation projects see Annex 1.

1.3.2 Drainage and irrigation of small marshes

Many hydraulic facilities in the middle of the country were damaged in 1994. To rehabilitate and develop these facilities, several initiatives were undertaken (see also Annex 1):

- 2000 ha of irrigated land in the region of Mutara in northeastern Rwanda were developed for the production of rice and soya.
- A plan for irrigating 1000 ha in Bugesera in the southeastern Rwanda was prepared and implemented.
- Studies of marsh drainage and development of the Nyabarongo and Akanyaru Farmers were trained in planning and management techniques.
- A water resource management plan was established.
- Juridical instruments for a better water resource management were set up.

Two fundamental objectives were defined at the World Food Summit in 1996 for implementation by 2010:

Development of 12 000 ha of small marshes and 60 000 ha on the hills of basins for efficient utilisation of water and conservation of soil

- Development of 5000 ha of large marshes for more efficient utilisation of water

1.4 Water resources for irrigation

Although Rwanda has abundant water resources, they are not evenly distributed. Rainfall is high in the western part of the country and low in the east. The issue of variability is critical for lands on hillsides where water cannot be retained. Farms in the eastern part of the country, where rainfall is lowest, are therefore the most vulnerable (ADF 2006).

With reference to surface water bodies, the eastern part of Rwanda has abundant rivers and lakes that could be harnessed for irrigation purposes. For groundwater resources, central and eastern parts of the country indicate good potential especially for springs and borehole development.

Currently, the most commonly used method is flood irrigation in the marshlands. Plans are afoot to set up demonstration farms in drought-prone eastern Rwanda to educate farmers about the advantages of irrigation. The importance of the role of irrigated agriculture in achieving food security and offering a way out of poverty is not in question. Where irrigation has been introduced, doubling of yields is commonly achieved. Additional benefits include the overall modernisation of agricultural production through the introduction of quality inputs such as hybrid seed, mechanisation, chemicals, fertilizers, extension systems and knowledge support.

1.5 Rationale for an IMP for Rwanda

In recent years, scientists and world leaders have repeatedly declared the priority of addressing the water needs of the 2 billion people expected to be added to the global population by 2020. The challenge is to achieve a balance between using water for food production while meeting expanding domestic and industrial requirements. Though opinions differ regarding the issues, the consensus is that a significant portion of water should be allocated for irrigation purposes.

The International Commission on Irrigation and Drainage estimated that current food production must double within the next 25 years to meet the needs of expanding population. In 1996, FAO, employing the slogan 'more crop per drop', estimated that in the near future (i.e. the present day) no less than 60% of crop production would have to come from irrigated agriculture (FAO 2003).

According to FAO, the intensification of irrigation is one of the most important tools that Africans should give priority to over the next few decades (FAO 1997).

Irrigation has long played a key role in feeding expanding populations and is undoubtedly destined to play a still greater role in the future. It not only raises the yields of crops, but also prolongs the effective crop-growing period in areas with dry seasons. This allows for multiple cropping (two, three and sometimes four crops per year) where previously only a single crop could be grown. The security provided by irrigation—less risk of crop failure due to lack of water—gives the farmers confidence to invest in additional inputs and activities that are needed to intensify production (pest control, fertilizers, improved seed varieties and better tillage methods).

The practice of irrigation consists of applying water to the part of the soil profile that serves as the root zone, for the immediate and subsequent use of the crop. Well-managed irrigation systems control the spatial and temporal supply of water to promote growth and yield, and enhance the economic efficiency of crop production. Water is applied according to the amount required and distributed according to time-variable crop needs. The aim is not only to optimise growing conditions in a specific plot or season, but also to protect the field environment against degradation in the long term. As a result, water and land resources can be utilised efficiently and in a sustainable manner.

Proper management of irrigation is the key to achieving the desired results. Poorly managed irrigation systems waste water and energy, deplete or pollute water resources, fail to produce good crops and cause soil degradation.

International experience derived from developed and developing countries demonstrates that the introduction of irrigation and associated technologies of fertilization, pest management, improved seed varieties and hybrids and advanced tillage systems improve agricultural production and its profitability.

The development of irrigation is thus essential for the advancement of agriculture, particularly in emerging economies. Irrigation expansion is the key to increased food production and improved food security—it is also an important means of generating foreign currency.

1.5.1 The situation in Rwanda

Although the agriculture sector in Rwanda employs 90% of the labour force, the food and nutrition needs of the population cannot presently be met, as evidenced by the high prevalence of malnutrition (MINECOFIN 2002). Moreover, agriculture, despite its high potential, does not contribute substantial revenue to the economy. Rwandan agriculture is primarily undertaken at the subsistence level, providing little surplus for local markets.

Coffee and tea, the main sources of hard currency in Rwanda, represent less than a fourth of the value of imports. This situation results from both low yields and declining prices in global markets.

According to the Rwanda 2020 Vision, weaknesses in the agriculture sector stem from many factors, some of which are long-standing. In the field of land-use planning, territory is used in an ineffective and unsustainable manner. Housing is scattered, farming activities proceed without pre-established planning and various factors combine to deteriorate profitability and erode the land. Specifically:

- The self-sufficiency approach to food production has inhibited agricultural modernization and specialisation.
- Diversification of income sources at the family level due to the inability to generate income from the land has hampered development of agricultural professionalism.
- High population growth rate has led to overexploitation of land, soil erosion and loss of soil fertility.
- The crops under cultivation are unprofitable.
- Poverty among farmers limits the purchase of agricultural inputs.
- Agricultural research and extension are inadequately funded, as are market development and agricultural processing facilities.
- Production factors such as manpower, elementary tools and water are assigned low value.

The introduction of irrigation, together with associated agricultural operations, can mitigate these shortcomings.

1.6 Aim and objectives of an IMP

The aim of an IMP for Rwanda is to develop and manage water resources to promote intensive and sustainable irrigated agriculture and to improve food security.

Specifically, the plan's objective is to provide Rwanda with a planning tool for rational exploitation of its soil and water resources. This tool is intended to lead to an increase in crop production for local consumption, as well as to promote production of high-value crops for export. The planning tool will support decision making by:

- identifying the most favourable areas to establish irrigation water infrastructure;
- prioritising distribution of irrigation water;
- identifying means of transporting water to selected sites; and
- establishing irrigated agriculture in small-, medium- and large-scale projects on hillsides, marshlands and other topographically suitable areas.

Moreover, decision making will be made with regard to:

- articulating national policy options and identifying the structure and management of policy for irrigation water distribution;
- identifying options for upgrading the agricultural value chain through appropriate training and extension, promoting the use of inputs, introducing mechanization, training in post harvest management and marketing;
- recommending options for water harvesting and storage;
- proposing solutions for drainage and flood mitigation;
- recommending locations and management of water resources for Irrigation and other purposes; and
- identifying energy requirements.

1.7 Methodology

The IMP is the outcome of a long-term strategy based on a defined and structured methodology. A four-layer scheme was proposed and developed to analyse the relevant data and information and then to construct the methodology.

Layer 1 Basic introduction regarding physical conditions

The first layer consists of the collection of physical data, namely:

- Climate data include comprehensive, countrywide data inclusive of temperatures, precipitation and evaporation.
- Land and soil data include land cover, topography, cartography and relief, parent materials/soils and identification of watershed basins.
- Water resource data include hydroclimatic, hydrometric, hydrogeological, and water resources available for utilisation.

Additional information relevant to the analysis includes data on infrastructure, demographics, policy, planning, legal issues (such as land tenure), administrative and government structure (such as local government control), and information relevant to environmental status and policy intentions.

These data are organized using geographic information systems (GIS) methodology as a tool for agricultural analysis.

Layer 2 Agricultural production conditions

This layer includes analysis of agricultural (biophysical) conditions and parameters. The analysis is a decision-making tool designed to identify PIAs based on predefined ACZs. PIAs and ACZs are determined by developing a list of criteria, applying grades to them and prioritizing suitable areas using GIS technology. The criteria are verified manually, reviewed and mapped. This method produces a decision support tool by assigning scores to critical criteria relevant to each irrigated area.

The criteria for defining agricultural production areas and PIAs are analysed using FAO methodology and guidelines. These include:

- Agronomic factors (climate, land and soil, water resources)
- Physical installations (infrastructure)
- Land valorization and improvement (land planning, maintenance and improvement)
- Conservation and environmental factors
- Socioeconomic and political factors (demographic issues, human resources, policy)

PIAs within ACZs are derived from the classification system provided by Verdoodt and Van Ranst (2003). A decision making tool has been developed for prioritizing these areas. Scored or evaluated criteria include block size, topography and slopes, water source altitude, distance from water source, soil factors, road quality and accessibility, energy availability, human environment status such as organizational level and labour availability, extension, research and development, technical support and regional or national policy factors.

Not all criteria lend themselves easily to quantification. In cases such as social factors and policy trends, a qualitative analysis and assessment is provided to support decision making.

Analysis of data is conducted in two stages:

- a 'Macro' stage is utilised to develop a general list of possible PIAs; and
- a 'Micro' analysis within specific areas is utilised to select plots suitable for irrigation development.

Layer 3 Choice of crops

The third layer utilises methodology similar to that of the second layer to allocate crops to irrigated areas. Crop selection criteria are based on potential growing areas and a list of additional criteria to facilitate choice of possible crops:

- Production area (analysed in Layer 2)
- Land-crop compatibility analysis or suitability to PIA

- Crop water requirements
- Crop value and profitability
- Distance to market and shelf life
- Production potential
- Local demand
- Existing processing industries
- Export potential
- Human environment, skills and labour availability
- National or regional priority

As and when relevant and logical, a score is assigned to crops according to criteria, and further assessment enables support for decision making and utilisation of the tool. A scoring method is used to prioritise proposed crops, and to develop a short list of selected crops for regions. The result of this analysis is a list of possible crops suitable for irrigated cultivation.

Layer 4 Choice of an organizational structure for the IMP

The fourth layer is based on the previous three, and includes additional criteria for evaluating the organization of the master plan and management structure. Alternative organization strategies are provided for comparison, and a preferred organizational structure for the IMP is suggested (Figure 1). A framework is offered for the administration of water resources; management and control; costing, metreing and monitoring (quantity and quality); and the development of a forecasting tool for water supply and demand.

The IMP organizational proposal follows from the crop assessment outcome. Alternative structural options are examined to select an appropriate organizational structure for Rwanda in light of the political, organizational, historical and cultural environment.

Additional criteria are incorporated upon completion of the above analyses in order to suggest an appropriate organizational structure. These additional criteria include:

- Characteristic production areas
- Water resources
- Crops of choice
- Organizational considerations
- National and regional policy
- Environmental impact
- Economic considerations, investment capacity issues and allocation of funds
- Sociological considerations

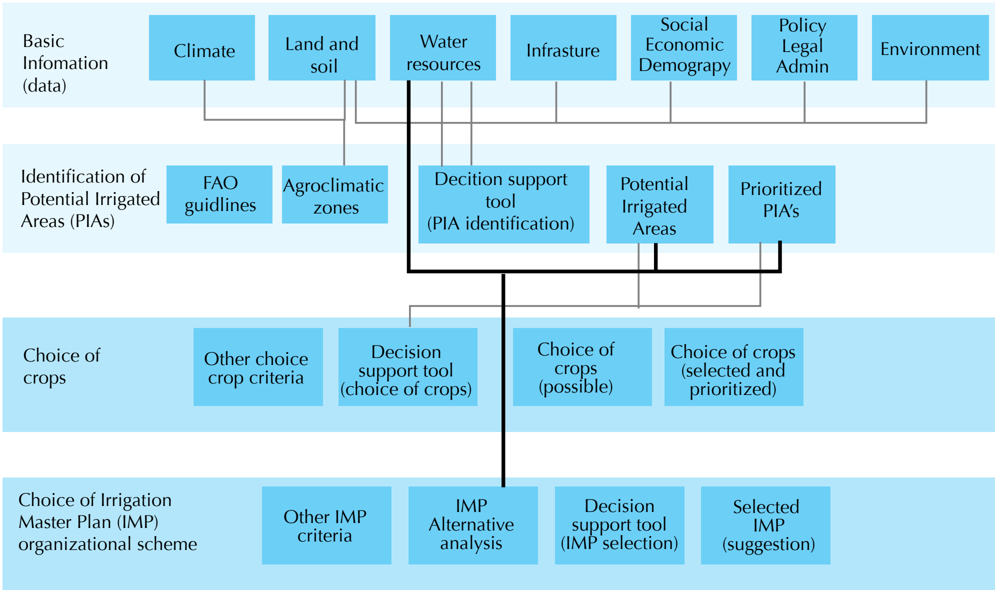


Figure 1: *IMP development matrix*

General summary of the analytical tools

First and foremost, the decision-making tools employed to build the IMP are based on comprehensive data collection. The evaluation process that follows is divided into four distinct layers to facilitate analysis and decision making with regard to sites, crops of choice and organization of irrigation water management.

Several examples, including a range of PIA possibilities and crop options, are provided in this report. Further analysis uses quantitative grading of criteria and a scoring system to prioritize the proposed irrigation areas, crops, and organizational management.

1.8. Development of GIS for site localisation and visualisation

GIS as a planning tool

GIS were first introduced more than 20 years ago, but much of the conceptual basis for GIS derives from the work of a landscape planner, Ian McHarg, in his seminal work Design with Nature (McHarg, 1992). Using many excellent examples, McHarg demonstrated a special technique that featured overlaying transparent maps, each representing various characteristics of the land, in order to clarify the implications of planning decisions and thus aid in landscape design. More than a decade later, the software tools that came to be known as GIS were developed, facilitating the easy implementation of McHarg's procedure.

Although GIS were initially used to conduct analyses for landscape planning, many current users never get beyond using the systems to collect, store, update and create maps from geographic data (i.e. computer mapping). Taking the next step and using GIS as an analytical tool to support planning decisions is crucial for effective planning based on all relevant data. When GIS are used in a structured analysis procedure, the results are often of great interest.

Land-use managers need a tool that allows them to easily differentiate between higher quality sites with the potential to support agriculture or forestry, and poorer sites that must be managed entirely for their landscape value and ecosystem services such as soil conservation, species protection and stream erosion prevention.

Table 1 shows an example from Israel of how data provided by GIS were used to determine which sites in a wooded area in a semi-arid environment could be managed for wood production. Geographic layers were first created by selecting for each criterion as above. These were then overlaid, producing a map of those areas meeting all of these conditions at once. This outcome provided forest managers with suggested sites to be managed for conifer wood production, and to allocate other areas for landscape and conservation purposes. This process of combining geographic data in a specific way under given conditions to produce new geographic layers is today called running a 'geographic model'.

Table 1: *Analysis of GIS data layers*

Layer	Criteria	Explanation
Slope	< 20%	Harvesting is too expensive at greater slopes
Forest roads	< 50 m	Harvesting is too expensive at greater distance from roads
Rock cover	< 35% of area covered with bare rock or boulders	Such cover makes access difficult for tractors which carry out management activities
Rainfall	More than 350 mm/ year average	Arid areas have poor rates of wood production
Tree species	Coniferous only	Standard management techniques for wood production here relate to conifer species

Source: McHarg, 1969; Design with Nature

The strength of this technique is that once the tool for GIS analysis has been developed, it can continue to be refined. For example, policy changes or the results of field study may indicate the need to revise the criteria and re-run the model, which can easily be done.

1.9 The GIS methodology

Once a geo-database is compiled, each of the four layers can be used as decision variables. We can use sequential GIS intersections between the layers to select areas having desired characteristics and filter out irrelevant areas.

Below is an example utilising some of the data layers we collected. Fields with potential for irrigated agriculture would fulfill the following criteria expressed as a series of conditions:

- Well-drained sandy clay to clay, deep soil
- Up to 40% slope (although 16–40% slopes are discouraged unless tree crops are planted or radical terraces are established to avoid landslides—detailed studies must therefore be conducted on sites with steep slopes)
- Political location (province, district, sector)
- Location outside gazetted areas (national parks, forests, marshlands, urban areas)
- Specific ACZ
- Proximity to electricity (to power the pumps)
- Accessibility (roads)
- Proximity to groundwater and/or surface water resources (the sources must provide enough water throughout the irrigation season without impacting negatively on the environment)

To select the optimal fields that correspond to the conditions, a sequence of GIS intersections between the layers is performed, and the resulting suitable polygons are depicted on the GIS map.

1.10 Rationale for an IMP development matrix

According to both international and national estimates, developing irrigated agriculture for Rwanda is a high priority. Only a National Master Plan for Irrigation can provide a framework for such development. This plan must include the entire range of irrigation techniques, from the most traditional to the most modern.

The objective of the Master Plan is therefore not only to delineate a plan itself but also to provide a tool to allow a continuation of the planning process. The methodology explained in this section provides such a tool. In addition to organizing the data, the methodology includes four layers supporting three interrelated decisions:

- Where to irrigate?
- What crops to plant?
- How to manage water resources?

The first layer or tool allows the flexible compilation of the basic data according to changeable criteria.

The second provides a structured method for selecting potential irrigated areas.

The third provides a method for selecting crops appropriate to given sites.

The fourth includes a method for deciding on which administrative level to make different types of decisions concerning irrigation.

Along with the methodology, we have also provided examples of the use of the tool, fed with certain criteria. Phase II will demonstrate the application of this methodology to a number of actual sites.

1.11 Policy issues

No comprehensive irrigation development policy or strategy has yet been developed in Rwanda. Small-scale, 'informal' irrigation has been practiced in the country since the 1980s, mostly on the fringes of marshes. This is considered informal irrigation since it was developed spontaneously, without planning and with little or no technical assistance.

At the time of writing this report, no water board existed in Rwanda. However, plans are being made to establish a Central Water Board within MINIRENA. Decisions taken with regard to water infrastructure and irrigation are presently divided between various authorities in different ministries. Decisions regarding water rights and allocation must take into consideration the impact irrigation will have on other systems. For example, the Rwanda Environmental Management Authority (REMA) and the Water and Sanitation Unit (WSU), both within the Ministry of Lands, Environment, Forestry, Water and Mines (MINIRENA) must review and approve all irrigation projects. Final decisions regarding water allocation are vested in the Cabinet.

Choosing to develop an IMP to upgrade Rwandan agriculture as a route to economic growth is unquestionably a prudent decision.

Chapter 2

Biophysical profile

2.1 Introduction

Any successful planning process must take into account a considerable quantity of basic data of many types. A master plan for irrigation, for example, must include not only biophysical data but administrative, social and economic data as well. It is very important to establish at an early stage how the data are to be collected and utilised so that meaningful and practical recommendations can be made. GIS, the principal tool selected for obtaining and processing data in this study, was applied in three areas:

- Data collection and storage. All electronic or physical data acquired digitally or by digitisation from paper maps were stored in a common database using a common coordinate system.
- Data conversion and mining. Much of the data that referenced geographic information was received in tabular form. Because these data were converted into map format to facilitate analysis, this report contains more maps and fewer tables.
- Data analysis. GIS allowed both stored and converted data to be combined into an explicit analysis.

The intention of this study was not only to utilise the collected data, but also to provide the Government of Rwanda with a useful analytical process that can be put to use in Phase II of the project.

Biophysical data collected included information about climate, administrative units, infrastructure, soils, topography, orthophotography and water resources. These data were collected from various governmental agencies, public domain sources, paper maps and the internet.

2.2 The GIS database of biophysical profiles

The multi-thematic geo-database compiled for Rwanda consisted of a number of data layers divided into four categories.

Administrative and infrastructural data

- Administration (provinces, districts, sectors)
- Cities, towns and market centres
- Gazetted (protected) areas
- Infrastructure (roads, electricity grids)

Land and soil data

- Geology
- Lithology (the soil's parent materials)
- Geomorphology
- Soil types (FAO classification), soil depth and soil texture
- Topographical maps (raster format)
- Elevation contour lines
- Digital elevation models
- Slopes
- FAO land use and land cover classification
- Land suitability classification

Climatic data

- Rain
- Temperature
- P/PET
- ACZs

Water resource data

- Hydrology (rivers, streams, lakes)
- Hydrometric stations
- Main watersheds
- Sub-watersheds
- Springs
- Wells and boreholes

It should be noted that Ebony/ICRAF team was unable to utilise some of the above data because the GIS information/data were either incomplete or not available. The data required for Phase II will therefore include:

- Site-specific soils (GIS layers and its access database)
- More detailed infrastructure (GIS layers and access database [e.g. electricity])
- More detailed topographic data (both GIS and AutoCAD layers)
- More detailed geological (GIS layers and access database)
- More water resources (GIS layers and access database [e.g. hydrometric stations, groundwater data]).
- Land use GIS layer
- Orthophotography in digital format or Quickbird™ satellite imagery
- Land tenure GIS layer
- Socioeconomic GIS layer
- Other relevant GIS data

The data were compiled and thematically organized in a geodatabase format. All geographic data were converted to the same map projection (Transverse Mercator, GCS_Arc_1960) to enable storage, viewing, spatial analysis and map production using standard GIS tools.

Most of the maps are in vector format; others are in raster format. These are the two basic GIS formats that support efficient and effective data analysis. Vector data are organized as geometric shapes (polygons, lines or points). For example, road data are organized as a line layer. The second format, raster, is generally used for continuous data (e.g. altitude) and organized as a rectangular matrix (or grid) of values.

2.3 Administrative and infrastructural data

Prior to 1 January 2006, Rwanda comprised 12 provinces. In 2006, however, the Government decided to establish new provinces. The most recent map that we have

(October 2007) shows Rwanda divided into 5 provinces. The GIS layer stores the provinces' names, areas and principal towns.

Each province is divided into districts. Altogether there are 30 districts. The GIS layer stores each district's name, area and principal town name. Each district is divided into sectors. There are a total of 416 sectors. The GIS layer stores sector names, principal towns, secondary towns and market centres (Appendix 1a and Appendix 1b).

Many data sources were used to compile comprehensive road maps (Appendix 1c). The GIS layer stores information about each road type: main, secondary, dirt and path. The high voltage electrical lines and main electrical facilities are shown in Appendix 1e.

2.4 Land and soils data

2.4.1 Topography and cartography

Topographical maps

Raster layers of geographic data can also be produced by scanning existing maps. Once scanned, the digital topographic layer can be used to include other layers such as administrative and hydrological data and elevations. A Raster Catalogue (scale 1:50 000; projection GCS_WGS_1984) was prepared.

Orthogonal photography

An ortho-photo is a raster layer produced by digital processing of an aerial photograph. It ensures that the map scale is the same over the entire photograph. The ortho-photo can be utilised as a background and overlaid with other GIS layers. This allows for precise and meaningful comparisons of GIS data with land forms, vegetation or settled areas that appear in the photograph.

An ortho-photograph of Rwanda was downloaded from ComputaMaps Bright Earth™. The pixel resolution is 125 m, and the raster projection is UTM.

Digital elevation model (DEM) and contour lines

The DEM is an essential layer for many GIS analyses. It can be used to derive important characteristics of the land surface such as slopes aspects and watersheds. For the purpose of this study, DEM data were obtained from the Shuttle Radar Topography Mission, a global project conducted by the National Space Agency (NASA) of the United States. This project provided basic elevation data, and after considerable processing an elevation grid for Rwanda was produced (Figure 2)

The elevation contours map, which is based on the DEM, has contour intervals of 20 m (Appendix 2b).

A slope grid was prepared for use in later analyses. Four slope categories are depicted in the following categories: 0–6, 6–16, 16–40, > 40 (Figure 3).

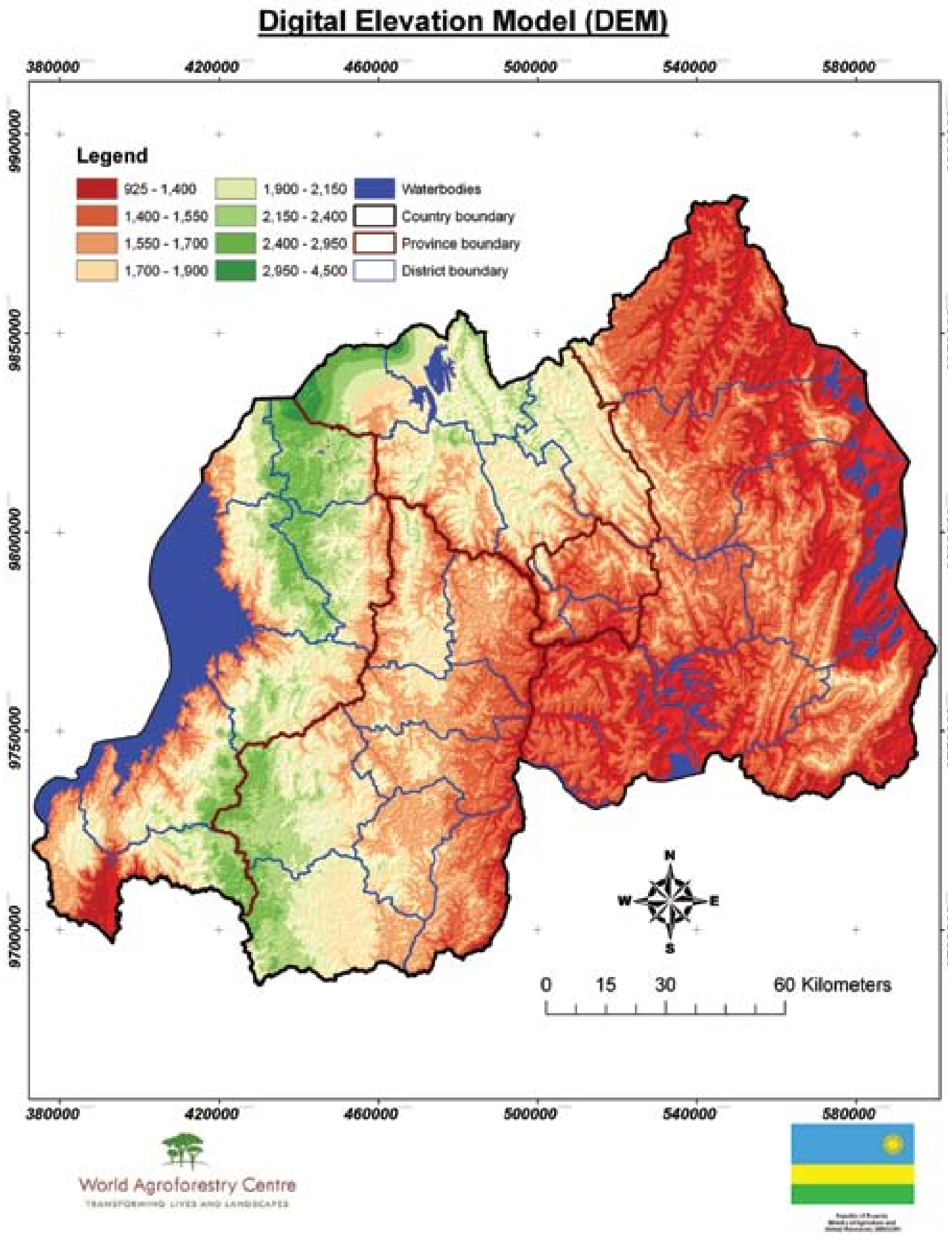


Figure 2: *DEM for Rwanda*

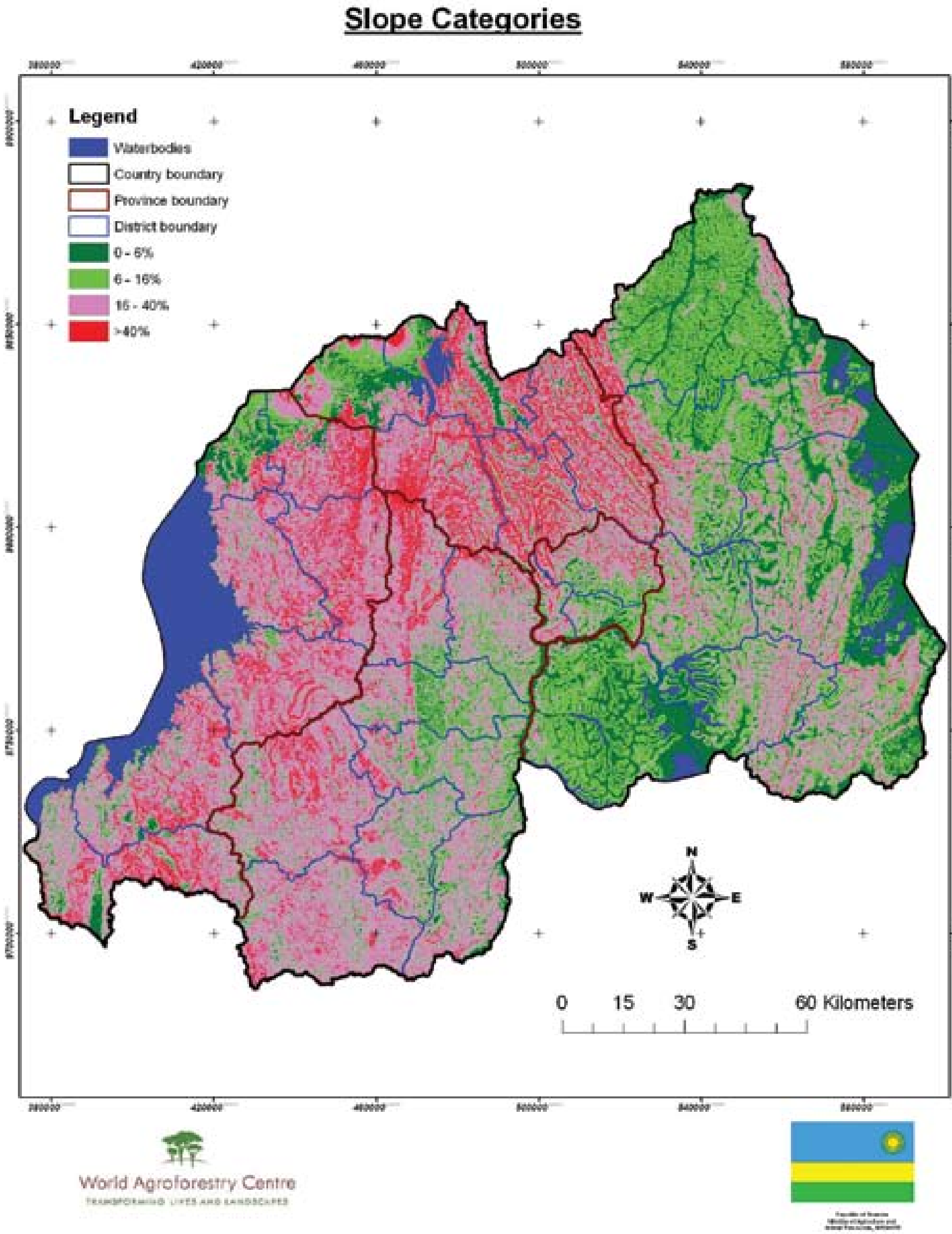


Figure 3: *Slope classes*

2.4.2 Parent materials and soils

A Raster Catalogue (at scale 1:100,000 projection; GCS_WGS_1984) was prepared for Rwanda Geological Maps (Appendix 2c).

A lithology map (the soils parent materials) was prepared (Appendix 2d). The landscape, as influenced by the geology and lithology, is described by geomorphology (Appendix 2e). The different geomorphologic types used in the GIS layer are given in Table 2.

Table 2: *Geomorphologic types used in GIS layer*

Relief	Name
A	Alluvial plain
c	Angular hills
C	Rounded hills
d	Old peneplain
D	Recent peneplain
p	Small plateau
P	Large plateau
v	Volcano top and slope
V	Volcanic plain
z	Angular hills and headlands
Z	Rounded hills and headlands

Source: Adapted from Verdoodt and Van Ranst (2003)

2.4.3 Pedological studies

Soil information was mostly obtained from previous soil survey work covering a span of nearly 20 years. The different soil types are given in Appendix 4. The soils legend is given in French as well as a rough translation in English. Both the USDA soil taxonomy and FAO-UNESCO soil classification systems were used. Over 275 soil series were identified. Some of the soil profiles were analysed for exchangeable bases, cation exchange capacity (CEC), pH, carbon and nitrogen. Summarised below are the major soil types of Rwanda.

2.4.4 Major soil types of Rwanda

The soils pattern in Rwanda is quite complex because of striking differences in parent materials (Appendix 2c and Appendix 2d), land forms (Appendix 2e), altitude (Appendix 2a and Appendix 2b) and climate. The soil map shows the intricate relationship between geology and landforms (Figure 4). Generally, the soil map legend tends to reflect geology at the highest level followed by a subdivision (second level) according to soil depth. Important differences in soil properties have been recognised at the third level. Within the third level, the soils have been ranked according to their drainage conditions, from well-drained to very poorly drained soils.

The first entry in the legend, geology, is intended to give the map user an insight into the geology of Rwanda as it affects soil formation. The major sequence is sedimentary and metamorphic rocks, resulting into the formation of shallow (< 50 cm) to deep (> 100 cm), yellow to red, well-drained soils. This is followed by parent materials derived from granite, gneisses and basalts. The soils are predominantly light-textured, well-drained, yellow to red, shallow to deep. The final sequence in terms of parent materials are represented by alluvial and colluvial deposits, resulting into the formation of organic and/or mineral deep soils of varying drainage, colour and texture.

The second entry is soil depth as reflected in the weathering rates of the underlying parent materials. As mentioned above, the soils are either categorised as shallow (< 50 cm), moderately deep (50–100 cm) or deep (> 100 cm). 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. Soil depth and texture were two of the criteria used to assess the potential suitability of the soils for irrigation (Appendix 5). The third entry in the legend is the description of the main soils or soils of the individual soil mapping units. It is worth emphasising that at the country level a soil mapping unit rarely comprises a single soil. Thus, as indicated in the soil legend, some soil mapping units occur as inclusions or as soil complex. The soils are classified using both USDA and the FAO-UNESCO classification systems. A deliberate attempt has been made to summarise the major soil types occurring in Rwanda using the FAO-UNESCO classification system (Appendix 6). For ease of reference and location, mapping codes and locality names using the series names have been retained. The soils are arranged from those with argillic B horizons (Luvisols, Acrisols, Lixisols, Alisols, Phaeozems), those with special argillic B horizons (Solonetz), those that are highly weathered (Ferralsosl), those developed from recent volcanic rocks (Andosols), those that are poorly drained (Vertisols, Gleysoils, Histosols, Podzols) and those with a cambic B horizon (Cambisols). The last column in Appendix 6 gives a simple description of salient features of the major soil types to provide non-soil specialists such as agronomists and planners an insight as to important soil features without weighing them down with complicated soil classification terminology. Due to the high number of soil units identified it has not been possible to present them in the map legend (Figure 4). An example of an exploded view of the soil types occurring in a small area in south eastern part of Rwanda is given in the map legend.

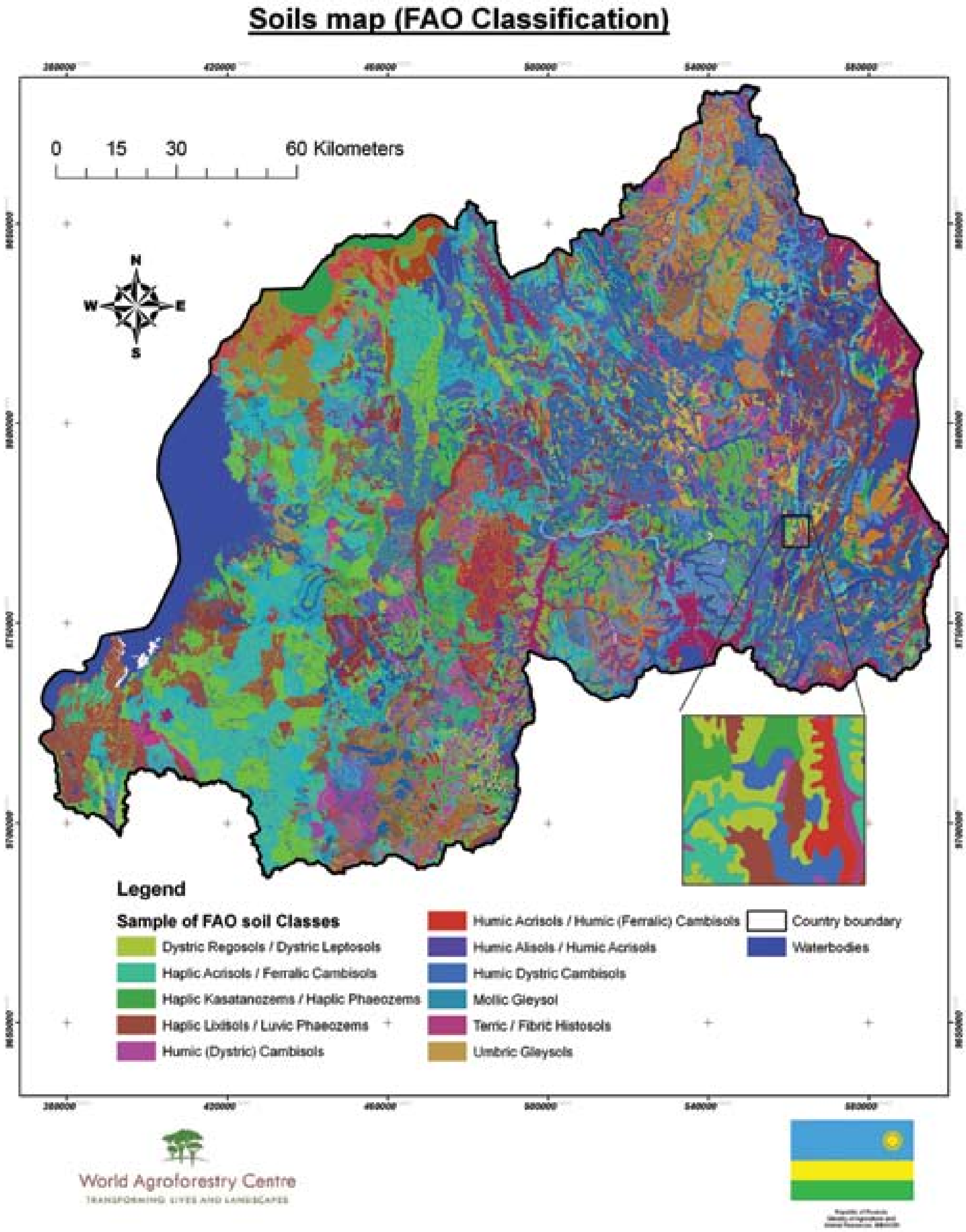


Figure 4: *Soil map (FAO-UNESCO classification) (source MINAGRI)*

2.4.5. Land cover and agriculture

Rwanda's land is fragile because of mountainous topography, thin soil layers and limited vegetative cover. Population pressure has forced settlement on marginal areas, resulting in overgrazing, severe soil erosion, soil exhaustion and desertification.

FAO created a very detailed survey of land cover. More than 1600 polygons with 42 different land cover types provide information on agricultural and other land covers, which are stored in the GIS layer. Table 3 lists these 42 land cover types while Figure 5 shows generalized land use/land cover for Rwanda.

Table 3: *Major kinds of land use and cover types*

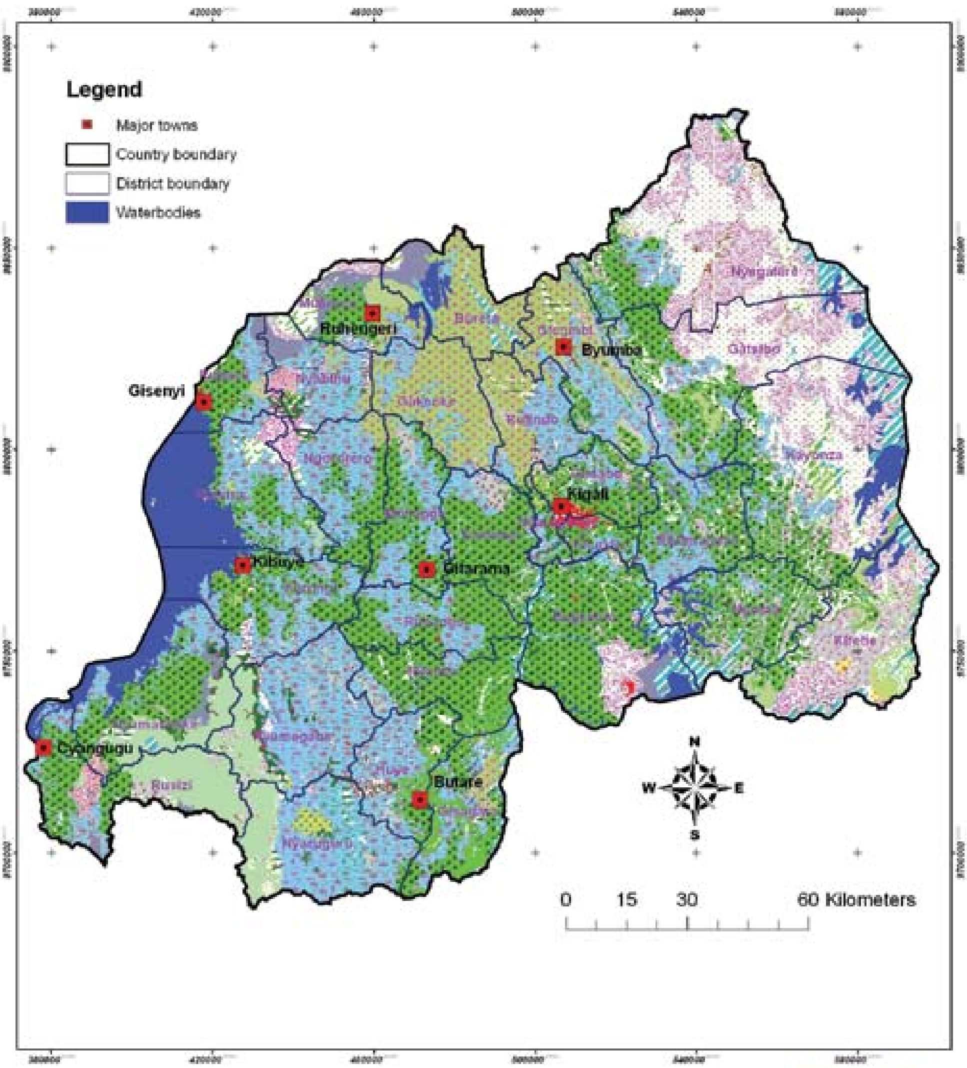
Major kinds of land use	Cover type	Land cover description
Trees and shrubs	Shrubs	Closed shrubs
Trees and shrubs	Natural forest and trees	Closed trees
Savannah and grassland	Grass	Closed to open herbaceous vegetation
Savannah and grassland	Grass	Closed to open herbaceous vegetation on permanently flooded land—fresh water
Savannah and grassland	Grass	Closed to open herbaceous vegetation with sparse trees in temporarily flooded land—fresh water
Agriculture	Crops	Combination of banana plantation (60–70%) and rainfed herbaceous crop (30–40%)
Agriculture	Crops	Combination of forest plantation and rainfed herbaceous crops—two crops per year (approx 30% each—remaining polygon surface natural vegetation)
Agriculture	Crops	Combination of rainfed herbaceous crops—two crops per year—and forest plantation (approx. 70–80% and 20%–30%)
Agriculture	Crops	Combination of rainfed herbaceous crops—two crops per year and shrub plantation (approx 40–60% and 20–40%); remaining forest plantation Eucalyptus, Pinus and cypress
Agriculture	Crops	Combination of rainfed herbaceous crops—two crops per year and shrub plantation (approx 40–60% and 20–40% remaining natural vegetation)
Agriculture	Crops	Combination of rainfed herbaceous crops and forest plantation (approx 40–60% and 20–40%; remaining natural vegetation)

Major kinds of land use	Cover type	Land cover description
Agriculture	Crops	Combination of rainfed herbaceous crops and shrub plantation (approx 40–60% and 20–40%; remaining natural vegetation)
Agriculture	Crops	Combination of shrub plantation and rain-fed herbaceous crops (approx 60–70% and 30–40%)
Agriculture	Crops	Combination of shrub plantation and rain-fed herbaceous crops—two crops per year (approx 40–60% and 20–40%); remaining forest plantation (eucalyptus, pinus and cy-press)
Agriculture	Crops	Combination of shrub plantation and rainfed herbaceous crops—two crops per year (ap-prox 40-60% and 20-40%; remaining natu-ral vegetation)
Agriculture	Forest plantations	Forest plantation (eucalyptus, pinus and cy-press; mixed units with natural vegetation or other; field area approx 60% polygon area)
Agriculture	Forest plantations	Forest plantation—eucalyptus, pinus and cypress
Agriculture	Crops	Irrigated cerbaceous crop
Agriculture	Forest plantations	Isolated (in natural vegetation) forest planta-tion (eucalyptus, pinus and cypress); field density 10–20% polygon area
Agriculture	Crops	Isolated (in natural vegetation); rainfed her-baceous crop (field density 10–20% poly-gon area)
Agriculture	Crops	Isolated in natural vegetation; rainfed her-baceous crop—two crops per year— field density 10–20% polygon area
Trees and shrubs	Natural forest and trees	Multilayered Trees Broadleaved Evergreen
Trees and shrubs	Natural forest and trees	Open broadleaved deciduous trees
Trees and shrubs	Shrubs	Open shrubs
Trees and shrubs	Shrubs	Open shrubs (on temporarily flooded land, fresh water)

Major kinds of land use	Cover type	Land cover description
Agriculture	Crops	Post flooding herbaceous crops
Agriculture	Crops	Post flooding herbaceous crops (mixed units with natural vegetation); field area approx 60% polygon area
Agriculture	Crops	Rainfed herbaceous crops
Agriculture	Crops	Rainfed herbaceous crops—two crops per year (mixed units with natural vegetation); (field area approx 60% polygon)
Agriculture	Crops	Rainfed herbaceous crops; two crops per year
Agriculture	Crops	Rice fields
Savannah and grassland	Savannah	Savannah (shrub or tree and shrub)
Agriculture	Forest plantations	Scattered (in natural vegetation; forest Plantation (Eucalyptus) or Pinus and Cypress (field density 20–40% polygon area)
Agriculture	Crops	Scattered in natural vegetation or other; rainfed herbaceous crops (field density 20–40% of polygon area
Agriculture	Crops	Scattered in natural vegetation; rainfed herbaceous crops; two crops per year; field density 20–40% of polygon area
Agriculture	Shrub plantations	Scattered in natural vegetation; shrub plantation; undifferentiated (field density 20–40% polygon area)
Agriculture	Shrub plantations	Shrub plantation—undifferentiated
Agriculture	Shrub plantations	Shrub plantation—undifferentiated (mixed units with natural vegetation; field area approx. 60% polygon area
Savannah and grassland	Grass	Sparse herbaceous vegetation
Agriculture	Shrub plantations	Tea plantation
Urban areas	Urban areas	Urban and associated areas
Water bodies	Water bodies	Water bodies

Source: Modified from FAO Africover 2000/2001

Landuse/Landcover



World Agroforestry Centre
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Source: Modified from FAO Africover 2000/2001

Figure 5: *Generalized land use / land cover map*

2.5 Climate data

Before 1994, nearly 200 meteorological stations were installed in Rwanda. Some of the stations began data collection as early as 1907. Each station collected data on rainfall, temperature and potential evaporation, and stored the information for statistical analysis. During the violence in 1994 a great deal of historical hydrological data disappeared. At present, incomplete historical data (mostly since 1940) is available from 100 stations. This data includes average annual rainfall as well as information on the intensity, frequency and duration of rain events. Only six rain gauging stations that are currently collecting data.

2.5.1 Temperature

The average annual temperature over most of the country is 20 °C. Temperatures and daily fluctuations are controlled by topography. The thermal gradient (lapse rate) is 0.56 °C per 100 m.

Rwanda has four temperature zones:

- Eastern Plateau: altitude < 1500 m asl, temperature 20–21 °C
- Central Plateau: altitude 1500–2000 m asl, temperature 17.5–19 °C
- Highlands: altitude > 2000 m asl, temperature < 17°C
- Imbo and Bugarama Valleys: altitude < 1500 m asl, temperature 23–24 °C

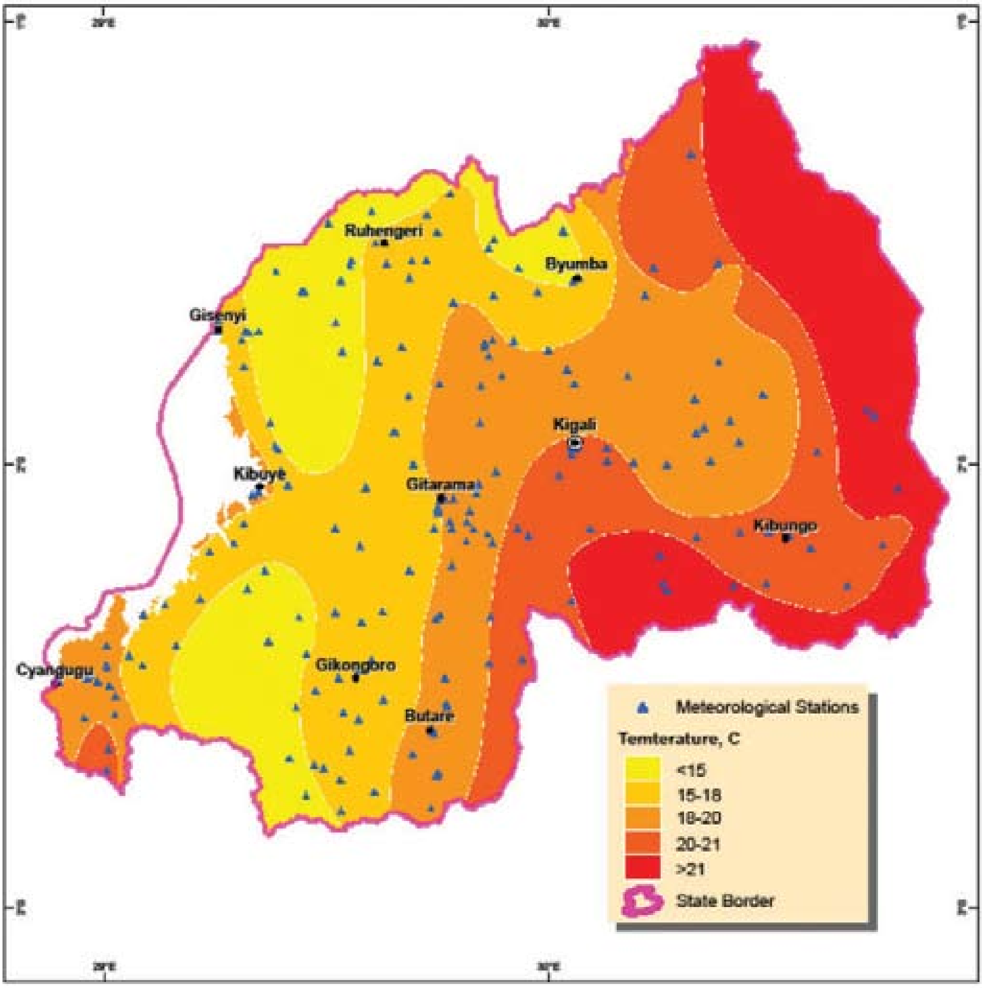
The surface spatial analysis for average temperature is shown in Figure 6. The temperature gradient starts from the west which is cooler (< 15 °C) and gets hotter towards the east (> 21 °C). The map also gives the original locations of rain-gauging stations in the country.

2.5.2 Precipitation

The surface spatial analysis for average rainfall is shown in Figure 7. There are two rainy seasons (mid March to mid June and mid September to mid January) and two relatively dry periods with occasional light rains. The average annual rainfall ranges from 750 mm to 2200 mm. The lowest rainfall occurs in the northeastern part of the country (750 mm); in the northwestern and southwestern parts of the country it reaches 2200 mm. The rainfall layers were generated by collecting average monthly and annual rainfall data from all the stations and using interpolation techniques to produce 20-metre resolution layers.

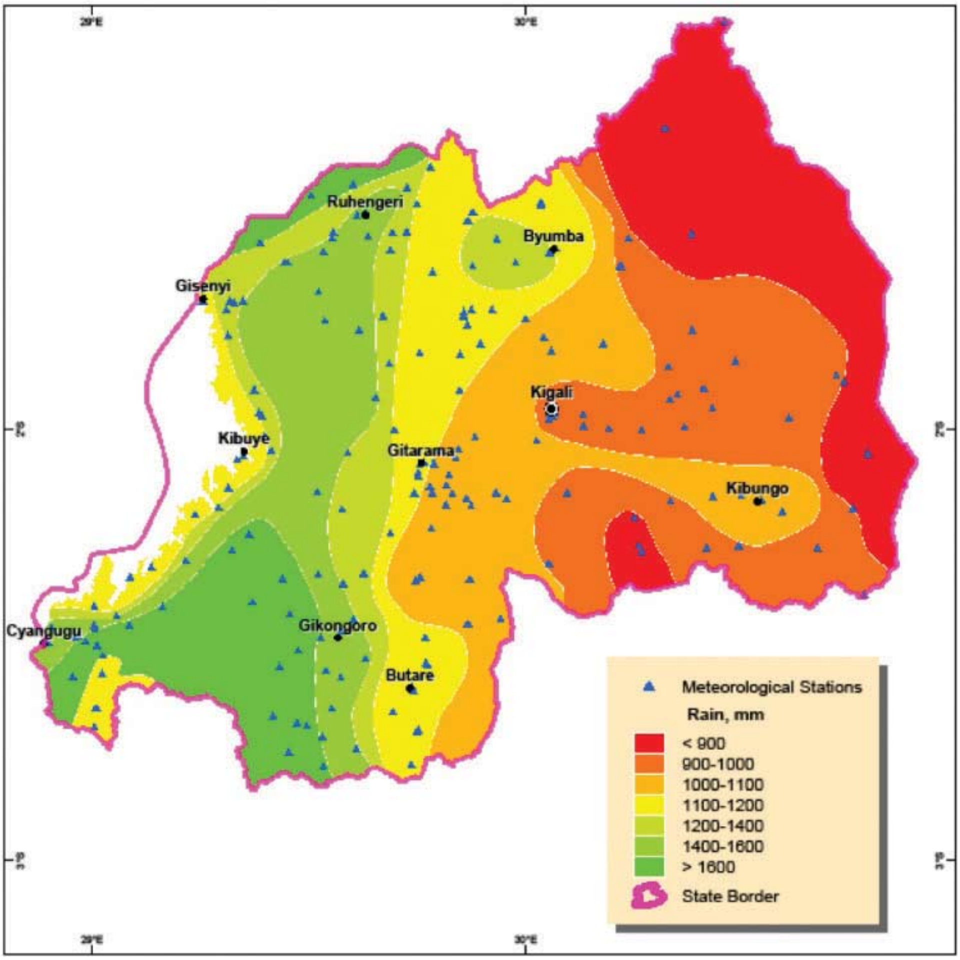
2.5.3 Precipitation / evapotranspiration

The relationship between precipitation and evapotranspiration is critical in designing irrigation for a particular site. Daily data for these parameters (averaged monthly) were obtained from eleven meteorological stations from different areas of Rwanda. These figures enable us to easily see the time period, which varies by station, when a water deficit for agriculture exists—i.e. when evaporation exceeds precipitation. In addition, we see the extent to which this deficit varies between different areas of the country. The results of country analysis are discussed in depth in Chapter 6.



Source: MINAGRI

Figure 6: *Temperature map*



Source: MINAGRI

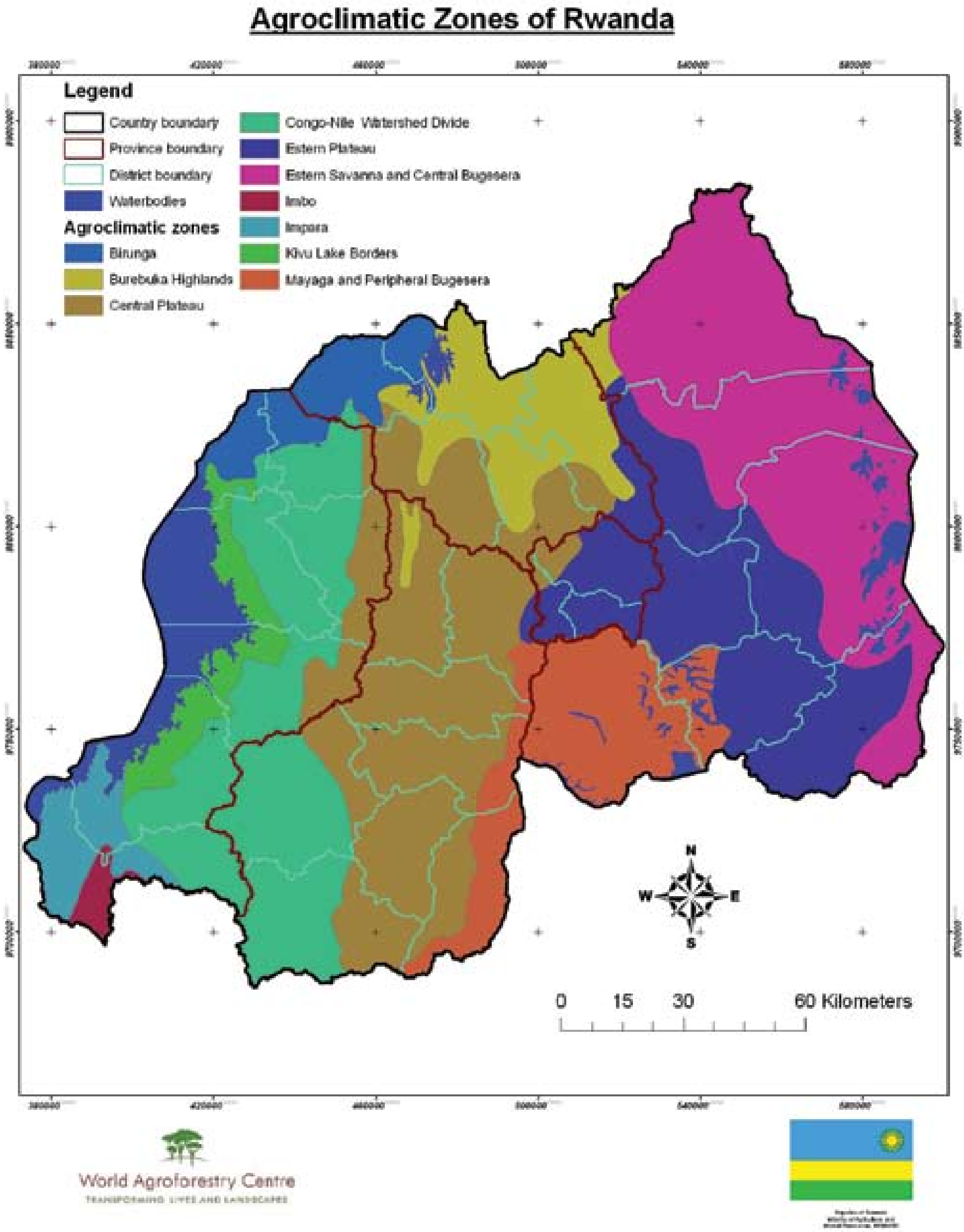
Figure 7: *Precipitation*

2.6 Agroclimatic zones

The averaged climatic information (temperature, rainfall and altitude) were used to divide Rwanda into 10 ACZs (Source: Modified from Verdoodt and Van Ranst, 2003 Figure 8 and Table 4). The ACZs can be used to classify the country according to agricultural suitability.

These ACZs were further subdivided into 38 agro-ecological zones (AEZs). While ACZs are defined by temperature and rainfall, AEZs are characterised according to pedological and climatic criteria. The basic information for this classification is taken from the PNUD/FAO/RWA/006 database.

The 10 ACZs include 28 primary drainage basins and 352 secondary basins. In the primary basins, 283 marshes were identified.



Source: Modified from Verdoodt and Van Ranst, 2003

Figure 8: *Agroclimatic zones*

The data describing the wetlands or marshes includes:

- Area of the basin generating flow to the marsh
- Area of the marsh
- Altitude of upper reaches

- Altitude of lower reaches
- Length of main waterway

Two criteria were chosen for comparison of secondary basins:

- Water storage capacity of marshes
- Quantification of flash-flood risk in the main basins

These parameters are of extreme importance for planning water management in various basins, and for evaluating relevant project engineering costs in the basins.

Characterization of ACZs

ACZ 1 – Imbo
This zone is located in the southwest, in the drainage basin of the Rubyiro. Much of the area is covered by marshes. The slopes in the upper reaches of the basin are mild (1%) and level off in the lower reaches of the river. The water exploitation from the areas is considerable.

ACZ 2 – Impara
The zone is located north of the Rubyiro and includes 20 sub-basins, all draining to Lake Kivu. The slopes are high, exposing the zone to risk of violent flash floods. This zone is not favourable for massive storage of water.

ACZ 3 –Kivu Lake Borders
This zone is characterised by numerous sub-basins, all draining to Lake Kivu. Because these sub-basins have high morphological slopes, the marsh area is rather limited. The zone is known for the incidence of major floods generated by high rainfall. In two sub-basins located at altitudes exceeding 1900 m, the storage capacity of the marshes is significant, notwithstanding the relatively low marsh index.

ACZ 4 – Birunga
In the southwestern part of ACZ 4, the hydrographic network is not permanent. In its northeastern part, four sub-basins extend over an area of 110 km^2. In the basins of Kabaya-Kilimbi, the slopes are medium, the average altitude is > 1900 m, the storage effect of the marshes is significant and floods are uncommon. In the basins of the Mpenge-Nyamutukura, Mugara, Mubona and Mwora, slopes are steep and the danger of flooding is considerably higher.

ACZ 5 – Congo-Nile Watershed Divide
The zone extends at elevations ranging from 1900 to 2000 m with regional morphology characterised by steep slopes. Due to these features and the high rainfall, the danger of flooding is high. The marshes are very important as storage regulators, particularly in the most elevated parts of the zone. In certain sub-basins soils developed on unstable volcanic debris.

ACZ 6 –Buberuka Highlands
This zone extends through the central northern part of the country, including the high plateaus around Lake Bulera and the upper reaches of the Nyabarongo. In most

of the zone's sub-basins, the marshes play an important role as natural water storage regulators. These sub-basins are located at high altitudes and differ mainly by their slopes.

ACZ 7 – Central Plateau
In this zone, the risk of flooding is lower than elsewhere, and the role of marshes as flood regulators is minor. This zone includes123 sub-basins that differ according to their natural characteristics.

ACZ 8 - Mayaga and Peripheral Bugesera
This zone extends south of Kigali and is characterised by numerous lakes and large areas covered by marshes. The slopes are usually mild and the danger of flooding is not acute. Nevertheless, the buffering role played by marshes is important.

ACZ 9 – Eastern Plateau
The zone extends over highlands and hills of medium altitude. Marshes do not play an important role in this area.

ACZ 10 – Eastern Savannah and Central Bugesera
This zone is located in the northeastern part of the country and coincides with the ancient limits of Akagera Park. It includes numerous lakes and wide areas covered by marshes extending along the Akagera River. The slopes are mild and danger of flooding is not acute.

Table 4: *Characterisation of ACZs*

ACZ	Stations	Altitude (m)			Mean temperature (ºC)			Total rainfall (mm year^{-1})			Dry period (days)		
	No.	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Imbo	1	< 1000	-	-	24	-	-	1154	-	-	122	-	-
Impara	16	1666	2100	1400	19	21	17	1710	2360	1203	56	62	31
Kivu Lake Borders	13	1638	1890	1465	20	21	18	1225	1420	1087	66	92	31
Birunga	17	1960	2500	1460	17	20	14	1317	1678	1110	15	62	0
Congo-Nile Watershed Divide	23	2058	2550	1450	17	21	13	1542	2276	970	27	92	0
Buberuka Highlands	16	1957	2312	1500	17	21	15	1267	1553	1033	41	152	0
Central Plateau	44	1749	2110	1400	19	22	17	1298	1993	1025	59	123	0
Mayaga & Peripheral Bugesera	16	1403	1500	1325	21	21	20	1101	1310	901	109	153	62
Eastern Plateau	33	1575	2200	1370	20	21	18	1038	1255	891	86	123	31
Eastern Savannah & Central Bugesera	16	1386	1485	1280	21	25	20	902	1258	632	126	153	92

Source: Verdoodt and Van Ranst 2003

Chapter 3

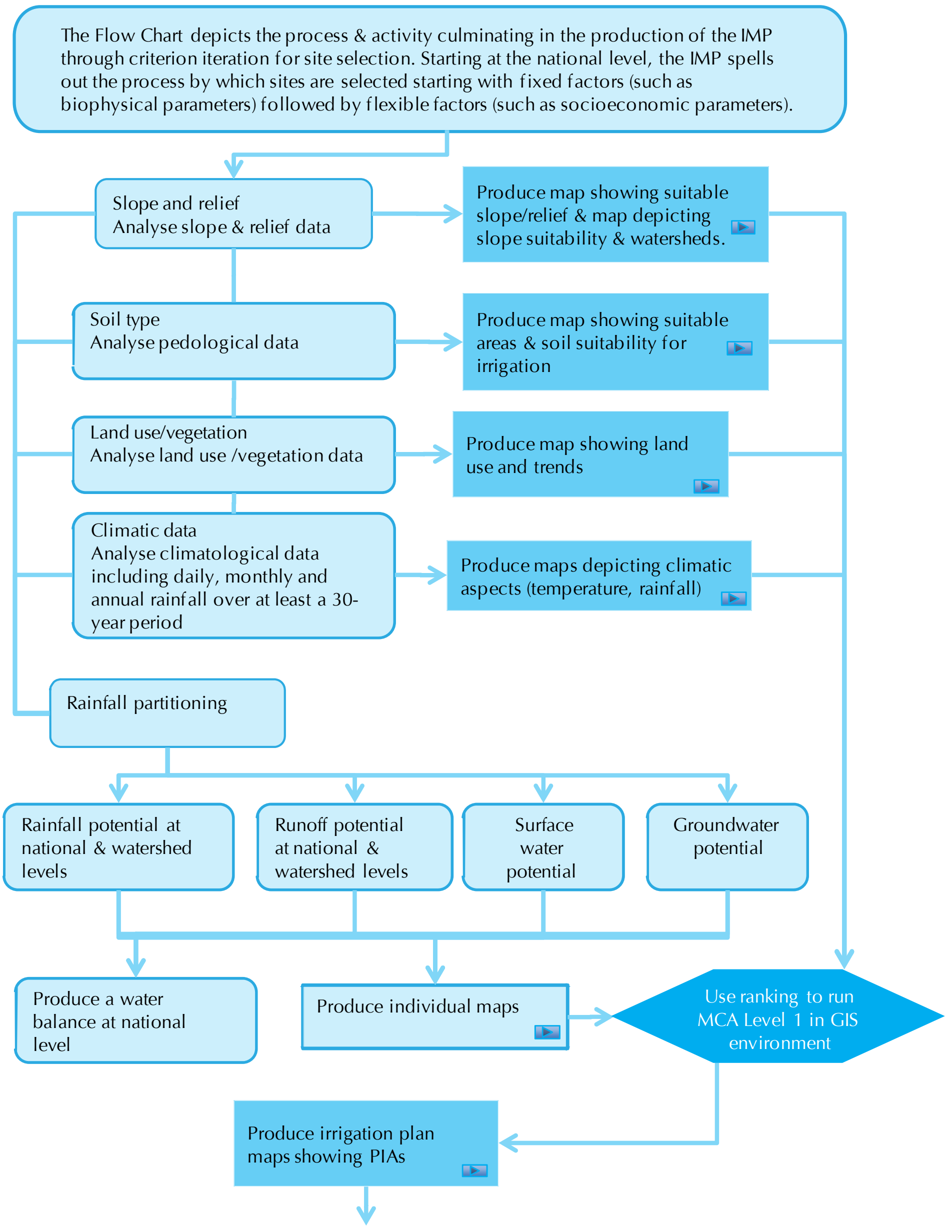
Identification of Potential Irrigation Areas

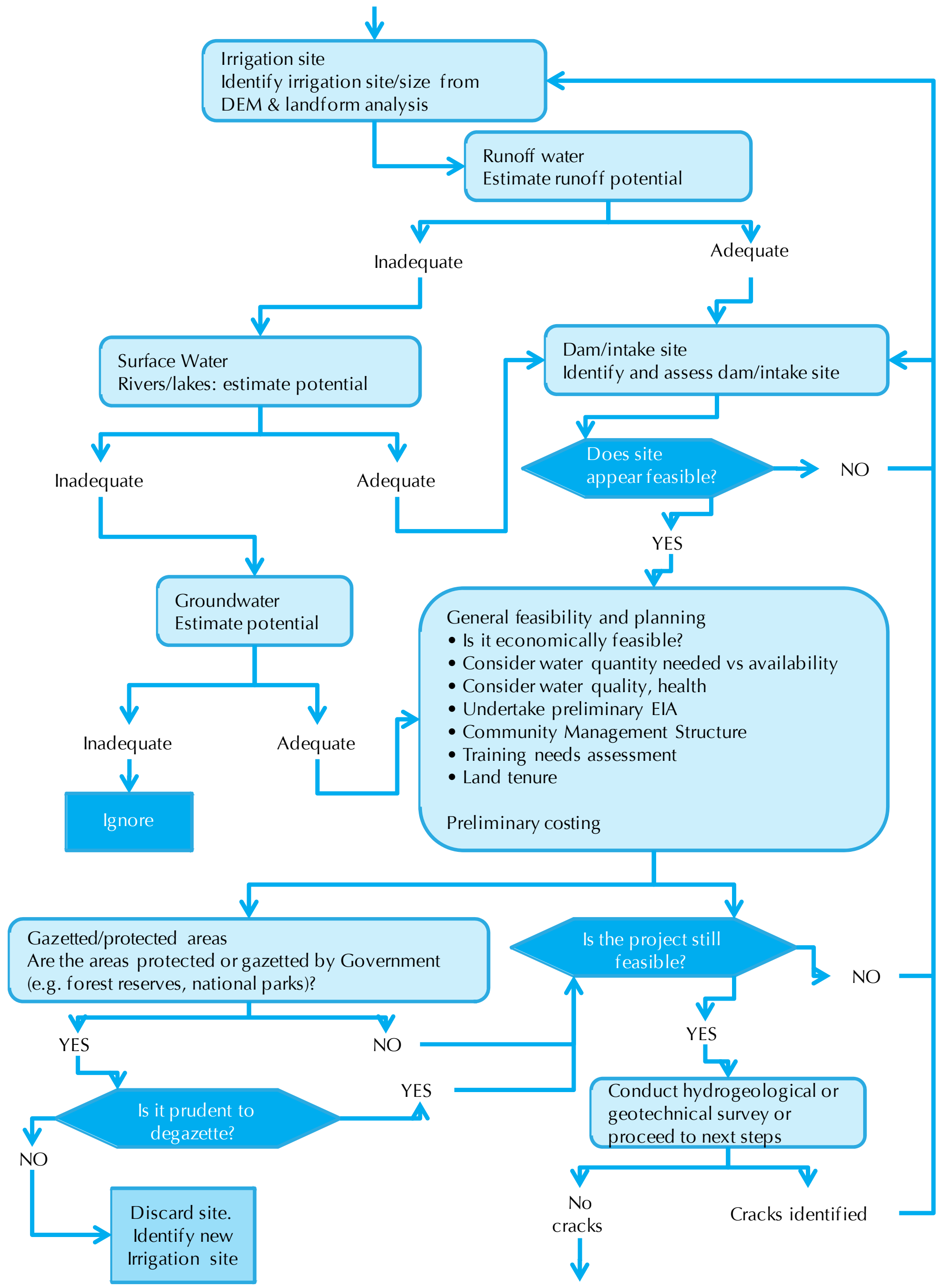
3.1 Development of a Potential Irrigation Area (PIA) decision support tool

The tool used to facilitate the selection of PIAs is a flow chart that depicts the process leading to the production of the Irrigation Master Plan (IMP). The IMP is produced by examining the criteria for site selection, including detailed planning for the selected sites. This chapter focuses on the identification of PIAs at the national level.

The IMP Flow Chart (Figure 9) takes into account engineering, pedological, climatic, agronomic and socioeconomic tenets in combination with GIS. It is a newly developed tool that enables the decision maker to choose from among relevant options, rank areas in order of suitability and support priority settings for scheduling the development and allocation of irrigation resources.

IMP Flow Chart




Irrigation site
Identify irrigation site/size from
DEM & landform analysis
Runoff water
Estimate runoff potential
Inadequate
Adequate
Surface Water
Rivers/lakes: estimate potential
Dam/intake site
Identify and assess dam/intake site
Does site
appear feasible?
NO
YES
Inadequate
Adequate
Groundwater
Estimate potential
General feasibility and planning
• Is it economically feasible?
• Consider water quantity needed vs availability
• Consider water quality, health
• Undertake preliminary EIA
• Community Management Structure
• Training needs assessment
• Land tenure
Preliminary costing
Inadequate
Adequate
Ignore
Gazetted/protected areas
Are the areas protected or gazetted by Government
(e.g. forest reserves, national parks)?
Is the project still
feasible?
NO
YES
NO
YES
Is it prudent to
degazette?
YES
NO
Conduct hydrogeological or
geotechnical survey or
proceed to next steps
Discard site.
Identify new
Irrigation site
No
cracks
Cracks identified

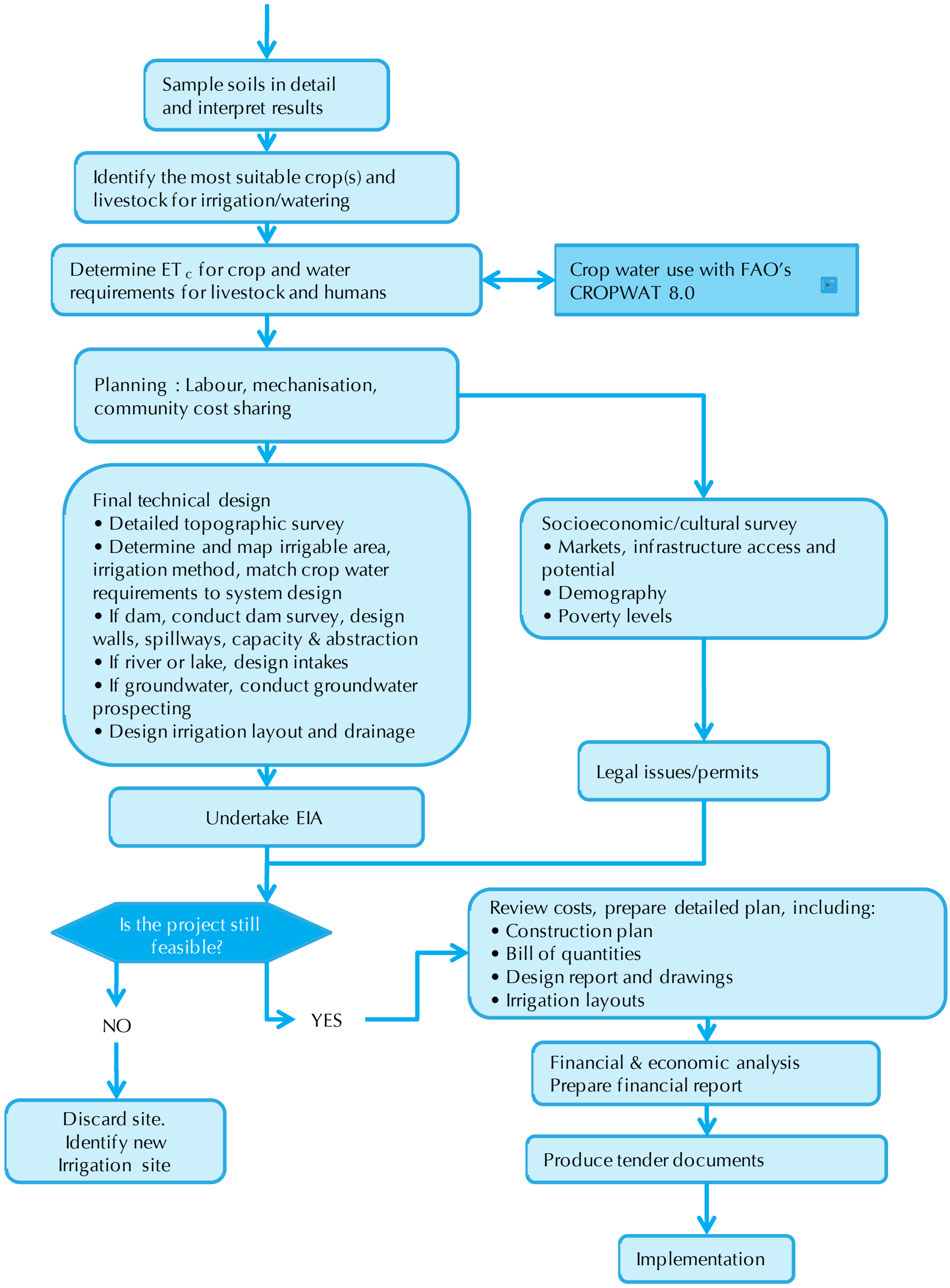


Figure 9: *IMP Flow Chart*

The Flow Chart process largely conforms to FAO guidelines, which emphasise the necessity of evaluating land by taking into account both biophysical and socioeconomic parameters. These parameters must undergo detailed multi-criteria assessment and scoring using standardization and evaluation procedures within a GIS environment, as well as analysis at both national and site development stages.

Biophysical parameters examined for site selection include:

- Slope/relief
- Soil type
- Land use/landcover
- Climate
- Water

Socioeconomic factors include:

- Demographic patterns (population density and distribution, gender, labour, age groups)
- Infrastructure (roads, electricity grids, domestic water supply, markets)

According to FAO, the main objective of land evaluation is to predict future conditions after development has taken place. Benefits to farmers as well as to the national economy must be forecast with respect to agricultural sustainability without damage to the environment.

Some factors that affect land suitability are not controllable (e.g. temperature) while others are changeable at a cost (e.g. micro-relief). Land suitability must therefore be assessed and classified with respect to specified land use systems such as cropping, irrigation and management systems. Land evaluation requires a comparison of the outputs on different land types. In other words, evaluating land is essentially an economic concept. However, the actual economic analysis is conducted at site level.

Because not every relevant factor is defined or weighed quantitatively in each case, decisions concerning which sites or areas are selected frequently rests on subjective parameters rather than explicit analysis. Section 3.2 explains each criterion in detail and shows how the criteria are standardized and assessed using a multi-criteria analysis (MCA) evaluation method. Maps are provided for each criterion as well as a composite map that integrates all the criteria.

3.2 Criteria used in the determination of PIAs

The process of grading each PIA utilises the tool shown in Figure 9. Each site resulting from the GIS analysis is graded by its physical and other characteristics. These grades may also be affected according to the relative importance of a particular parameter. The final score for a site is found by multiplying each grade by its weight and summing the total.

3.2.1 Slope and relief

Slope is chosen as the first major criterion for five reasons.

1. Slope informs on positioning of the water supply domain as regards the irrigation command area and infrastructure (i.e. conveyance, storage and delivery mechanisms).

2. If water supply is based on gravity-fed schemes, the cost of production reduces as compared to schemes dependent on pumped water whose source is located downstream.
3. Irrigation engineers assess slope regimes to determine the type of irrigation to be used. That is why it is not prudent to join slope regimes that could jeopardize the planning for the type of irrigation to be developed.
4. With technical guidelines and policies, slope can be used to set limits on how far irrigation can be implemented. While setting such limits, considerations are made on environmental conservation, food security and human settlements.
5. Steep slopes (above 40%) need modification through terracing to enhance their conservation capacity for water, soil and nutrients. Modification is a costly venture. On the other hand, gently sloping or flat lands often receive eroded soils and nutrients from upstream catchments. In addition, they are often located on the lowlands, which benefit from gravity-fed irrigation.

Table 5: *Scoring of slope classes*

Slope (%)	Points
0–6	4
6–16	3
16–40	2
> 40	1

The slope was classified into four categories and ranked between 1 and 4 points to build into an MCA, depending on irrigation suitability (Table 5). The gentler the slope regimes, the higher the rankings for reasons adduced above. The converse is also true.

3.2.2 Soil types

Pedological classification was used to capture the different types of soils, denoting their physical and chemical characteristics. The Ebony and ICRAF IMP team identified four classes of soil according to their suitability for irrigation (Table 6). The best classes with higher points have good physical and chemical properties in reference to their inherent soil fertility, drainage, depth, texture and water holding capacity.

Table 6: *Scoring of soil classes*

Soil suitability	Points
Class 1	4
Class 2	3
Class 3	2
Class 4	1

Once identified, the soil data were fed into the GIS environment for mapping. Each soil class was assigned a unique identity with a coding scheme (e.g. a numbering or lettering process) that supports spatial analysis at the MCA stage. The suitability classes for irrigated agriculture for the different soil types of Rwanda are shown in Figure 10.

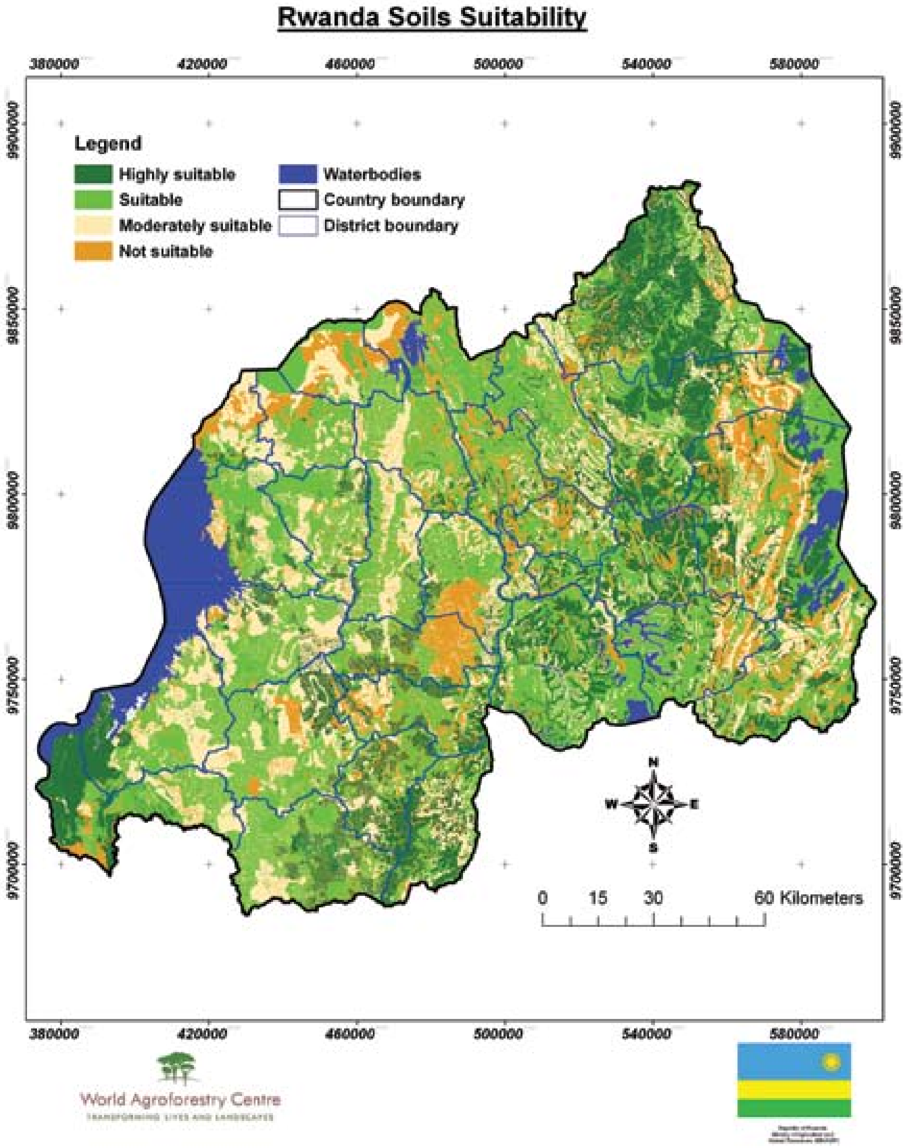


Figure 10: *Soil suitability for irrigation*

3.2.3 Land use and land cover parameters

These are subjective criteria that target areas already annexed for protection by the government on behalf of the public. Such areas include forest reserves, national parks, wetlands/ marshlands, urban areas and buffers around urban areas. These areas are thus excluded in the mapping process by GIS. Accessible areas such as open fields, grasslands, shrub lands, marshes and forests are sometimes crucial to people's livelihoods. Yet they remain outside the purview of environmental impact assessments because they are excluded from consideration for irrigation development.

Buffer zones are important because they protect delicate ecosystems and resources that may be harmed by proximity to a proposed irrigation site. Recommended specifications of buffers are as follows (Organic Law on Environment 2005):

- Stream side management zone: 10 m on each side
- Around lakes: 50 m from highest water level

3.2.4 Infrastructure

Proximity to roads

The importance of proximity to infrastructure in general, and to roads in particular, cannot be overstated. The threshold value for the sites in this analysis was initially to be fixed at 3 km, but due to good road networks throughout the country, this parameter was not utilised because every area identified was accessible.

Proximity to electricity

The availability of electrical power to operate water pumps and service production centers is significant. Distance threshold values of potential sites to high voltage power lines were to be set to under 10 km for this analysis although electricity will not be a limiting factor in the near future given expansion plans of the Government of Rwanda.

3.2.5 Human environment

Availability of labour

The availability of a suitable labour pool is an important consideration. The high population density throughout most of the country and the percentage of the population employed in agriculture indicates that this is not a limiting factor in Rwanda.

Access to extension and research

The availability and access to extension and research services is crucial to success in introducing irrigated agricultural projects. This is not rated in this analysis because it is understood that the project itself will have to provide this important service since there is no well-established and functional extension service in most of Rwanda.

3.3 Multi-criteria analysis to identify PIAs

Once all the necessary layers were prepared through reclassification, ranking and scoring, they were subjected to MCA where weight was assigned to each layer based on its importance. Layers such as slope and soil were awarded more weight than others. The system was then run to produce results. The results were then validated through transfer of the products to other advanced software with different capabilities and through field visits.

Using advanced GIS techniques and tools to further analyse the digital elevation models and landforms helped in the refinement of PIAs. The best sites are those located below catchments and water reservoir areas, irrespective of whether a single watershed or cascades of watersheds allow for this condition. This allows for use of runoff water by gravity in order to reduce costs.

Chapter 4

Water resource availability

4.1 General background

Although water resources are abundant in Rwanda, they are unevenly distributed in space, category, and quantities. The western region receives considerably higher amounts of rainfall compared to the east. During rainfall seasons, runoff generated in the hillsides quickly flows to the valley bottoms, marshlands, rivers or lakes creating an economic water scarcity owing to inadequate infrastructure (such as lined ponds or dams). Such infrastructure may be a costly venture for small to large-scale land users respectively. Unless supported by supplemental water, hillsides can thus support limited farming during dry seasons. Although the eastern part of the country has low rainfall, its lowlands are inter-sparsed by a good network of surface water bodies with significant flows and stock.

There have been attempts by various consultants commissioned by MINIRENA to study and compile surface and groundwater data through the PGNRE project. Analysis of these data reveal that the central and eastern parts of the country have good potential for the development of springs, wells and boreholes for domestic, livestock and crop production.

Besides irrigation, utilisation of these water resources have to take into account other demands that includes hydro-electricity generation, industrial, environmental and domestic water use.

4.2 Water resources data

Availability of information and data
As stated in chapter 1, Rwanda's data archives for precipitation and surface water flow were almost entirely destroyed during the 1994 genocide. At present, the Government is making a praiseworthy effort to establish modern, computerised hydrological databases and a national monitoring system. The present assessment is based on data collected by various foreign consultants and summarised by MINIRENA. However, Rwanda's assessment of its water resources is based on limited and relatively short-term data. Information regarding the quantity and quality of water resources is inadequate, and most of the available data are often unreliable. Resources for collecting and processing the basic data on hydrology and hydrogeology are also insufficient.

There is at present an acute shortage of human resources specialised in water technologies, many of the most capable scientists and technicians having been killed or left the country during the violence. Other important constraints are inadequate dissemination of existing information, unequal distribution of water in time and space, lack of public awareness of the value of water and the link between health and sanitation, and inefficient use of water in agriculture.

Existing hydrological data
Several important hydrological studies were conducted in different regions of Rwanda to elucidate specific regional and local hydro-agricultural and hydro-electric problems. These studies were based on indirect calculations derived from meteorological data, such as extrapolating data from one basin to another or employing the limited meteorological and morphological information currently available.

Since 1955, the Hydrological Service of Rwanda changed supervisory ministries several times. At present, the service is very limited in its resources. Hydrometric data for the 1950–99 period, which was based on measurements at 35 gauging stations, was documented in hydrological yearbooks, but field measurements were discontinued during the past several years. Currently, only four gauging stations are operational, and their calibration and reliability are questionable.

Moreover, the data obtained from the 35 stations mentioned above were not representative of Rwanda's hydrology because most of them were located on the large rivers. It is necessary to study the smaller rivers and drainage basins in greater detail, and to extrapolate and compare their characteristics.

Recently a hydrological database called RWA/89/006 was established by FAO in an attempt to define the typical parameters of the drainage basins of Rwanda. The following parameters were included:

- Average annual and inter-annual rainfall data
- Area of drainage basins
- Coefficient of compaction calculated from the ratio between the area of the basins and their perimeters (this ratio is proportional to the intensity of storm events)
- Average slope of the basins
- Density of the hydrographic network
- The marsh index (the ratio between the total area of the marshes and the total area of the basin)

Analysis of hydroclimatic data

The temperature and precipitation data from all the stations was analysed using high-level interpolation techniques in a GIS environment. Necessary adjustments to improve accuracy such as the incorporation of an altitude layer in the temperature interpolation were also considered in the processing of the data. The generated temperature layer was later used in the crop section (Chapter 6).

The generated rainfall layer was then taken into a new analysis platform along with the slope, soils and land use / land cover data for spatial analysis. The idea was to generate a runoff potential layer that would enable the estimation of the volume of runoff water at every point in Rwanda. Cumulative runoff volumes were then estimated at watershed levels with 1000 km^2 thresholds being used. Figure 11 shows runoff potential volume per watershed.

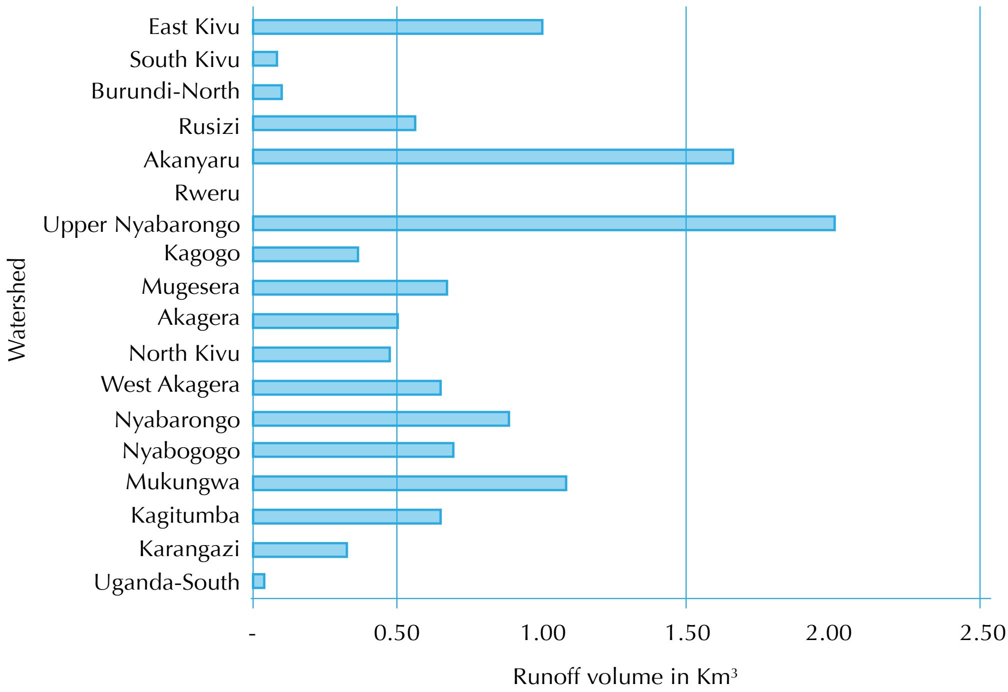


Figure 11: *Runoff potential volumes per watershed*

4.3 Hydrography

4.3.1 Introduction

The hydrographic network in Rwanda is abundant and dense. The country's area (26 338 km^2) is divided between the Congo River Basin in the west, and the Nile River Basin in the east. The Upper Nile Basin, which occupies 76% of the country's area (20 017 km^2), drains 90% of the surface waters through the Nyabarongo and Akagera Rivers, the main tributaries of Lake Victoria. The Akagera Basin contributes 10% of the water in the Nile watershed.

The Congo River Basin, which occupies 24% of the country's area (6321 km^2), drains 10% of the surface waters, from the Lake Kivu Basin to Lake Tanganyika.

Water occupies 8% of the land area—about 2110 km^2. Lakes cover 1669 km^2, and Rwanda's portion of Lake Kivu accounts for 65% of this total. Rivers occupy 72.6 km^2 and marshes and flooded shallows account for 770 km^2. Most of the lakes and rivers are fed by marshes.

Many sources were used to compile comprehensive data on Rwanda's 104 rivers, lakes, reservoirs and water bodies (Figure 12). The names, lengths and areas of the lakes and rivers are stored in GIS databases.

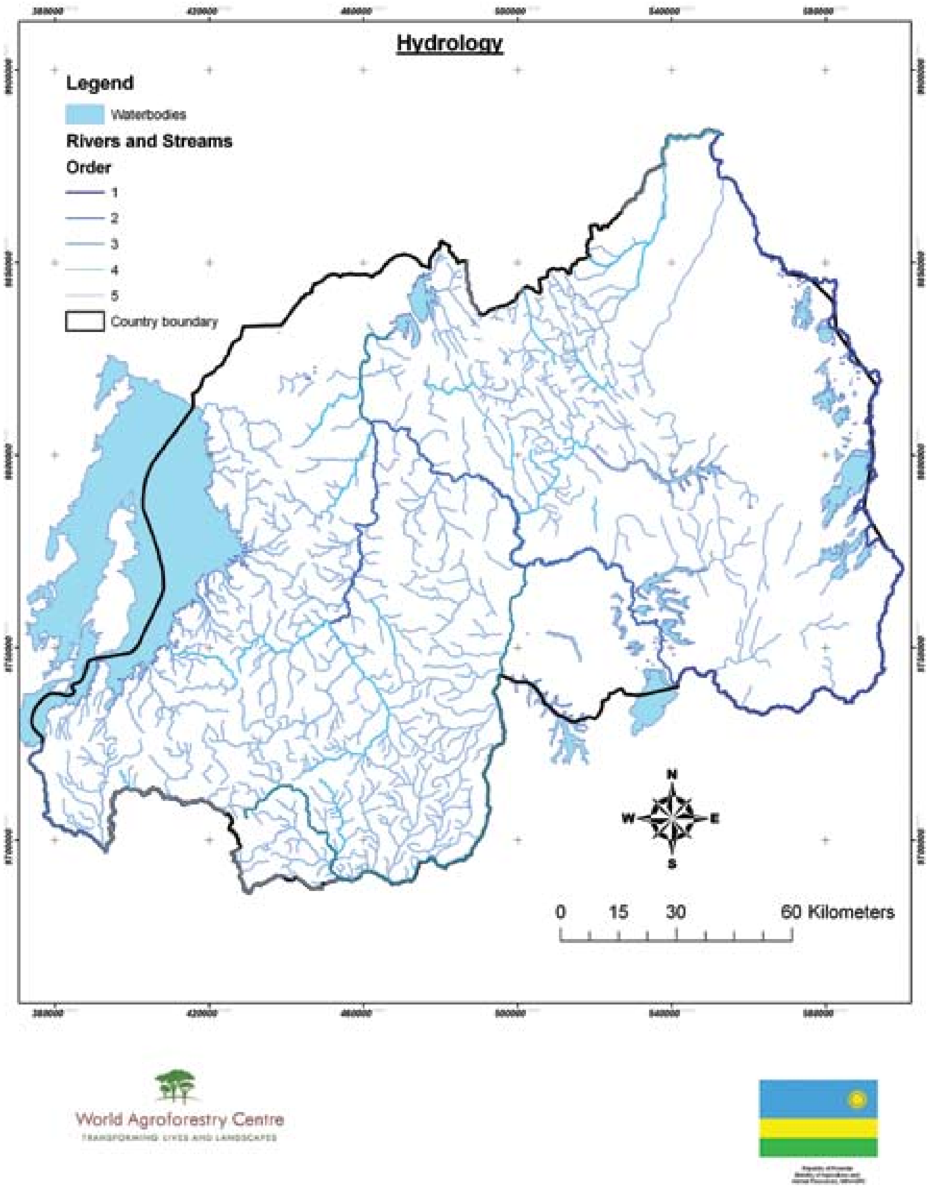


Figure 12: *Hydrography (lakes and rivers)(Data source: PGNRE)*

4.3.2 Rivers and streams

Figure 13 shows Rwanda's main rivers, and the remaining surface-flow gauging stations. The highest river flow rates were recorded during the months of April and May. The lowest flow occurs during August and September. The lithology of the waterways has direct bearing on the rates of surface flow, whereas tectonics and the distribution of volcanic rocks influence the shape, direction and the cross-sections of the rivers.

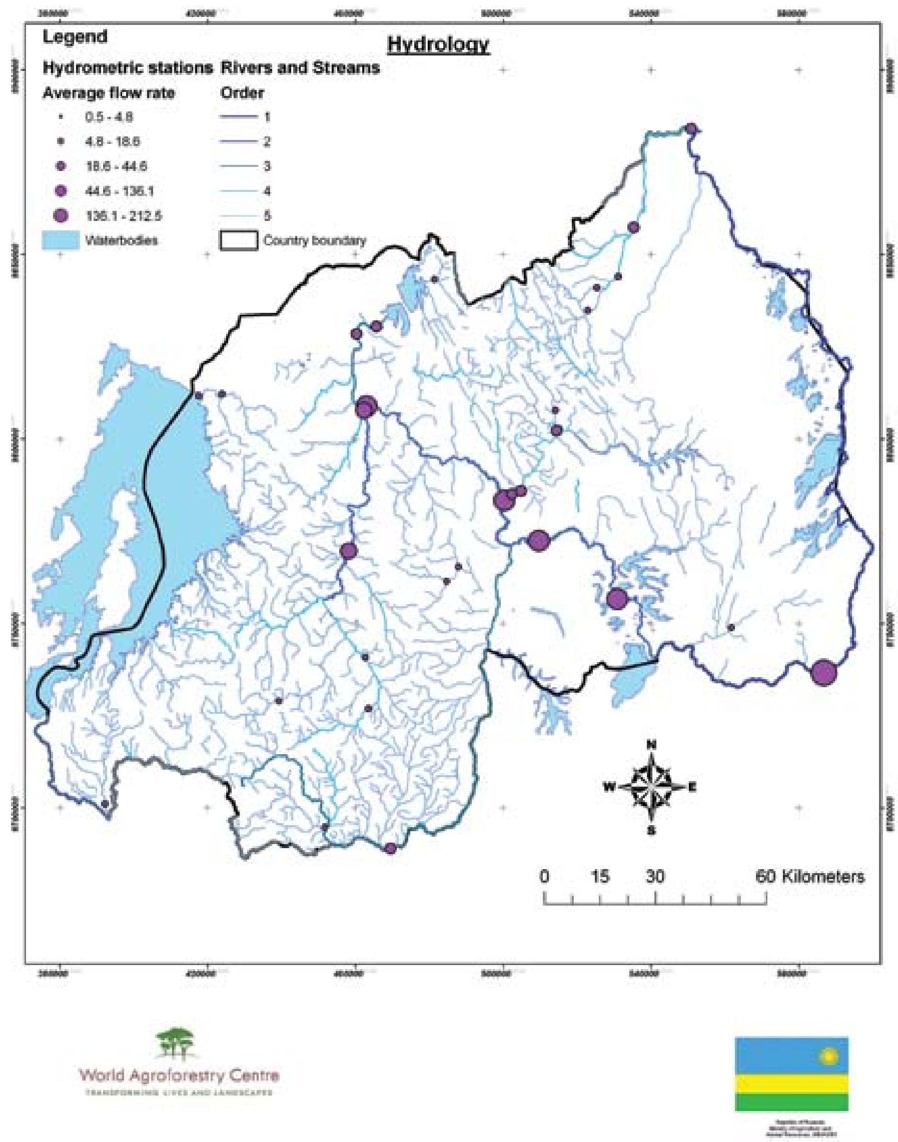


Figure 13: *Hydrometric stations (data source: PGNRE)*

Nineteen rivers flow in Rwanda. About 85% of the surface flow drains to the Nile Basin and the rest to the Congo River (Figure 14). The total average annual surface water flow is assessed at 9.5 x 109 m3 (FAO/AQUASTAT 1995 and 2005). At present it is not clear what volume of water is pumped out of the rivers and exploited for various needs.

Sixty-eight gauges (of which 30 have flow-rate data) provide partial but essential information about the potential use of surface water for irrigation (Figure 13 and Table 7).

Table 7: *Hydrometric gauges on rivers*

ACZ	ID	No. of records	Min (m^3s^{-1})	Max (m^3s^{-1})	Avg (m^3s^{-1})
Birunga	70001	18	0.8	3.5	1.9
	70002	48	0.8	5.8	2.9
	70013	13	4	8.4	6.6
Burebuka Highlands	70025	41	3.2	12.6	6.3
	70026	41	0.2	3.9	1.2
Central Plateau	70007	10	14.3	89.3	44.6
	70008	16	33.5	174.7	92.7
	70009	20	1.9	8.1	3.5
	70012	9	17.2	57.6	35.2
	70014	35	0.4	11.6	3.6
	70017	66	0.7	33	6.7
	70018	5	0.3	1	0.5
	70027	22	0.6	3.1	2.1
	70028	87	0.04	9.5	1.9
	70031	69	0.03	8.9	0.8
Congo-Nile Watershed Divide	70020	23	2.4	15.4	4.6
Eastern Plateau	70005	63	27.5	338	108.2
	70011	5	0.2	1.4	0.5
	70015	39	1.6	72.3	9.6
	70016	22	2.9	27.6	10
Eastern Savanna and Central Bugesera	20	85	3.9	44.1	11.5
	21	31	3.7	32	8.1
	70003	51	99.9	592	212.5
	70021	23	0.05	3.6	1
	70029	22	0.8	5.4	1.8
	70030	18	0.6	2.8	1.1
Imbo	84	9	2.3	6.9	4.8
Mayaga and Peripheral Bugesera	70004	57	48.3	286	124.7
	70006	6	79.3	191.2	136.1
	70010	24	7.7	54.4	18.6

Data source: PGNRE

Analysis of hydrometric stations data

Because hydrometric station data was insufficient for providing an estimate of river flow volume, 18 threshold watersheds with catchment areas of at least 1000 km^2 were selected and used with the data available to estimate the volumes flowing annually at the outlets of each of these watersheds (Table 8 and Table 9).

Table 8: *Estimated minimum flow rates and yearly volumes per watershed*

ID	Watershed (> 1,000 km^2)	Estimated minimum river flow rate (m^3s^{-1})	Estimated minimum river volume (km^3)
1	Uganda-South	-	-
2	Karangazi	107	3.37
3	Kagitumba	3.87	0.12
4	Mukungwa	16.33	-
5	Nyabogogo	2.88	-
6	Nyabarongo	28	-
7	West Akagera	3	-
8	North Kivu	0.83	0.03
9	Akagera	105	-
10	Mugesera	80	-
11	Kagogo	99	-
12	Upper Nyabarongo	17.17	-
13	Rweru	-	-
14	Akanyaru	20	-
15	Rusizi	2.26	0.07
16	Burundi-North	-	-
17	South Kivu	-	-
18	East Kivu	-	-
		Total	**3.59**

Table 9: *Hydrometric gauges discharge (m^3s^{-1}) grouped by ACZ*

ACZ	No. of gauges	Min range	Max range	Avg range
Birunga	3	0.75–4	3.5–8.4	1.9–6.6
Burebuka Highlands	2	0.2–3.2	3.9–12.6	1.2–6.3
Central Plateau	10	0.03–33.5	98–174.7	0.5–92.7
Congo-Nile Watershed Divide	1	2.4	15.4	4.63
Eastern Plateau	4	0.17–27.5	1.4–338	0.5–108.1
Eastern Savanna and Central Bugesera	6	.05–99.9	2.8–592	1–212.5
Imbo	1	2.3	6.9	4.8
Mayaga and Peripheral Bugesera	3	7.7–79.1	54.4–286	18.6–136.1
Impara	-	-	-	-
Kivu Lake Borders	-	-	-	-

Data source: PGNRE

Watersheds

Watershed basins were delineated by performing a GIS surface analysis to the DEM. The major division between the Nile and Congo Rivers, together with main watersheds (catchment areas greater than 1000 km^2), are shown in Figure 14. Because sub-watersheds are important to the issues of environmental impact, water resources and soil conservation, it was necessary to clearly identify them. Their areas are expressed in km^2 (Table 10). The drainage systems within each sub-watershed were also modelled.

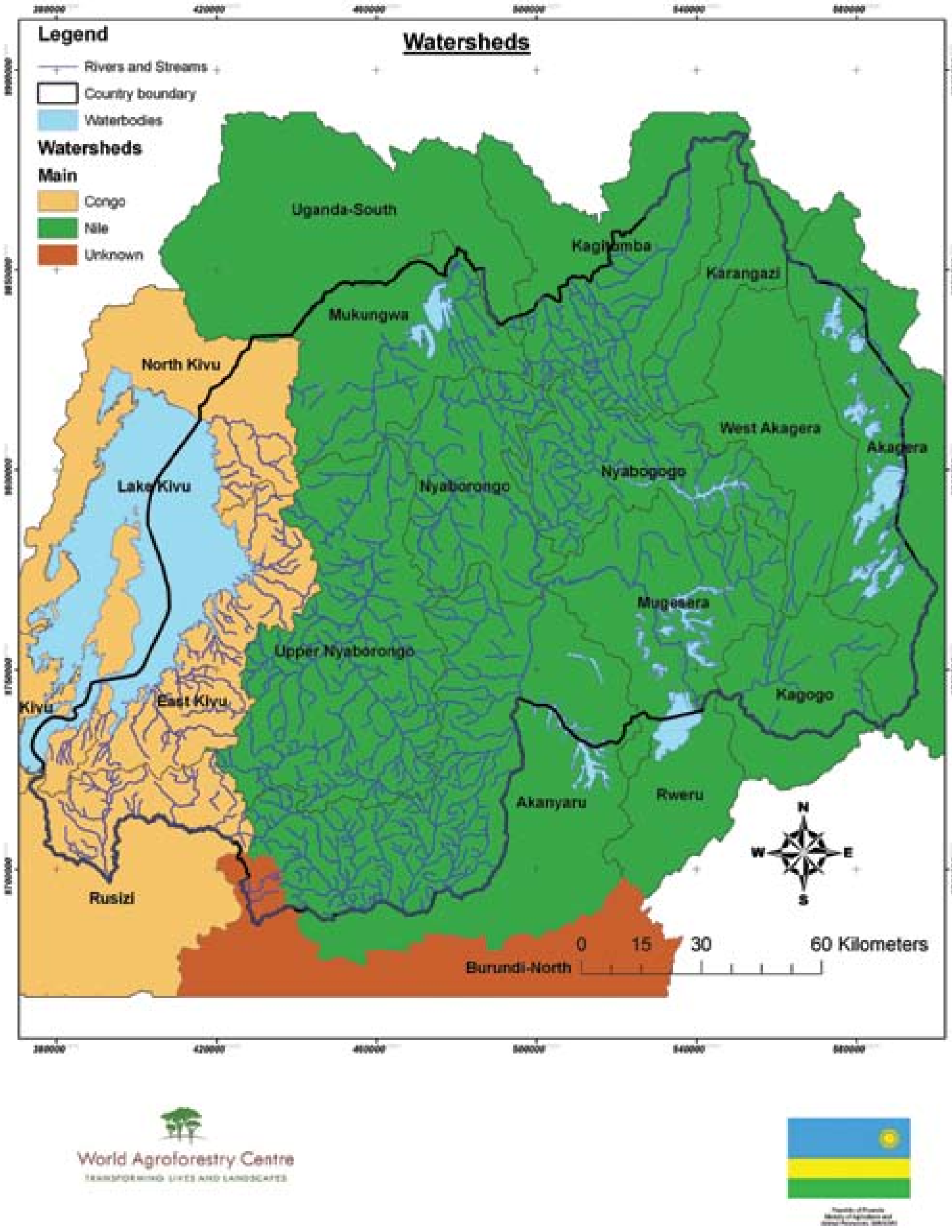


Figure 14: *Main basins, Congo and Nile*

Table 10: *Watershed areas in km²*

Watershed ID	Watershed name	Watershed area (km^2)	Runoff volume (km^3)
1	Uganda-South	32 582 155	0.04
2	Karangazi	10 538 107	0.33
3	Kagitumba	27 330 601	0.65
4	Mukungwa	18 950 162	1.09
5	Nyabogogo	16 550 520	0.70
6	Nyabarongo	16 547 173	0.89
7	West Akagera	17 085 454	0.66
8	North Kivu	21 478 604	0.48
9	Akagera	37 137 637	0.50
10	Mugesera	21 047 086	0.68
11	Kagogo	14 168 573	0.36
12	Upper Nyabarongo	33 460 580	2.01
13	Rweru	10 016 474	0.00
14	Akanyaru	53 204 704	1.66
15	Rusizi	30 381 884	0.57
16	Burundi-North	22 308 325	0.10
17	South Kivu	9 532 133	0.09
18	East Kivu	15 617 613	1.00
	Total	407 937 784	11.82

4.3.3 Lakes

In the north and west, Lakes Buhera Ruhondo and Kivu are deeper than 50 m. Other lakes (Mugesera, Sake, Bilira, Cyohoha, Rweru and Ihema) are shallower, with depths not exceeding 10 m.

Using high resolution DEM and lake boundaries along with advanced GIS modelling techniques, the volumes of each lake were estimated and tabulated (Table 11).

Table 11: *Estimated lake volumes*

Lake ID	Lake name	Surface area (m^2)	Volume (m^3)
1	Bulera	51 916 704	3 115 816 667
2	Ruhondo	27 580 052	868 250 500
3	Muhazi	34 442 452	454 233 033
4	Mugesera	21 228 700	253 190 033
5	Bilira	6 558 084	84 959 933
6	Sake	58 291 101	595 059 300
7	Gaharwa	4 691 529	40 304 233
8	Kirimbi	2 875 802	19 230 400
9	Mirahi	2 645 833	17 143 700
10	Rumira, Kidogo	4 459 255	25 428 367
11	Gashanga	2 019 200	19 940 933
12	Cyohoha south	19 226 403	182 696 100
13	Cyohoha north	8 424 334	241 771 067
14	Nasho, Kagese, Cyambwe, Rwampanga	77 935 096	960 109 767
15	Rwanye, Kizinga	7 405 171	47 737 533
16	Muhindi	123 519 823	1 859 406 867
17	Hago	25 272 265	294 013 500
18	Kwumba	36 800 706	289 711 400
19	Ihema	18 820 546	705 915 633
20	Lake Rwakibare	32 422 599	2 603 505 900
21	Lake Kivu	1 068 600 981	181 560 657 400
22	Lake Rweru	33 832 572	422 571 133
	Total	**1 668 969 208**	**194 661 653 400**

4.3.4 Marshes

The marshes of Rwanda are part of the hydrographic system. Their hydrological regime is directly dependent on the particular drainage basin. Any attempt to regulate surface flow in certain drainage basins has to consider the entire basin, and not only its separate areas such as the marshes, which are an integral part of the basin. Within drainage basins, the marshes and the lakes play the role of natural storage reservoirs which regulate peak flows and peak floods and maintain a stable base-flow during the dry seasons. Excessive drainage of marshes (to meet agricultural needs) change the natural regime of river flow by increasing peak-flows and decreasing base-flow.

The marshes of Rwanda are divided into three categories:

- Marshes in high-altitude areas. Typically these have narrow shapes and develop organic soils that ultimately become peat. These marshes serve as buffer zones, facilitating retention and storage of water (Byumba, Gikongoro and Ruhengen). Some of them are exploited for marshland cultivation or for tea plantations.
- Marshes at medium altitudes. These marshes often have larger dimensions and extend over the central plateaus (Butare, Kigali, Gitarana). Traditional agriculture is practiced in these areas.
- Marshes at low altitudes. These are known as collecting marshes. They are the largest and occur in the central and eastern parts of the country. The marshes extend along the main rivers (the primary hydrographic network) such as the Nyabarongo, Akanyaru, and Akagera. They act as buffers, filling up during the rainy season and promoting a constant outflow rate during the following dry season. These marshes are covered by papyrus and are scarcely exploited for agriculture.

The role of marshes in regulating the storage of water

It is extremely important that the marshes preserve their water storage capacity. This is particularly important for the high-altitude marshes and those extending along the upper reaches of the waterways. These marshes maintain a constant rate of drainage towards the lower parts of the basins throughout the dry season. Excessive drainage and irresponsible management of the marshes will cause them to dry out, lower water storage capacity, diminish the drainage flow and increase the risk of flash floods.

For each of the 352 secondary drainage basins, a storage index was therefore defined in the database. This parameter was defined by considering both the maximum altitude of the basin and the marsh index (percentage of marshland in the drainage basin). The altitude of the basin is of considerable importance because the higher it is located, the higher is the amount of rainfall over the basin. The marsh index defines the capacity of the basin to store water and to regulate the flow of water out of the basin—the higher the index, the better the hydrological conditions. The ten ACZs were defined by the threshold values of these parameters.

Risks of major floods

Four parameters were considered to classify floods:

- average annual rainfall, including intensity and hourly and daily rates;
- the marsh index;
- the compaction index (this parameter considers the outline of the basins and constitutes the ratio between the peri metre of the basin and that of a circle of the same area—this index is proportional to the time of flash flood generation); and
- the slope index (the ratio between the altitude and the length of the main waterway—if the slope is high, the time of reaction and accumulation is short).

The primary hydrographic network, which includes the principal rivers and lakes as well as the big marshes, is characterised by the following features:

- The flow gradients are usually mild (less than 1%).
- The ratio of marshes to the total area of the basin is high.
- The marshes cover large territories.
- A major part of the marshland is exploited by agriculture.

The regulation and management of large marshes require important and expensive engineering. The management of water in such areas is complicated and not compatible with the small farms, which currently operate in these areas.

4.4 Hydrogeological potential

The hydrogreological potential of Rwanda is presented here based on the available data.

4.4.1 Aquifers

With the exception of the large alluvial plains and of the volcanic terrains, most aquifers are of local extent and do not extend over large areas. Moreover, the acquifers occur within quartzitic rock formations, in fissured rocks or in subcrops of rocks altered by erosion. These are local occurrences and contain limited amounts of water. There are several types of exploited aquifers.

Aquifers in quaternary sediment formations
In certain marshy areas within peat layers, clastic aquiferous interlayers occur, forming continuous aquifers of poorly permeable strata that contain acid groundwater. Although the permeable strata are not deep, their specific yields are low to intermediate. Alluvial beds such as sand, gravel and some clay occur in numerous parts of the country, mainly in the valleys. Their aquiferous properties are determined by their clay content. These aquifers are usually exploited by shallow wells of up to 12 m with yields of up to 6 m^3 h^{-1}. Over the past two decades, the Japan International Cooperation Agency (JICA) drilled over 200 such wells that were mainly used to provide water for cattle. Most of the relevant documentation was destroyed in the 1994 violence.

Aquifers in quaternary volcanic formations of Birunga
These are basalts and tuffs that occur mostly in the northwestern part of the country. These are highly permeable and, considering particular depths, create excellent aquifers with high specific yields. These are regarded as the best aquifers of the country with very high storage capacity and relatively high yields (up to 110 m^3 h^{-1}). The water is usually pumped from strata occurring in the 30–90 m depth range. In the southwestern part of the country, the hydrogeological properties of the volcanics have been insufficiently investigated. From the available observations, it appears that their potential as regional groundwater resources is lower than that of the Birunga.

Aquifers in granites and overlying granitic sands
Granites are exposed in roughly half of the country. Usually these are fresh, tight and

unaltered, very hard rocks that supply very small amounts of groundwater, and this only when these rocks occur in tectonically affected areas and are thoroughly fissured. In best cases, the shallow wells (which are quite costly) yield 1–3 $m^3 h^{-1}$. Drilling into granites is costly and the results unpredictable. In low-lying areas, aquifer properties improve, but yields from these rock formations are usually unsatisfactory. In cases where the granites are covered by their erosive products (granitic sands) and local replenishment conditions are suitable, higher yields can be expected. JICA and other donors have invested large amounts of money in shallow geophysical prospecting, but these initiatives have not succeeded in improving yields.

Aquifers in schists and altered schists

These rocks have high clay content and yield very poor amounts of groundwater.

Aquifers in quartzites

These occur over wide areas of the country. These are very hard and tight rocks and yield noteworthy amounts of groundwater only if they are thoroughly fissured. In such cases, yields are high and compare well to those of volcanics.

Summing up, groundwater exploitation should be considered mainly from:

- volcanics (most favourable);
- alluvial beds (favourable);
- altered quartzites (less favourable); and
- granites, schists and overlying sands (least favourable).

The greatest need for groundwater exploitation is in the eastern part of the country where water is needed for cattle and human consumption. In these areas the only existing aquifers are granitic, characterised by very low transmissivities and yields in the 1–5 $m^3 h^{-1}$ range. In these areas, the only reasonable way to exploit groundwater is by aquifer harvesting; that is, by sinking a large number of relatively shallow wells into well-defined areas of fissures, or by identifying zones of high rock alteration that enhances their permeability.

4.5 Water quality

The natural composition of river water is suitable for irrigation. The detailed chemistry is influenced by the lithology of the rocks making up the drainage basin. Water quality is generally good, but localised problems are caused by high sediment loads and toxic materials from mining, fuel and oil. The water of certain rivers, for example, contains up to 0.5 mg Cu L^{-1}. The highest allowable concentration for drinking and irrigation water is 0.05mgL^{-1}. There is also microbiological pollution from untreated domestic sources, which is a health threat. According to Rwandan estimates, 3% of river waters are heavily polluted by nitrates and 44% by bacteriological pollutants (mostly faecal).

The detrimental effect of aquatic weeds is also a major concern, and water quality problems caused by soil erosion are significant

4.6 National water balance

All water resources (rainfall, runoff, surface water bodies) as well as groundwater were assessed to determine their potential at both national and watershed levels. Hydrologic principles were applied in combination with GIS techniques to determine the rainwater partitions. This involves employment of runoff coefficient, which takes into account the products of land use / land cover, average precipitation, slope and catchment area. Components of the rainwater partitions were then used in water balance equations. A study earlier conducted by ICRAF on analysis of rainwater potential revealed that at the national level Rwanda has approximately 28 billion-m^3 water volume in annual rainfall. About 4.3 km^3 are generated as runoff water, 9.5 km^3 are lost to evaporation, 5.3 km^3 are transpired by all vegetation and 4.3 km^3 percolate into the groundwater system (Figure 15).

In view of the large available reserves of water in Rwanda, the development of irrigation is not limited on the national scale by water availability. However, supply is limited on the local and regional scale.

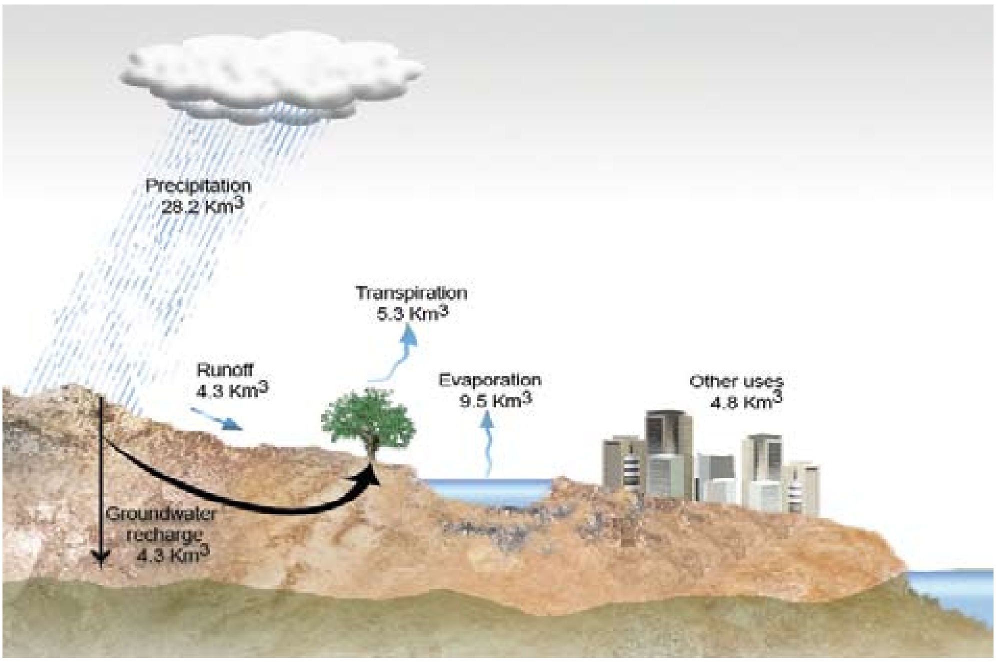


Figure 15: *National water balance for Rwanda*

4.7 Water usage

The estimated total annual water consumption was 150 million m^3 in 2000. Agriculture accounted for 68%, domestic needs 24%, and industry 8% of total consumption. Table 12 summarises the population from 1990 to 2004 and the water supply coverage during that period.

Table 12: *Water supply data*

	Population			Water supply coverage (%)					
Year	Total	Urban	Rural	Total		Urban		Rural	
	(x 1000)	(%)		Total	HC*	Total	HC	Total	HC
1990	7096	5	95	59	1	88	24	57	0
1995	5439	8	92	64	2	89	28	62	0
2000	8025	14	86	70	5	91	32	67	1
2004	8882	20	80	74	8	92	34	69	1

**HC = houses connected*

Renewable water resources

FAO (http://www.fao.org/nr/water/aquastat/water_res/rwanda_wr.xls) summarises the renewable water resources in Rwanda as follows:

- Total renewable water resources: 16.5 $km^3\ y^{-1}$
- Total groundwater volume: 7 $km^3\ y^{-1}$
- Total surface water volume: 9.5 $km^3\ y^{-1}$

International waters: stakeholders

Rwanda participates in various initiatives aimed at regional development of water that flows over international borders.

- The Nile Basin Initiative (NBI). Rwanda participates in this initiative with other countries traversed by the Nile.
- The Organization for Development of the Kagera River (OBK). Since the 1970s, OBK has endeavoured to ensure better use of common resources in Rwanda, Burundi, Tanzania, Kenya and Uganda. The Kagera River forms the border between Rwanda and Tanzania, and flows into Lake Victoria.
- Big Lakes Economic Community (CEPGL). On the Ruzizi River, two dams were built to provide energy to Rwanda, Burundi and the Democratic Republic of Congo in an interconnected network. A third dam, Ruzizi III, is under consideration.
- No organization operates in the Congo River Basin.

4.7.1 Proposed strategies for water exploitation

Considering the evidence presented in the preceding figures and maps, the areas where demand for water is most acute are the eastern and southeastern parts of the country. The possibilities for exploitation of groundwater and lake water are favourable in these areas.

The quartzite lithology of the aquifers in these areas and the technical difficulties of drilling into such rocks suggest that maximum use should be made of surface flow and lake water. Considering the relatively high rainfall (> 650 mm y^{-1}) and the hilly relief, the construction of small reservoirs for storing surface flow could be a suitable method for supplying clean and safe water for irrigation and for domestic consumption.

Alternatively, local harvesting of groundwater could be considered by surveying areas of intense fissuring or faulting and constructing sophisticated means for water collection such as shallow wells, drains, horizontal drilling and eventually galleries like those employed in the Canary Islands. In areas where the only possibility of water supply would be from wells, in order to overcome the shortcomings caused by the occurrence of thin and shallow aquiferous strata, emphasis should be given to drilling of large-diameter wells. To ensure exploitation of highly permeable strata, use should be made of numerous cheap geophysical methods developed during the past two decades to trace shallow alluvial beds or accumulation of clastic material in granitic terrains.

In the central and western areas of the country, water supply could be based on exploitation of springs—keeping in mind that this water requires purification. In the northwestern part of the country water could be supplied from highly productive volcanic aquifers.

Rwanda is blessed with enormous volumes of surface water. In order to facilitate its exploitation, it is necessary to make detailed studies of smaller rivers and drainage basins, and to compare the hydrological characteristics. But because these data are unavailable, their exploitation was precluded in this study. It is of primary importance that such investigations be initiated.

Hydrological studies must be accompanied by surveys of water quality and chemistry. Any plan to exploit water from rivers and lakes should consider the purification of these waters, which are heavily polluted.

Conclusions

Rwanda is characterised by high precipitation and has very large unexploited reserves of both surface and groundwater. These reserves exceed by far the expected demands.

The major water problems of Rwanda are:
- lack of hydrological and hydrochemical data;
- lack of hydrometric, hydrochemical and environmental monitoring;
- heavy anthropogenic pollution; and
- occurrence of aquifers with low permeability.

Large areas of marshes exist that store enormous volumes of water with potential value for irrigation, but these wetlands must be handled very carefully so as not to disrupt their capability to store water and prevent destructive floods.

The most acute demand is in the eastern and southern part of the country. These are the areas where the possibilities for exploitation of groundwater and lake water are favourable. The best and easiest possibilities for groundwater utilisation exist in the northwestern part of the country. There are large amounts of groundwater occurring in highly productive volcanic aquifers.

In order to overcome the shortcomings caused by the occurrence of thin and shallow aquiferous strata, emphasis should be given to digging or drilling large-dia metre wells as well as to the capping and regulation of springs.

Chapter 5

Irrigation domains

In order to utilise the least-cost technological options for water abstraction and distribution, the IMP partitions the country into six irrigation domains. Each domain is defined by the category, availability and accessibility of a given water resource vis-à-vis the biophysical and climatic features that influence its mode of abstraction and utilisation.

These domains do not necessarily equate to the potential irrigable areas. On the contrary, they serve as a general guide for locating the ideal water resources for a given area. The fact that a domain represents a dominant water resource does not preclude other water resources or technological options. For example, a domain generally characterised by groundwater as a potential resource may contain pockets that allow for harnessing and storing of runoff in small reservoirs.

The flow chart produced by ICRAF clarifies the prioritisation and order in which the appropriate water resources are chosen. Rwanda's irrigation domains (Figure 16) are thus categorized as:

- Runoff for small reservoirs
- Runoff for dams
- Direct river and flood water
- Lake water resources
- Groundwater resources
- Marshlands

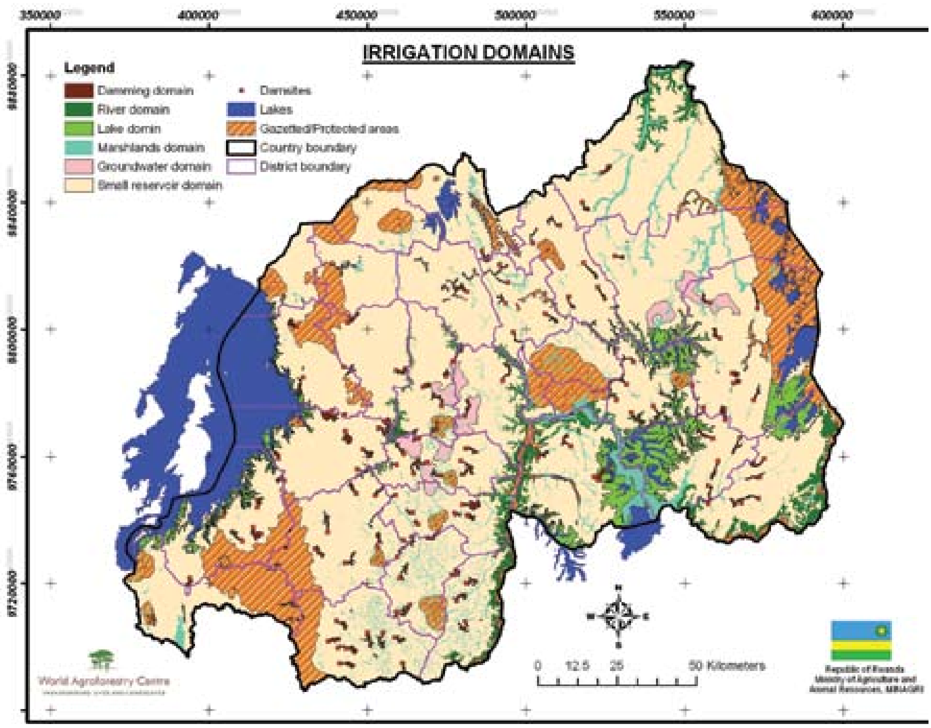


Figure 16: *Irrigation water sources domains*

5.1 Runoff for dams

This domain is dominated by slopes that range between 0% and 40%. The slopes meet the FAO limit set for irrigation development and have good potential for generating runoff that can easily be harnessed into dams and floodplains. This runoff often accumulates into small perennial streams classified as 3, 4 and 5 under the hierarchical system developed by MINIRENA. These streams are indicators of a guaranteed supply of water into the dams with eventual flow to take care of downstream ecosystem and users. The relief in this domain provides a topo-sequence that enables damming or floodwater conservation that allows for abstraction and supply of water by gravity to the command areas through supplemental or spate irrigation.

ICRAF developed tools that used engineering principles in a GIS environment to determine 74 potential damming sites (dam sites 1 to 74) in Rwanda of 10 to 20m embankment heights (Appendix 8). The other 31 damming sites were identified by the Land husbandry, Water harvesting and Hill-side irrigation project (LWH) i.e. dam sites 76 to 107. Potential sites to be irrigated by these dams have been determined along with their constituent areas. In Eastern and Southern provinces, where the P/PET ratio is below 1 for more than four continuous months, 76 dam sites have been identified (Figure 27). Note that this number of dams is subject to change as a reduction or increase in embankment heights would result in additional dams for small-scale irrigation.

Maps have been made for each of these dam sites for reference by policy makers to facilitate decision making. The maps highlight on the catchment areas, damming sites, abstraction mechanisms and command areas at both district and site levels.

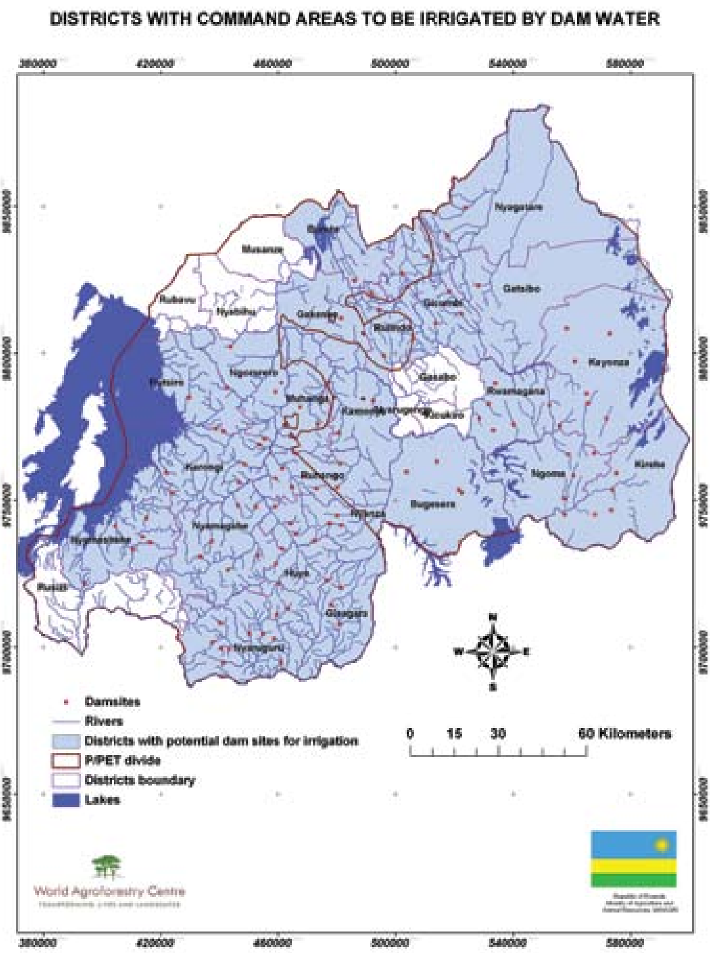


Figure 17: *Districts with potential for irrigation using dams*

5.2 River and flood water domain

This domain is characterised by riparian lands on major rivers. It falls into classes 1 and 2 of MINIRENA's classification system. Main rivers contain adequate water resources that can be accessed and abstracted to the command areas through pumping. The static head of water must not exceed 100m and must have a corresponding expanse or horizontal reach of command areas with respect to the slope. These two dimensions have to take into account the piping infrastructural and pumping costs. Depending on the width of the river, a vegetative strip of at least 10m is reserved on both sides to prevent erosion of the riverbanks. Often, some rivers are diverted to allow abstraction and supply of water by gravity to the command areas.

From the GIS and engineering analysis, five rivers have been identified in this domain: the Akanyaru, Nyabarongo, Muvumba, Kagitumba and Akagera. These rivers traverse 18 districts of Rwanda (Figure 18). All these districts have PIAs except two districts where the PIAs occur in gazette/protected areas. Maps that show where these clusters are located have been produced for each district. The PIAs constitute a total of 79 847 ha in this domain.

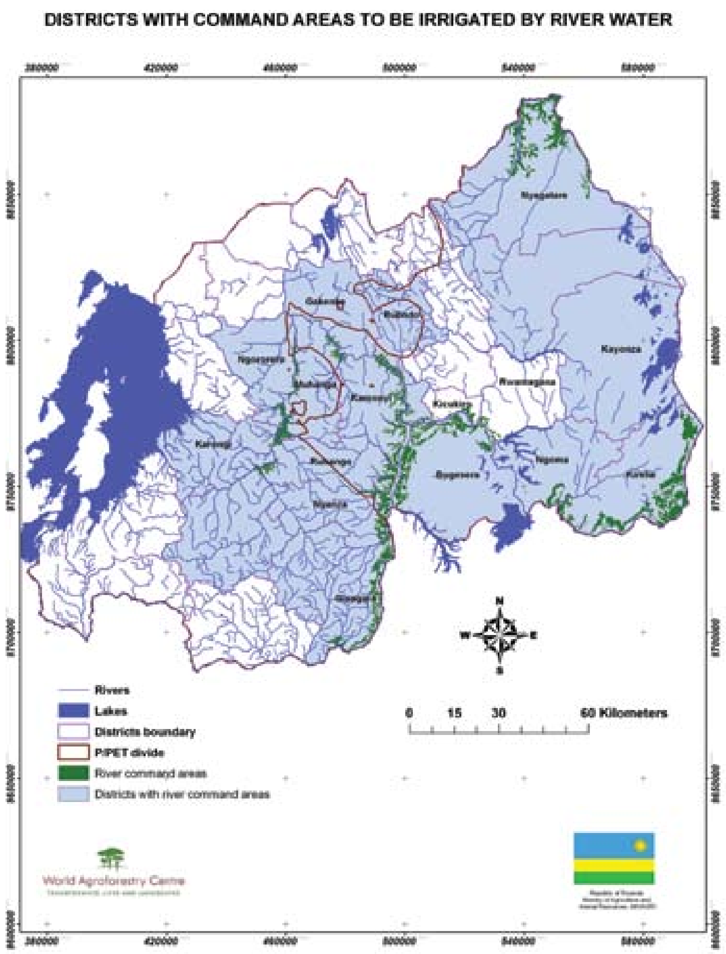


Figure 18: *Districts with command areas to be irrigated by river water*

5.3 Lake water resources domain

This domain is characterised by lands adjacent to lakes (Figure 19). Lakes in Rwanda are relatively large and often contain adequate water that can be accessed and abstracted to the command areas through pumping. Vegetative strips of 50 m along the banks are reserved for conservation of the lakes. The lakes of Rwanda have been clustered for management purposes by PAIGELAC as follows:

Cluster 1: Lakes of the North: Ruhondo and Bulera
Cluster 2: Lake Muhazi
Cluster 3: Lakes of the East: Nasho, Ihema, Cyambwe, Rwampanga, Rwakibare, Kagese
Cluster 4: Gisaka zone: Mugesera, Sake, Bilira
Cluster 5: Bugesera zone: Gashanga, Kidogo, Rumira, Mirayi, Kilimbi, Gaharwa
Cluster 6: Lake Kivu.

From the GIS and engineering analysis, 16 of the above lakes have been identified as potential sources of irrigation water. These lakes are located in Eastern and Westeren Provinces. They include Lakes Ihema, Nasho, Cyohoha, Cyambwe, Muhazi, Mpanga, Mugesera, Sake, Bilira, Gashanga, Kidogo, Rumira, Mirayi, Kilimbi, Gaharwa and Kivu. Plan maps for the irrigation command areas around these lakes will be developed so that policy makers can refer to them for decision making. The plan maps that show where these clusters are located have been produced for each district. The potential sites constitute a total of 100 107 ha in this domain.

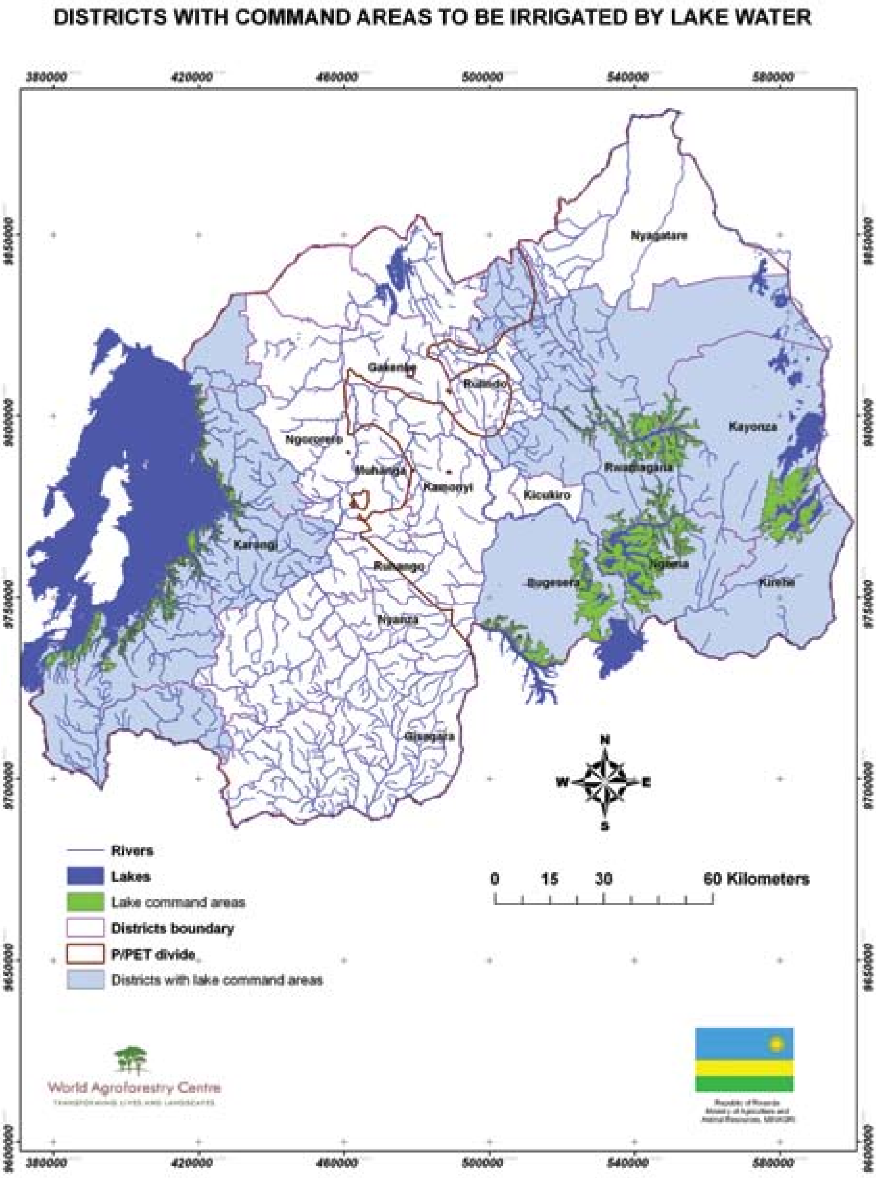


Figure 19: *Districts with command areas to be irrigated by lake water*

5.4 Groundwater resources domain

This domain is characterised by low-lying areas situated in sub-humid to semi-arid zones. Because rainfall is erratic, the generation of runoff for either supplementary or full-scale irrigation is unreliable. Moreover, the topography is not conducive for damming.

However, these areas may receive underground flows originating from infiltrated and percolated rainwater following upstream rainfall events. This form of recharge may contribute to the enhancement of groundwater potential. However, groundwater may not constitute a higher priority than other water resources such as rivers or lakes in terms of economic viability, particularly with respect to abstraction and water supply to the command areas.

Currently, insufficient data are available to assist in the quantification of groundwater volume in this domain. Current data has been sourced from JICA, MINIRENA and PDRCIU/IFAD. The data include location of wells, pumping yields in m3 h-1 and depth in metres. In addition, a hydrogeological map was obtained from IFAD with the objective of providing water for livestock and human consumption (Appendix 7). The data is therefore skewed towards supply for domestic use. However, there is an attempt to interpret what the current data would mean for irrigated agriculture.

A summary of this data is presented in Table 13, which shows that 652 boreholes have been recorded spanning 19 districts. Of these, only 100 of the boreholes in 15 districts have yields above 3 m3 h-1. Further analysis of the districts revealed that only Gasabo, Nyarugenge, Kicukiro, Kayonza and Kirehe have boreholes with yields above 10 m3 h-1. The estimated PIA for the groundwater domain is 36 432 ha.

Table 13: *Borehole distribution and yields per district*

District	No. of boreholes	Productive boreholes with > 3 m^3 h^{-1}	Existing productive boreholes (%)	Yield (m^3 h^{-1})	Depth
Nyagatare	161	17	11	3 to 8	-
Gatsibo	74	26	35	3.6-9	-
Kayonza	117	31	26	3.2-15	43-83
Ngoma	36	4	11	3.12-9	-
Rwamagana	12	1	8	3.12	-
Kirehe	13	1	8	10.2	-
Bugesera	103	1	1	4.6	-
Gasabo	13	2	15	4.8-60	20
Kicukiro	20	5	25	3.6-18	15
Nyarugenge	32	5	16	3-36	20
Kamonyi	1	1	100	3.6	-
Nyanza	22	3	14	3.3-4.5	-
Nyamgabe	4	1	25	3.9	-
Musanze	1	1	100	9	-
Burera	1	1	100	6	-
Ruhango	7	-	0	-	-
Rusizi	23	-	0	-	-
Nyabihu	10	-	0	-	-
Rulindo	1	-	0	-	-
Total	**652**	**100**	-	-	-

Exploration for groundwater should be undertaken for boreholes with higher yields for irrigated agriculture. Currently, it is observed that boreholes with high potential are located close to groundwater-related ecosystems such as marshlands, taking advantage of Rwanda's topo-sequence where runoff from the highlands flows into lowland environments (Figure 20). The practice of drawing water close to marshlands depletes groundwater resources. Further research is needed on sustainable methods for abstracting groundwater close to these surface water bodies.

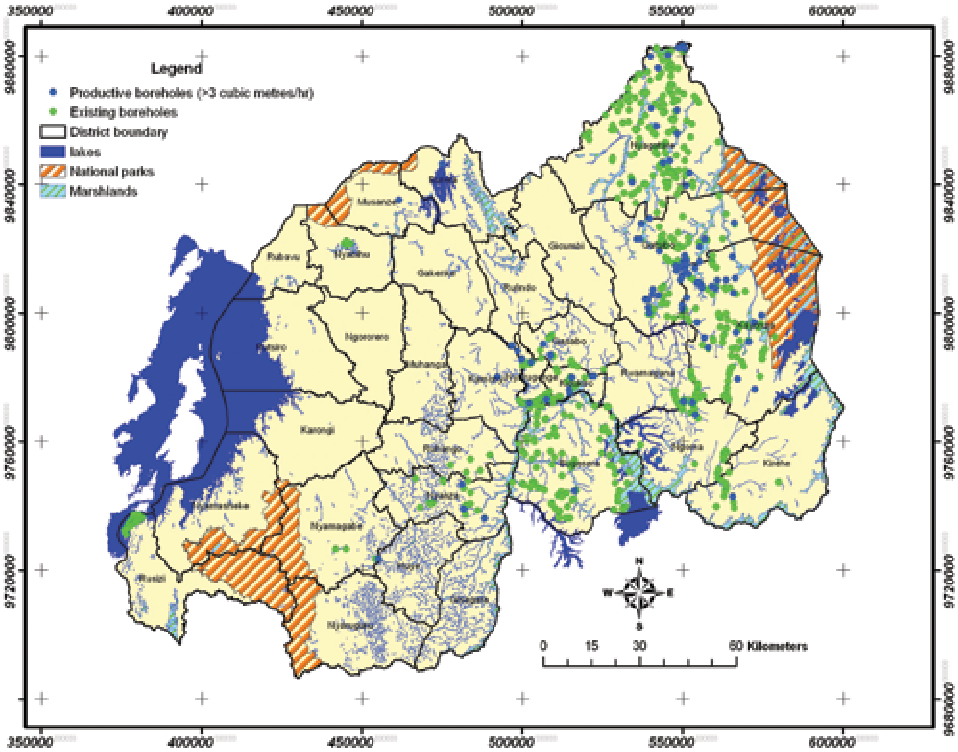


Figure 20: *Location of boreholes in relation to water bodies (marshlands and lakes)*

5.5 Runoff for small reservoirs domain

This is a cross-cutting domain, with slope ranges between 2% and 60%. Save for the marshlands, this domain traverses the other domains of dams, rivers and lakes. It is occupied by 7.6 million small-scale rural landholders (about 80% of Rwanda's 2010 population).

Given the large family units (six children per couple), this brings the household representation for the domain to approximately 855 000. Current land holdings for small-scale farmers averaging about 1 ha per farmer would generate sufficient *in situ* runoff to irrigate half-acre (2020 m^2) plots. The total irrigable area for this domain would thus be 125 627 ha. Depending on the location of farms, these half-acre plots require small reservoirs of up to 300 m^3 capacities.

Runoff can be harvested from *in situ* roof and ground catchments, including water from external upstream catchments. This water can be stored in small reservoirs such as above ground masonry tanks, underground spherical or sausage tanks, lined or unlined ponds and trapezoidal underground tanks (See Figure 21).

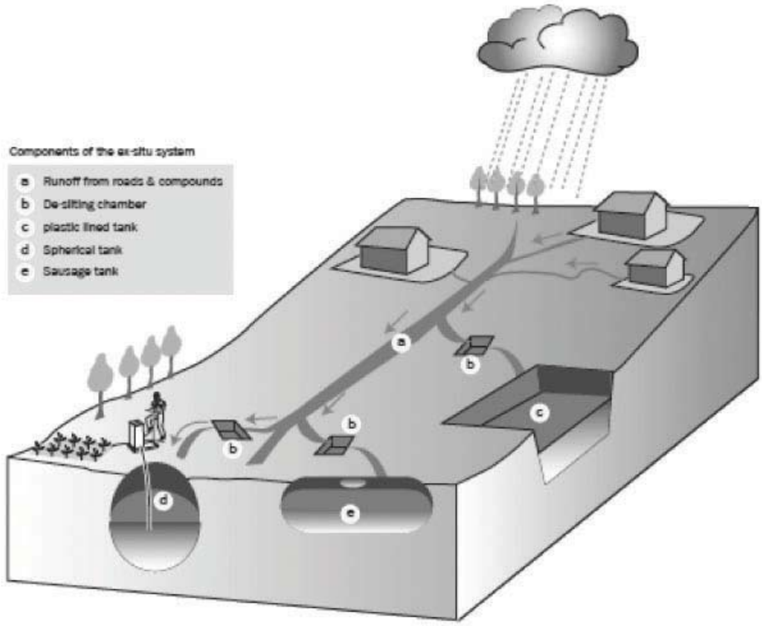


Figure 21: *Ex-situ rainwater harvesting system for supplementary irrigation*

Farmers can be introduced to the use of simple abstraction mechanisms such as gravity where topography permits or rope-and-washer, treadle and rower pumps that can convey water from surface or underground reservoirs to raised tanks.

With simple filtration, this water is then led through main and lateral pipes for sprinkler or drip mechanism. Although hand sprinkling is possible, it should only be used as an initial process. With funds available, this should be replaced with sprinkler or drip irrigation systems. In sprinkling, low pressure wobblers are desirable. On the other hand, a drip kit is pre-customized to a select crop.

Drip-irrigation technology offers affordable entry into commercial vegetable production, giving smallholders an opportunity to generate income by selling their surplus. Maintenance costs are negligible because only manual filtering using fine sieves is required. The economics of high-value enterprise shows a high payoff for drip irrigated crop production. In cases where drip irrigation has been implemented, the net present value (NPV), benefit cost ratio (BCR), payback period (PBP) and internal rate of return (IRR) authenticate the strong financial viability of the enterprise. Unless a reliable and sustained output market is established, income generation is not possible. Market opportunities thus provide a driving force for these users.

With access to micro finance, installation of drip irrigation infrastructure in greenhouse environments would enhance water- and fertilizer-use efficiencies leading to profit maximisation. This is already happening in Kenya, where a finance institution (Equity Bank) partners with a private irrigation firm (Amiran Kenya Limited) to offer microcredits and technical support.

5.6 Marshland resource domain

Like the domain for small reservoirs, marshland is a cross-cutting domain with slopes up to 2%. It traverses the other domains of dams, rivers and lakes.

The estimated total area of marshes in the country is 275 689 ha, of which 55 896 ha are fully protected, 204 198 ha are non-protected but with limitations while 15 595 ha are non-protected without limitations. The latter two categories add up to 219 793 ha which is the marshland potential for irrigation.

Forty-one percent of the inventoried marshlands are covered by natural vegetation, 53% (148 344 ha) are under cropping and about 6% are fallow fields. This inventory is based on satellite analysis that can take into account marshlands as small as 3–5 ha.

The following practices are proposed.

a. Total protection

• Marshlands reserves of biodiversity recognised under RAMSAR convention to be protected	1
• Marshlands belonging, at least partially, to a national park or reserve (including their buffer zones)	22
• Spring marshlands	3
• Dam marshlands	8
Total marshlands proposed for total protection	38

b. Use under specific conditions

• Crossing-border marshlands	25
• Marshlands belonging to 2 or more Districts	182
• High altitude (>1800 m) peat marshlands	9
• Other peat marshlands	78
• Marshlands providing drinking water to cities	20
• Marshlands providing drinking water to villages	-
• Marshlands of Bugarama depression	6
• Marshlands with ≥100 ha or more under cropping (total surface / surface under cropping)	365
• Marshlands of ≥15 ha, partially under cropping, covered by ≥30% of natural vegetation	102
• Marshlands of <15 ha, partially under cropping, covered by ≥ 70% of natural vegetation	1
Total marshlands proposed to be used under specific conditions	475
Total marshlands proposed for use without specific conditions	347

5.7 Summary of potential irrigable areas

Based on the bio-physical conditions and other relevant data, ICRAF has determined the potential irrigable areas for Rwanda, a summary of which has been given in Table 14 and Table 15.

The assessment of Rwanda's irrigation potential indicates that the country has a national irrigation potential of 589 713 ha, taking into consideration the following domains:

- Runoff for small reservoirs (125 627 ha)
- Runoff for dams (27 907 ha)
- Direct river and flood water (79 847 ha)
- Lake water resources (100 107 ha)
- Groundwater resources (36 432 ha)
- Marshlands (219 793 ha)

Table 14: *Potential irrigable areas per district*

ID	District	Irrigation domain						Small Reservoirs
		Lake	River	Runoff	G	M	Total	
1	Burera	-	-	168	-	3 378	3 546	125 627 (Cross-cutting domain)
2	Kicukiro	-	987	-	-	3 256	4 243	
3	Karongi	3 737	704	2 648	-	1 178	8 267	
4	Rusizi	1889	-	-	-	4 209	6 098	
5	Nyabihu	-	-	-	-	1 522	1 522	
6	Rubavu	383	-	-	-	367	750	
7	Gakenke	-	433	246	-	5 139	5 818	
8	Ngororero	-	1 320	629	-	1 123	3 072	
9	Nyarugenge	-	1 023	-	-	2 370	3 393	
10	Kirehe	5 391	19 329	1 309	-	14 436	40 465	
11	Ngoma	23 930	1 514	1 250	-	11 485	38 179	
12	Nyamasheke	11 587	-	1 419	-	2 264	15 270	
13	Huye	-	-	1 413	-	9 036	10 449	
14	Gisagara	-	7 584	1 272	-	15 324	24 180	
15	Rwamagana	12 664	830	1 514	-	5 268	20 276	
16	Kayonza	13 587	-	2 130	6 299	7 984	30 000	
17	Nyanza	-	5 967	954	1 633	10 920	19 474	
18	Ruhango	-	1 631	2 231	8 322	9 130	21 314	
19	Muhanga	-	4 575	767	4 747	4 462	14 551	
20	Kamonyi	-	6 063	1 032	7 934	8 626	23 655	
21	Gicumbi	930	-	1 110	-	6 859	8 899	
22	Rulindo	-	884	951	-	7 112	8 947	
23	Nyaruguru	-	-	2 415	-	8 698	11 113	
24	Gatsibo	5 308	-	205	7 497	16 398	29 408	
25	Nyagatare	-	15 193	486	-	23 971	39 650	
26	Nyamagabe	-	303	2 064	-	4 478	6 845	
27	Rutsiro	3 048	-	566	-	716	4 330	
28	Musanze	-	-	-	-	1 616	1 616	
29	Bugesera	17 115	11 507	1 128	-	23 845	53 595	
30	Gasabo	538	-	-	-	4 623	5 161	
Total for each domain		**100 107**	**79 847**	**27 907**	**36 432**	**219 793**	**464 086**	

Grand total of irrigation potential for Rwanda

G = Goundwater; M = Marshland

Table 15: *Potential irrigable areas with slope categories per district*

ID	District	Command area (Ha) Slope categories			Total
		0-6%	6-16%	16-40%	
1	Burera	3 394	48	104	3 546
2	Kicukiro	3 594	584	65	4 243
3	Karongi	2 040	1 911	4 316	8 267
4	Rusizi	4 497	769	832	6 098
5	Nyabihu	1 522	0	0	1 522
6	Rubavu	419	86	245	750
7	Gakenke	5 227	250	341	5 818
8	Ngororero	1 274	513	1 285	3 072
9	Nyarugenge	2 506	464	423	3 393
10	Kirehe	26 856	10 540	3 069	40 465
11	Ngoma	22 092	12 109	3 978	38 179
12	Nyamasheke	4 650	4 099	6 521	15 270
13	Huye	9 349	627	473	10 449
14	Gisagara	16 810	3 350	4 020	24 180
15	Rwamagana	8 886	8 076	3 314	20 276
16	Kayonza	16 883	5 519	1 299	23 701
17	Nyanza	12 444	4 004	1 393	17 841
18	Ruhango	10 167	1 043	1 782	12 992
19	Muhanga	5 094	1 609	3 101	9 804
20	Kamonyi	9 894	2 995	2 832	15 721
21	Gicumbi	7 248	693	958	8 899
22	Rulindo	7 544	724	679	8 947
23	Nyaruguru	8 976	636	1 501	11 113
24	Gatsibo	17 536	2 897	1 478	21 911
25	Nyagatare	31 231	7 340	1 079	39 650
26	Nyamagabe	4 793	766	1 286	6 845
27	Rutsiro	1 296	1 023	2 011	4 330
28	Musanze	1 616	0	0	1 616
29	Bugesera	35 221	15 890	2 484	53 595
30	Gasabo	4 726	145	290	5 161
	Total	**287 785**	**88 710**	**51 159**	**427 654**

Chapter 6

Criteria for crop selection and estimated crop water requirements

6.1 Crop selection support tool criteria

The system proposed to facilitate selection of crops is a scoring and assessment method in which criteria deemed significant to crop selection are scored individually according to quantitative and qualitative grades for each category: food security, crop value and suitability for export.

Quantitative and qualitative grades have been developed for each criterion. In addition, criteria are weighted according to their relative importance. Final scores are the sums of the quantitative grades.

This tool will enable analysis of relevant crop options and will rank crops in order of their suitability. The tool supports priority setting for scheduling development and allocating resources. The criteria set for the selection and prioritizing of crops are provided in Table 16.

Table 16: *Crop choice criteria*

1. Crop considerations			
1.1 Suitability to PIA	1.2 Crop value and profitability	1.3 Shelf life (raw or processed)	1.4 Distance to market or port
2. Market considerations			
2.1 Production potential (amount)	2.2 Domestic demand	2.3 Processing facilities	2.4 Export potential

3. Human environment		4. Allocated priority
3.1 Labour availability	3.2 Existing experience	4.1 National or regional priority

6.1.1 Crop considerations

Suitability to PIA

Crop considerations include the suitability of crops to PIAs according to major agronomic factors (1.1). Crop value and profitability of crops are assessed with respect to the added value of crops under irrigated agriculture and their ability to cover in-field investments in irrigation equipment and the margins returned thereafter compared to traditional rainfed production (1.2). Shelf life and distance to market combine the capacity of a crop to reach the market in premium quality given Rwanda's landlocked geography and the intended market—domestic or foreign (1.3 and 1.4).

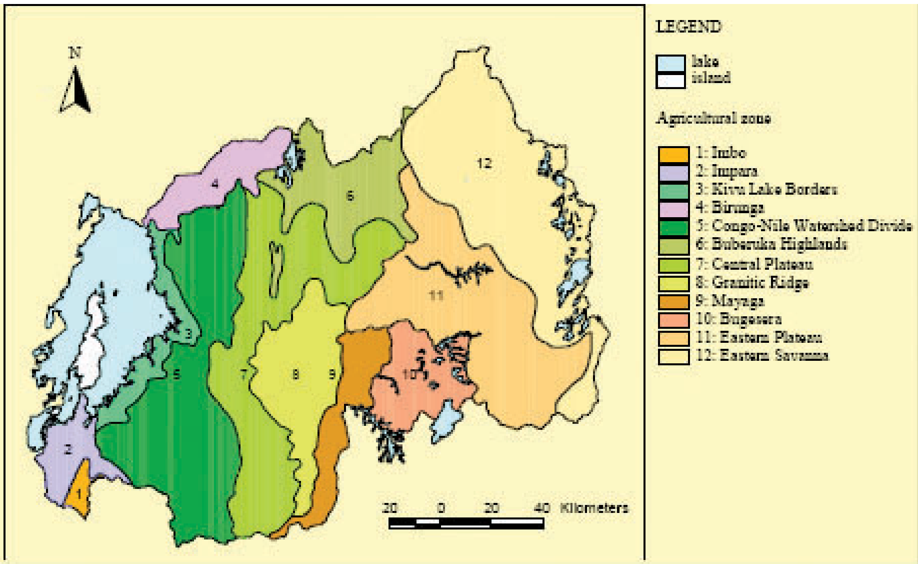
Crop selection with regard to matching crops to PIAs is determined over time within trial plots designed to assess suitability and quantified response to irrigation water. Trial initiation is planned within the framework of Phase II of this project at demonstration sites presently on the drawing board. List of potential crops and crop groups for testing are provided herewith according to present knowledge of Rwanda's climate, soils and conditions.

Crops are divided into those intended for food security and import substitution and high-value and cash generation crops (Table 17).

Table 17: *Suggestions for food security, import, high-value, substitution and cash-generating crops*

High-value and substitution open-field crops: vegetables and fresh herbs	Cash-generating crops; greenhouse production	Food security and imported field crops
Irish potato	Vegetables:	Maize
Beans	Tomato	Soybeans
Sweet potato	Pepper	Carrot
Onion	Cucumber	Peanut
Tomato	Horticultural crops:	Sesame
Eggplant	Avocado	Chickpea
Zucchini	Banana	-
Cabbage	Dates	-
Watermelon	Guava	-
Melon	Grapefruit	-
Broad bean	Lemon	-
Green bean	Lychee	-
Pineapple	Macadamia nuts	-
Hot pepper	Mango	-
Radish	Nectarine	-
Snow peas	Orange	-
Beet	Papaya	-
Coriander	Passion fruit	-
Dill	Peach	-
Parsley	Persimmon	-
-	Pomegranate	-
-	Pommelo	-
-	Strawberry	-
-	Flowers:	-
-	Roses	-
-	Orchids	-

An example of crop allocation to potential irrigated areas within ACZs is presented in Table 18. Figure 22 also depicts a selection of suitable crops according to Agricultural zones in Rwanda. Table 19 summarises the choice of regional crops in the ACZs as suggested by MINAGRI's suitability maps.



crop	agricultural zone 1	2	3	4	5	6	7	8	9	10	11	12
banana	+[a]	+	+	+		+	+	+	+	+	+	
cassava	++	+	+	+				+	+	++	+	+
sweet potato	+	+	+	+		+	++	+	+	+	+	+
potato				++	+	+						
groundnut	+	+	+					+	+	+	+	+
soybean	+	+	++				+	+	+	+	+	+
common bean	+	+	+	+		+	+	+	+	+	+	+
pea		+		+	++	+						
sorghum		+	+	+		+	+	+	+	+	+	+
maize	+	+	+	+	+	+	+	+	+	+	+	+
coffee		+	++				+	+	++		+	
tea		++	+		++							

[a] + = reported by Delepierre (1974) but of no importance after crop regionalisation
\+ = reported by Delepierre (1974) and regionally important after crop regionalisation
++ = reported by Delepierre (1974) and nationally important after crop regionalisation
\+ = not reported by Delepierre (1974) but regionally important after crop regionalisation

Source: Verdoodt and Van Ranst 2003

Figure 22: *Selected suitable crops according to agricultural zones*

Table 18: *Example of crop allocation to PIAs within ACZs*

AEZ	Peanuts	Roses	Vegetables (greenhouses)	Vegetables (open)	Water-melon	Melon
Imbo	-	-	-	-	-	-
Impara	-	-	-	-	-	-
Birunga		x			-	
Congo Nile Watershed Divide	-	x	-	-	-	-
Buberuka Highlands	-	x	-	-	-	-
Central Plateau	-	-	-	-	-	-
Granitic Ridge	-	-	-	x	-	-
Mayanga	x	-	-	x	-	-
Bugesera	x	-	-	x	-	-
Eastern Plateau	x	-	x	x	-	x
Eastern Savannah	x	-	x	x	-	x

Table 19: *Choice of regional crops in ACZs*

ACZ	G	B	Coffee	Tea	Beans	Maize	C	Potato	Rice	T
Imbo	9	9	4	5	10	10	10	5	10	4
Impara	7	8	10	7	10	10	8	7	10	8
Kivu Lake Borders	9	9	10	6	10	10	8	7	8	9
Birunga	4	5	5	7	10	9	5	10	5	10
Congo-Nile Watershed Divide	4	5	5	10	10	8	5	10	5	10
Burebuka Highlands	4	5	5	10	10	8	5	9	5	10
Central Plateau	7	6	10	6	9	7	7	8	8	6
Mayaga and Peripheral Bugesera	9	9	9	5	7	7	10	7	9	5
Eastern Plateau	9	6	8	4	6	6	8	7	7	7
Eastern Savannah and Central Bugesera	8	6	6	5	6	6	6	6	9	5

G = Groundut; B = Banana; C =Cassava; T = Triticale

Suitability key: 10 = high, 9 = high to moderate, 8 = moderate, 7 = moderate to marginal, 6 = marginal, 5 = marginal to unsuitable, 4 = unsuitable

Crop value and profitability

Analysis of crop value and profitability with regard to irrigation will be analysed by crop in two stages. Initially, crop response to irrigation will be determined and potential yields under irrigated conditions assessed.

Table 20 describes the present situation under rainfed conditions in Rwanda, various assessments of potential under rainfed situations and the potential of irrigated production.

Table 20: *Current, expected and potential crop yields (t ha^{-1}) under rainfed and irrigated condition*

Crop	National reported yield (2003)	FAO reported yield (2006)	MINAGRI expectation	National optimal performance	Yield potential under excellent irrigation
Banana, plantain	-	7.2	-	-	40
Cassava	-	4.9	-	-	20
Sweet potato	4.6	5.7	3–9	20–30	50
Potato	4.2	9.2	-	10	30
Groundnut	0.6	0.6	-	1.5	4
Soybean	-	0.6	-	-	3
Common bean	1	0.8	3–6	2.0	7
Sorghum	0.8	1.1	0.5–0.9, 2	3–4	6.5
Maize	0.5	0.8	-	3.5	10
Wheat	-	0.9	-	-	2
Rice	-	4.5	-	-	8
Sugarcane	-	30.4	-	-	100
Coffee	-	1.2	-	-	-
Tea	-	1.2	-	-	-

Sources: Verdoodt and Van Ranst 2003, MINAGRI 2003, Janssens 2001, FAO 2006

Yields and yield potential in Rwanda

Yield and profitability will be assessed using a yield response chart like the one shown in Figure 23, together with additional revenue assessment and margin calculations to return the cost of irrigation installation. The cost of irrigation installation for a crop under evaluation must be justified with a significant margin by the incremental yield, as well as the associated income gained from the investment in irrigation.

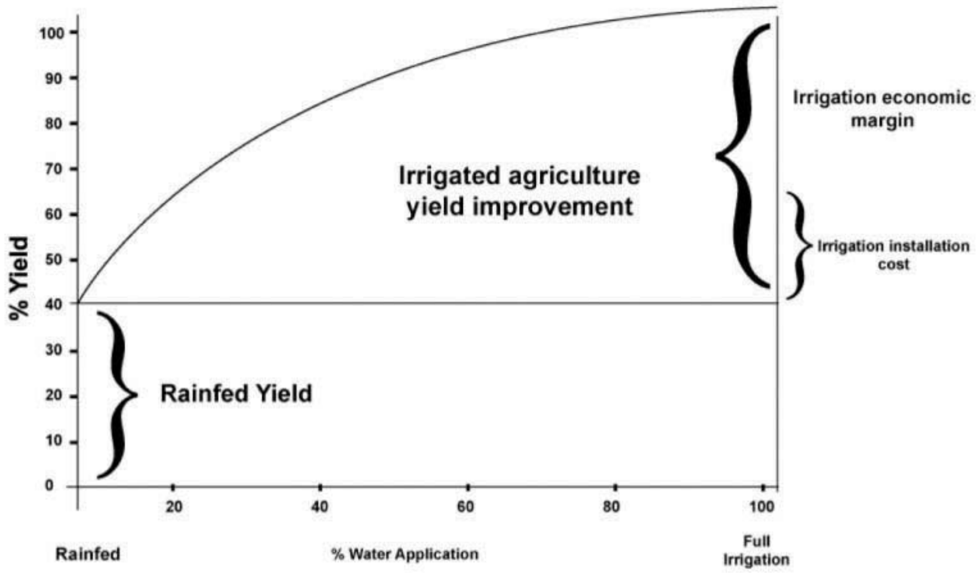


Figure 23: *Crop yield response*

The crop response to irrigation in Figure 23 covers installation costs and provides a reasonable margin. A numerical example can be provided for sweet potato production. Reported sweet potato yields under rainfed conditions in Rwanda are 5.7 t ha-1. According to MINAGRI, the market prices for sweet potato averages USD 0.15 per kg. Grower income is estimated at 60% of $0.15, or $0.09. This takes into consideration relatively low costs to market and a vendor margin to cover sales costs.

Optimal yield potential is reported at 25 t ha^{-1}, although other reports state as much as 50 t ha^{-1} under irrigated conditions (Table 21). Taking the conservative figure of 25 t ha^{-1} for irrigated sweet potato provides a very conservative analysis and based on a 20% grower margin, this indicates an economic margin of USD 150 ha^{-1}. This operational income is calculated after covering expenditures of USD 450 ha^{-1}, and an irrigation installation cost of USD 2000 ha^{-1} (depreciated over 10 years at USD 200 annually).

Table 21 and Figure 24 illustrate the projected profitability for sweet potato production under irrigation.

Following actual yield response trials within the framework of Phase II, further economic analyses will be developed for a series of crops.

Crop considerations with regard to shelf life (1.3) and distance to market (1.4) will be considered in light of Rwanda's landlocked situation. Crops are divided into those for local consumption, processing and export (high value by air and others by land and sea if justified). Grades will be allocated regarding particular crop potential with respect to shelf life and distance from market destination.

Table 21: *Projected profitability for sweet potato production under irrigation*

Item description	Quantification	
Market price ($ ha^{-1})	0.15	
Grower margin (%)	60	
Grower revenue ($ ha^{-1})	0.09	
	Rainfed	Irrigated
Yield (t ha^{-1})	5.7	25
Grower revenue ($ ha^{-1})	513	2250
Grower margin (%)	20	20
Grower operational income ($ ha^{-1})	102.6	450
Irrigation installation ($ ha^{-1})	-	2000
Depreciation (10 years)	-	200
Grower net income ($ ha^{-1})	-	250
Irrigation income margin ($ ha^{-1})	-	150

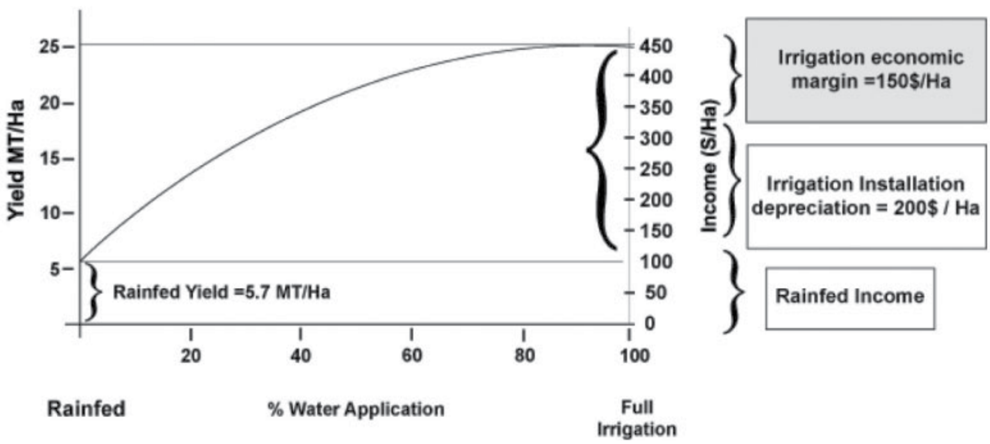


Figure 24: *Sweet potato crop yield response*

6.1.2 Market considerations

Market considerations include an assessment of potential amounts (2.1), the domestic demand for products (2.2), particularly for food security purposes, an analysis of processing potential and ability to market and export value-added and enhanced shelf-life processed goods such as concentrates, conserved fruits, dried produce etc (2.3).

Export potential grades the ability of a crop to be exported as a high value crop exported by air or other crops suitable for export by land and sea (usually value added and processed) (2.4).

Rwanda's agricultural characterisation plan

The following specific characteristics of Rwanda should be considered for selection of appropriate agricultural crops:

Objective characteristics

- Densely populated country
- Low rate of arable land per capita
- Agriculture sector composed of small farm units
- Food self-sufficiency in deficit

Relative advantages

- Temperate equatorial climate and fertile soils, enabling year-round production of a wide range of crops
- 'Virgin soil' that has never been treated with chemicals and might therefore be suitable for bioorganic and/or ecologically friendly production
- Cheap and available work force
- Affirmative government policies
- International funds available for development
- Proven success with farmers' cooperatives and value chain management

Relative disadvantages (including remediable factors)

- Landlocked country, poor accessibility to seaports
- Remote from potential export markets
- Poor infrastructure for shipping perishables to markets
- Lack of advanced agricultural technologies and know-how
- Poor marketing infrastructure, lack of producer collaboration in marketing

Analysis of optimal product characteristics

Considering the characteristics listed above, crop selection should give high priority to the following:

- Basic food crops according to the domestic consumption needs aimed at import substitution.
- Crops that yield maximal nutritional value per hectare, and best response to irrigation and fertilization.

Considering the relative advantages listed above, the crop selection process should prioritize the following:

- Crops that are most preferred and consumed by the local community
- Crops that can be harvested twice a year, or can be combined with other crops to enable two harvests annually
- Products that can be locally processed, provide added value, and stimulate industrial activity
- Products that can provide maximal benefits and premium prices if cultivated organically
- Exportable products that best utilise unique climatic advantages to gain a competitive position in international markets
- Exportable, labour-intensive products that allow for relative cost advantage
- Considering Rwanda's relative disadvantages, crop selection should give low priority to highly perishable crops that require sophisticated logistic infrastructure,

exportable crops with low price/weight ratio, products that cannot bear high transportation costs and crops that involve advanced technologies.

Prioritisation strategy

The proposed criteria for crop selection are initially based on market considerations. Investment in irrigation infrastructure and the required technologies can be justified only when the crop can be economically produced. A feasibility analysis will be performed for each and every optional product to verify potential demand and crop competitiveness.

Irrigated land will therefore be dedicated, as a first priority, to local consumption. This implies an import substitution strategy to create a positive balance of food imports and exports. Demand is guaranteed for these crops, and following introduction on the local market they will likely be competitive with imported commodities.

Simultaneously, high-value cash crops should be produced. Development of high-quality crops requires time and cultivation should therefore be planned and implemented without delay. The optimal strategy for cash crop development:

- Crops already produced that must be intensified and upgraded
- Crops that can be processed (dried) and do not require fast delivery to export markets
- Crops that may pay expensive air transportation, and yet still be competitive
- Crops that can be locally processed and give added value.

Recommended practical product choice

This master plan does not attempt to recommend specific products and their scope, but provides the tools for crop choice and defines principles, criteria and priorities.

Crop selection should be divided into two main categories: commodity food crops and high-value cash crops. While the principal criterion for food crop selection is obvious—to ensure food self-sufficiency—cash crops are selected according to economic considerations. These products must be competitive in international terms even if they are sold locally because Rwanda's borders are open for competition from neighbouring countries.

Commodity food crops

Rwanda imports approximately 200 000 t of agricultural food products. The problem of self-sufficiency is the priority target of the planned irrigation programme. Moreover, food consumption is predicted to increase during the coming years due to population increase and an improved standard of living. The working assumption suggests estimated additional food production needs for Rwanda for the coming 5 years at the level of 500 000 t. This goal can be achieved in light of the potential increase in output once irrigation is widely introduced. Selection of products within this prioritized scope should be dictated by local demand. Reliable data on imported products should be the main tool for this purpose.

It is important to consider that the assortment of preferred food products could change with consumers' improved standard of living, thus affecting local demand for specific food products and dictating changes in production planning. Effective prediction of consumption trends is an important tool in crop selection.

Apart from nutritional value and import substitution considerations, crop choices should also consider the comparative advantages of various crops. Once the costs of the production of a particular crop become higher than the costs in a neighbouring country, it would be logical to import this product and dedicate the local farmland to another, more competitive crop.

Over-production of the basic food products should not be a serious consideration, since demand for food in neighbouring countries is reliable. In addition, new initiatives for biofuel production can play an important role in the total field crop sector's supply/ demand balance.

High-value cash crops

Following are examples of analysis of main cash crops and their suitability for irrigated farming development in Rwanda.

Coffee

Rwanda's renowned PEARL coffee project and the Maraba Coffee Cooperative are excellent examples of successful exportable cash crop development in horticulture through advanced management of a value chain. Highlights to consider in strengths, weaknesses, opportunities and threats (SWOT) for premium coffee are shown in Table 22. This is an excellent indication of the potential of smallholder organizations in accessing international markets. Development organizations throughout the globe try to learn from Rwanda's coffee experience and to adopt its principles. Despite the project's success, coffee cultivation can be developed further. Apart from improved sales promotion and investments in processing equipment, the introduction of modern irrigation can increase the project's success by improving quality and increasing output. The continued commercial success of this crop can serve as a trigger for other horticultural initiatives in the country by emulating this value chain approach.

Table 22: *SWOT analysis for premium coffee*

Factor	Nature	Rate
Strengths	Proven success and worldwide reputation	High
	Accumulation of knowledge and technologies	High
	Local entrepreneurs and public-private partnerships	High
	Agronomic suitability to the country's climate	High
	Availability and cost-competitiveness of labour force	Medium–good
Weaknesses	Relatively high investment requirements	Medium
	Dependence on foreign coffee marketing networks	Medium
Opportunities	Expanding by investing in washing stations for coffee berries	High
	Organic cultivation	Good
	International branding of Rwanda's premium coffee	Good
Threats	Increasing competition from other countries such as Ethiopia	Medium
	Premium coffee market size is still limited	Medium

Green beans

Fresh green beans are one of the most consumed vegetables in Europe (in the Netherlands green bean is the number one consumed fresh vegetable). Europe is self-sufficient in bean production during the summer, but imports large quantities during the winter (December through March). Egypt, Morocco and recently Ethiopia are the leading suppliers of green beans (fresh butter beans and lima beans), while Kenya leads the supply of extra fine beans (French beans). Most of this produce arrives in Europe by airfreight.

Market information indicates that the combined exports of Kenya and Ethiopia cannot meet current market demand. If a thorough market survey approved these indications, Rwanda has an excellent chance of becoming another important supplier. Moreover, Kenyan exporters of fresh green beans would likely be interested in purchasing (or contract growing) from Rwandan farmers to satisfy European demand.

European importers may be interested in developing contract production in Rwanda, as they did in Ethiopia, provided that production takes place on irrigated land to ensure accuracy in delivery time and consistency in quality. Also, fresh beans are highly labour-intensive. Rwandan farmers might therefore have a relative advantage by utilizing the available low cost workforce.

Introduction of this crop would not be difficult, since extra fine beans are not remarkably different from the beans currently grown in the country. A well-managed value chain can promote this product to a very high level within a short time. SWOT highlights to consider for green beans are shown in Table 23.

Table 23: *SWOT analysis for fresh green beans for export*

Factor	Nature	Rate
Strengths	Agronomic suitability to the country's climate	High
	Availability and cost-competitiveness of labour force	High
	Experience in growing similar products	Good
	Air freight service available	Good
Weaknesses	Currently poor logistic infrastructure	Medium
	Lack of skilled professionals	Medium
	Dependency on foreign traders	Medium
Opportunities	Utilising the current gap in supply to Europe	High
	Organic cultivation	Medium
	International exposure through Kenyan traders	High
Threats	Increasing competition from other countries	Medium
	Increasing air freight rates	Medium

Roses

Cut flower export is feasible for Rwanda, thanks to its climatic conditions and low-cost workforce. Flowers can be competitive if air freighted, an advantage over other horticultural crops. The current infrastructure and critical mass are not viable for direct chartered flights to Europe, but Nairobi is an international hub for flowers. Flowers are also air freighted from Entebbe and Addis Ababa, indicating that it is feasible for Kigali to do likewise (directly or via trans-shipments).

The rose market in Europe has gone through a dramatic change in recent years. Big-budded roses ('tea hybrids') are again the most popular (after some 40 years), while the small-bud 'sweetheart' varieties are losing market share. This trend negatively affects Kenyan and Ugandan growers, which are focused on small roses. So far, only Ecuador, and with less success Colombia, provide high-quality big roses. Recently, the Netherlands dramatically switched its own production from small to big varieties; however, production in Holland involves high-energy costs. The natural conditions in Ecuador allow for production of the largest and highest quality roses, which no other country has yet managed to emulate. Dutch, Kenyan, Ethiopian and Ugandan growers are intensively searching for high altitude sites with climate conditions similar to Ecuador.

Rwanda's geoclimatic conditions offer a unique advantage for producing quality roses. Located near the equator, Rwanda's high mountains offer optimal conditions. Appropriate sites should be searched at altitudes above 2000 m, with low 6–9°C night temperatures, 22°C day temperatures, and not less than 5 hours of sunshine. Once such sites are located, foreign investors would likely establish production facilities in Rwanda. Foreign investors bring the know-how, the market access and skilled managers.

Rwanda's lower altitude sites are as good for quality rose production as those of its neighbours—Kenya, Uganda, Tanzania and Ethiopia. Another advantage of floriculture exports, as compared to other fresh horticulture crops, is that newcomers may join the Dutch flower auction system. Every producer has access to the entire European market, and can compete on an equal basis with stronger and experienced producers. There is no need to gain co mmercial contacts or to establish a marketing network. This concept works perfectly for Ethiopia, Israel, Kenya, Zambia, Zimbabwe and other countries.

Once roses become a well-established product, many other floriculture products would likely follow, benefiting from roses' critical mass. SWOT highlights to consider for cut roses are shown in Table 24.

Table 24: *SWOT analysis for cut roses*

Factor	Nature	Rate
Strengths	Unique agronomic suitability to the country's climate	High
	Existence of local entrepreneurs	Good
	Air freight service available	High
	Availability and cost-competitiveness of labour force	High
Weaknesses	Relatively high investment requirements	Medium
	Currently poor logistic infrastructure	Medium
	Lack of skilled professionals	Medium
Opportunities	Attracting well-established foreign investors	High
	Organic cultivation	Low
	International exposure through the Dutch system	High
	International branding of Rwanda's premium roses	Good
Threats	Increasing competition from other countries	Medium
	Market preference trends might change	Low

Value-added activities

Many horticultural crops offer economic options by processing and exporting their products. Export of dried fruits, for example, does not require sophisticated logistics. Fruit juices and concentrates have a regional market in addition to markets in Europe, North America and Japan. A premium price can be obtained in many of these countries when the products are certified as organic. Exotic fruits are available in Rwanda—passion fruit, pineapple, mango, papaya, and so on—ideal for the development of processing industries. This option is likely to be more competitive in international markets than exporting the fruits as fresh produce. As shown in the foregoing tables, the complications and expenses involved with fresh produce transport from Rwanda to export markets make them less competitive.

Consider the current situation of passion fruit juice concentrate. Ecuador, the main supplier to international markets, cannot meet the international demand. Demand for passion fruit concentrate rose sharply in 2006 because of its ability to balance flavour in fruit juice blends. Recent passion fruit prices in Ecuador were as high as USD 400 a tonne, much higher than the average price for fresh imported passion fruit in the EU during the same year (less than USD 300 a tonne). Rwanda, with its well-established passion fruit production, might find a better opportunity in juice concentrates than in fresh fruit exports.

Apart from export value, the processing industry significantly improves the supply-demand balance on local markets, avoids over-supply and therefore increases the profitability for fruit growers.

Development of horticultural processing requires advanced value chain management and private-public collaboration. Based on the example of Rwanda's successful coffee value chain experience, it would be advisable to implement the same approach to the fruit processing industry. SWOT highlights to consider for processed fruits are shown in Table 25.

Table 25: *SWOT analysis for processed fruits (dried fruit and fruit juices)*

Factor	Nature	Rate
Strengths	Unique agronomic suitability to the country's climate	High
	Availability of especially tasty fruits	High
	Availability and cost-competitiveness of labour force	High
	Proven experience in private-public partnership and in value chain management	High
Weaknesses	Relatively high investment requirements	Medium
	High energy costs for drying facilities	Medium
	Undeveloped export marketing channels	Medium
Opportunities	International branding of Rwanda's fruit products	High
	Organic cultivation	High
	Triggering the development of value-adding industries	High
	Balancing supply vs demand in domestic markets	Good
Threats	Increasing competition from other countries	Medium
	Juice prices may fluctuate strongly	High

6.1.3 Human environment

Human environment factors such as the availability (3.1) and skills of the people who inhabit the PIAs must be considered when selecting crops (3.2)(Table 16). Training in can be conducted after evaluating the capability of workers to shift from rainfed subsistence agriculture to, for example, intensive irrigated greenhouse production of roses. Another important consideration is the effort required to train such workers.

Typically, Rwandan growers own small plots of land and engage in the production of crops for self or domestic consumption. They have not been exposed to modern pressurised irrigation techniques such as dripping or sprinkling. If irrigation is applied at all, it is mainly flood irrigation. However, the fact that most producers are young enhances their receptivity to the introduction of new technologies. Another parameter facilitating adoption is high unemployment rate in rural areas, exceeding 50%. Intensified cropping resulting from the application of inputs such as water, fertilizer, high-quality seeds, pest control measures and postharvest treatment is highly labour-intensive.

Additional criteria for the identification of prospective growers under intensive cropping include:

- previous experience with irrigated crops (even if this experience relies on flood irrigation);
- level of education and litreacy; and
- size of the farm (growers cultivating several plots or larger units usually possess higher managerial skill).

Since the current experience of growers in irrigated, intensive cropping is low, a team of professional extension and research workers is required to lead them into this new environment. Because Rwandan extensionists and researchers presently lack expertise in modern techniques of irrigation, extension methodology, intensive cropping, quality standards and postharvest treatment, the project will have to begin by providing a training programme for extension and research workers in Israel.

Growers in the irrigated model areas will be grouped into water user associations (WUAs) and in one cooperative for each model area. The WUAs will provide a mechanism through which growers can forestall state authorities that might otherwise apply land consolidation measures in an effort to streamline water supply and distribution in the earmarked areas. The cooperation of growers will facilitate the interaction with the extension-delivery system to promote the technical needs of intensified cropping methods. Through participatory activities, the cooperatives could adopt this approach in their interaction with extension. WUAs, unified by a series of common problems, will be approached by extension workers as a group. The group will be exposed to extension methods, regularly scheduled meetings, joint visits to members' plots and discussions of common interest.

The primary extension strategy is to give high priority to export-oriented growers. New irrigation technologies and methods adopted by these growers will spill over to more conventional growers. Contact farmers identified by extensionists could develop demonstration plots and act as focal points for the diffusion of new technologies.

Extension workers will approach both men and women growers through a series of orientation meetings in which the objectives and tools of the new programme can be presented and explained. These meetings can then be followed by technical training sessions with the participation of all interested growers in the model areas.

As a result of the primary training activities, and in consultation with the cooperatives, extensionists could identify lead growers who would be likely candidates for cultivating highly intensive export or cash crops.

6.1.4 National priorities and policy

National policy comprises a critical factor in prioritizing crop production (4.1)(Table 16). High grades will be allocated to crops by local professional personnel. This applies particularly to preferences concerning food security crops for local consumption and import substitution versus high-value crops intended for export.

In addition to technical considerations such as geographical conditions and village types in the selection of crops, political considerations as formulated by the government must also be part of the equation. These factors reflect the development priorities of the central or regional administration as to the allocation of funds. They might include, for example, matters of vision such as the long-term development of a particular area with the assistance of high-income crops or the strengthening of certain sectors of the farming population. Although these priorities might introduce considerations not fully in line with the technical parameters identified by the project, it is understood that it is the prerogative of the government to promote agriculture according to its development policy.

6.2 Crop choice summary

Choice of crops and correct matching of these to PIAs will also be approached by using a decision support tool. Table 16, which lists the criteria used for the selection of crops, appeared at the beginning of Chapter 6.

In this section crops are analysed according to the four major criteria groups: (1) Crop considerations; (2) Market considerations; (3) Human environment; and (4) Allocated priority. Four potential crops and industries have been analysed in greater depth as examples: premium coffee, green beans, cut roses and processed (dried) fruits. Table 26 provides an example of the usage of the decision support tool for these crops in general grading specifications.

As information accumulates and pertinent grades are allocated to specific PIAs and crops, a comprehensive list of crops and priorities for development will be enabled.

This tool comprises a summary of PIA selection and the matching of crops for incorporation into the full agricultural development programme for Rwanda in a systematic manner, thus constituting a basis for further development.

Table 26: *General grading specifications for four sample crops*

Type of crop	1. Crop considerations			
	1.1	1.2	1.3	1.4
	Suitability to PIA	Crop value and profitability	Shelf life (raw or processed)	Distance to market or port
Coffee	Various PIAs	High	High processsed	-
Beans	Various PIAs	Medium	High fresh	Near
Roses	Highlands	High	High fresh	Near
Dried fruits	Various PIAs	High	High processsed	-
	2. Market considerations			
	2.1	2.2	2.3	2.4
	Production potential	Domestic demand	Processing facilities	Export potential
Coffee	High	Export	Available	High
Beans	Medium	Export	-	High
Roses	Medium	Export	-	High
Dried fruits	High	Export	To be developed	High
	3. Human environment		4. Allocated priority	
	3.1	3.2	4.1	
	Labour availability	Existing experience	National or regional priority	
Coffee	High	Exists	Export priority	
Beans	High	Exists	Export priority	
Roses	High	To be developed	Export and hillside	
Dried fruits	High	To be developed	Export and hillside	

6.3 Crop water requirements

This section is relevant to and integrates the results of the preceding chapters on PIAs and crop choice. For this reason it is included in the crop choice chapter, after the chapter summarising criteria for crop selection. In this section, estimates of crop water requirements were calculated to reconcile requirements on both national and ACZ levels to water quantities known to be available for irrigation.

6.3.1 Criteria for crop selection and estimated water requirement

Precipitation and potential evapotranspiration (P/PET) for total months

A 30-year climatic database from 1960 through 1989, supplied by FAO and the World Meteorological Organization (WMO), was normalised for Rwanda on a monthly basis. Climatic values included total monthly precipitation (P), potential evapotranspiration (PET) (Allen et al. 1998) and mean monthly maximum and minimum temperatures. The ratio of normalised P to PET was calculated to give P/PET values greater than 1 for total months throughout the year (Table 27). When the P/PET ratio is equal to or greater than 1, precipitation meets or exceeds the reference PET demand for that period. Figure 26 shows the total months during which the P/PET ratio is greater than or equal to 1 for Nyagatare. Although the neighbouring area has a total of 1 month when P/PET ≥ ≥ 1, Nyagatare has a total of 2 months when P/PET ≥ ≥ 1; April when P/PET = 1.3 and November when P/PET = 1.0.

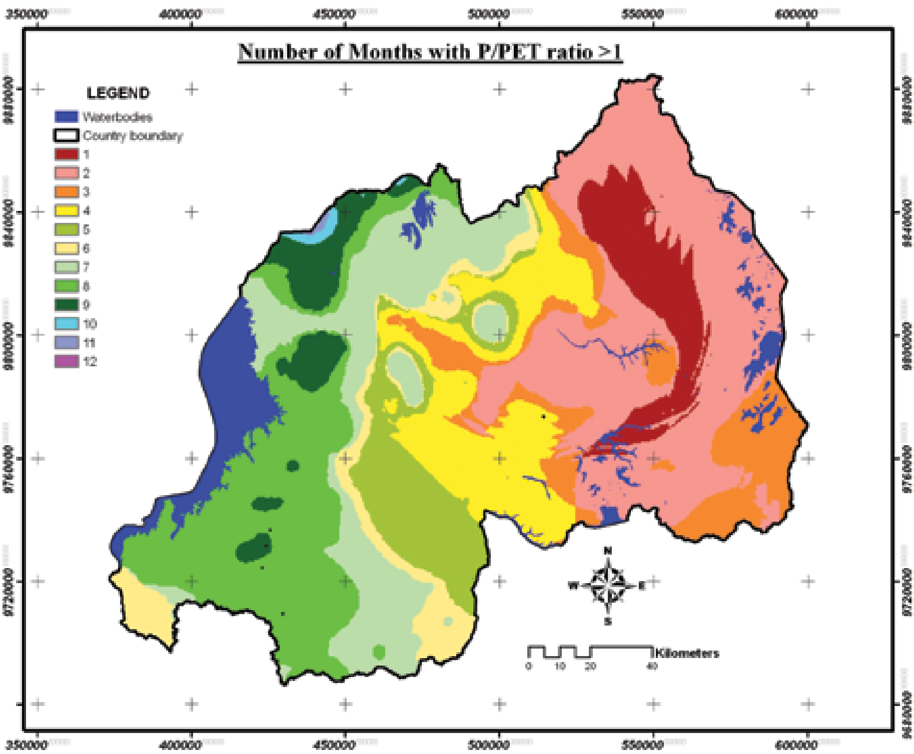


Figure 25: *Thirty-year normalised P/PET ratios indicating distribution across Rwanda for total number of months when P/PET ≥ 1.*

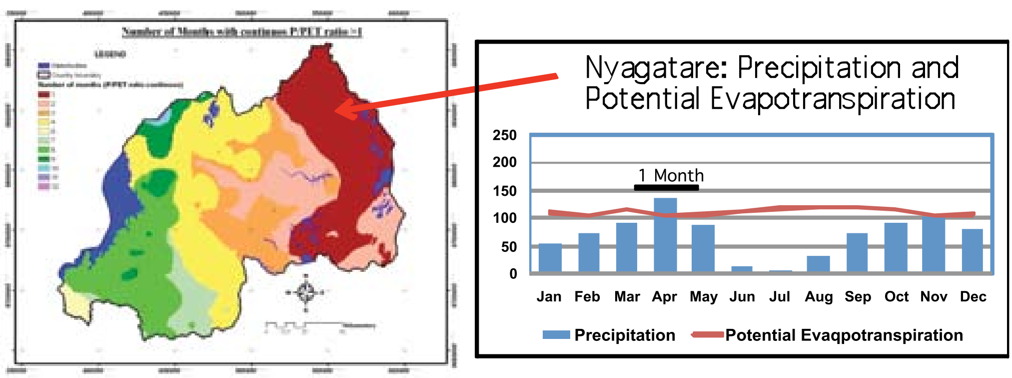


Figure 26: *Thirty-year normalised P/PET ratios indicating distribution across Rwanda for total number of months when the P/PET ≥ 1 and a chart of Nyagatare with the mean monthly values for P/PET*

Areas of the country where the P/PET ratio was greater than 1 on a monthly basis were determined using GIS (Table 27). In a total of 1537 km^2, only one month has a P/PET ratio greater than 1 (e.g. when P > PET). Across the country, there are 9778 km^2 where P is greater than PET during 3 or fewer months. It is evident that precipitation-deficit regions occur in the eastern portion of the country.

Table 27: *Areas in Rwanda with total number of months having P/PET ratio > 1*

Total months with P/PET ≥ 1	Area (ha)	Area (km^2)
1	153 650	1 537
2	602 300	6 023
3	221 775	2 218
4	268 250	683
5	183 425	1 834
6	124 125	1 241
7	358 625	3 586
8	502 275	5 023
9	98 925	989
10	7 900	79
11	2 300	23
12	150	2
Total	**2 523 700**	**25 237**

P/PET for consecutive months

When considering months with P/PET ≥ 1 as a good indicator of periods throughout the year characterised by deficit precipitation, it is important to bear in mind that Rwanda experiences a bimodal rainfall pattern. Identification of consecutive months during which P/PET ≥ 1 is a better indicator of deficit precipitation during the rainy season than simply considering the total number of months throughout the year. Table 28 shows results of the areas in the country where P/PET ≥ 1 for consecutive months. When considered in this manner, the areas in severe deficit (with P/PET > 1 for a single consecutive month) increases from 1537 km^2 (Table 27) to 5790 km^2 (Table 28).

Table 28: *Areas in Rwanda with consecutive months having P/PET ≥ 1*

Consecutive months with P/PET ≥ 1	Area (ha)	Area (km²)
1	579 000	5 790
2	363 425	3 634
3	308 325	3 083
4	562 050	5 621
6	28 400	284
7	115 275	1 153
8	457 950	4 580
9	98 925	989
10	7900	79
11	2300	23
12	150	2
Total	**2 523 700**	**25 237**

Although Nyagatare has a total of 2 months when P/PET ≥ 1 (Figure 26), there is only one occurrence when P/PET ≥ 1. The areas where P/PET ≥ 1 for 3 or fewer consecutive months increase from 9 777 km^2 to 12 507 km^2 (Table 28). This quantifies the sizable portion of eastern Rwanda characterised by severe precipitation deficits for 1–3 consecutive months (Figure 27).

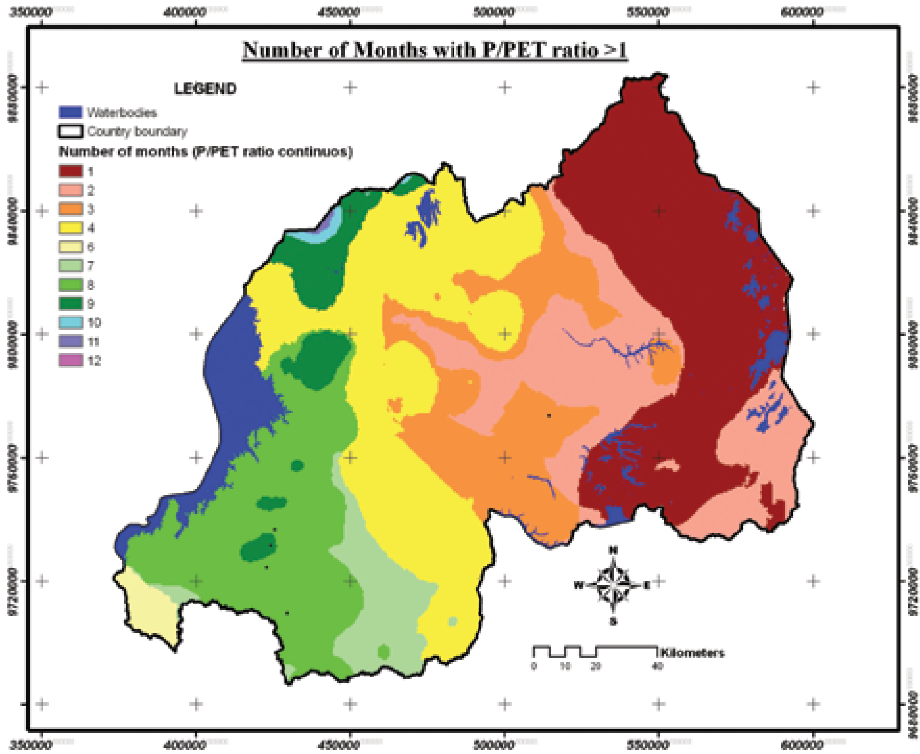


Figure 27: *Thirty-year normalised P/PET ratios indicating the distribution across Rwanda for consecutive number of months when P/PET ≥ 1*

6.3.2. Crop water requirement: a case study with mango

Although crop water requirements for specific irrigation sites are beyond the scope of the present study, it is possible to demonstrate a procedure that can be used when the pilot sites are selected. The FAO software program CROPWAT (version 8.0) was used to compare 3 sites with P/PET ≥ 1 for 1 or 2 consecutive months with suitable soils for irrigation purposes. The selected crop was mango, a perennial crop with a broad range of adaptation regimes and sufficiently high in value to provide income to growers.

Chosen sites were Gashora in Bugasara District, Gitarama in Muhanga District, and Nyagatare in Nyagatare district. Thirty-year climatic data are presented for these three sites in Table 29, Table 30 and Table 31.

Of the three sites, Nyagatare had the lowest mean annual precipitation at only 842 mm compared to Gashora with 906 mm and 1077 mm for Gitarama. Gashora, on the other hand, had a greater annual PET (1409 mm) than either Nyagatare (1337 mm) or Gitarama (1372 mm). The mean annual P/PET ratio for Gitarama was the highest at 0.81 mm per decade compared to Gashora with 0.66 mm and Nyagatare with 0.64 mm. Gashora had the highest mean monthly maximum and minimum temperatures, resulting in a mean annual temperature of 9.5 °C compared to 9.3 °C for Gitarama and 8.6 °C for Nyagatare.

Table 29: *Thirty-year mean monthly precipitation, PET, P/PET, maximum and minimum temperatures and mean daily PET for Gashora*

Month	P (mm decade^{-1})	PET (mm decade^{-1})	P/PET	Max temp (°C)	Min temp (°C)	PET (mm day^{-1})
Jan	81	113	0.72	27.4	15	3.6
Feb	90	105	0.86	27.9	15.3	3.8
Mar	110	118	0.93	27.7	15.5	3.8
Apr	153	108	1.42	26.7	15.7	3.6
May	100	108	0.93	26.8	15.6	3.5
Jun	16	115	0.14	27.9	14.5	3.8
Jul	5	125	0.04	28.3	14.2	4
Aug	17	131	0.13	29	15.1	4.2
Sep	49	133	0.37	29.1	15.3	4.4
Oct	82	129	0.64	27.8	15.3	4.2
Nov	113	113	1	26.5	15.3	3.8
Dec	90	111	0.81	26.6	15.2	3.6
Total/mean	**906**	**1409**	**0.66**	**27.6**	**15.2**	**3.9**

Table 30: *Thirty-year mean monthly P, PET, P/PET, maximum and minimum temperature and mean daily PET for Gitarama*

Month	P (mm decade^{-1})	PET (mm decade^{-1})	P/PET	Max temp (°C)	Min temp (°C)	PET (mm day^{-1})
Jan	92	111	0.83	26.4	14.8	3.6
Feb	100	104	0.96	26.6	15.1	3.7
Mar	117	116	1.01	26.6	15.2	3.7
Apr	169	104	1.63	25.7	15.3	3.5
May	132	104	1.27	25.4	15.5	3.4
Jun	29	112	0.26	25.7	14.3	3.7
Jul	9	122	0.07	26.6	14.1	3.9
Aug	32	128	0.25	27.4	15	4.1
Sep	78	129	0.6	27.5	15	4.3
Oct	108	124	0.87	26.5	15.1	4
Nov	113	110	1.03	25.7	14.8	3.7
Dec	98	108	0.91	25.2	14.8	3.5
Total/mean	**1 077**	**1 372**	**0.81**	**26.3**	**14.9**	**3.8**

Table 31: *Thirty-year mean monthly P, PET, P/PET, maximum and minimum temperature and mean daily PET for Nyagatare*

Month	P (mm decade^{-1})	PET (mm decade^{-1})	P/PET	Max temp (ºC)	Min temp (ºC)	PET (mm day^{-1})
Jan	54	110	0.49	26.8	13.2	3.5
Feb	71	105	0.68	27.1	13.5	3.8
Mar	92	115	0.8	26.8	14	3.7
Apr	135	105	1.29	26	14.4	3.5
May	87	106	0.82	26	13.9	3.4
Jun	14	112	0.13	26.6	12.5	3.7
Jul	8	118	0.07	27.1	12.2	3.8
Aug	32	120	0.27	27.4	13.4	3.9
Sep	74	119	0.62	27.3	13.7	4
Oct	91	115	0.79	26.6	13.6	3.7
Nov	105	104	1.01	26	13.8	3.5
Dec	79	108	0.73	26.1	13.5	3.5
Total/mean	**842**	**1 337**	**0.64**	**26.7**	**13.5**	**3.7**

The 30-year normalised dataset for monthly P and PET for Gashora, Gitarama, and Nyagatare were used with the FAO software package CROPWAT (version 8.0) along with soil data for a medium loam soil and crop growth data for mango. Monthly P and PET values were statistically partitioned into decade or daily values for calculating crop water and irrigation requirements. The model was initiated on 1 May 2009, the first month following a full month with P/PET ratios greater than 1 at each site.

Crop water requirement outputs by decades for the three sites include crop coefficients (Kc), crop evapotranspiration (ETc), effective precipitation (Peff) determined by the United States Department of Agriculture (USDA) Soil Conservation Service method, and irrigation requirement (IrrReq).

ETc is the product of PET and Kc (ETc = PET x Kc) while IrrReq by decade is the difference between ETc and Peff (IrrReq = ETc – Peff).

Crop coefficients for mango were 0.90 early in the season, gradually increased to 1.22 at the height of the growing season, and rapidly decreased to 1.16 by the end of the season. ETc for each site rose from approximately 30 mm per decade at the beginning of the season to a maximum during the last decade of October of 54 mm at Gashora, 52 mm at Gitarama and 49 mm at Nyagatare, and then falling to 36 mm per decade by the end of the season.

This resulted in a total ETc of 1510 at Gashora, 1478 mm at Gitarama and 1437 at Nyagatare. The highest total Peff of 885 mm was at Gitarama, followed by 761 mm at Gashora and 723 mm at Nyagatare. IrrReq, calculated as the difference between ETc and Peff, was greatest at Gashora, which required 755 mm of irrigation, followed by Nyagatare (715 mm) and finally Gitarama (621 mm).

The IrrReq for the three sites is plotted in Figure 28. Throughout the season, Gitarama required less irrigation than the other sites. During the first quarter, both Gashora and Nyagatare had similar IrrReq, but IrrReq was greater for Gashora than for Nyagatare during the second quarter of the season. All three sites had similar IrrReq during November and December, but IrrReq was greater at Nyagatare, followed by Gashora and Gitarama for the remainder of the season. It is strikingly apparent that the peak irrigation season at these sites coincides with the minimum P and maximum PET periods from June through September and again from early January through February.

The CROPWAT model was used to schedule irrigation for mango at Gashora, Gitarama and Nyagatare when 100% and 50% of readily available moisture was depleted. As more stored soil moisture was used, when 100% of readily available soil moisture was depleted at each site, the gross and net irrigation applications (net = 70% of gross) were greater following the 50% depletion schedule than for the 100% depletion schedule.

Peff was higher under the 100% depletion schedule at all sites. While irrigation applications were lower and Peff was greater under the 100% regime, soil moisture deficits were greater when the irrigation schedule was set for 100% depletion of readily available soil moisture. As soil moisture deficits usually result in crop stress and reduced yield, a more frequent irrigation schedule may be appropriate but on-site verification trials will be required.

Regardless of the scheduling strategy, crops still used similar amounts of water at either the 100% or 50% depletion regimes. The crop water demand was highest at Gashora with a total season use of 1 506 mm followed by Gitarama with 1 474 mm of crop water use. Nyagatare required the least amount of irrigation where the crop water use was 1 432 mm.

Table 32: *Thirty-year mean Kc, ETc, Peff and IrrReq for Gashora, Gitarama and Nyagatare starting at the end of the long rainy season for mango crop*

Month	Decade	Kc	Gashora			Gitarama			Nyagatare		
			ETc (mm decade⁻¹)	Peff (mm decade⁻¹)	Irr Req (mm decade⁻¹)	ETc (mm decade⁻¹)	Peff (mm decade⁻¹)	IrrReq (mm decade⁻¹)	ETc (mm decade⁻¹)	Peff (mm decade⁻¹)	IrrReq (mm decade⁻¹)
May	1	0.9	31.5	32.6	0	30.5	38.6	0	31	29.3	1.7
May	2	0.9	31.5	29.7	1.8	30.2	37.4	0	30.8	26.4	4.4
May	3	0.9	35.6	21.5	14.1	34.4	28	6.4	34.9	19.1	15.8
Jun	1	0.9	33.3	11	22.3	32.4	15.9	16.5	32.6	9.6	23
Jun	2	0.9	34.2	2.5	31.7	33.6	6.5	27.1	33.6	2	31.6
Jun	3	0.9	34.8	2.2	32.6	34.2	5.3	28.9	33.8	2.2	31.6
Jul	1	0.9	35.4	2.2	33.2	34.8	3.8	31.1	34.1	2.4	31.6
Jul	2	0.9	36	0.7	35.3	35.5	1.1	34.4	34.3	1.3	33
Jul	3	0.9	40.3	2.3	38	39.7	4.1	35.6	38	4.3	33.7
Aug	1	0.93	38.3	3.7	34.6	37.7	7.2	30.5	35.7	7.3	28.4
Aug	2	0.96	40.4	4.8	35.7	39.8	9.4	30.4	37.3	9.6	27.7
Aug	3	1	47	8.2	38.8	46.1	13.8	32.2	43	13.6	29.3
Sep	1	1.04	45	11.9	33.1	44.1	19	25	40.9	18.6	22.3
Sep	2	1.07	47.3	15.2	32.1	46.2	23.5	22.7	42.6	22.8	19.8
Sep	3	1.11	48.1	18	30.1	46.6	25.6	21	43.1	23.8	19.3
Oct	1	1.15	48.9	21	27.9	47	28	19	43.5	24.6	18.9
Oct	2	1.18	49.6	23.9	25.7	47.3	30.6	16.7	43.8	26	17.8
Oct	3	1.22	54.4	26.3	28.2	52	30.7	21.4	48.6	27.1	21.5
Nov	1	1.22	48.1	29.6	18.5	46.2	30.9	15.3	43.4	28.9	14.5
Nov	2	1.22	46.5	32.6	13.9	44.9	31.5	13.4	42.4	30.4	12
Nov	3	1.22	45.3	30.3	15	44.1	30.2	14	42.4	27.9	14.4
Dec	1	1.22	44	27.1	16.9	43.3	28.5	14.9	42.3	25	17.2
Dec	2	1.22	42.8	25.3	17.5	42.6	27.3	15.3	42.2	23	19.2
Dec	3	1.22	47.5	24.7	22.9	47.4	26.9	20.4	46.9	20.8	26
Jan	1	1.22	43.6	23.8	19.8	43.5	26.3	17.2	43	17.6	25.4
Jan	2	1.22	44	22.9	21.1	44	25.8	18.3	43.4	14.9	28.5
Jan	3	1.22	49.2	23.8	25.3	48.8	26.5	22.3	48.3	16.9	31.4
Feb	1	1.2	44.8	24.8	20	44	27.2	16.8	43.8	19.4	24.4
Feb	2	1.18	44.8	25.4	19.4	43.7	27.7	15.9	43.7	20.9	22.8
Feb	3	1.16	35.2	27	8.2	34.5	29.1	5.4	34.4	22.7	11.7
Mar	1	1.14	43.3	28.4	14.9	42.5	29.9	12.6	42.3	24.1	18.2
Mar	2	1.12	42.5	29.7	12.8	41.8	30.9	10.9	41.5	25.6	15.9
Mar	3	1.1	44.6	32.6	12	44	34.3	9.7	43.9	28.8	15.1
Apr	1	1.07	38.7	37.5	1.2	38.3	39.4	0	38.4	34.1	4.3
Apr	2	1.05	36.9	41.2	0	36.6	43.3	0	36.9	38	0
Apr	3	1.03	36.1	36.8	0	35.4	40.4	0	35.9	33.7	2.2
Total			**1 509.50**	**761.2**	**754.6**	**1 477.70**	**884.6**	**621.3**	**1 436.70**	**722.7**	**714.6**

Assumptions:
Medium textured loamy soil Maximum rooting depth: 0.9 m
Total available soil moisture: 290 mm m⁻¹ Refill to 100% of field capacity
Maximum infiltration rate: 40 mm day⁻¹ Field irrigation efficiency: 70%

Kc = crop coefficient; ETc = crop evapotranspiration; Peff = effective precipitation; IrrReq = irrigation requirement

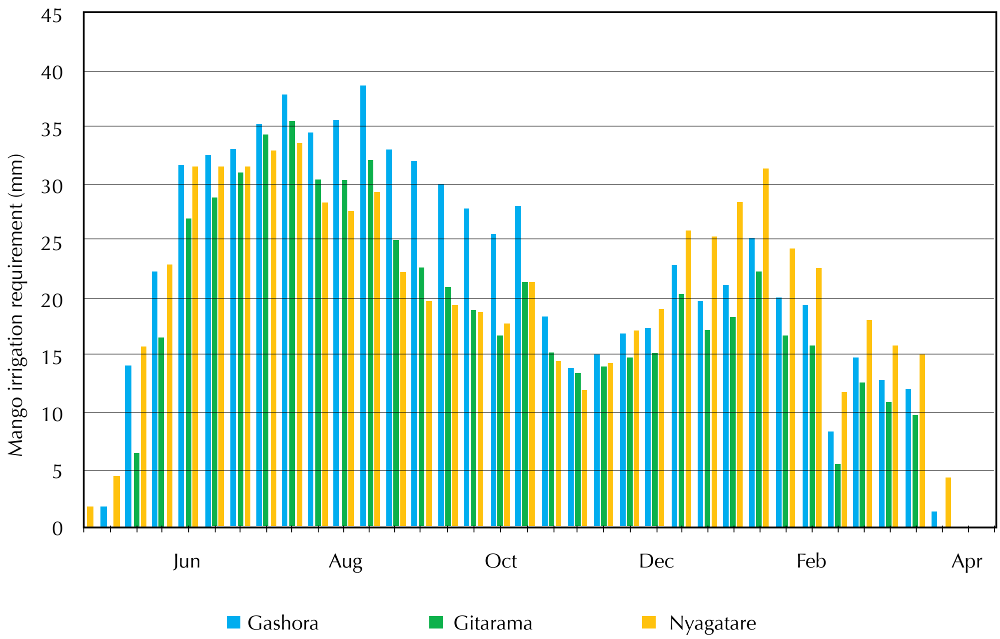


Figure 28: *Thirty-year mean irrigation requirements by decade for mango derived from CROPWAT version 8.0 for Gacharo, Gitarama and Nyagatare*

Conclusions

Identifying areas in Rwanda with a P/PET ratio greater than or equal to 1 on a monthly basis provides a mechanism for identifying areas with insufficient precipitation to meet potential evapotranspiration demand. Refining this procedure to determine the number of consecutive months when P/PET ≥ 1 provides a mechanism for identifying areas where cropping seasons have periods of insufficient P to meet PET. The areas with fewer consecutive months with P/PET ≥ 1 are more suitable for irrigation. Given the high costs involved with the establishment of an irrigation scheme, these areas should be prioritised over areas with a greater number of consecutive months with P/PET ≥ 1.

FAO's CROPWAT model provides an excellent tool for determining crop water use for a particular region. The climatic inputs required are P and PET, the same variables required for determining the P/PET ratio. Accompanying the model are standardised input files for crops and soil type. The model was used to determine water use for mango in three areas of Rwanda where there were 1 or 2 consecutive months with P/PET ≥ 1. The model was also used to schedule mango irrigation at the same sites using either 100% or 50% depletion of the readily available soil moisture as the critical value for initiating water application.

Chapter 7

Water supply and irrigation systems for Rwanda

7.1 Water supply

7.1.1 Water supply system

Water supply systems are utilised to carry water from a source to consumers. These consumers include domestic users, industry and agriculture. This section only deals with water supply for agricultural use.

Water supply systems include several sub-systems:

- Water source
- Pumping station
- Storage facilities
- Conveyance
- Connection from supplier to user

7.1.2 Water Source

Sources include rivers, streams, lakes, rainfall stored behind dams or in reservoirs and underground water that can be pumped from aquifers. Based on rainfall records, most of Rwanda can be irrigated from rivers and lakes for a major part of the year.

It may be necessary to add storage by building dams across stream beds or reservoirs off stream, i.e. to the sides of streams and rivers. Such reservoirs are usually built by constructing embankments around the reservoir site and by using soil from the site itself as material for the embankments.

It is important to emphasise that reservoirs must have the capacity to supply all the necessary irrigation water for the dry season as well as supplementary irrigation for dry periods during the rainy season.

When surface water is insufficient, it may be necessary to bore wells to increase water supply from underground sources. Underground water availability should be checked through a hydrogeological survey. Both water quality and quantity are important.

A hydrogeological survey can determine:

- Availability of underground water
- Suitability of the groundwater
- Amount of water available for continuous use
- Suitability of soil/rock formations to release ground water for pumping

7.1.3 Pumping water

Irrigation by sprinklers, mini sprinklers or drip tubing is possible through the use of pipes under pressure. The pressure may be natural if the water is supplied by pressure pipes from a source high enough to produce the necessary pressure head for irrigation. When the source is too low, it is necessary to pump the water to produce the pressure. Irrigation of hillsides in Rwanda will most probably be possible only by pumping the water.

Where slopes are minimal (1–2%), furrows or border strips can be irrigated by gravity feed. Steeper slopes will erode if surface irrigated, and should therefore be irrigated by pressure systems (sprinklers, mini-sprinklers, drip tubes).

One source of stored water can be created by building an earth dam across a small subsidiary stream near the point where it enters a large main stream. The stored water derives partially from the catchment area above the dam and partially from water diverted from the main stream. The diversion ditch from the mainstream to the reservoir above the dam should have little or no slope. An overflow spillway can be added if necessary. The amount of water stored will depend on the area of the watershed as well as the quality of the soil in the streambed and in the dam.

Stored water from a dam can be pumped to hillside areas adaptable to irrigation. It can be conveyed in pipes to lower-lying areas creating pressure for irrigation. In many cases it is necessary to construct an operational reservoir that holds sufficient water for 24–48 hours of use. The source of irrigation water determines the type of pump required. A pumping plant includes water metering devices, filtration, valves, fittings and other control devices.

The cost of a pressure irrigation system is based on construction and equipment (buildings, pumps, motors, electric connection, etc.), as well as operating costs including cost of electricity and maintenance. Diesel motors may be used where no electricity supply is currently available. If electricity supply is expected, a diesel generator should be preferred as a temporary power source.

7.1.4. Water storage

All irrigation systems need storage to be efficient and dependable. It may be necessary to design, build and operate a seasonal water storage facility.

In smaller systems with nearby, dependable water sources, an operational reservoir may be sufficient. The volume of an operational reservoir may be sufficient for a 1-day or a 1-week supply. A seasonal reservoir must be capable of holding sufficient volume to supply irrigation water throughout the dry season and also for supplementary supply for dry periods during the rainy season.

Under ideal conditions, the reservoir should be constructed on a site that can support irrigation to the entire area. When the soil used to construct the reservoir can be compacted to prevent seepage loss, costs are lower. Where suitable soil for compaction is unavailable, a plastic liner can be used. After the irrigation site has been chosen, it is be possible to design the required reservoirs. The equipment required depends on the site and the topography.

7.1.5 Water conveyance

Water is delivered from the source by gravity, by pumping to the irrigated area or by open canals and pipes. Pipes may be of steel, cast iron, plastic or other synthetic material. Choice of pipe depends on availability, cost or other criteria. Generally, plastic pipes up to 25 cm dia metre are least expensive. Other costs include control valves, one-way valves, air-release valves, drainage valves and measuring devices.

When it is possible to irrigate by gravity, surface irrigation, furrows or border strips, the supply can be open ditch/canals. Design of the irrigation system begins at the point of delivery to each consumer and continues upstream to the source. There should be a device to allow measurement of water to each consumer, as well as measurement at the source or junction. Water use efficiency can only be determined when the water is metreed and recorded.

7.1.6 Connecting consumers

It is easier to meter water conveyed through pipes under a pressure system. Such systems consist of:

- two valves with a metre between the supplier's valve (control) and the consumer's valve;
- filters, where necessary; and
- control (open, close) and metre readings, automatically controlled by the water supplier. Control can be by electric wire connections or by radio/telephone.

Water supplied through open ditches can be measured in several ways, both at the source and near the consumer. Such devices are part of the design of the ditch/canal and require accurate placing (Figure 29).

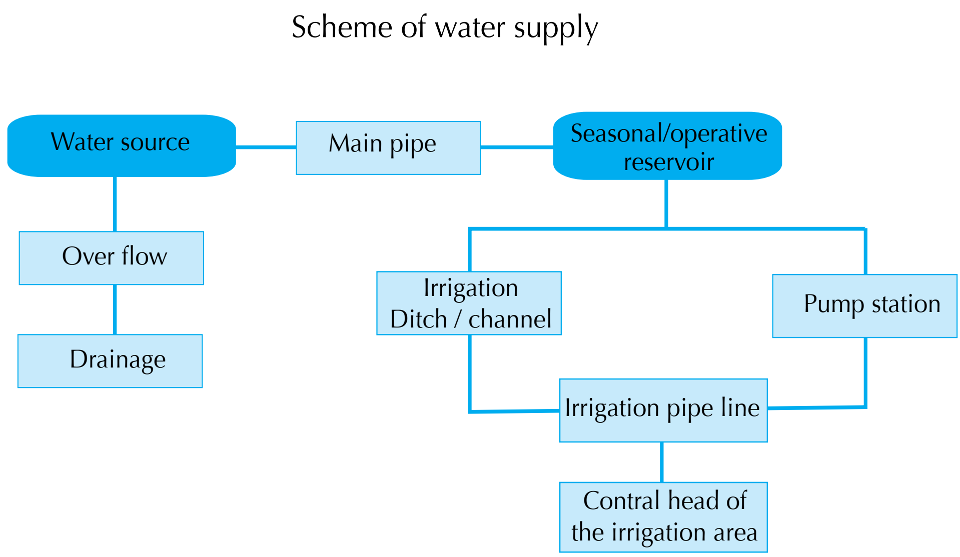


Figure 29: *Flow chart of a typical irrigation project*

Figure 30 and Figure 31 are schematic maps of two sites, the Akagera River along the Tanzanian border (scale 1:20 000) and Lake Cyambwe (scale 1:50 000).

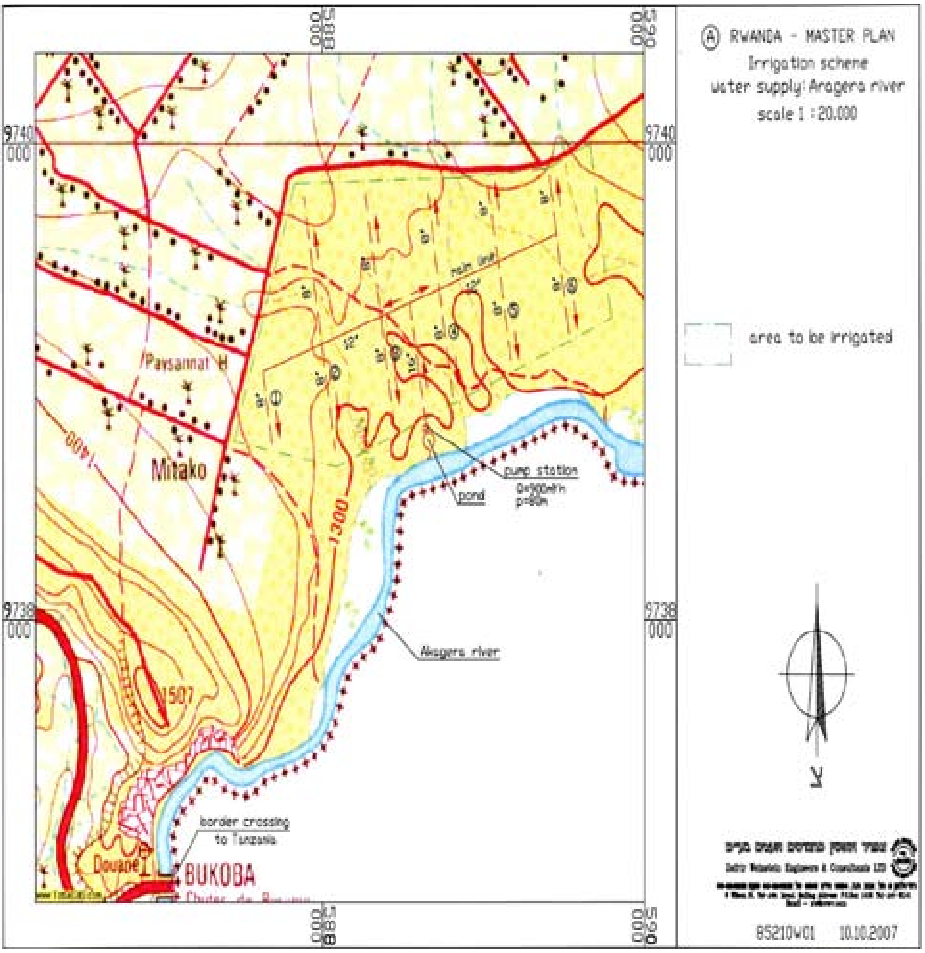


Figure 30: *Map of water supply from Akagera River (scale 1:20,000)*

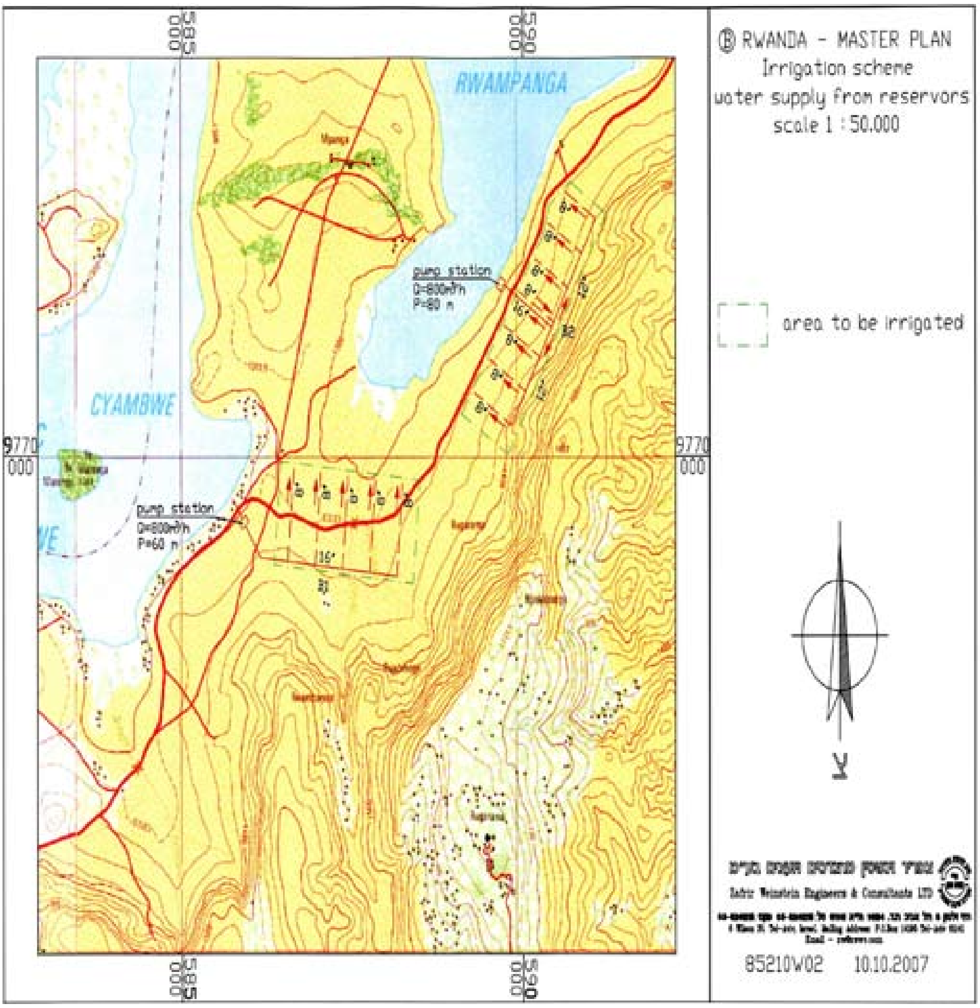


Figure 31: *Map of water supply from reservoirs (scale 1:50,000)*

7.1.7 Irrigation systems

Irrigation supplies water to the plants in addition to or instead of rainfall. It must be controlled in order to get optimal crop yields. Irrigated crop yields are frequently as much as 4 to 5 times greater than for the same crop without irrigation.

There are several different types of irrigation methods: surface irrigation, manual and semi-manual basin irrigation, overhead sprinkler systems, ground sprinkler systems, low-pressure pipe systems, and drip irrigation systems. The ultimate decision regarding the irrigation system to be used is complex and multidimensional, dependent on physiological, environmental and financial issues.

1. Surface irrigation

Surface irrigation can be supplied by:

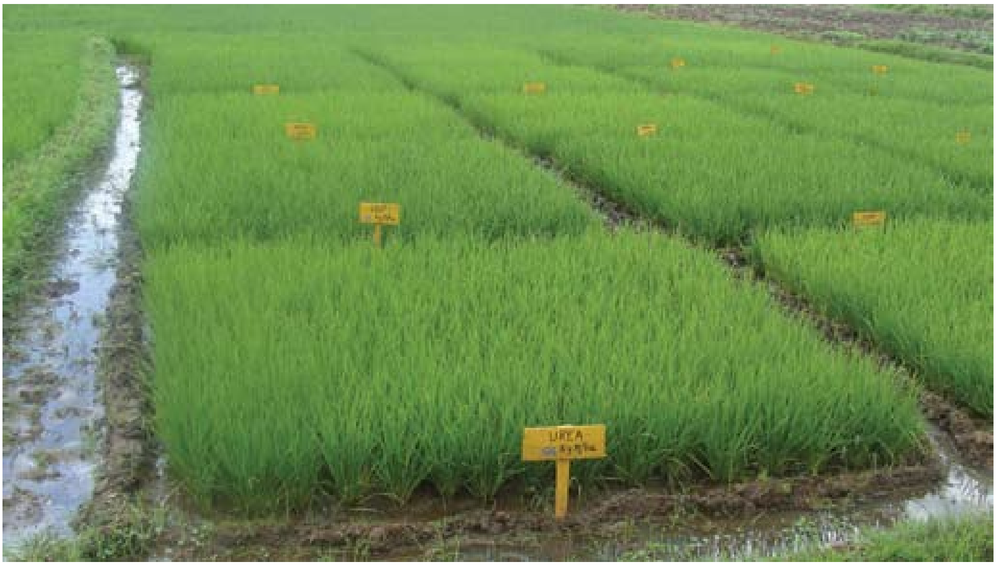
- Furrows: plants planted in rows between two furrows
- Border strips: for plants such as wheat, or other grains when the strip is flooded, between two low dikes or ridges, usually 3–12 m in width, depending on the water supply
- Flooding: used in larger areas for various crops, usually where large amounts of water are available

The advantages of surface irrigation include:
- Low initial costs
- Relatively simple device
- Relatively easy operation by the farmer

The disadvantages include:
- Inefficient use of water, much higher use on a per-hectare basis (water use can be 2-3 times more per hectare per year than with pressure systems)
- Areas must be leveled to fill in low spots and remove high points; ditches must be laid out with flat slopes to prevent erosion; leveling has to take into account the type of soil and the problem of removing top soil when soil depth is limited
- Application of fertilizer by irrigation water is less efficient than in pressure systems
- Labour-intensive compared to pressure systems

Surface irrigation is applicable to areas with an ample supply of water and relatively flat slopes. It is preferable where there is sufficient labour available at a reasonable cost. In surface (or flood) irrigation, the designated plot is leveled to a specific gradient and water is conducted by gravity in open channels and furrows from the water source throughout field. This traditional system is widely used for rice and other paddy crops, as well as field and row crops. While initial land preparation and upkeep costs can be high, little mechanical equipment is required. The efficiency of flood irrigation is low because of the intensive use of water and consequent surface evaporation. Land use is also less efficient, since part of the plot serves as a water conduit, leaving less area for planting. Flooding can also hinder plants' oxygen intake, as water covers a large part of the plot for an extended time. Excessive flooding leaches essential nutrients from soil and can leave salt residue.

Manual or semi-manual basin irrigation is common throughout Africa, and is widely used on a non-commercial basis throughout the world. Small basins of 20–30 m2 are constructed with soil walls, and the farmer delivers water directly to the basin in a controlled manner. This can be done by moving flexible hoses from a water source from basin to basin, by manually opening and closing furrows into the basin using one's foot or a spade, or by handcarrying water in sprinkler cans or buckets. Manual irrigation is an efficient system only in areas where manpower costs are very low. Thus it is not used for commercial farming in developed countries, but it is widespread in Africa, Asia and parts of South America.



Basin irrigation for rice

2. Pressure irrigation

There are several modern methods of pressure irrigation:

- Sprinkler
- Mini-sprinkler
- Irrigation machines
- Drip tubes

Sprinkler irrigation is essentially artificial rain. There are two main types:

- Permanent: the pipes remain in place in the field during the entire season.
- Moveable: the pipes are moved every irrigation from one place to another. Labour costs replace the cost of the greater length of pipes used in the permanent type.

Sprinklers turn 360 degrees and can operate with pressure of 2.5 to 6 atmospheres. Spacing between sprinklers determines the pressure and type of sprinkler to be used. Small individual plots are usually designed for 3 atmospheres.

Sprinklers can apply large quantities of water in a relatively short time depending on the ability of the soil to absorb water, thus enabling irrigation for fewer hours per day. This is especially useful when strong winds prevail during certain parts of the day. Night irrigation also reduces evaporation of water.

Other pressure systems may have to operate during more hours per day, including late nights or early mornings.

Mini sprinklers
Mini sprinklers can be full or semi-circle. They are non-rotating and irrigate a fixed area. The operating pressure can be in the range of 1 to 3 atmospheres (10 to 30 M). These units are often used in orchards. Ground-level sprinkler systems generally provide water under the crop canopy. Mini sprinklers are ideal for fruit production when root systems are wide and near the surface, but they are also used in nurseries and greenhouse systems.

Mini sprinklers

Irrigation machines
These systems are used for very large areas. There are two basic variations:
Centre pivot. A flexible pipeline on wheeled struts that turns around a single source of water with a flexible connection. The unit can turn 360 degrees or any part of a circle, depending on the field being irrigated. The irrigated area is circular.

In-line. With this system, the irrigation travels the length of the field. Water supply is from a flexible pipe the length of the field. The irrigation line can swing 180 degrees and return in a field parallel to the first run, or it can return for the next irrigation. The equipment usually stays in one field during a season. Irrigation is generally close to the ground, at times below the top of plants, and can irrigate most hours of the day. The pressure needed is usually 4 atmospheres (40 M).

Overhead sprinkler irrigation is suitable for most row and field crops. Water is sprayed over the crop canopy by high sprinklers on fixed posts, by sprinklers on posts that can be moved by hand, by automated sprinklers moving in a line or from a centre pivot, or from water cannons. These systems are adaptable to any farmable slope, whether uniform or sloping. The method is suitable for most soils, but not for soils that easily form a crust. The water supply must be free of sediment to avoid blocking the sprinkler nozzles and damaging the crop. The requirement for low- or high-volume sprinklers is determined the crop and the soil. Overhead sprinkler systems require substantial investment and regular maintenance by trained workers.

Several low-pressure pipe systems also offer possibilities for hillside agriculture. Gated pipes constructed from metal or canvas with holes up to a 0.5-cm dia metre conduct water over several hundred metres and provide some dispersion of water. Some systems look like drip systems with a centre line and detachable lateral hose lines with tiny punched holes instead of drippers. These systems lose less to evaporation than flood systems and cost less than true drip systems.

3. Drip irrigation

Drip irrigation delivers small amounts of water over relatively long periods as close to the irrigated plant as possible. The depth of irrigation is adjusted to the desired root zone of the plants. The interval between irrigations allows the most efficient use of water, as there is almost no evaporation and water loss below the root zone is minimal.

The drip tube is restricted by the amount of water released at each point. The initial cost is high, but operational costs are minimal and the workers can do weeding and other farming operations while the irrigation is automatically controlled. Drip tubes can be placed above ground, or slightly below ground—usually for permanent plants like trees and orchards. Drip irrigation systems require special filters to remove foreign material in surface waters which would otherwise plug the small openings in the tube.

Drip irrigation has proven itself to be the most effective system in terms of reducing water loss and improving crop yields. It is suitable for row, tree and vine crops. It can be adapted to any farmable slope and is suitable for almost all soils. This method is particularly suitable for poor quality water and can be very efficient in water use.

The main disadvantages to drip irrigation are its installation and maintenance costs. Also, drip irrigation requires water free from sediment to avoid blockage of the emitters, so filtration and sediment basins can also add to cost and service requirements.

Drip system for tomatoes

The choice of irrigation method depends on factors specific to the site and the agricultural plan: land contour, soil permeability and type, plot size, crops cultivated, required labour inputs, water source and availability and economic costs/benefits. Balancing these factors will identify the appropriate type of irrigation method.

Land contour/slope

The irrigated plot can be in many topographic forms: steep hill, flat land, moderate slope, marshland or any combination of the above. Sprinkler or drip irrigation are often used on steeper or sloping land as these systems require minimal land leveling.

Soil permeability and type

Irrigated farming can be effective on many types of soil. Soil structure, texture as well as chemical properties determine its suitability for agriculture and for irrigation. When a variety of soils are found within one irrigation scheme, sprinkler or drip irrigation are usually recommended because they ensure even water distribution. Clay soils with low infiltration rates are usually suited to surface irrigation.

Plot size and crops

The plot size and crops to be cultivated are important determining factors in the choice of an irrigation method. Surface irrigation can be used for all types of crops, but sprinkler and drip irrigation, because of their high capital investment, are usually used for high-value crops. Drip irrigation is more suitable for irrigating individual plants, trees or row crops, but is not suitable for close-growing crops.

Required labour inputs
Surface irrigation and manual basin irrigation require more labour input than sprinkler or drip irrigation. Surface irrigation also requires accurate land leveling and frequent maintenance. Sprinkler and drip irrigation are less labour-intensive in terms of land leveling, system operation and maintenance, but the need for skilled maintenance may increase costs.

Water source and availability
Water source, quality, proximity and availability determine the suitability of the conduit and the type of irrigation. Heavy sediment and siltation will clog sprinklers and drip irrigation systems unless a filtration mechanism is installed. The chemical composition of the water also determines which method is most suitable. For example, if surface irrigation is used with saline water, the soil will retain large amounts of salts and the crops will suffer. Limited availability of water indicates a need for methods that conserve water, such as sprinkler and drip.

Economic costs / benefits
The costs of construction, installation, operation and maintenance should be taken into account when choosing an appropriate irrigation method. The costs should then be compared and balanced with the benefits in terms of yield, suitability to site, quality and expected financial return.

All of the above systems can be used in Rwanda. Detailed designs can suggest optimal use of the various types of irrigation, taking into account soils, topography, drainage, channels, slopes, and objects in the fields (buildings, trees, rock outcrops, etc). The agricultural potential of the area must be considered to ensure that appropriate equipment can be designed for future expansion.

Figure 32 and Figure 33 show irrigation design samples.

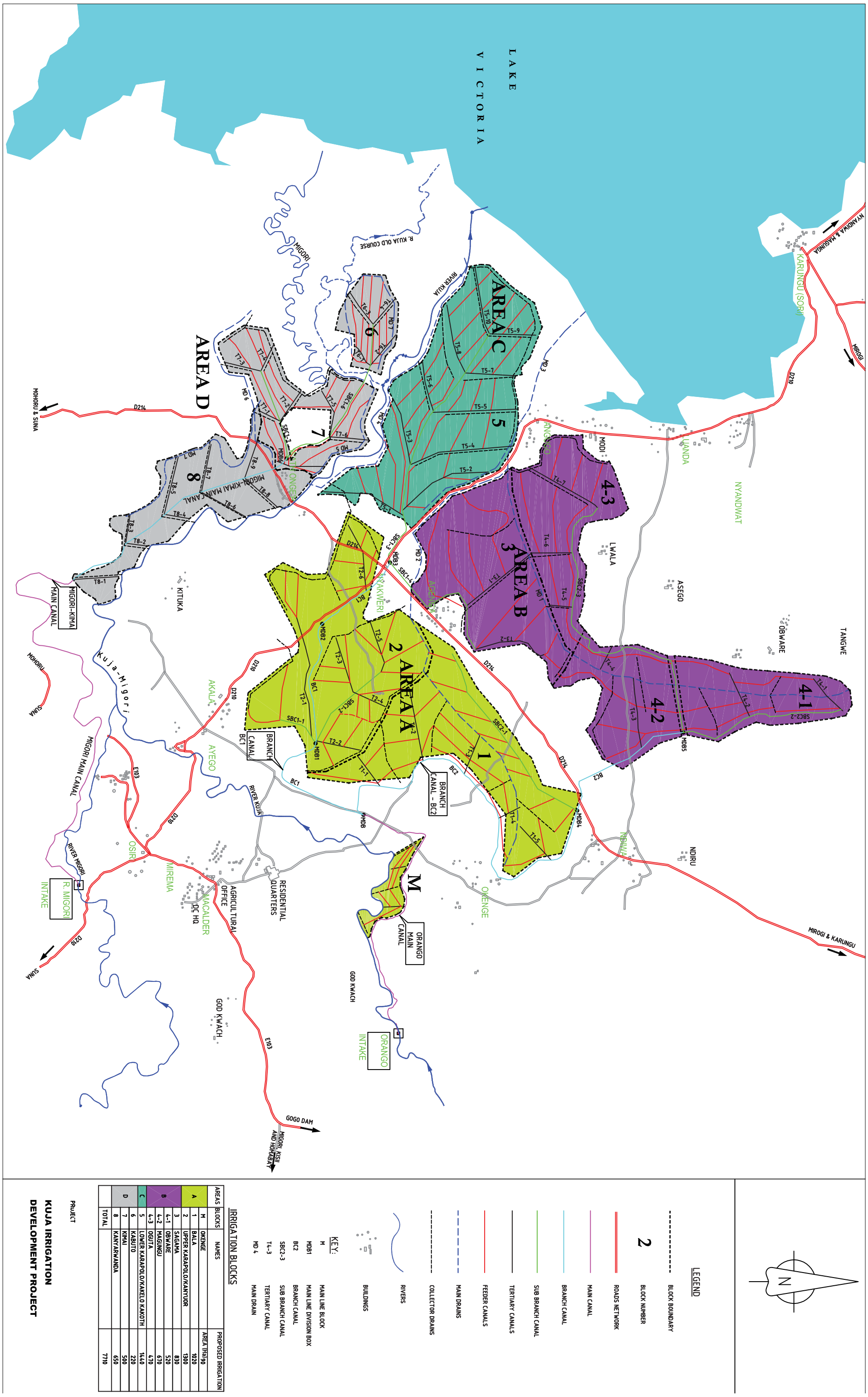


Figure 32: *Sample map of irrigation site*

Figure 33: *Pumping and fertigation equipment*

7.2 Estimated cost for a sample irrigation project

Execution of an irrigation scheme requires the following stages:

- Data collection and evaluation
- Planning and design of the project
- Implementation

Data collection and evaluation involves gathering information from soil surveys, water analyses and topographic surveys. The scale of the topographic map depends on the type of irrigation project proposed. For example, a furrow irrigation project requires a more detailed scale because of the precision required for preparing the land. Upon completion of the surveys and analyses, and contingent on confirmation of acceptable water quality and suitable soil characteristics, the team can begin the planning and design stage. The cost of the project will largely depend on the results of the surveys.

Based on the detailed data collected from the surveys, the engineers can begin to plan and design the pumping stations and layout of the project. Upon completion of the detailed design, the team will begin implementing the project.

The cost breakdown is presented in Table 33. It should be noted that some costs are not included in this rough estimate (i.e. management costs, finance, taxes, transportation costs to the site, and rented or purchased equipment).

Table 33: *Cost breakdown for sample furrow irrigation project on a 100-ha site (USD)*

Surveys, soil and water analysis	55 000
General and detailed design	95 000
Implementation and activation of the project	350 000
Total	**500 000**

Pressure irrigation systems

Table 34 shows rough cost estimates for pressure irrigation equipment, assuming that the source of water is available at the site.

Table 34: *Cost estimates for irrigation equipment (USD ha^{-1})*

Drip irrigation	5 000–7 000
Sprinkler irrigation	5 000–7 000
Centre pivot sprinkler	4 000

Chapter 8

IMP alternatives: organization and control of irrigation supply management

8.1 Introduction

The specific organizational structure for managing irrigation water supply is an integral part of an IMP and critical to its implementation and success. The type of management structure determines the effectiveness of the supply and management of irrigation water. These structures will vary depending on the socioeconomic factors of the locality. Consequently, some structures may be effective in some areas, while faring poorly in others.

These differences usually have to do with social and cultural factors. For example, certain communities have stronger traditions of collective action than others. Other factors are the nature of the irrigation supply, its regularity and its importance in relation to rainfall. Where the supply is reasonably predictable and distribution is regulated by long-established, well-accepted rules, there is little need for formal organization of supply. On the other hand, where irrigation distribution is complicated by less predictable supply or where it is supplemental to variable rainfall, the need for cooperation between users with regard to management of irrigation delivery is greater (Campbell 1995).

It is imperative therefore that the proposed IMP include a suggested organizational structure and function that provides alternatives for various sociocultural and economic settings. The purpose of this chapter is to outline organizational alternatives for the management of water resources, supply of water for irrigation, and the operation of supply systems.

The general scheme used to propose an optimal IMP organizational structure is depicted in Figure 34.

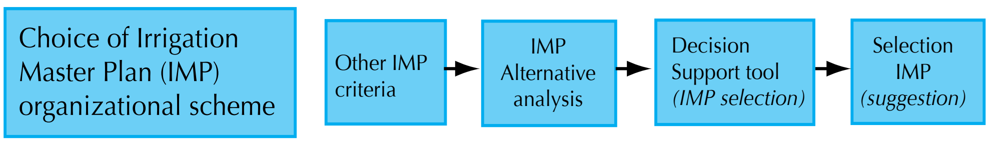


Figure 34: *IMP organization*

The major criteria determining an optimal organizational structure for irrigation water management include the following factors.

- Location and distribution of water resources
- PIAs as determined by a separate set of selection criteria
- Rainfall patterns and predictability in the PIAs
- A national policy for usage and distribution

8.2 Organizational objectives for water management

In order to compare different organizational structures for water management, the following organizational objectives are defined and suggested as points of reference for testing advantages and disadvantages of the alternatives.

Major objectives

- Plan, establish, supervise, monitor, evaluate and maintain water supply projects for irrigation.
- Manage natural water resources for irrigation purposes in an environmentally sustainable manner.
- Ensure long-term, reliable supply.
- Manage water supply in a cost-effective manner to ensure long-term economic sustainability of supply.

- Provide agricultural and technical know-how regarding crop irrigation.
- Ensure high water-use efficiency and prevent loss.
- Collaborate with authorities and agencies engaged in agriculture, infrastructure, industry and environment.
- Collaborate, liaise and develop fruitful relationships with local government authorities and farmer associations.
- Collaborate with various offices, agencies, NGOs and other organizations.
- Develop and expand irrigation enterprises.
- Financially manage irrigation enterprises, including collection of national and local funds, and efficiently mobilise these funds.
- Build and develop capabilities and competence within the organization.
- Handle legal and regulatory issues regarding water policy.

8.3 Activities undertaken by a water organization

Effective water organizations must demonstrate initiative and professional competence to conceive and design water enterprises. Activities comprise planning, organizing, operating and financing water supply from source to end user. Irrigation water management is a composite effort that requires high levels of management and coordination competence to ensure reliable supply.

Required activities are listed below.

Monitoring
Monitoring water volume for both quantity and quality at the inlet to the source, at the reservoir and at the outlet must be performed continually. This includes recording of available amounts, seasonal and long-term fluctuation, and comparison to the water extraction plan.

Specific uses for irrigation water have different requirements. One water supply is acceptable if it produces better results or causes fewer problems than an alternative supply. Problems vary both in kind and degree, and are modified by soil, climate and crop, as well as by the skill and knowledge of the user. As a result, there is no set limit on water quality; rather, its suitability is determined by various conditions that affect crop yield. The problems most commonly encountered and used as a basis to evaluate water quality include soil salinity, water infiltration rate and toxicity. The importance of constant monitoring of water quality is necessary to ensure that high yields are sustained.

The quantity of water is equally important. Loss of irrigation water from leakage is as significant as contamination in irrigated agriculture.

Planning
Long-term and seasonal supply schedules must be devised with respect to source capacity, demand for irrigation water and future development plans. The water capacity and distribution should be well planned to avoid conflicts of water use and

crops losses due to water scarcity. WUAs should ensure regular water supply and in cases of water scarcity that distribution of water is equitable.

Operation
Water supply facilities and infrastructure must be established to comply with planned and forecasted demand. The people charged with managing and operating irrigation systems and infrastructure should be adequately capacitated through regular training.

Process
Water supply at the required capacity must be maintained, both quality and pressure, according to a plan and defined requirements. This involves pump planning; installation and maintenance; filtration; water metering; and maintenance of pipelines, valves, filtration, pressure regulators and outlets. The process may include water volume regulation via storage facilities and reservoirs as well as various water treatment procedures such as filtration and chemical treatment.

Outlet
Management of water outlets should be undertaken in close proximity to the end user sites. Outlet management involves valve maintenance and metreing for monitoring flow rates, leakage and charges to consumers.

Other evaluation criteria
Other criteria for the selection of an organizational structure of the irrigation water supply system include sociological considerations (demography, skilled vs non-skilled worker availability) and economic considerations (profitability, cost of installation, investment capacity).

8.4 IMP organizational structure alternatives

Two of the most important factors affecting the choice of an appropriate form of an IMP organizational structure are the size of the project area and its level of economic development. The leading principles for irrigation water administration must include a legal framework, a central regulatory mechanism and a structure that guarantees user participation. Other important factors include the objectives of government and the character of existing institutions.

Three alternative organizational structures for irrigation management are herein analysed. These three are organizations based on a countrywide, regional and local level. They are further explained and analysed in a comparative manner.

8.4.1 Central control

Definition: Water management, development and maintenance are controlled centrally though a responsible government agency. Although local issues are handled by a regional branch office, the level of regional involvement is low. Decision making is undertaken at the national level and local water issues are administered from above.

Central level structures operate through the interaction of several departments or organizational units connected through a clear chain of command. Successful coordination at the national level must be capable of procuring the technical and financial support necessary at the project level. The government must also be willing to delegate a considerable amount of authority and autonomy to the individual project authorities, or accept that the government itself must implement such activities.

Water is a primary national resource, usually limited in availability. Water supplied through rainfall or inflowing rivers, arriving at random, is a common national resource. The central government must therefore control water resources and supervise distribution and management. This is particularly true when high levels of precipitation variance exist between different zones. Other factors best suited to central control are water policy and distribution priorities, environmental and conservation issues and water quality maintenance and conformation to established standards.

Another important consideration promoting central control of water resources is the government's ability to raise funds, both domestically and internationally, and to allocate budgets to develop and maintain the water systems at a national level.

On the negative side, central organizational systems are typically cumbersome and remote from the local water users. Moreover, government commitment to irrigation development in many developing countries tends to be ad hoc and unsustained. Interest may be strong in drought years, but declines when followed by a series of normal years. Public support will increase as levels of agricultural and rural development rise and more farmers and rural communities, appreciating the value of a green agricultural environment, begin to mobilise their political strength to support irrigation infrastructure.

8.4.2 Regional control

Definition: Water resources and irrigation development and maintenance are managed at a regional level (i.e. within a catchment basin, province or district). Responsibility for water development, harvesting and supply is administered and controlled within a region with a significant level of autonomy. Lessons learned from irrigation development schemes demonstrate the advantages of regional management and development (MAF 2001).

Some findings and recommendations:

- The scheme development must include farmers early in the planning process and include an iterative process of feedback to farmers.
- Scheme promoters must be able to identify all potential benefits and beneficiaries of a scheme early in the process.
- Consultation is needed with all stakeholders with an interest in water resource allocation early in the feasibility process.
- Wherever possible, efforts should be made to maximise the nonproductive

benefits of water resource enhancement, including other productive uses (such as the generation of electricity) as well as environmental, recreational and cultural considerations.

- It is critical to have a lead agent or champion in the initial promotion and feasibility analysis of schemes.
- Provision of information and support to farmers and other beneficiaries to assist decision making on how to manage and maximise benefits is essential to encourage rapid uptake and efficient resource use.

Most of these factors indicate a strong requirement for close collaboration and cooperation between the developers and promoters of irrigation projects and the future users and local population. This is possible through strong local management and leadership, including participation of local leaders and water users in the planning and implementation process.

On the negative side, since water is a national resource, water usage requires monitoring at a national level. Coordination between regions in control of common water sources calls for central regulation, particularly if water needs to be distributed among regions.

8.4.3 Local control

Definition: Water sources are controlled at the local level by village leaders and WUA managers. Local water user cooperatives organize borehole water production, pump facilities at riversides and lakes, and so on. Beneficiaries are relatively few because such operations are typically small.

Because local structures are fragmented, a high level of initiative and local stakeholder involvement is enabled. Such projects require little administration and managing them is usually inexpensive.

On the negative side, control is deficient and pumped water volumes can go unmonitored. Such projects are often inefficient and unreliable. Costs are relatively high per unit of water and breakdowns lead to shortages and crop failure. Water usage is difficult or impossible to monitor and the ability to raise funds is low.

8.5 An IMP analysis and the development of a decision support tool

MCA and decision making are performed by grading the proposed alternative organizational structures according to various objectives, activities and other criteria. Analysis is performed for each item. The total score gained by an alternative can be used as a guideline to support decision making regarding the optimal organizational structure for managing irrigation water supply.

A comparative analysis for the selection of an organizational structure for irrigation management is provided Annex 2. Issues highlighted include the major criteria, organizational objectives, organizational activity requirements and other evaluation criteria. Criteria groups are weighted according to their relative significance in this analysis and grades are adjusted accordingly.

Figure 35 shows suggested hierarchical structure of irrigation management at national level. The suggested regional irrigation authority (Figure 36) is a semi-autonomous entity responsible for the management and supply of irrigation water for agricultural purposes. This entity would have the authority to initiate, plan, implement and finance projects based on local water resources and retain a high level of autonomy.

The responsibilities of the regional authority include:

- planning of irrigation projects within the region based on demand and supply of water, while considering sustainable utilisation of water resources, rational usage and monitored supply;
- responsibility for installation and operation irrigation control mechanisms; and
- monitoring and metering water amounts at source and at outlet in order to optimise supply and energy requirement and to minimise costs.

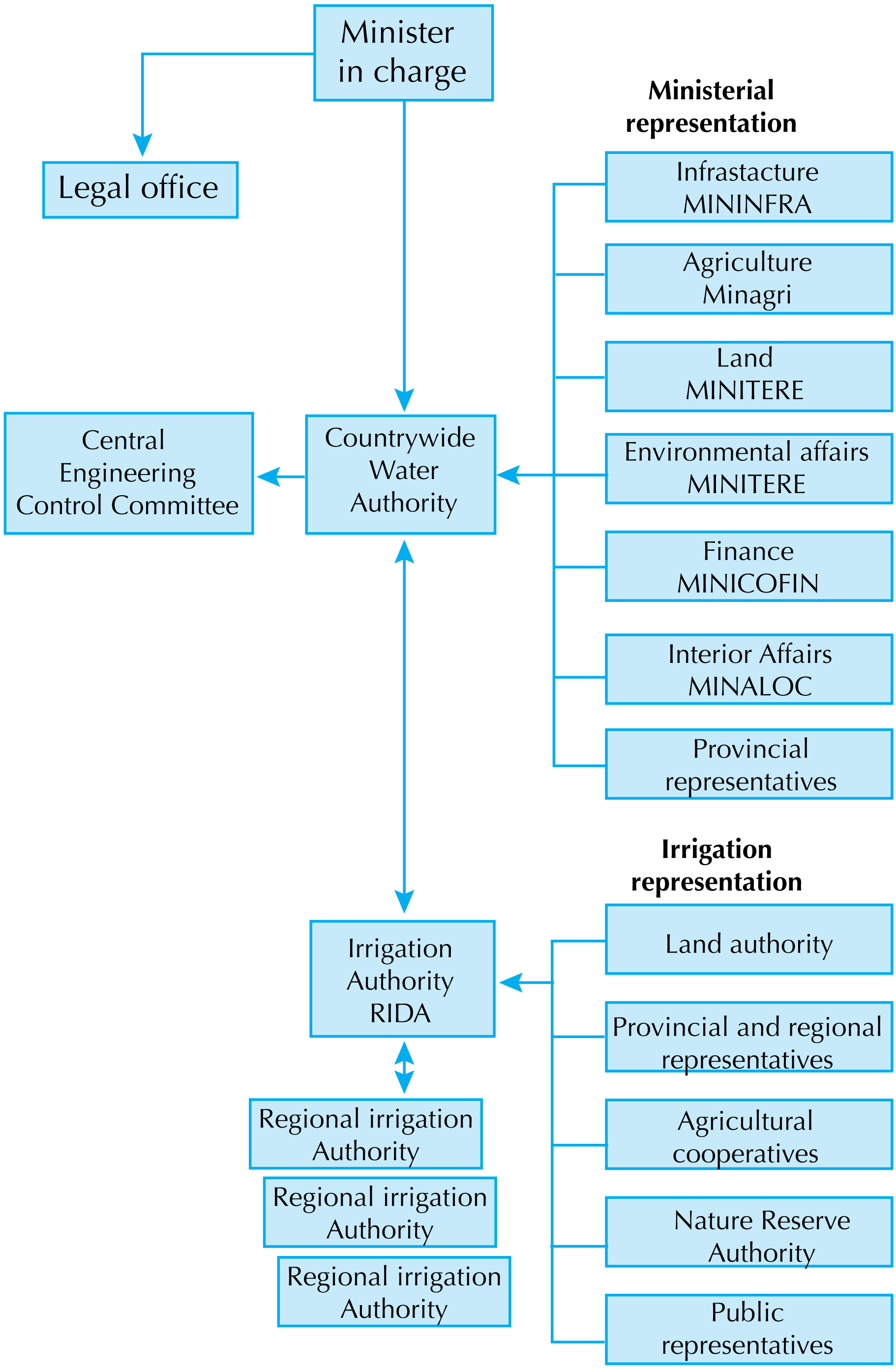


Figure 35: *Hierarchical structure of irrigation management at national level*

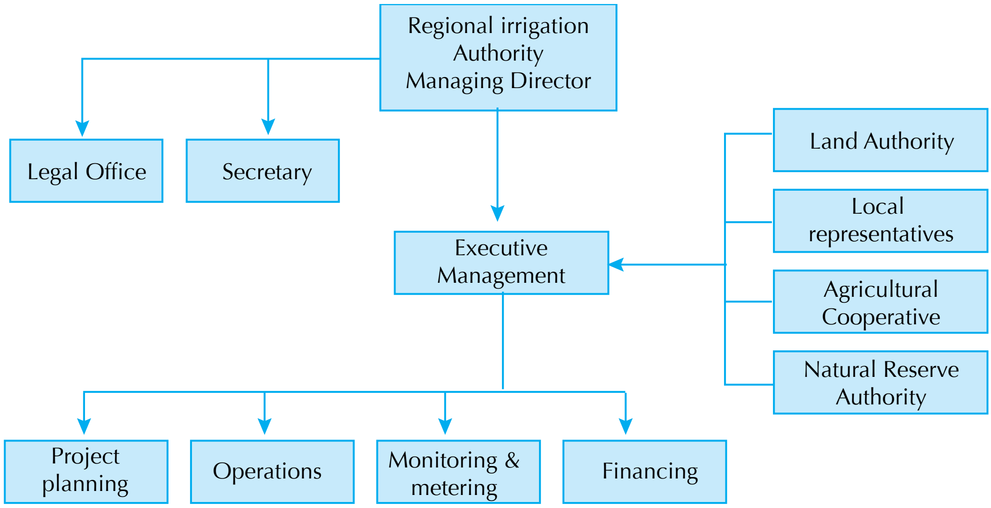


Figure 36: *Organization of regional irrigation authority*

8.6 Initializing, planning and implementing irrigation projects

Agricultural development based on advanced irrigation techniques in Rwanda requires a variety of considerations. Proper utilisation of water resources in an environmentally sensitive way can only be done by a central authority that can control water quantity, provide the necessary regulations for fertilizer and pesticide use, and monitor environmental impacts. Implementing modern agricultural techniques requires high levels of training in order to deal with the complex technology of water distribution. These elements can only be organized centrally at the national or regional levels.

On the other hand, the organization of rural, social and community life in Rwanda will have a crucial influence on the success of any project attempting to apply irrigation on a broad scale. Without a process of active dissemination that includes the local farmers and their communities, integration of the technology of irrigation into their lives will not take place and the movement towards Vision 2020 will stall.

The solution to this problem arises directly out of the analysis undertaken in the present study. As noted above, the national issues connected with developing irrigated agriculture must be controlled by a centrally organized body, a country-wide Water Authority that includes an Irrigation Board, either independent or attached to a government ministry. This authority would be responsible for determining available water volumes and regulating water usage and quality. This body would include representatives from all relevant ministries and agencies (agriculture, infrastructure, environment, finance and others).

Through the Irrigation Board, the government can set the price of water according to the type of use. This price will depend not only on policy considerations by also on the professional recommendations of the Water Authority, which will have the responsibility for collecting data and monitoring water use.

The initiation, planning and implementation of water projects should be the responsibility of a Regional Water Authority. This organization, being much closer to the rural communities and farmers, would have complete independence to initiate irrigation projects (subject, of course, to central government decisions with regard to water quotas and quality).

The Regional Water Authority would include professionals experienced in operations, monitoring and finance. Their responsibilities would include implementation of irrigation projects in the field. All aspects of integration, training, monitoring and inspection would fall under the purview of this authority. In addition, this body would collect water fees and encourage the establishment of irrigation cooperatives.

This study recommends placing emphasis on autonomous regional management of water resources to promote the integration of advanced irrigation techniques into the lives of local farmers. The provision of a bridge between the central government and the local community will serve the dual purpose of guarding the public interest and implementing government directives.

8.7 Summary

This section presents a conceptual framework for the Organization and Management (O&M) of Rwanda's irrigation water supply. Beginning with a definition of the criteria and objectives of the suggested IMP, the framework goes on to describe the activities to be undertaken by a water management organization, including monitoring, planning, operations, processes and outlets. Next, three major organizational options—central, regional and local—are discussed and analysed in detail by checking the performance of each alternative against 23 evaluation criteria. The analysis concludes that a regionally managed, state-controlled water management organization is most suitable. In order to visualize the suggested management schemes, the organizational structure of both a national and a regional water authority are presented and their major functions described (Campbell 1995, Ayers and Westcot 1985).

Chapter 9

Transition to modern irrigated agriculture

9.1 Need for modern irrigated agriculture

9.1.1 Current status of Rwanda's agriculture

In Rwanda, agriculture is the backbone of the economy, contributing about 36% of total GDP during the 2001–06 period and employing more than 80% of the population. The sector is very fragile, however, suffering from structural constraints compounded by climatic hazards and frequent external shocks.

Average agricultural growth over the last three years has remained at 3.6% against a target of 7%. This poor growth is due to structural weaknesses—decreased soil fertility, limited availability of inputs, inefficient technologies, lack of access to support services and vulnerability to external shocks. Production growth is attributable more to expanded cultivation than to increased productivity. Although production of most crops has increased, yields have fallen.

Public resources for agriculture have risen slightly during the past five years, from approximately 3–4% in the 2007 national budget. This figure is very low considering that the sector employs more than 80% of the active population. It is also far from the 10% target set by the New Partnership for Africa's Development (NEPAD).

9.1.2 Transition to modern agriculture

The goal of the Rwandan government is to foster a rapid transition from subsistence-based agriculture, in which the majority of Rwandan farmers are currently involved, to market-oriented commercial agriculture. This will require profound changes at all levels of the rural economy, as well as significant adjustment of production and consumption patterns. As productivity rises and rural households move from production of food staples for home consumption to production of cash crops destined for the market, productive opportunities will be created within and outside of the agricultural sector. It will take time for rural households to react to these new opportunities, since reacting effectively will require them to absorb new knowledge and acquire new skills, and the growth path is essentially unpredictable. This situation suggests that the support to market-oriented commercial agriculture must be flexible in order to adjust to the changing technical and institutional circumstances.

Planning for modern irrigation in Rwanda through diverse technologies will ensure sustainable food production through the introduction of high-value horticultural crops with good productivity and strong marketing potential.

9.2 National strategic irrigation planning

The Phase I assessment of Rwandan irrigation potential indicates that the country has a potential of about 589 713 ha, taking into consideration runoff, river, lake, groundwater (springs, shallow wells and deep wells), small reservoirs and marshland domains.

Following the keenness of the Government of Rwanda to transform the irrigation potential into reality in order to achieve food security, a number of interventions have to be initiated to develop short-, medium- and long-term strategic irrigation plans. These include:

- Financial and investment mechanisms
- Policy and legal issues
- Institutional arrangements
- Socioeconomic issues
- Marketing chain
- Environmental issues

According to MCA and ranking of the Rwanda irrigation domains as depicted in Table 35, Table 36 and Figure 37 below, marshlands score very highly on prioritisation. They form the bulk of the irrigable areas due to a number of factors, including moderate investment costs, size of command areas and time to establish the schemes. In addition, food security and returns from export are very high. However, the environmental sensitivity of marshes requires cautious management.

The small reservoir domain compares closely with the marshlands mainly owing to low investment levels, management skills and infrastructure. Their small size also makes implementation quick and easy.

The lake/river and runoff domains rank third and fourth in the MCA analysis. Their comparative lower scores against the marshlands are attributed to heavy investment costs and management skills.

The groundwater domain scored poorly owing to lack of adequate data. A framework for creating a long-term data bank that encompasses personnel and infrastructure data needs to be developed. Additional studies should be conducted to generate results for the groundwater data bank.

Table 35: *Multi criteria analysis of domain for prioritization*

MCA Parameter	Irrigation domain					
	Lake	River	Runoff	Groundwater	Marshlands	Small reservoirs
Total size PIAs (Ha)	100 107	79 847	27 907	36 432	219 793	125 627
PIS indiv areas (Ha)	1500	600	100	5	400	0.5
Investment costs	V. Heavy	Heavy	Heavy	Heavy	Moderate	Low
Management Skills	High	High	Moderate	High	High	Low
Infrastructure skills	High	High	High	Moderate	High	Low
Time for implementation	Medium	Medium	Long	Medium	Medium	Short
Returns from export	High	High	Moderate	Moderate	V. High	Moderate
Food security	High	High	Moderate	Moderate	V. High	High
Energy requirement	High	High	Low	V. High	Moderate	Low

Table 36: *Ranking of domains from MCA scores*

Parameter for MCA	Irrigation domain					
	Lake	River	Runoff	Ground-water	Marsh-lands	Small reservoirs
Total size PIAs (ha)	4	3	2	2	5	2
PIS indiv areas (ha)	5	5	5	3	5	3
Investment costs	2	3	3	3	4	5
Management skills	3	3	4	3	3	5
Infrastructure skills	3	3	3	4	3	5
Time for implementation	4	4	3	4	4	5
Returns from export	4	4	3	3	5	3
Food security	4	4	3	3	5	4
Energy requirement	3	3	5	2	4	5
Total	**32**	**32**	**31**	**27**	**38**	**37**

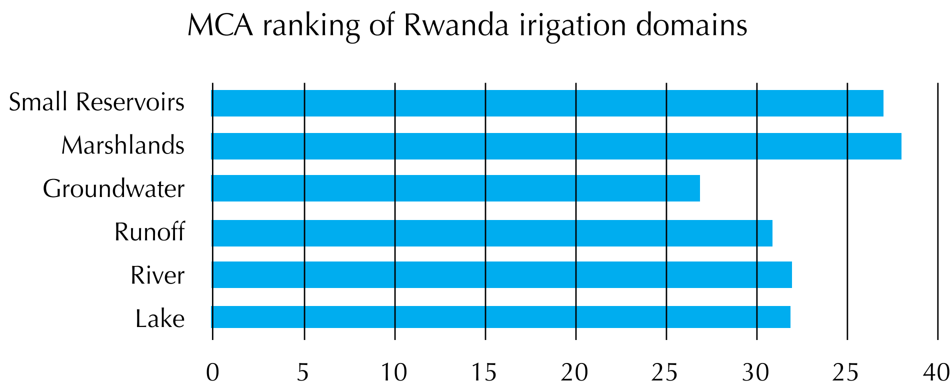


Figure 37: *MCA ranking of Rwanda irrigation domains*

From MCA, marshlands, lake and river domains require only a short time to plan owing to their easily accessible water as long as environmental impact assessments and irrigation scheme designs are conducted prior to use.

It is prudent for the Government of Rwanda to set up an Irrigation Board/Authority to oversee institutional arrangements. This board should coordinate the construction and rehabilitation of major irrigation infrastructure, provide a conducive environment for conducting research, coordinate national irrigation schemes and promote the marketing of crops produced in the irrigation schemes. Finally, the board should formulate and execute policies regarding national irrigation schemes in conjuction with the water resource authority.

9.3 Capacity building, training and technical assistance

Effective implementation of modern irrigated agriculture in Rwanda will require technical capacity in human resources and logistics. Project management personnel will need to understand socioeconomic and environmental issues and their indicators. Even with the existence of policies and laws (such as the Organic Law on Environmental Protection), evidence on the ground indicates significant shortcomings in the abilities of local- and district-level stakeholders to monitor, mitigate and manage irrigation performance. These shortcomings are critical because irrigation projects must be implemented at the community level.

During project planning and implementation, a capacity needs assessment is required to strengthen human resources. Expanding grower organizations into WUAs and empowering them with self-management and monitoring and evaluation (M&E) capability is essential.

The current human resource capacity of irrigation stakeholders in Rwanda is characterised by low technical capacity. Although staff levels appear to be sufficient for the task at hand, competence levels among staff members in the country's existing institutions vary greatly. Frequently, personnel from other departments are assigned duties related to irrigation water management. As a result, there is poor water management in irrigated areas. In many institutions, existing staff have been retained for core activities, leaving little if any human resources to directly oversee irrigation. In some cases, irrigation personnel are present but the level of training and technical capacity on irrigation principles and applications are insufficient.

Training and awareness creation of irrigation project implementation will be undertaken at different levels. These levels will involve the central Government, local authorities, the private sector, NGOs and WUAs. Training exercises will be customised according to each level's needs to ensure adequacy in the implementation of irrigation projects. Training and capacity building of various actors is essential to ensure that the proposed interventions are understood. Training is thus a continuous venture and an integral part of long-term strategic planning.

The technical assistance required in irrigation projects should focus on research and extension. These services address crop production issues with priority areas of irrigation systems, water management and intensified crop production.

9.4 Institutional requirements

Institutional requirements for irrigated agriculture will be divided into WUAs and cooperative societies. Both will create a participatory spirit under which new technologies will be disseminated. They will also provide technical assistance to members, extend credit, facilitate access to inputs and organize collective marketing. In Rwanda, associations of off-farm producers are emerging, and WUAs, organized in irrigation project sites, are becoming increasingly vocal and representative. MINICOM will provide capacity building for elected committee members and officials.

Each irrigation site will be served by at least one technical field advisor, depending on the size of the project and specific cropping requirements. A team of subject-matter specialists will lead and coordinate the work of irrigation site advisors. The latter will liaise with research and link up with the extension network to be established by PASNVA. The advisors will follow a regular field schedule to meet growers in their fields.

Upon establishment of an irrigation project, teams of research and extension specialists will be trained in irrigation, fertilisation and water management. Technology transfer will address the technical needs of irrigation farmers. Diffused technologies and approaches will spread to a second layer of growers engaged in subsistence farming.

Research support will be embodied in a jointly planned on-farm trial programme, and researchers will periodically visit project sites. Extension advisors will work closely with researchers and receive regularly scheduled in-service training from the research team. Technical support units will provide information and assistance to the project advisory team.

An irrigation project will establish an M&E schedule at each level: the WUAs, the cooperative societies and the projects themselves to ensure compliance with project objectives. This M&E system will follow up both qualitative and quantitative impact indicators to continuously monitor and improve project performance.

The Management Committee proposed in the structure depicted in Figure 35 will investigate the institutional linkages with a view to reduce duplication and establish new institutions or strengthen existing ones. This exercise will require medium- to long-term planning.

9.5 Policy and legislative framework

Since Rwanda is a signatory to various international conventions and laws, it is important that national projects are in line with existing institutions, policies and laws. Some of the relevant institutions, policies and laws are reviewed in this section.

9.5.1 Rwanda's institutional framework

Over the past 30 years, donor agencies have developed a strong partnership with MINAGRI, which is responsible for agricultural policy formulation, coordination and monitoring. Other partners include various Government ministries, the Rwanda Development Bank, NGOs and the private sector.

Development partners also work with decentralised authorities to empower local government and sector-level community development committees to implement project activities. Close partnerships are being forged with apex farmer organizations to enable them to become the voice of the rural poor.

MINAGRI faces a number of constraints, including limited human resources, poor information management and inadequate coordination, especially at the decentralised level. Important institutional changes are under way, however, such as the creation of three parastatal agencies to support extension services to farmers and the preparation of coordination mechanisms intended to lead to an agricultural sector-wide approach.

Since 1994, farmers' associations and cooperatives have increasingly provided technical assistance to members, extending credit, facilitating access to inputs and organizing collective marketing. Associations of off-farm producers are emerging, and farmers' organizations, organized in commodity chains, are becoming increasingly vocal and representative. The 2006 National Microfinance Policy is progressive and provides a good basis for sector growth, but institutional capacities and the legal framework for appropriate rural financial services still need development.

National NGOs are widely used as providers of technical support and advice to producers. International NGOs involved in the country's programmes include:

- SNV-Netherlands, which supports local governance and participatory democracy
- German Development Service, which provides M&E
- CARE International, which promotes HIV/AIDS mitigation and, in parallel with Duterimbere, innovative community finance
- The Clinton-Hunter Development Initiative, which promotes international market integration

9.5.2 Rwanda's policy framework

Environmental policy

The overall objective of Rwanda's environmental policy is the improvement of people's well being, the judicious utilisation of natural resources and the protection and rational management of ecosystems for sustainable development. The policy seeks to achieve these goals by integrating environmental aspects into all development policies at the national, provincial and local levels.

Health policy

Rwanda's health sector policy seeks to improve the quality of life and control diseases. The policy identifies the most common illnesses in Rwanda and puts priority on fighting these diseases. Irrigation projects and marshlands have a role to play in malaria prevention. Health policy in these subproject areas should emphasise environmental control of the disease vectors, especially in the marshlands.

Agriculture policy

The main objective of Rwanda's agriculture policy is to intensify and transform subsistence agriculture into market-oriented agriculture, which requires modern inputs, notably improved seeds and fertilizers. The policy emphasises marshland development for increased food production because the soils on hillsides are degraded. The policy promotes small-scale irrigation infrastructure development in selected marshlands while preventing environmental degradation. Rice cultivation is prioritised for import substitution. To achieve sustainable agricultural development, the policy emphasises the need to adopt integrated pest management practices.

Land policy
Rwanda's land policy calls for rational use and sound management of national land resources. The policy provides plans based on the relative suitability of lands and distinguishes various categories of holdings.

The policy promotes irrigating areas for crop production that are more or less flat and semi-arid while discouraging overgrazing and pasture burning. The policy also stipulates that marshlands meant for agriculture should be cultivated after adequate planning and environmental impact assessment.

Organic Land Law 08/2005 determines use and management of land in Rwanda. It states that the government guarantees the right to own and use land. Landowners shall enjoy full rights to exploit their land in accordance with existing laws and regulations. Furthermore, the law defines user safety and guarantees rights on land and plots. It is the state's right to consolidate land by putting together small plots in order to manage the land and use it in an efficient and uniform manner to enhance productivity.

Irrigation policy
There are pertinent policy and legal issues for considerations by the Government in order to set the right environment for implementation of irrigation schemes. Currently no irrigation policy exists in Rwanda. However, there is an immediate need to formulate this policy to foster the adoption of irrigation technology and development. Technocrats will provide guidance or various irrigation disciplines and forward these to parliament for legislation and ratifications. The policy makers need to formulate and implement a national irrigation policy that will:

- develop and support irrigated agriculture;
- coordinate the development and utilisation of water resources for irrigation and other purposes;
- update and implement the Water Resources Master Plan;
- collect, store, analyse and disseminate hydrometeorological, hydrological and other data;
- formulate appropriate water resources legislation;
- undertake studies and investigations to allow the efficient use of Rwanda's water resources;
- resolve issues of competing water demands and other issues of water resource management;
- facilitate the reduction of tariffs for electrical and fuel energy;
- reduce the cost of irrigation equipment; and
- offer tax rebates for those importing irrigation equipment.

The government is responsible for infrastructural development to create an enabling atmosphere, and development partners are encouraged to provide technical support, advise farmers and manage irrigation projects. The government must focus on providing sound national planning, monitoring and evaluation of irrigation development.

While it might be tempting initially to provide financial assistance to this sector, the long-term strategy should be to establish a cost-sharing principle that the water users rather than the government will finance irrigation operation and maintenance.

Policy decisions about irrigation need to be made within the context of broad socioeconomic considerations that will provide extension and research services, environmental protection, adequate health standards and participation of women at all levels.

9.5.3 Rwanda's legislative framework

Rwanda is revising and enacting new institutional, policy and legislative framework in all sectors after having operated under a colonial framework until after the troubles of 1994. Most ministries have already developed their sector policies and strategic plans, most of which are based on the strategy of poverty reduction.

Law on environmental protection and management
The most relevant legislation is the Organic Law on Environmental Protection, Conservation and Management. The legislation sets out the general legal framework for environmental protection and management in Rwanda. MINITERE is responsible for putting in place this law.

Article 67 of the law specifies that the analysis and approval of environmental impact assessment is conducted by the Rwanda Environmental Management Authority (REMA) or any other person given written authorisation. This article specifies that every project/investment must have an environmental impact assessment report before funding.

Law on the use and management of land
The law on the use and management of land determines how land should be used in Rwanda. It also institutes the principles of legal rights concerning land. Chapter II of the law categorises land according to its use.

Article 12 gives the state ownership over land that makes up the public domain, including lakes, rivers, springs and wells. Water throughout the country is reserved for environmental conservation—natural forests, national parks, swamps, public gardens and tourist sites among others.

Article 29 gives the state control over swamps. The law calls for an inventory of all swamps and their boundaries, the structure of the swamps, their use, and how they should be organized. No person can claim to be the owner of swamps by right of eminent domain. Ministerial orders must certify modalities of how swampland shall be managed, organized and exploited. All irrigation projects must accordingly follow the recommendations stipulated under the articles of this law.

9.6 Strategies for intensification of production systems

9.6.1 Economic development and poverty reduction strategy

The government of Rwanda plans to implement the Economic Development and Poverty Reduction Strategy (EDPRS), which includes an agricultural development and investment programme for the 2007–11 period. As defined under EDPRS, the overall agricultural sector goal is to achieve sustainable economic growth and social development leading to the increase and diversification of household incomes and ensuring food supply and food security for the entire population. The specific objectives are:

- Annual growth rates of 7% for agricultural GDP (against a 2001–05 baseline value of 4.2), 8% for agricultural export output (against a 2006 baseline value of 7%) and 6% for food crop production (against a 2006 baseline value of 0%)
- Average real per capita income increase of 8% in agriculture against current trends of 4%
- Twenty percent increase in off-farm employment in all districts compared to 2005–06, particularly for women
- Reduction of the population below minimum food requirements to 16% from 20% in 2006

9.6.2 Strategic Programme for Agricultural Transformation

The Strategic Programme for Agricultural Transformation (SPAT)—Programme Stratégique pour la Transformation de l'Agriculture (PSTA) in French—will serve as the operational framework for the implementation of the EDPRS agricultural investment programme. Its strategic objective is to achieve the targets defined in the larger planning frameworks of the EDPRS and Vision 2020. SPAT focuses on four key programmes:

- Intensification and development of sustainable production systems
- Support to professionalisation of producers
- Promotion of commodity chains and development of agribusiness
- Institutional development

For Rwanda's IMP, the focus is on the intensification and development of sustainable production systems. The projected outcome for this programme is to achieve sustainable and intensified production systems in the cropping and animal resources sectors through combined interventions to improve the management of natural resources, raise the level of competitiveness and diversification of domestic sectors, and achieve greater food security among vulnerable segments of the population.

The activities to be undertaken and the targets to be realised to achieve the above development objectives are organized into six sub-programmes:

- Sustainable soil conservation
- Marshland development
- Irrigation development

- Support for the supply and utilisation of agricultural inputs
- Improvement and diversification of animal production
- Improvement of food access and vulnerability management

9.6.3 Strategy for irrigation development

In irrigation development, the country's target is to increase the share of area under irrigation. In order to achieve this target, there is the need to:

- Develop and promote irrigation systems, including small-scale systems for hillsides and lowlands, as well as water-harvesting systems and other water-collection techniques, plus construct at least 1000 micro-dams to cover around 200 ha annually.
- Promote diverse irrigation technologies, including surface irrigation, pumping and sprinkler irrigation.
- Build about 800 community water-harvesting structures (community ponds) with a capacity of over 300 m3.

9.6.4 Strategy for delivery of agricultural services

The purpose of the Agricultural Services and Training Centre (ASTC) is to coordinate extension, research and training, and to provide services such as inputs and postharvest management. Apart from benefits for the core irrigation projects, ASTC can serve as a base from which to disseminate irrigation and related technologies to satellite farmers outside of the core project.

ASTC can serve functions beyond technology adoption and dissemination. Farmers can use the facilities to set up cooperatives and WUAs, building on experience learned at the core project site. ASTC can also be used as a mechanism for providing credit for inputs.

This can be the framework for:

- Institutional support with MINAGRI services
- Re-organization of rural areas
- Provision of credit for investment in rural areas
- Provision of on-site experience to allow policy makers to develop site-specific strategic plans for agricultural development

9.6.5 Strategy for diffusion of appropriate technologies

To commercialise production through irrigated agriculture, a highly professional group of technical leaders will conduct research on new and site-specific technologies in collaboration with the growers, and then diffuse appropriate technologies to all the growers in the project. Thus, there will be need to recruit and train an extension team to provide advisory support to the growers in each selected pilot site. The team will consist of project-level subject-matter specialists and irrigation advisors.

In the framework of the project, newly recruited advisors and research staff specialised in irrigation and water management will be trained in irrigation and fertilizer application. They will study water management techniques in either regional or international training or in local tailor-made courses. Recruitment of the advisors will ensure a blend of graduates and experienced field staff.

The extension-delivery policy will rely on a wide array of dissemination methods, including regular field visits, pre-season and post-season meetings, field days, mass media (radio programmes, leaflets and published recommendations), slack-season training sessions, demonstration plots and study tours. In this way extension staff will be fully involved in:

- generating technologies through field experimentation and demonstration;
- diffusing technologies through a multitude of delivery methods; and
- adopting technologies through the M&E programme.

9.6.6 Strategy of an Environment and Social Management Framework

The Environment and Social Management Framework (ESMF) is an instrument through which environmental and social impacts are identified, assessed and evaluated. The key objectives of the ESMF are to:

- provide a framework for the integration of social and environmental aspects at all stages of project planning, design, execution and operation of various sub-components; and
- ensure positive social and environmental impacts of sub-projects and minimise and manage any potential adverse environmental and social impacts.

The ESMF spells out the potential impacts in a project due to the planning, design, implementation and operation and outlines the required management measures. Appropriate institutional arrangements towards implementing the measures proposed and the capacity building efforts required must be provided in the framework. The adoption of the ESMF will ensure that the projects meet environmental and social requirements at all levels and are also consistent with the applicable policies and provisions of development partners like the World Bank. The ESMF will be applied at all stages of a project including project identification, screening, prioritization, preparation, implementation and monitoring.

Application of the ESMF to projects enables preparation of a standardised environmental and social assessment documents for appraisal and implementation.

In any chosen alternative for the management of irrigated agricultural projects in Rwanda, the subject of environmental protection should be a central consideration. Environmental management will entail the following mechanisms.

- Training and on-the-ground guidance (i.e. extension service) of the farmers to ensure the assimilation of advanced working methods, the tools and techniques for soil conservation and erosion prevention, irrigation planning, appropriate application of fertilizer application and herbicide and pest control
- Supervision and regulation regarding herbicide and fertilizer use, water quotas and prevention of secondary pollution caused by agricultural development (residues of fuels and oils, residues of packaging materials, etc.)
- Regular monitoring of water and soil quality and of biodiversity in ecological habitats and nature reserves

- Planning: each irrigation project should be examined as part of the whole watershed in which it is planned—issues such as soil conservation, water quality and consumption, and sewage treatment must be taken into account in relation to the overall area of the watershed

Because of Rwanda's topographic conditions, environmental values and risks, it is appropriate, at least in the early stages, to develop pilot projects whose outcomes can provide feedback on benefits and potential environmental damage.

9.7 Sustainability of irrigated agriculture in Rwanda

9.7.1 Purpose of sustainable irrigation

The purpose of sustainable irrigation in Rwanda is to sustain both the water supply and the environment. Water supply encompasses both the availability of water and the infrastructure to sustain water supply and use. The environment takes into account the water source and the land and air systems that support human production activities. As water demands for irrigation use change over time because of policy and technological changes, the relationship between water use and the environment needs to be continually reviewed and adopted. Sustainable water management should ensure a long-term, stable, and flexible water supply to meet crop water demands while simultaneously mitigating or preventing negative environmental impacts due to irrigation.

A guiding rule for sustainable irrigation water management is to minimise the interference of the irrigation system with the associated environmental system, including the effects on the water bodies that receive irrigation water through wind-drift, surface runoff or drainage to groundwater. In addition, to sustain irrigation profit over the long term, irrigation water management must meet legislative requirements with respect to the environment.

Table 37 summarises the indicators of an environmentally sustainable irrigation project.

Table 37: *Indicators of an environmentally sustainable irrigation project*

Policy	National	Regional	Local
Existence of rules and regulations for protecting water quality	√	--	--
Existence of rules and regulations for environmental protection	√	--	--
Existence of an educational mechanism aimed at providing guidance for irrigation methods, fertilization and pest-control implementation	√	√	√
Existence of an inspection and enforcement mechanism	√	√	--
Existence of a mechanism for determining water quota for irrigation without risking other uses and needs (human use, aquatic habitats, etc.)	√	√	--
System and operation management			
Existence of a monitoring mechanism for downstream water volumes and quality in watersheds containing irrigation projects	√	√	--
Existence of a mechanism for water level and quality monitoring in aquifers and lakes	√	√	--
Regular visual monitoring of runoff from agricultural fields and sedimentation in ditches	--	--	√
Random sampling of fertilizer and herbicide residuals in irrigation ditches and streams adjacent to irrigated areas	--	√	--

9.7.2 Participatory irrigation management

Participatory irrigation management (PIM) is where farmer organizations take over O&M and irrigation management transfer (IMT) where responsibility is transferred from government entities to NGOs. PIM is defined as farmers' participation in irrigation and drainage systems, such as planning, operation, management and investment in main, secondary or farm-level irrigation canals. In contrast, IMT may involve transfer of all or partial management responsibilities of subsystem levels or for entire systems.

In Rwanda, PIM will be promoted for improved irrigation service delivery. Participation of farmers is essential for sustainability and effective transfer of management from government to WUAs. PIM as a management strategy to meet development objectives lies in the balanced pursuit of participation and user management control. Transfer of management to WUAs is the general approach for PIM with government's ownership of the facility. The state will manage the headworks and main canals, while legally recognised WUAs will employ their own technical staff for the management of the secondary and tertiary levels of the canal networks.

The PIM approach should match the local capacity level and cultural background. Clear authority must be given to the management entity based on sociocultural context of the population in the targeted area to strengthen the sense of ownership. A supportive environment for private participation through regulation also needs to be in place. WUAs must be given the right to manage water charge collection and to collect penalties from non-payers. Prior consent from farmers is essential and support from village leaders is the key to successful PIM.

9.7.3 Financial sustainability and return to investments in irrigation

Good leadership and political will are fundamental to motivating irrigation farming. Parliament must pass a law that supports the tenets expounded in the IMP—tenets that should ultimately become ingrained and protected in national development plans. These plans should have budget estimates that can be used for disbursements and monitoring. These estimates, presented using financial and economic tools such as cost -benefit ratio and net present value, are important for responsible financial management as depicted in the Table 38 and Table 39.

An Irrigation Development Trust Fund (IDTF) should also be established for use in soliciting capital investment in irrigation-related projects. Capital should be made available to the smallholder farmers, outgrower farmers, large-scale commercial/ private farmers, manufacturers and WUAs. The small-scale and outgrower farmers would be able to use these funds to source equipment such as treadle pumps, rope-and-washer pumps and low pressure irrigation kits. Large-scale/private farmers can use these funds to source centre pivots systems, drip schemes and fixed assets such as dams, pump/farm housing, irrigation machinery and farm inputs. Except for recurrent expenditures, establishment of the IDTF, solicitation of capital infrastructure and procurement of fixed assets are short- to medium-term ventures.

Table 38: *Budget 2010–2020*

Strategy	Year											Budget (% in USD)
	10	11	12	13	14	15	16	17	18	19	20	
Development of IDTF												73
Infrastructure development												10
Training & capacity building												12
Strengthening research capacity												1
Institutional arrangements												2
Market study and development												2
Grand total												**100**

Short-term Medium-term Long-term

Table 39: *Cost-benefit analysis*

Variable	USD million											Total
	10	11	12	13	14	15	16	17	18	19	20	
Total cost												
Total benefits												
Net benefits												
Cost-benefit ratio												

Irrigation projects should address financial sustainability. This will be achieved by ensuring that:

- the user charge should cover the operation and maintenance costs;
- O&M costs are clearly defined; and
- irrigation service charges are collected and used transparently.

At the same time, to lessen a financial burden on smallholder farmers, monetary support should be considered through the provision of government subsidies. IMT can improve the problem of small service charges and low collection rates, as an increase in water charges is the marked outcome of management transfer. However, even with the improved collection rate and the higher charges, O&M costs may not be fully covered. Therefore, financial support, even if it is substantially lower after IMT, or cost-sharing arrangements between the government and the association, will be needed for sustainable irrigation services. In estimating the ability to pay and to set the fee levels, a balance between sustainability and affordability of the poor needs will be well managed. It is crucial to include a sustainable O&M plan in the project design with farmer participation. Transparent fiscal management should be in place to ensure accountability and sustainability.

9.7.4 Monitoring the quality of irrigation water

Water quality is a key factor in irrigated agriculture. Therefore it is important to monitor quality standards on a frequent basis to avoid potential problems.

Often farmers are unfamiliar with the many determinations that are made on a routine water test. This also makes interpretation of the results somewhat difficult. The following is a brief summary of these quality factors, as well as guidelines which may be used to determine their effect on plant growth.

- Electrical conductivity (EC) is a measure of the total salt content of water based on the flow of electrical current through the sample. The higher the salt content, the greater the flow of electrical current. EC is measured in mmho cm^{-1}, which is the opposite of ohms of electrical resistance. Since the conductivity of most water is very low, EC is generally reported in thousandths of an mmho or millimhos cc^{-1}.
- Carbonate + bicarbonate (CO_3+ HCO_3) are actually salts of carbonic acid (the acid formed when carbon dioxide dissolves in water). When in combination with calcium and/or magnesium ($CaCO_3$, $MgCO_3$) there is an alkalizing effect. This is generally mild because they are slightly soluble salts of moderately strong bases and weak acids. A stronger alkalizing effect may occur in the presence of sodium (Na_2CO_3) because this is a highly soluble salt of a strong base and weak acid. Carbonates and bicarbonates are reported in milli-equivalents per litre.
- Calcium and magnesium (Ca, Mg) are cations (positively charged ions) which are present in water. In most cases the sum of Ca and Mg are reported in milli-equivalents per litre. Together Ca + Mg may be used to establish the relationship to total salinity and to estimate the sodium hazard.
- Sodium (Na) is another cation occurring in most irrigation water. Along with Ca and Mg, Na is present in total amounts usually exceeding 0.1%. Sodium is often responsible for alkalinity problems when linked to chloride (Cl) and sulfide (SO_4) but seldom from Ca or Mg.
- Chloride (Cl) is an anion (negatively charged ion) frequently occurring in irrigation water. Cl determinations are used to establish the relationship to total acidity as well as to indicate possible toxicities to sensitive crops.
- pH: acids, when mixed with water, ionize into hydrogen ions (H+) and associated anions. The stronger the acid, the greater the amount of ionization. Weak acids (such as those in irrigation water) generally ionize to less than 1.0%. The H+ ion activity of these acids is stated in terms of the logarithm of the reciprocal of H+ ion activity or pH.

The quality of irrigation water is dependent on total salt content, the nature of salts present in solution and the proportion of Na to Ca, Mg, bicarbonates and other cations. Table 40 presents guidelines on the interpretation of the water quality factors. Table 40 lists the water quality parameters and their critical levels, which must be utilised in water quality monitoring.

Table 40: *Water quality standards for irrigated agriculture*

Quality	EC X 10^{-3}	Total soluble salts (ppm)	Na content (%)	SAR	pH
Excellent	0.25	175	20	3	6.5
Good	0.25–0.75	175–525	20–40	5 Mar	6.5–6.8
Permissible	0.75–2.0	525–1400	40–60	10 May	6.8–7.0
Doubtful	2.0–3.0	1400–2100	60–80	15 Oct	7.0–8.0
Unsuitable	> 3.0	> 2100	> 80	> 15	> 8.0

For approximate conversion of EC to parts per million (ppm) use the following calculations: millimhos ppm = (EC x 10^{-3}) x 670; micromhos ppm = (EC x 10^{-6}) x 0.67.

Table 41: *List of irrigation water quality parameters*

Parameter	Unit	Max value
General salinity – electrical conductivity (EC)	ds m^{-1}	1.4
Biochemical oxygen demand (BOD)	mg L^{-1}	10
Total suspended solids (TSS)	mg L^{-1}	10
Chemical oxygen demand (COD)	mg L^{-1}	100
Ammonia (NH4)	mg L^{-1}	20
Total nitrogen (N)	mg L^{-1}	25
Phosphorous (P)	mg L^{-1}	5
Chlorides (Cl)	mg L^{-1}	250
Sodium (Na)	mg L^{-1}	150
Fecal coliform (FC)	FC counts 100 mL^{-1}	1000
Dissolved oxygen (DO)	mg L^{-1}	0.5
Sodicity (SAR)	Mmol L^{-1}	5
Boron (B)	mg L^{-1}	0.4

9.8 Social dimensions of irrigated agriculture in Rwanda

9.8.1 Significance of social dimensions in Rwanda

In Rwanda, it is important to consider the central role of local people in irrigation development and to recognise that an irrigation project could produce effects detrimental to the welfare of the very people it intends to benefit. Thus, it is essential that the environmental assessment of a proposed irrigation project include an analysis of the project's social dimensions.

Most development partners are increasingly aware of the critical role of environmental and social aspects in the design and implementation interventions for sustainable irrigation development. This awareness has increased the importance of beneficiary participation, poverty reduction, the role of women in development and environmental management, involuntary resettlement and vulnerable groups such as children and local people. This concern for the social aspects of development is articulated in government and development partner policies, reflected in strategic frameworks, and incorporated through various multilateral agency guidelines, manuals and handbooks, not to mention instructions to project management staff.

Development partners' environmental review process, in fact, specifically mentions the need for social analysis and public participation. Environmental assessment reports and summaries must include:

- a social acceptability assessment of the proposed project; and
- recommended mitigation measures such as a resettlement plan and an indigenous people's planning framework, as necessary.

9.8.2 Social dimensions and associated processes

Issues of concern

The concept of social dimensions captures the key elements of human perspectives in development and aims at avoiding or mitigating the adverse effects of development interventions on groups that do not have the capacity to absorb such effects. The concept begins with the explicit recognition that people are the centre of development, and that development is for all people. It recognises that economic growth is a prerequisite for development in general and social development in particular. Furthermore, it recognises that:

- the poor, women, and vulnerable groups contribute to economic growth;
- their empowerment enhances social harmony, which is essential to economic growth; and
- returns from investments in women and the poor are often comparable to and may exceed returns from investments in infrastructure, energy, industry and agriculture.

Four key social dimensions are considered in environmental and social impact assessment operations.

1. Poverty reduction involves helping the poor through: (a) assistance directly targeted at supporting productive activities that generate employment and income; (b) identification of development policies and investments that expand employment opportunities for the poor; and (c) improvement of the access of the poor to health, family planning, education and related services, and expansion of these services.
2. Gender and development consist of promoting policies and activities that help all people develop their full potential, improve their productivity, increase their contribution to the economy and share in the rewards of development as equal partners.

3. Human resources development, including population planning, involves investments to help improve the skills, living standards, and quality of all people, and increases their contribution towards sustained and accelerated economic growth.
4. Vulnerable groups include children and women, ethnic minorities, illegal settlers and squatters, disabled people and immigrants. Conditions for these people may be made worse by policy reform, a new programme, or some form of project intervention. Social safety nets and compensation mechanisms must therefore be provided so that they are not adversely affected by such changes.

Although analysis of social factors that influence a project will continue throughout the entire life of a project, the most crucial stage occurs during project design or the conduct of the project feasibility study when all relevant social dimensions of the proposed project are examined thoroughly and incorporated into the project's design. The analysis conducted as part of the feasibility study is called social analysis, and may cover an assessment of:

- the groups expected to benefit and use the services provided by the project,
- the needs of the groups,
- their demands,
- their absorptive capacity,
- gender issues, and
- possible adverse effects on vulnerable groups and the need for measures to mitigate or compensate those adversely affected.

As the scope and content of social analysis differ among and within sectors, it is necessary to conduct an initial social impact analysis (ISIA) during the project identification stage. The ISIA will identify the major population groups that may be affected, beneficially and otherwise, by the proposed project. It will also identify the specific social dimension issues examined during the social analysis conducted as part of project preparation. A general description of the objectives, scope and methodology for ISIA should be developed by various partner institutions. In addition, development partners and donor agencies have policies and norms of good practice that relate to issues such as gender, involuntary resettlement, indigenous peoples, participatory processes and involvement of NGOs.

In line with donor policy on indigenous peoples, the ISIA conducted as part of project design should include specific considerations of indigenous peoples as a potentially affected population. If the ISIA identifies indigenous peoples specifically as a significantly and adversely affected population, or vulnerable to being so affected, an indigenous people's planning framework (IPPF) acceptable to the donor must be prepared by the government or other project sponsors. The framework should include key elements such as specific measures to mitigate negative effects and provide necessary and appropriate assistance and compensation so that the circumstances of the affected peoples will be at least as favourable as would have existed before the intervention.

The IPPF should be prepared and submitted to the development partner/donor by the Government or private sector project sponsor along with the feasibility study for the project. The IPPF should include an Executive Summary, with salient issues of the summary to be included in the report and recommendations to be considered in the management review meeting, and, in every case, in the final report and recommendations for consideration.

If necessary, pertinent sections of the IPPF should be included in the environmental and social impact assessment report to complete the description of the physical environment, the potential impacts of the project, and the negative impacts to mitigate, offset, or compensate for, adverse impacts. The IPPF will also confirm the social acceptability of the proposed project, as the Framework could not have been prepared without prior consultations with, and involvement of, the affected indigenous peoples.

9.8.3 Gender analysis in irrigation development

Role of gender in irrigation projects

Because women are major contributors of labour for both cash and food crop production, their participation in the design and implementation of irrigation development projects is essential to the achievement of development objectives at the community level. It is therefore important that women's needs and concerns are determined and assessed as part of irrigation project design. For instance, user-friendly and affordable technologies will have to be identified to encourage their participation and boost the livelihoods of the poor.

In all irrigation development projects, gender considerations must be addressed as part of the social analysis process. If the ISIA identifies significant gender issues, these will be examined further through detailed gender analysis. The results of the ISIA and subsequent social analysis will form part of the project feasibility study, and relevant sections of the social analysis report will be incorporated into the environmental and social assessment report for the irrigation project.

Gender analysis is a framework for considering the impact of an irrigation development intervention on both women and men. Gender analysis explores who does what, where, when, and for what time period. It assesses the differences in social roles between females and males and the constraints faced by females in gaining access to, and participating in, development activities. It evaluates the implications of such constraints in the design of development strategies, policies, interventions, and projects so that unequal access and opportunities between females and males can be avoided. A gender analysis framework is a flexible instrument with the ultimate purpose of assisting in the design and implementation of irrigation projects that maximise the productivity and participation of both men and women, and that includes appropriate implementation arrangements for strategies, policies and interventions.

Gender issues in Rwandan agriculture

One result of the 1994 genocide is that nearly 38% of households are currently headed by single women with others being headed by children. Small holdings dominate, with farms averaging 0.75 ha. Each farm comprises 5 to 6 members, half of them below 15 years of age. Irrigation means intensification since irrigated fields require more preparation, more investment in infrastructure, more water, more input and more labour than before to ensure a significantly greater benefit. Technology choices to be made in irrigation schemes should take these issues into consideration. They should not exclude women, children or people affected by HIV/AIDS. The method of water lifting technology, for example, should not require too much labour.

Decisions related to crop production (crop selection, plot size, rotation) are taken by both genders. However, men tend to decide about the inputs to be purchased, the labour to be hired and quantities to be sold. Women make decisions related to deployment of household labour and marketing for food crops, not for cash crops. Overall, in Rwanda there is a high level of participation by women in agricultural decisions, but women have only have limited control of the production system.

1. *Land tenure*. Irrigated land is commonly owned and inherited, mainly passed down matrilineally. This pattern follows that of the swamp rice cultivation traditionally undertaken by women. Horticultural gardens are generally considered to be part of the female domain. Vegetables are grown exclusively by women.
2. *Income.* Income from rice is generally low because a high proportion of the crop is retained to meet the needs of the family. Marketing is often undertaken only to obtain cash for specific debts. Women do not necessarily control the benefits in proportion to the work they contribute.
3. *Water control.* Responsibility for water application to the fields is taken equally by both genders within formal land and water management committees. The majority of active rice growers are female, but water control is mainly managed by men. Women claim that they work much harder than men as a result of the introduction of vegetable gardens and improved rice schemes.

9.8.4 Attitudinal changes in irrigated agriculture

Adoption of a new technology, such as irrigation, is a complex phenomenon. Farmers' attitudes toward irrigation differ enormously between projects and can differ substantially even within a project area. Several socioeconomic factors contribute to the farm-level decisions affecting adoption.

The introduction of irrigation into areas with a traditional pattern of agriculture necessitates social changes that are sometimes unacceptable to the local community. For example, where women are generally responsible for cultivating fields, the introduction of controlled water irrigation requires men to become familiar with the new technology of pumps and mechanization. Negative perceptions with respect to culture, the economics of irrigation and impacts on environmental quality, particularly through soil salinity, may be significant deterrents for adoption of irrigation. Planning for large-scale irrigation must be cognizant of attitudes of potential adopters.

Additionally, during the planning stages, more attention should be paid to the development of proper educational programmes, as well as extension packages, to ensure that potential adopters formulate correct attitudes towards the new technology.

9.8.5 Socioeconomic concerns in irrigated agriculture

For irrigation projects to succeed, several factors must be taken into consideration. Among these are capacity development and institutional strengthening in support of farmer organizations, the provision of extension and training to farmers on various sustainable practices, support for marketing and financing and provision of institutional strengthening to government institutions such as MINAGRI for improving their long-term capacity for hillside intensification, sustainable land management and the associated environmental, social due diligence, food security, family income and national wealth creation. Irrigation schemes, however well-intended, often have both positive and negative impacts on people. The type of technology used for irrigation, the level of institutional capacity and the type of irrigation scheme management (local, government or joint leadership) will determine the success or failure of irrigation schemes. Local communities need to take ownership of projects being introduced to their areas to ensure sustainability.

Other factors that may affect the success of the schemes include water reliability, cropping patterns, food preferences, attitudes towards irrigation, access to market and pricing systems, reliability of physical infrastructure and source of capital investments. For example, irrigation schemes should consider using equipment that is user-friendly, locally available and that can be easily maintained and repaired. When equipment is imported, spare parts should be made available to local outlets and adequate personnel trained on how to repair them.

The government has a critical role to play in ensuring that irrigation projects are instrumental in improving food security and alleviating poverty. It should develop policies and regulations that influence irrigation equipment manufacture, importation, promotion and servicing. Lower-priced imports and joint manufacturing arrangements can ensure use of cost-effective and advanced irrigation technologies.

The government should also develop policies and mechanisms to facilitate equitable access to credit by smallholder farmers while playing a direct role in extension service training and provision of other technical support services. The government can also assist agricultural universities in strengthening their programmes on irrigation through short courses, research and innovation grants, and also assist in testing and demonstrating equipment at universities and demonstration centres. Capacity building is also crucial to avoid unscrupulous exploitation of farmers.

Another important role for the government is to take a lead role in mobilising real-time information on markets and to facilitate the creation of farmer networks for the dissemination and utilisation of such information. The importance of this function in creating markets for agricultural products cannot be overstressed.

9.9 Desirable elements of modern irrigated agriculture

- A strong central organization, supported by a comprehensive water laws, empowered to plan and design efficient irrigation systems, allocate water use and impose sanctions.
- Planning, where feasible, of grids for water distribution and joint operation of both surface water supplies and groundwater resources.
- For individual irrigation projects, well-founded decisions on the design of conveyance and distribution systems taking into account the on-farm irrigation technologies to be promoted.
- Decisions should be based on the long-term water supply and demand projections in the project area, as well as market prospects for crops.
- Implementing, with the irrigation infrastructure, a comprehensive social and economic development plan for rural areas that promotes the general wellbeing of the population.
- Implementing a strong research programme to develop or adapt on-farm technologies and practices for local conditions.
- A programme for testing, demonstrating, and disseminating recommended technologies.
- A strong irrigation extension service (irrigation advisory service) to advise farmers on irrigation technologies, technologies, practices, and scheduling.
- A strong agronomy programme to assist the irrigation extension service in determining optimal crop water requirements and developing recommendations for new cash crops.
- A programme to train irrigation engineers, technicians, government workers, and water users associations.
- An appropriate system of demand management consisting of water metreing, water pricing, and possibly water allocations based on carefully researched crop water norms. A system of graduated water prices may be adopted so that the excess use of water is heavily penalized.
- Strong private sector involvement in manufacturing irrigation equipment and possibly provision of irrigation water.
- Extension services to the farmers (to be initially supported by the government if necessary).
- Quality control of irrigation equipment through standardization and issuance of quality marks for locally manufactured products.
- Access to agricultural credit so that farmers can purchase modern irrigation equipment. This may have to be subsidized initially, or may contain a grant element to provide sufficient initiative.
- The promotion of water user associations, especially where the supply of water in bulk would be possible.

Chapter 10

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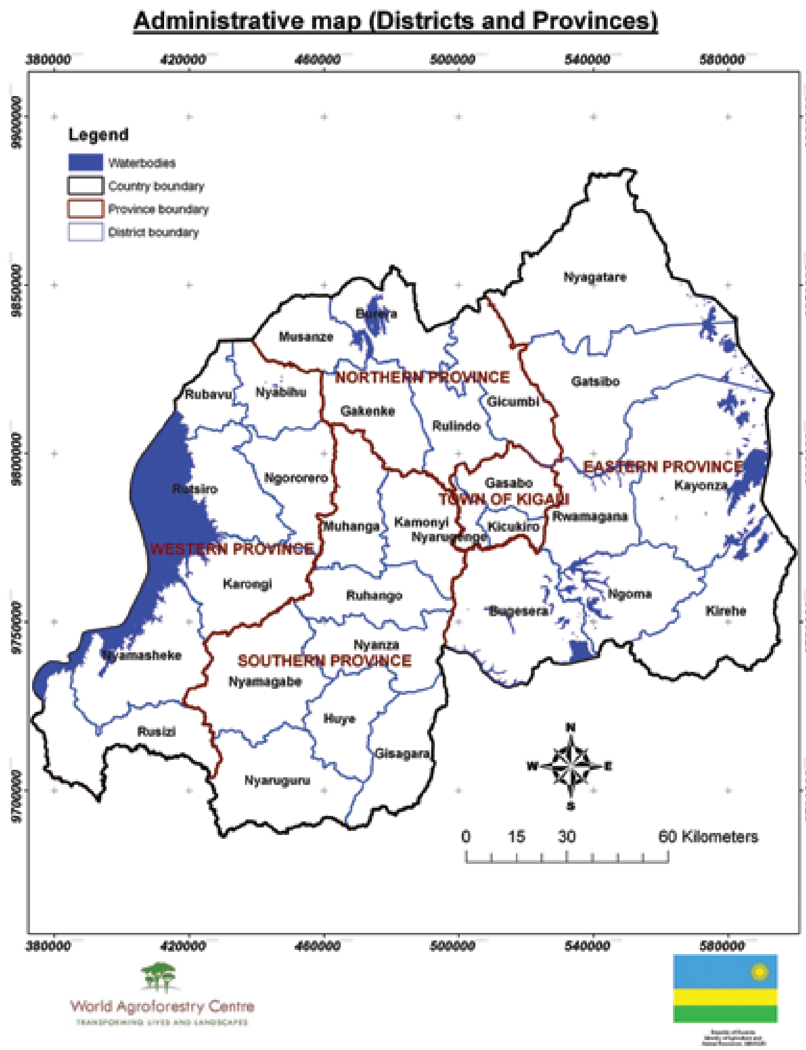
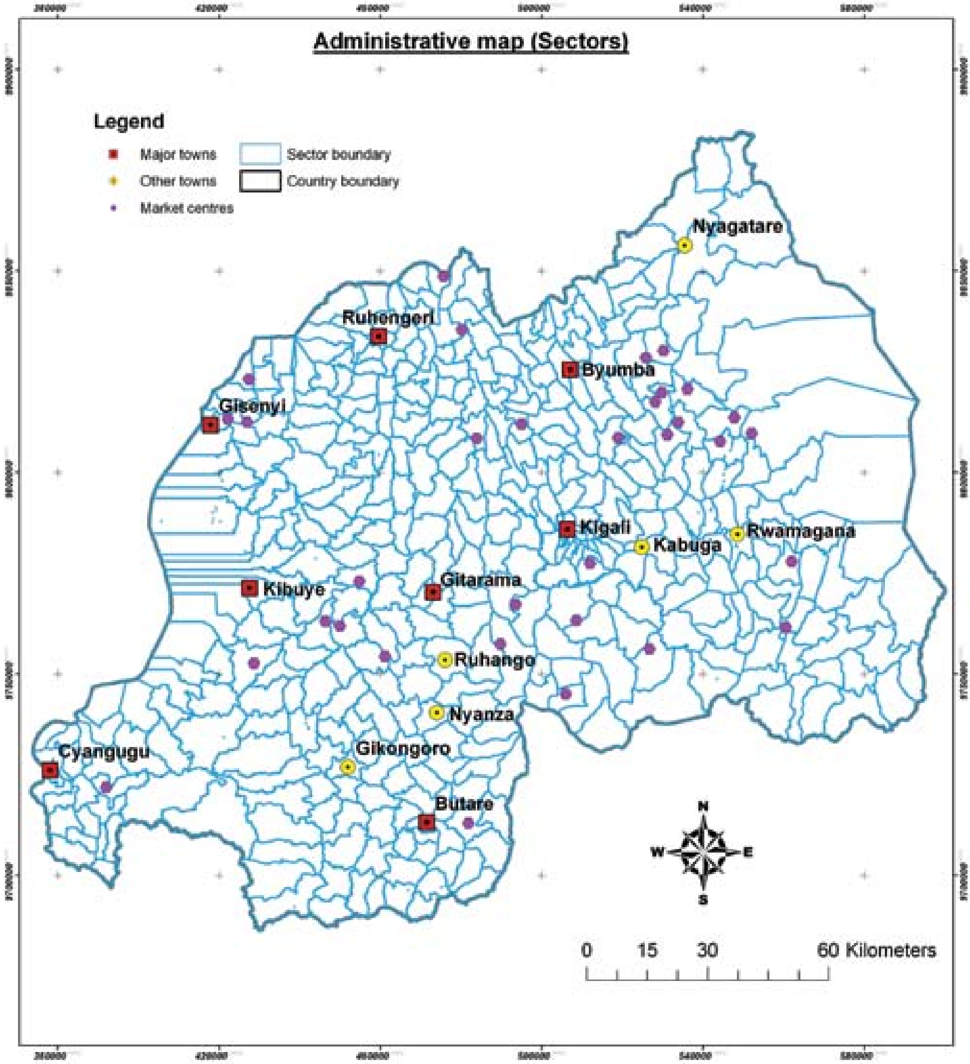
Appendixes

Appendix 1: Administrative and infrastructural maps

Appendix 1a: Administrative map (provinces and districts)



Appendix 1b: Administrative map (districts and sectors)



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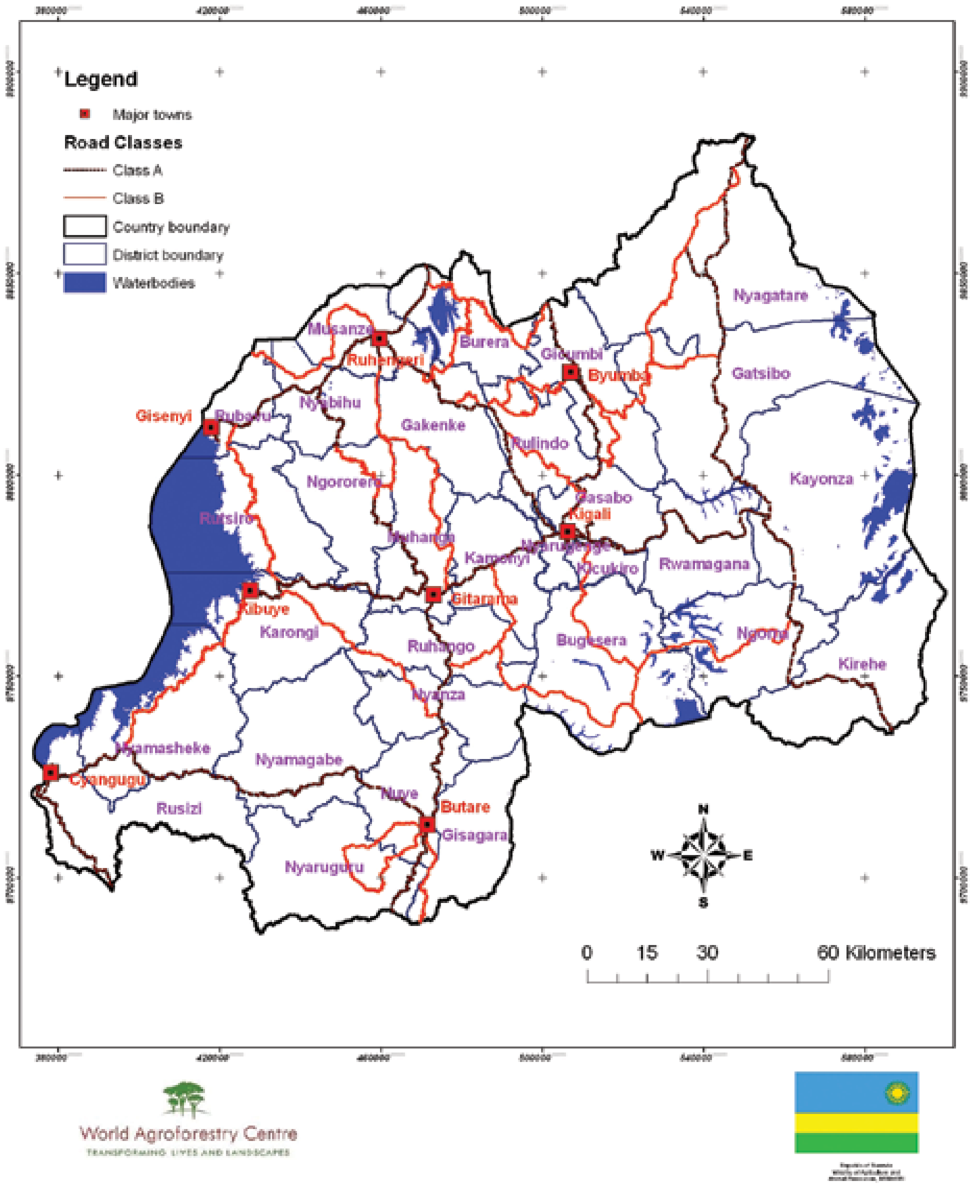
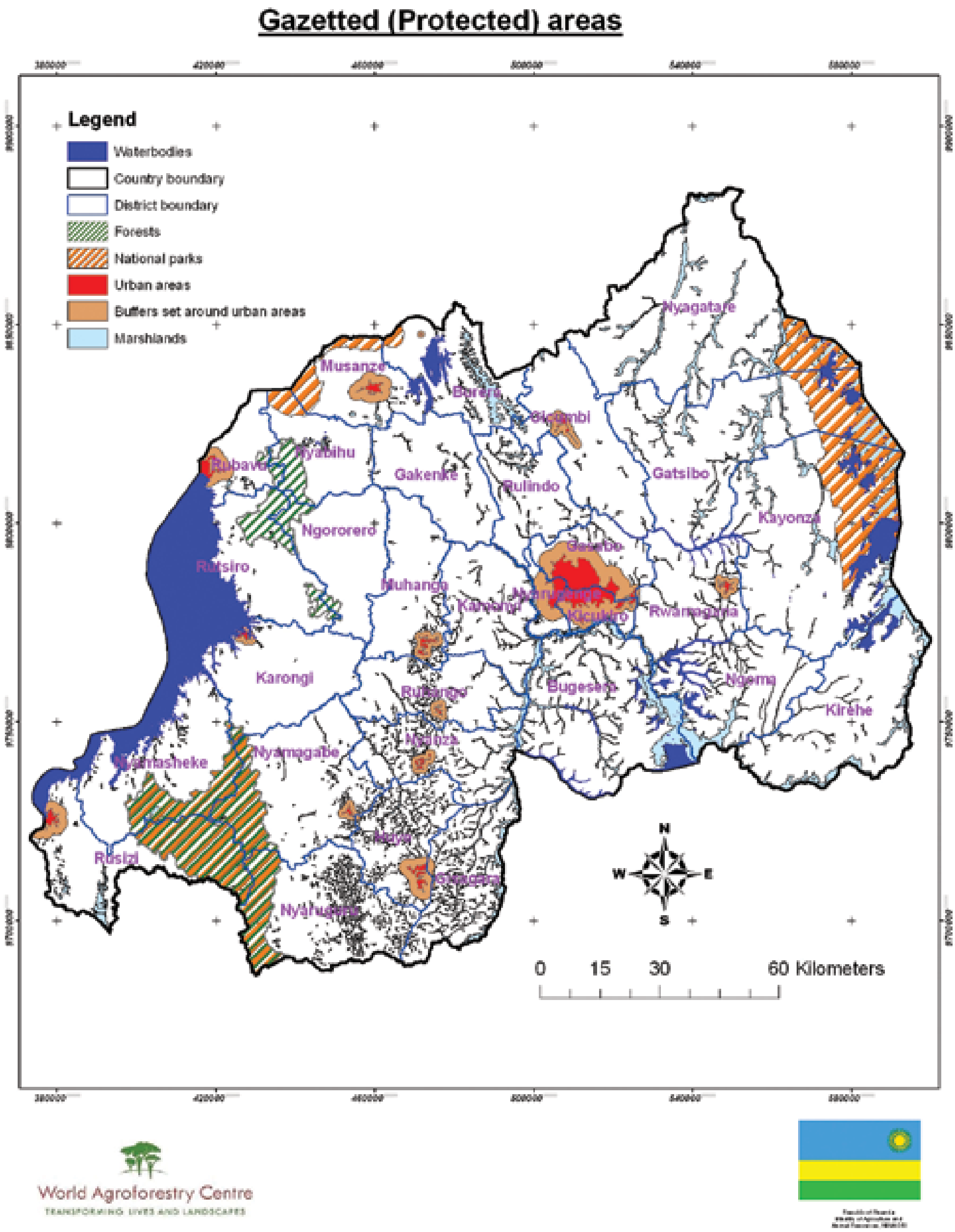
Appendix 1c: Major roads and towns

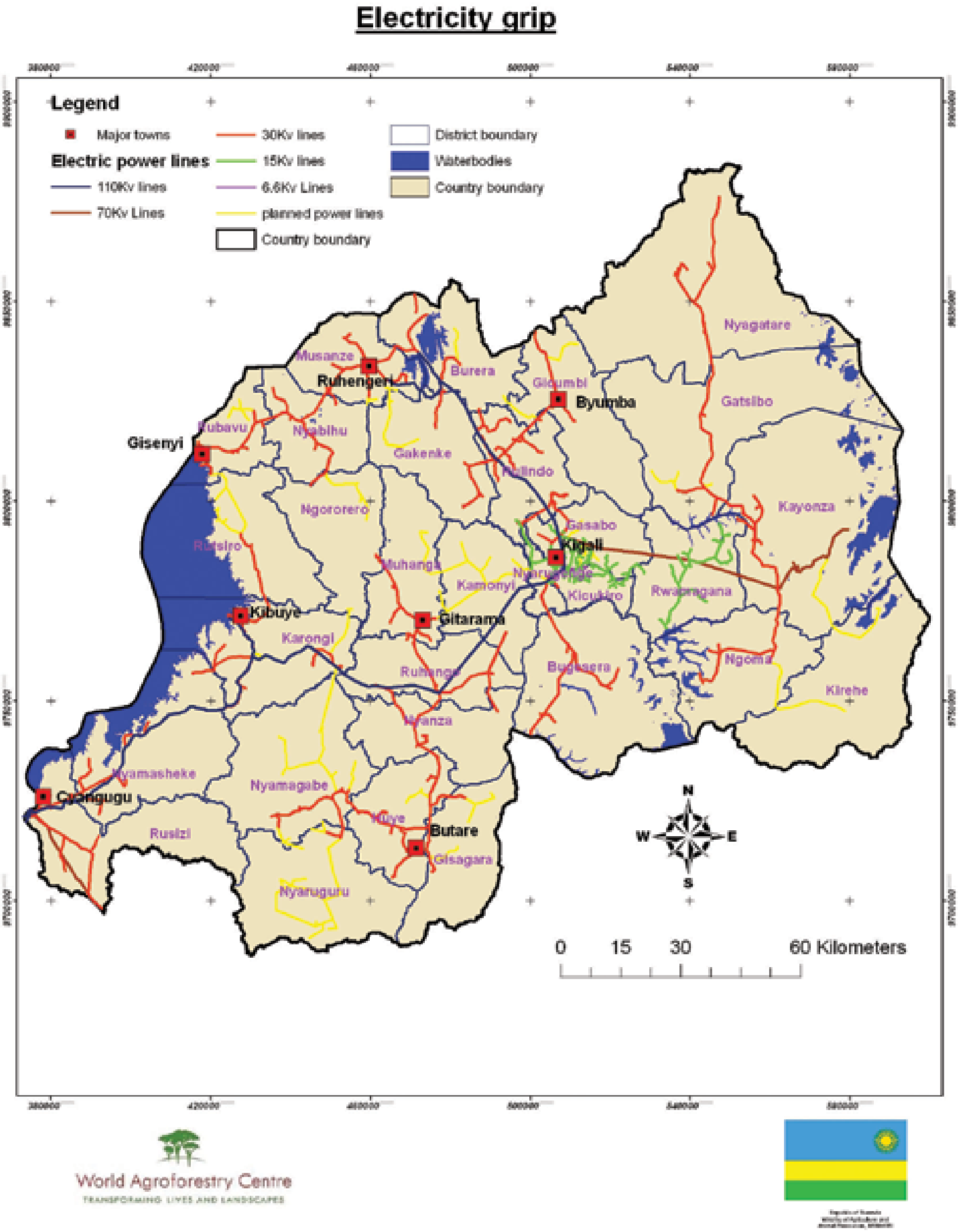
Road network



Appendix 1d: Gazetted (protected) areas (source MINAGRI & ICRAF)

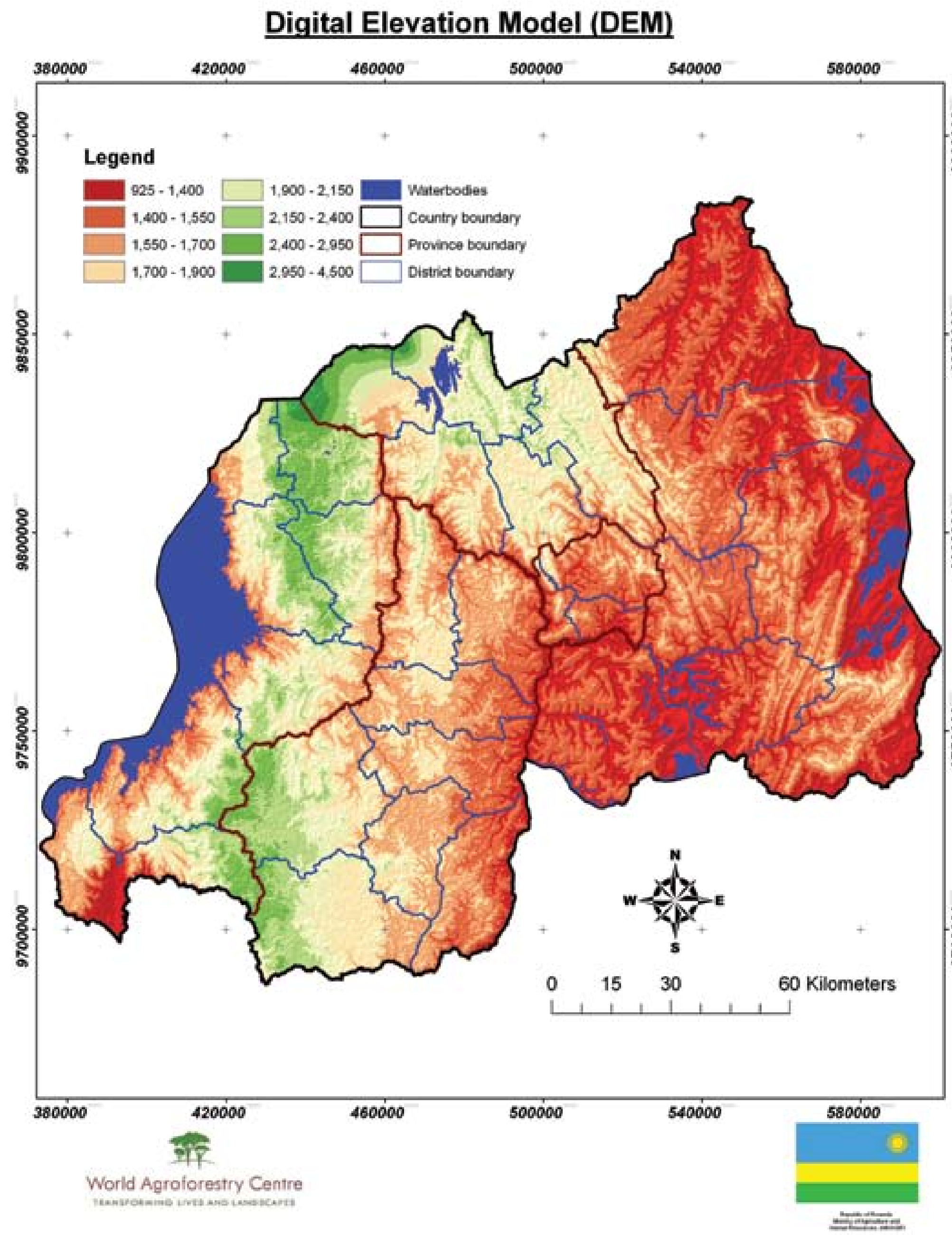


Appendix 1e: Electricity grid (source MININFRA)

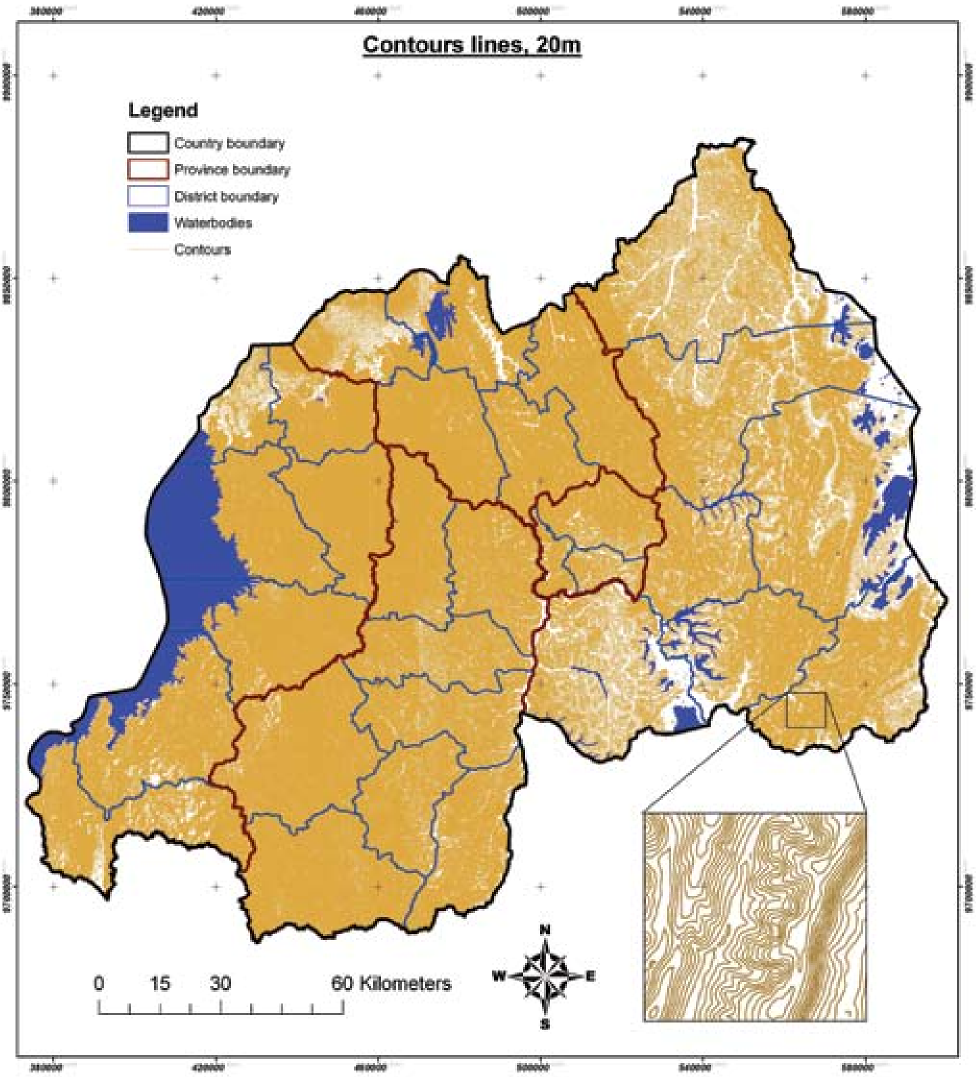


Appendix 2: DEM geoscience maps

Appendix 2a: Digital elevation model (DEM), 20 m resolution



Appendix 2b: Contour lines, 20 m



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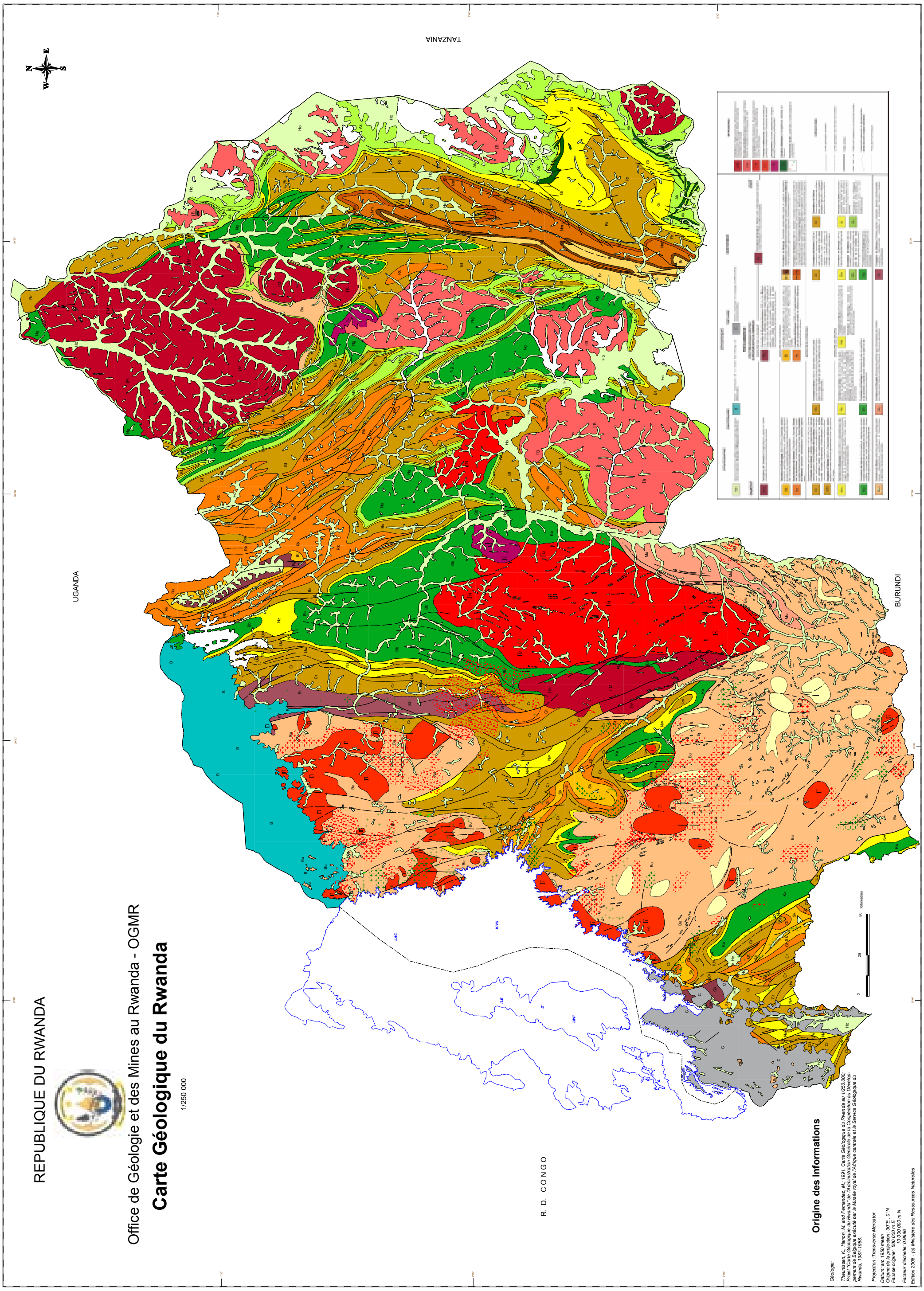
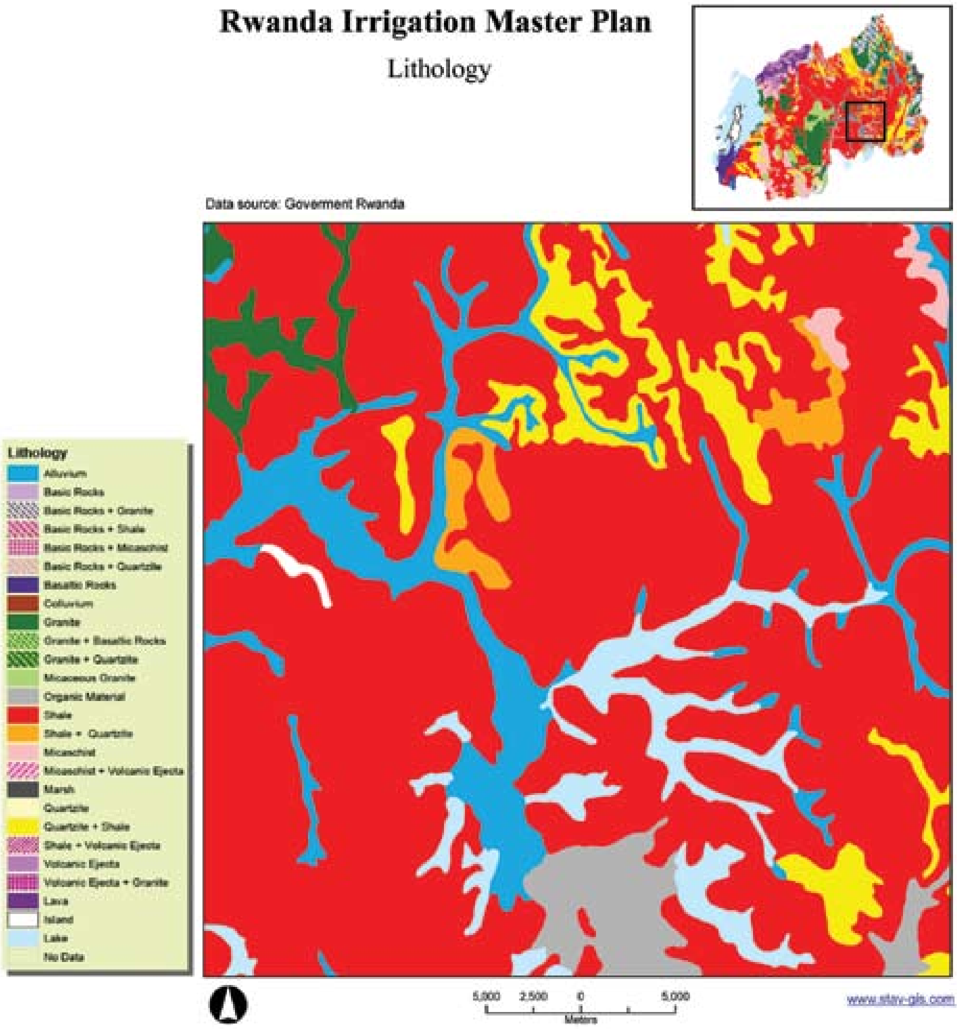
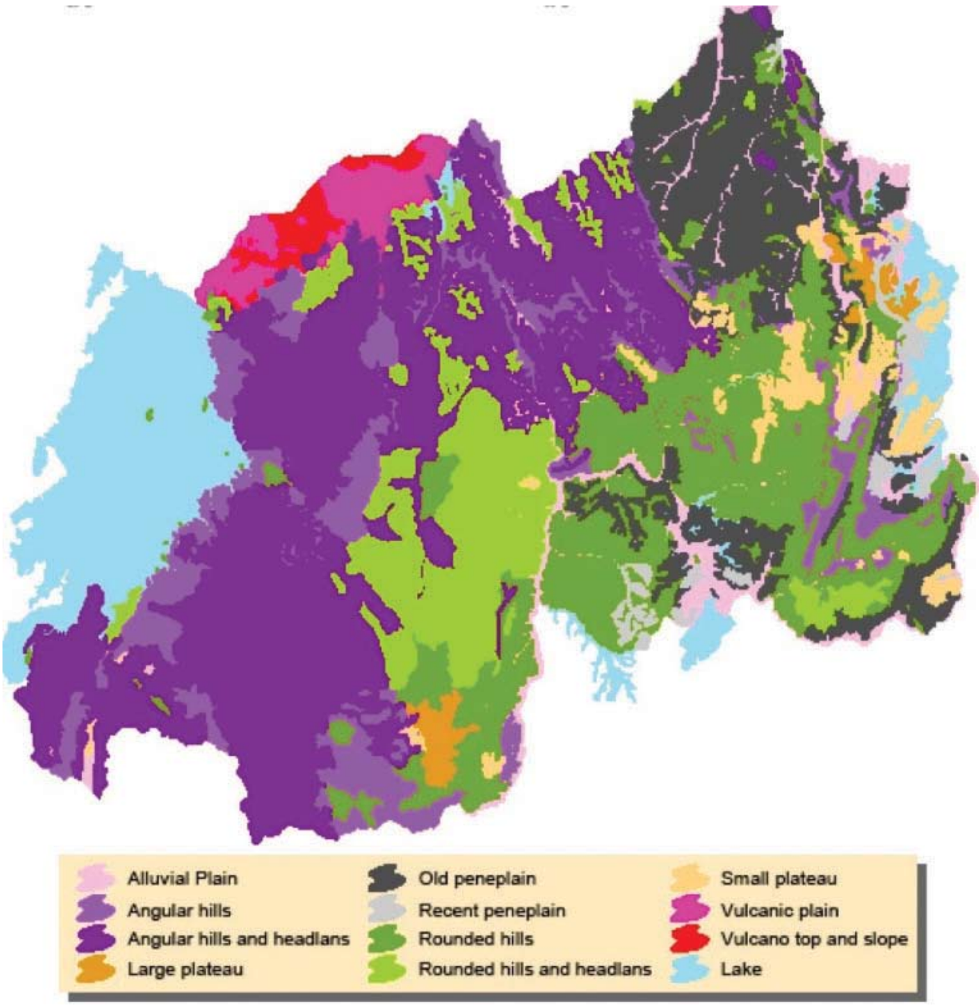
Appendix 2c: Geological map (source OGMR)



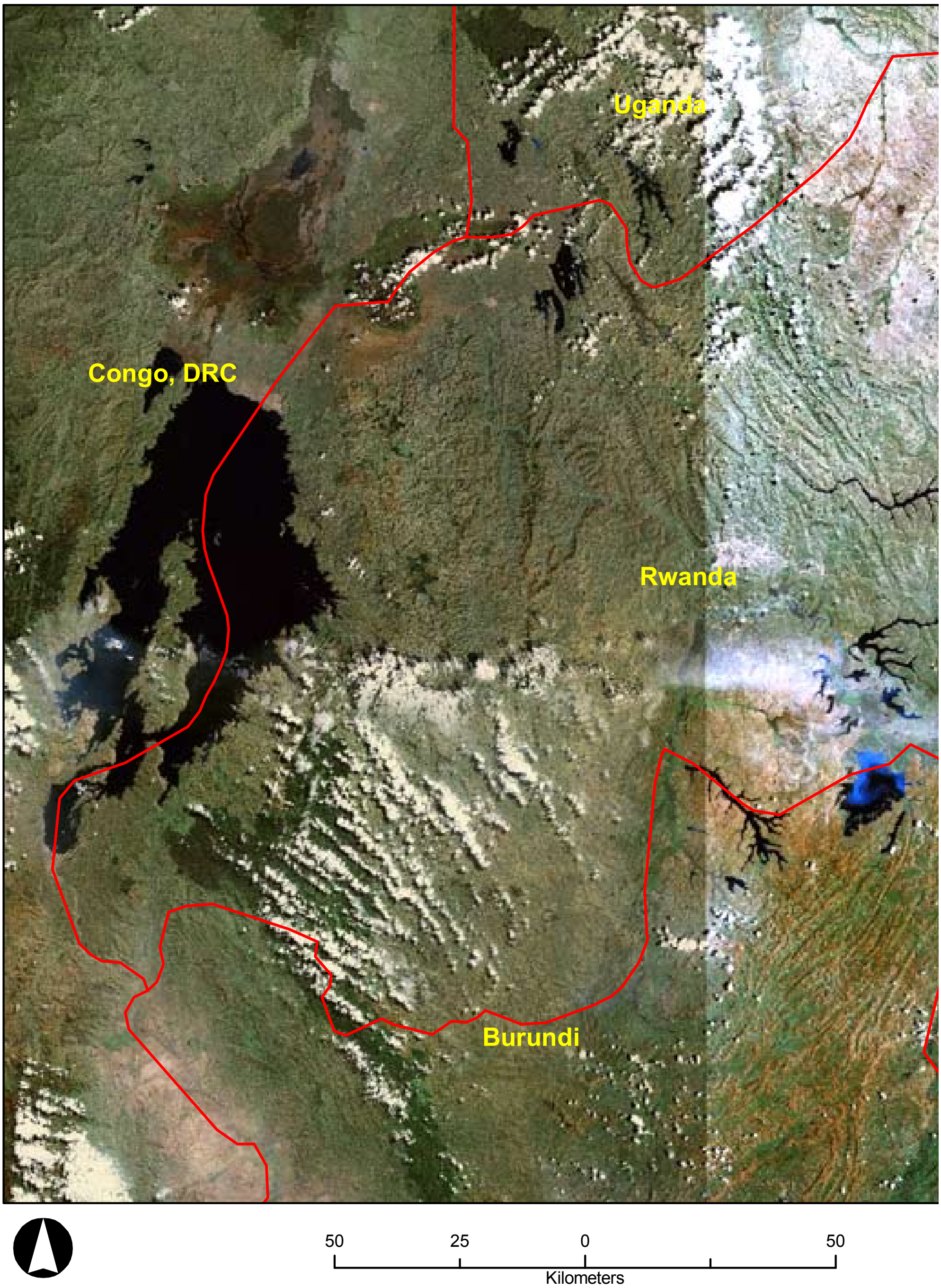
Appendix 2d: Lithology (source MINAGRI)



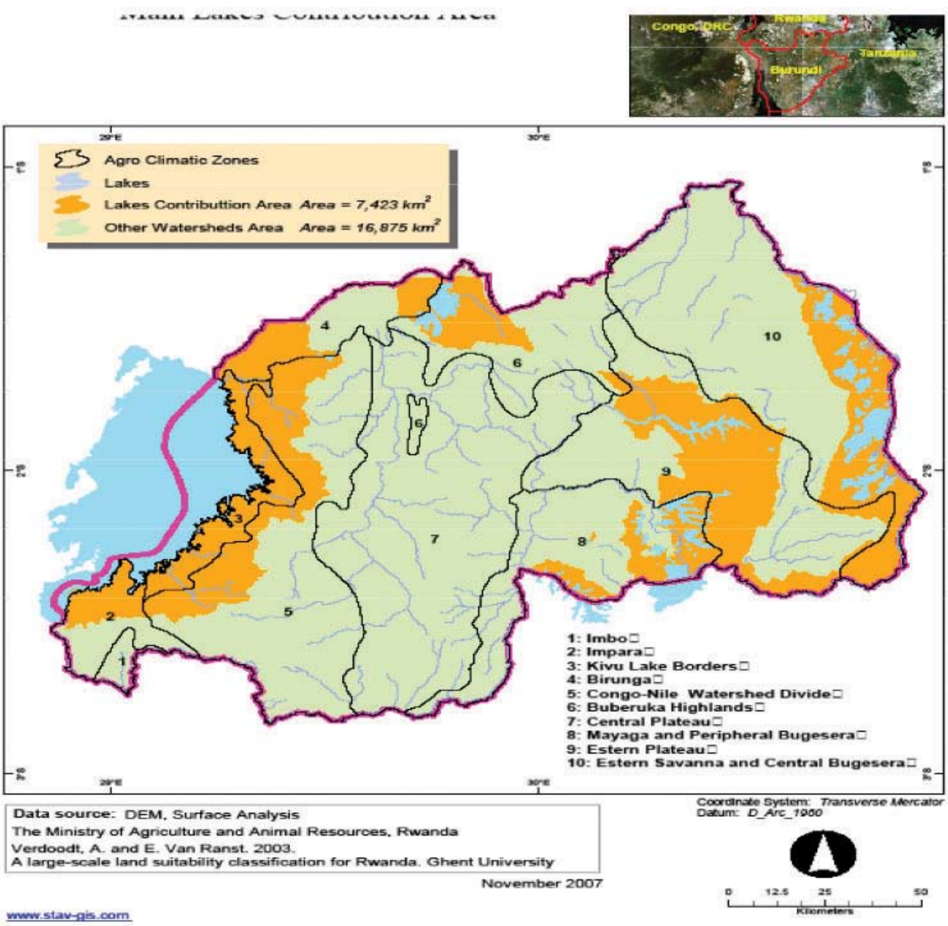
Appendix 2e: Geomorphology (source MINAGRI)



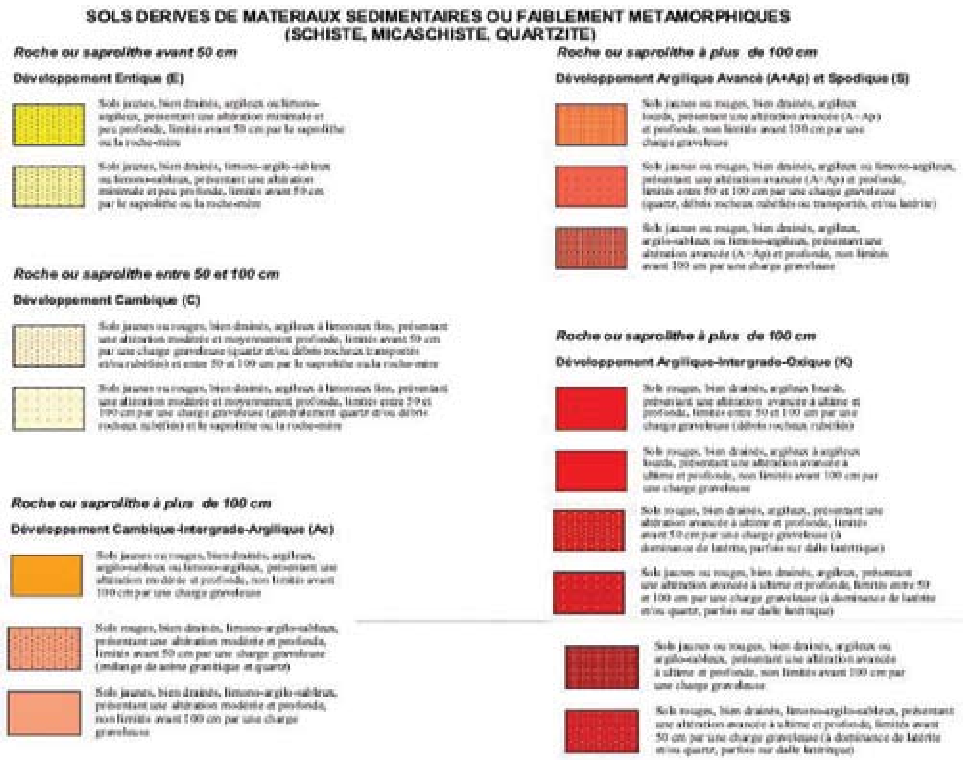
Appendix 2f: Orthophoto map, 125 m

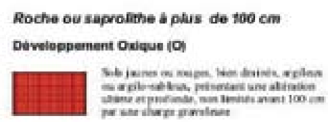


Appendix 3: Main lakes contribution area



Appendix 4: Map layers and legends





English translation:

Sedimentary or partially metamorphic

Base rock depth up to 50 cm.

- Well-drained yellow soils, loam or clay loam
- Well-drained yellow soils, sandy clay loam or sandy clay

Base rock depth 50 to 100 cm:

- well-drained yellow or red soils, loam, sandy loam

Base rock depth greater than 100 cm:

- well-drained yellow or red soils, loam, sandy loam or clay loam

Spondique

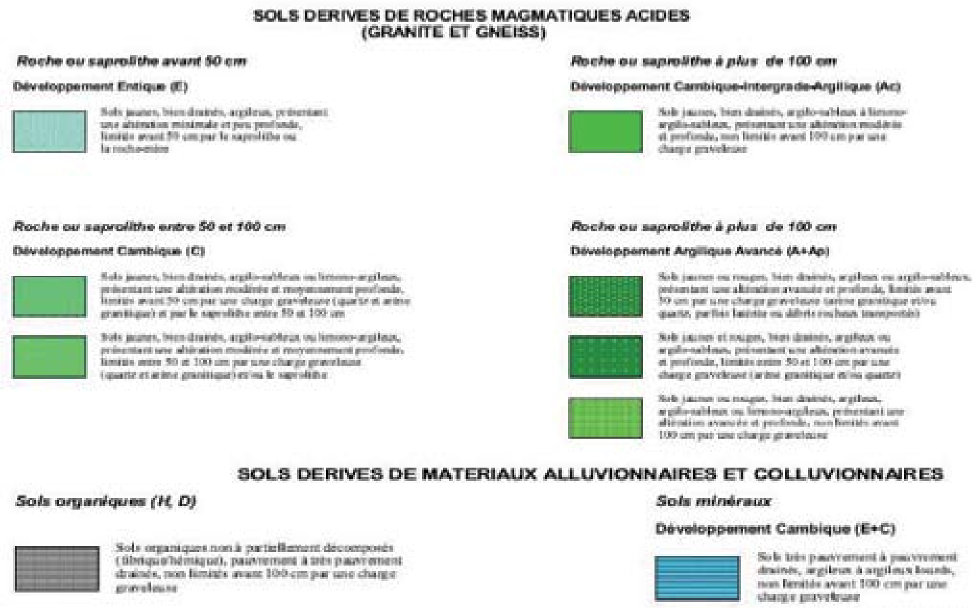
- Well-drained yellow or red soils, heavy loam
- Well-drained yellow or red soils, loam, sandy loam or clay loam

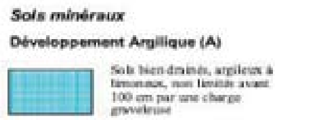
Integrade oxic

- Well-drained red soils, loam
- Well-drained yellow or red soils, loam,
- Well-drained yellow or red soils, loam, sandy loam
- Well-drained red soils, loam, sandy clay loam

Oxic

- Well-drained yellow or red soils, loam, sandy loam





Translation

Granite and gneiss
- Predominance
  - Entique: well-drained yellow soils, clay, sandy loam or sandy clay
- Oxic diagnostic horizon
  - Well-drained red soils, sandy loam
  - Well-drained yellow or red soils, loam, sandy loam
  - Well-drained yellow soils, sandy clay loam
  - Well-drained yellow soils, sandy clay loam
  - Well-drained yellow or red soils, sandy clay loam
- Integrade
  - Well-drained yellow soils, sandy loam
  - Well-drained yellow soils, sandy clay

Basalt
- Argilic diagnostic horizon:
  - Well-drained red soils, heavy loam
- Saprolithe
  - Well-drained red soils, loam or sandy loam

Alluvials
- Organic
  - Organic soils formed by decomposition
- Cambic diagnostic horizon:
  - Very poorly to poorly drained soils, clay, sandy loam or sandy clay
  - Well-drained soils, clay, sandy loam or sandy clay
- Vertic diagnostic properties:
  - Fairly to moderately drained soils, heavy loam
  - Well drained soils, heavy loam
- Argilic diagnostic horizon:
  - Fairly to moderately drained soils, loam or heavy loam
  - Well-drained soils, loam or heavy loam
  - Fairly to moderately drained soils, clay loam
  - Well-drained soils, loam to clay
  - Well-drained soils, clayey sandy loam or clayey

Appendix 5: Potential suitability of different soils for irrigation based on texture and depth

Soil type	FAO classification name	Depth	Texture	Suitability class
Aeric Andaquept	Andic Gelysols / Gleyic Andosols	< 0.50	L	4
Aeric Tropaquept	Umbric Gleysols	< 0.50	L	4
Aeric Umbric Tropaquult	Dystric (Humic) Cambisols	< 0.50	L	4
Andeptic Troporthent	Mollic Andosols	< 0.50	L	4
Andic Eutropept	Humic Cambisols	0.50-100	L	3
Andic Humitropept	Humic (Eutric) Cambisols	0.50-1.00	L	3
Aquic Dystropept	Gleyic / Dystric Cambisols	0.5-1.00	C	2
Aquic Hapludoll	Luvic Phaeozems	0.50-1.00	C	2
Aquic Tropudalf	Haplic (Gleyic) Luvisols	0.5-1.00	C	2
Cumulic Haplaquoll	Mollic Gleysol	0.50-1.00	C	2
Cumulic Hapludoll	Humic Cambisols	0.50-1.00	C	2
Dystropeptic Tropudult	Haplic Acrisols	> 1.00	L	2
Entic Eutrandept	Mollic (Haplic) Andosols	0.50-1.00	L	3
Entic Pellustert	Eutric Vertisols	0.50-1.00	C	2
Ferrudalfic Tropohumod	Haplic Podzols	0.5-1.00	L	4
Fluvaquentic Tropohemist	Terric Histosols	> 1.00	C	2
Fluventic Dystropept	Dystric Cambisols	< 0.50	L	4
Fluventic Humitropept	Dystric (Humic) Cambisols / Haplic (Humic) Alisols	< 0.50	L	4
Fluventic Ustropept	Humic (Eutric) Cambisols	< 0.50	L	4
Haplohumic Eutrorthox	Humic Cambisols	> 1.00	C	2
Humoxic Sombrihumult	Humic Acrisols (Sombric)	> 1.00	C	2
Humoxic Tropohumult	Humic Acrisols / Humic Ferralsols / Humic Alisols	> 1.00	C	2
Lithic Dystropept	Dystric Cambisols	< 0.50	L	4
Lithic Humitropept	Dystric Regosols / Dystric Leptosols	< 0.50	L	4
Lithic Troporthent	Dystric Regosols / Dystric Leptosols	< 0.50	C	3

Soil type	FAO classification name	Depth	Texture	Suitability class
Lithic Ustorthent	Dystric Regosols / Dystric Leptosols	< 0.50	C	3
Mollic Vitrandept	Vitric Andosols	0.50-1.00	L	3
Orthoxic Palehumult	Humic Acrisols / Humic Ferralsols	> 1.00	C	1
Orthoxic Tropudult	Haplic Ferralsols / Ferric (Haplic) Acrisols	0.50-1.00	C	2
Orthoxic Tropohumult	Humic Acrisols / Humic Ferralsols	0.50-1.00	C	2
Oxic Argiudoll	Luvic Phaeozems	0.50-1.00	C	2
Oxic Dystropept	Haplic Acrisols / Ferralic Cambisols	< 0.50	L	3
Oxic Humitropept	Humic Ferralsols / Humic Cambisols	0.50-1.00	L	3
Oxic Tropudalf	Haplic (Humic) Ferralsols / Haplic Lixisols	> 1.00	C	1
Oxic Ustic Dystropept	Ferralic Cambisols	< 0.50	L	4
Oxic Ustropept	Humic Ferralic Cambisols / Ferric Lixisols	0.50-1.00	C	2
Pachic Paleustoll	Vertic Luvisols	< 0.50	L	4
Paleustollic Chromustert	Eutric Vertisols / Mollic Gelysols	0.50-1.00	C	2
Sombrihumox	Humic Ferralsols / Humic Acrisols	> 1.00	C	1
Sombriorthox	Humic Alisols / Humic Acrisols	> 1.00	C	1
Sombriusthox	Humic Ferralsols	> 1.00	C	1
Tropeptic Eutrustox	Humic (Rhodic) Ferralsols	> 1.00	L	2
Tropeptic Haplustox	Rhodic Ferralsols / Haplic Acrisols / Xanthic Ferralsols	> 1.00	L	2
Typic Dystropept	Humic (Dystric) Cambisols	< 0.50	L	4
Typic Chromudert	Eutric Vertisols	0.50-1.00	C	2
Typic Chromustert	Eutric Vertisols	0.50-1.00	C	2
Typic Dystrandept	Umbric Andosols / Umbric Leptosols	< 0.50	L	4
Typic Eutropept	Haplic Alisols / Dystric Cambisols / Eutric Cambisols	< 0.50	L	4
Typic Eutrustox	Haplic Ferralsols / Dystric Regosols	> 1.00	C	1
Typic Haplustalf	Haplic Luvisols /Humic Alisols	> 1.00	C	1
Typic Haplustoll	Haplic Kasatanozems / Haplic Phaeozems	0.50-1.00	C	2

Soil type	FAO classification name	Depth	Texture	Suitability class
Typic Haplustox	Humic (Haplic) Ferralsols	> 1.00	C	1
Typic Humitropept	Humic (Dystric) Cambisols	0.50-1.00	L	3
Typic Natrustalf	Calcic Solonetz / Calcic Luvisols	Unsuitable	-	4
Typic Paleudalf	Ferric Lixisols	> 1.00	C	1
Typic Paleudult	Haplic (Humic) Ferralsols / Haplic (Humic) Acrisols	> 1.00	C	1
Typic Paleustult	Humic Nitosols / Humic Acrisols	> 1.00	C	1
Typic Pellustert	Eutric Vertisols	> 1.00	C	1
Typic Sombrihumult	Humic Alisols / Rhodic (Haplic) Luvisols	0.5-1.00	C	2
Typic Sombrihumox	Humic Ferralsols	0.5-1.00	C	2
Typic Tropaquept	Umbric (Dystric) Gleysols / Umbric (Dystric) Regosols	< 0.50	L	4
Typic Tropohumult	Humic Acrisols / Humic (Ferralic) Cambisols	0.50-1.00	C	2
Typic Troporthent	Humic (Ferralic) Cambisols	< 0.50	L	4
Typic Troposaprist	Terric / Fibric Histosols	> 1.00	L	2
Typic Tropudalf	Haplic (Chromic) Luvisols	> 1.00	C	1
Typic Ustropept	Humic Cambisols / Haplic Phaeozems	< 0.50	L	4
Udic Eutrandept	Mollic / Haplic Andosols	0.50-1.00	L	3
Udic Haplustoll	Haplic (Luvic) Phaeozems	0.50-1.00	C	2
Udic Paleustalf / Udic Paleustoll	Haplic Lixisols / Luvic Phaeozems	> 1.00	C	1
Ultic Haplustalf	Haplic Lixisols	> 1.00	C	1
Ultic Tropudalf	Vertic Luvisols / Vertic Cambisols	0.50-1.00	C	2
Ustic Humitropept	Humic Dystric Cambisols	0.50-1.00	L	3
Ustoxic Dystropept	Haplic Acrisols / Ferralic Cambisols	< 0.50	L	4
Ustoxic Humitropept	Humic Ferralsols / Ferralic Cambisols	< 0.50	L	4
Vertic Argiudoll	Luvic Phaeozems	0.50-1.00	C	2
Vertic Tropudalf	Vertic Luvisols / Luvic Phaeozems	> 1.00	C	1
Vertic Ustropept / Vertic Tropaquept	Gleyic (Vertic) Cambisols / Eutric (Mollic) Gleysols	0.50-1.00	C	2

Appendix 6: Major soil groups for Rwanda

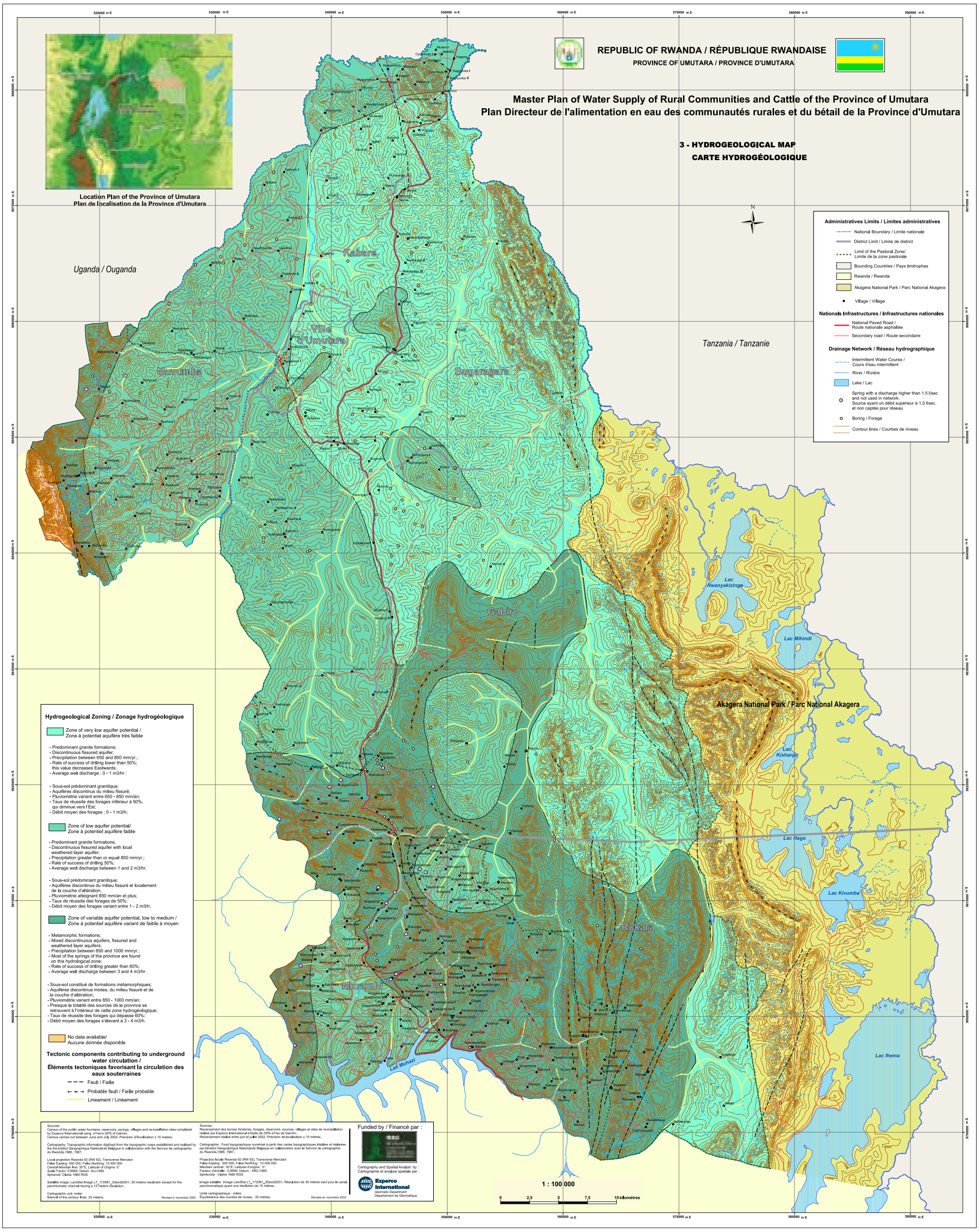
Soil type	Symbol*	Series*	Salient features
Luvisols			
- gleyic	AK, GT	Akabebya, Gitesi	Drainage problem within 100 cm depth
- vertic	BDE, GCC, GYZ, HNK, IT, MW	Bakokwe, Gacaca, Gatyazo, Hanika, Imitongore, Mugwato	Drainage problem, surface soil prone to cracking when dry
- haplic	KBE, MB, RUT	Kibuye, Mbarara, Rutovu	Base saturation (BS) > 50%
- chromic	MAB, MSK	Maraba, Masaka	Light in colour, base saturation, BS > 50%
Acrisols			
- humic	BTR, KIA, KIB KJJ, MAG, MSB, NGO, SOV	Bitare, Kabira, Kibilira, Kijojo, Magaba, Musebeya, Ngabo, Sovu	High soil organic matter (SOM) in the topsoil, low BS
- ferric	BYA	Byunga	Low BS, likely to have concretions
- haplic	KAR, MNI, RSA, SGR, FMB	Karabi, Munini, Rusatira, Sigira, Fumba	Low BS
- plinthic	MOO	Mbogo	Depth limitations due to plinthite, low BS
Lixisols			
- haplic	CWY, ISA, KI	Cyambwe, Isatura	Low CEC
- ferric	GTV	Gatovu, Kagitumba	Low CEC, likely to have concretions
- gleyic	BW	Bakokwe	Drainage problem
Alisols			
- haplic	BRG, KGM, KZB	Burega, Kangoma, Kizibere	Low base saturation
- humic	GSS, GIA, GSN, KOO, KIM, MUR, NYM	Gasasa, Gikaze, Gisunzu, Kagongo, Kimbogo, Muramba, Nyamutera	Low base saturation, high SOM in the topsoil
Phaeozems			
- luvic	BRI, HAS, GO	Buruseli, Hesha, Gasabo	No major limitations
- haplic	IB, INZ, MUH	Imbogo, Inzovu, Muhazi	No major limitations
Solonetz			
- mollic	LU	Luhwa	Not suitable due to high levels of sodium in the subsoil
Ferralsols			
- plinthic	AKR, KSA, MBU	Akaziramire, Kwisha, Mbure	Depth limitations, low fertility, low CEC
- xanthic	BUR, GSR, BIN	Burea, Gashora, Bihinga	Low fertility
- rhodic	DUH, GAK, IND, KIK, KIL, MBR, MGB, GSH, KRB	Duha, Gako, Indonyi, Kika, Kiliza, Mbare, Migambo, Gashiru, Kariba	Low fertility, highly weathered

Soil type	Symbol*	Series*	Salient features
- humic	GKG, KNB, KYZ, MLI, MRB, MSZ, NSI	Gakirage, Kinobe, Kiyonzi, Mulindi, Murambi, Musaza, Nsinda	High SOM in the topsoil, low fertility in the subsoil
- haplic	KRA, KIR, KVR, NZO, NYT	Karama, Kirambo, Kivuru, Ntyazo, Nyagatare	Low fertility
Arenosols			
- ferralic	MTK	Mitako	Light textured, low water holding capacity, low CEC
Andosols			
- mollic	CND, CAK, KOR, KKZ, MHR, RKR, TMA	Condo, Cyanika, Kora, Kukuzi, Muhabura, Rukore, Tamira	High levels of SOM, potential to fix P
- umbric	GGO, RSB, KNG, RUE, SBO	Gatongo, Karisimbi, Kinigi, Rusekera, Sabyinyo	High SOM, as above in P fixation but with BS < 50%
- vitric	GKB, KIY	Gikombe, Kimonyi	Light textured, usually silt loam, potential to fix P
- haplic	BOK, GOA	Bisoke, Gihora	Potential to fix P
Vertisols			
- eutric	BI, KB, KS, AM, MZ, RE, RA, RN	Biguzi, Kagambe, Kagese, Mabanza, Mubunza, Rugeme, Rwanganzo, Rwangingo	Drainage problem, BS > 50%
- calcic	RU	Rwagitunga	Drainage problem, accumulation of calcium carbonate
Gleysols			
- mollic	NT	Nyamatebe	Drainage problem but with a good fertile topsoil
- umbric	RM	Rumuli	Drainage problem, BS < 50%
Histosols			
- terric	CR, IR, RL	Cyarugira, Rugezi, Rukeli	Drainage problem, having highly decomposed soil organic material
Podzols			
- haplic	CUR, GBR, NA	Curaga, Gabiro, Nyakabungo	
Cambisols			
- gleyic	BB	Budubi	Soils in transitional stage of development (this applies to all the Cambisols), poorly drained

Soil type	Symbol*	Series*	Salient features
- dystric	BSS, BSK, BWI, GCB, GKK, GIM, GST, GIT, IMP, KBD, KAN, KG, KMA, KAM, KDW, KDM, MAH, MDS, MGD, MGZ, MUE, MUA, NBW, NYI, RUG, RNB, RWZ, RO, TUZ, ST, UKR, USK	Buseso, Bushekeli, Bwira, Gacumbi, Gakoko, Gihimbi, Gishyita, Gitonde, Impala, Kabarondo, Kagano, Kagogo, Kagoma, Kami, Kidahwe, Kidomo, Mahembe, Mudasomwa, Mugando, Mugozi, Murenge, Muruha, Ntobwe, Nyabitsina, Rugeshi, Runaba, Rwinzuki, Rwotso, Tuzana, Suti, Umukeri, Umusekera	Low base saturation of < 50% and of varying depth. See also above in terms of soil profile development.
- vertic	CYY, NKK	Cyunyu, Nkanka	Drainage, cracking when dry in the surface soil
- chromic	GRO	Gahororo	Light coloured soils
- humic	KBR, KOE, RAV, RUU	Kibari, Kigombe, Rubabu, Ruhuha	High levels of SOM in the topsoil
- eutric	GIR, MU, MSN, NMB	Gihira, Muganza, Musenyi, Nyarushamba	Has BS of > 50%
- ferralic	IRI, KBB, KTR, KBN, MTB, UR, RYA, RWB, TRE	Iriba, Kababisha, Kantere, Kibangu, Mutumba, Ruhanano, Ruhashya, Rwumba, Tare	High levels of iron and aluminium content

** Retained for ease of reference in the soil map.*

Appendix 7: Hydrogeological map of Umutara



Annexes

Annex 1: Marshlands / hillside development

Rehabilitation / construction of irrigation infrastructure

MARSHLANDS

Item	Ha	Province/ district	Status on 31/10/07 (%)	Starting date	Ending date	Total cost (x RWF 1.000)	Total cost (USD)	Observations
A. WORKS								
1. Works completed								
Rusuli-Rwamuginga (marshland + 1 dam)	170	Huye/ South	100	-	4/2/04	166 337	300 790	Irrigation canal 22 km; drainage 8 km
Cyarubare (marshland + 1 dam)	40	Huye/ South	100	-	4/2/04	163 130	294 991	Irrigation canal 8 km; drainage 3 km
Kinnyogo	53	Kirehe/ East	100	12/7/04	15/3/06	75 910	137 269	Irrigation canal 9 km; drainage 4 km
Ruvubu dam (rehabilitation)	0	Bugesera/ East	100	27/6/04	4/10/04	13 803	24 960	-
Gashora hill side irrigation	15	Bugesera/ East	100	-	31/12/04	33 399	60 396	-
Ntaruko hill side irrigation (rehabilitation: 8 km)	50	Karonge/ West	100	2/6/05	31/12/05	18 000	32 550	Irrigation canal 8 km
Dam of Kajevuba	0	Gasabo/ MVK	100	27/6/05	31/3/06	50 000	90 416	-
Cleaning out of Nyabugogo river (for drainage of Kajevuba marshland)	0	Gasabo/ MVK	100	16/8/05	31/12/05	50 000	90 416	Drainage 6 km
Nyarububa (hillside)		Rulindo/ North	100	8/11/05	31/1/06	48 000	86 799	-
Kibaya-Cyunuzi, Rwabikwano et Kiruhura (3 marshlands + 2 dams)	555	Ngoma/ East	100	1/7/05	23/8/06	1 733 200	3 134 177	Irrigation canal 62 km; piste 2.5 km
Codervam 2 & 3	220	Nyagatare/ East	100	27/6/05	31/8/06	80 100	144 846	Irrigation canal 7 km; drainage 7 km; piste 1 km
Base	65	Ruhango/ South	100	1/8/06	31/1/07	33 000	59 675	-

Item	Ha	Province/ district	Status on 31/10/07 (%)	Starting date	Ending date	Total cost (x RWF 1,000)	Total cost (USD)	Observations
Kanyonyomba (marshland + 1 dam)	600	Gatsibo/ East	100	16/5/05	31/12/06	2 374 900	4 294 575	Irrigation canals 48 km; drainage canals 18 km; roads 10 km
Ntende	25	Gatsibo/ East	100	1/5/06	28/2/07	70 000	126 582	Irrigation canals 3.4 km
Bugarama-Nord	205	Rusizi/ West	100	3/8/06	20/3/07	366 338	662 456	Irrigation canals 12.5 km
Bugarama-Est	240	Rusizi/ West	100	3/8/06	20/3/07	307 247	555 600	Irrigation canals 29 km; drainage canal 4.3 km
Agasasa (sectors)	180	Nyanza/ South	100	1/12/06	15/9/07	325 000	587 703	Irrigation main canals 12 km; river 5.7 km
Gatandara-Kabirundwe I & II	100	Rusizi/ West	100	9/5/05	30/6/07	85 140	153 960	Main irrigation canals 15 km
S/total	2518	-	-	-	-	5 993 504	10 838 163	-
2. Works under implementation								
Gisunzu hill side irrigation (rehabilitation: 8 km of canal)	50	Karonge/ West	90	2/6/05	30/11/07	23 000	41 591	Works of phase 2 to be started soon; 8 km of irrigation canal
Agasasa dam	0	Nyanza/ South	75	1/9/06	31/12/07	850 000	1 537 071	Long delay of Supervision Mission (starting on 19/2/07); heavy rain in April & May 07
Mukunguri	250	Kamonyi/ South	92	2/10/06	30/11/07	692 500	1 252 260	Main irrigation canals 41 km; river 13 km; long delay due to bad management of the contractor and heavy rain since Feb to May 07

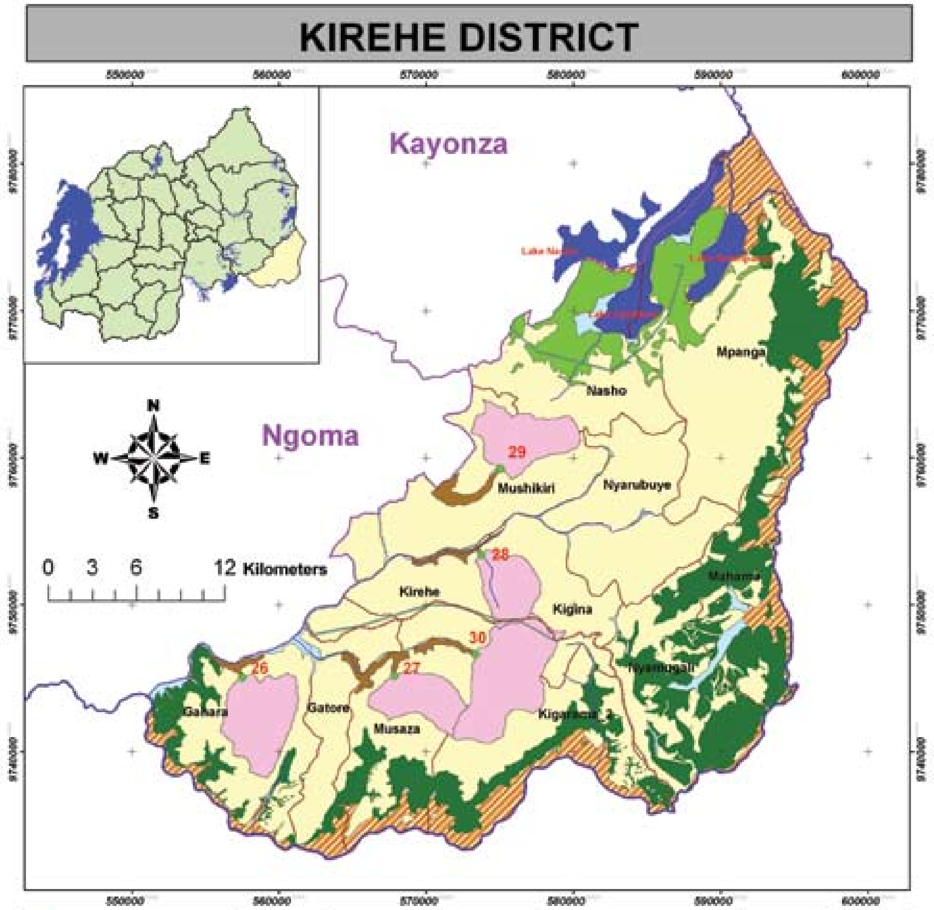
Item	Ha	Province/ district	Status on 31/10/07 (%)	Starting date	Ending date	Total cost (x RWF 1,000)	Total cost (USD)	Observations
Rwasave	100	Huye/ South	97	2/10/06	31/10/07	325 000	587 703	Irrigation canals 19 km; river 6.4 km; road 6 km; long delay due to bad management of the contractor
Dam B of Kanyonyomba marsland	0	Gatsibo/ East	80	11/6/07	31/12/07	212 000	383 363	Works undertaken by CGC with the remainder of his contract
Additional & urgent works in Bugarama-East & Bugarama-Nord	20	Rusizi/ West	60	3/9/07	30/11/07	49 500	89 512	-
Nyarububa (drainage)	60	Gasabo/ North	0	20/10/07	20/2/08	73 340	132 622	River 2.3 km; irrigation canals 3.8 km
Additional works in Rusuli & Cyarubare marshlands	0	Huye/ South	95	23/8/06	31/10/07	45 175	81 691	Delay due to bad management, work suspended
S/total	480	-	-	-	-	2 270 515	4 105 814	-
3. Works under procurement								
Kajevuba (irrigation and drainage canals)	95	Gasabo/ MVK	Bids opening on 2/11/07	16/12/07	31/5/08	160 000	289 331	River 5.5 m; drainage 2 km; irrigation canals 8 km
S/total	95	-	-	-	-	160 000	289 331	-
Total works	3093					8 424 019	15 233 307	-
B. STUDIES AND SUPERVISION								
1. Studies completed								
Supervision works in Rusuli & Cyarubare	-	-	100	-	4/2/04	20 643	37 329	Works in phase 1

Item	Ha	Province/ district	Status on 31/10/07 (%)	Starting date	Ending date	Total cost (x RWF 1,000)	Total cost (USD)	Observations
Study for rehabilitation of Mukunguli & Kinyegenyege marshlands	-	-	100	-	31/12/04	167 380	302 676	Works in phase 1 (Mukunguri only)
Study for development of Muvumba scheme N° 5	120	-	100	-	31/11/04	70 427	127 354	Works in phase 2
Kamiranzovu marshland	143	-	100	-	1/6/05	16 000	28 933	Works in phase 2
Study on dam security (Rwanda)	-	-	100	-	30/6/05	10 343	18 703	-
Splitting of marshlands	-	-	100	-	31/7/05	1 609	2 910	-
Additionnel studies around Kanyonyomba marshland	-	-	100	-	-	19 150	34 629	Works in phase 2
Study for drinking water supply projet around Rusuli & Cyarubare marshlands	-	-	100	-	-	10 089	18 244	Works in phase 2
Nyarubogo & Kinyegenyege (by Hydroplan)	330	South/ Nyanza	100	1/6/04	6/4/06	157 460	284 738	Works in phase 2
Nyarububa (irrigation/ drainage)	–	Rulindo/ North	100	25/9/06	31/3/07	19 723	35 665	Works in phase 1; supervision RWF 10 100
Kajevuba (irrigation and drainage canals)	–	Gasabo/ MVK	100	25/9/06	30/4/07	8 644	15 631	Works in phase 1
Rugeramigozi dam	–	South/ Muhanga	100	1/12/06	30/4/07	12 942	23 403	Works in phase 2
Rugazi-Bisenga (+ 2 dam)	90	East/ Kayonza	100	1/2/07	30/9/07	34,186	61,819	Works in phase 2
Gisaya (+ 1 dam)	79	East/ Ngoma	100	26/12/06	30/9/07	26 100	47 197	Works in phase 2
Sagatare-Nyamazi-Rwabutazi (+ 1 dam)	172	East/ Kirehe	100	15/2/07	20/10/07	31 100	56 239	Works in phase 2

Item	Ha	Province/ district	Status on 31/10/07 (%)	Starting date	Ending date	Total cost (x RWF 1,000)	Total cost (USD)	Observations
Upper Kibaya (+ 1 dam)	84	East/ Ngoma	100	15/3/07	20/10/07	25 682	46 441	Works in phase 2
Rwagitima/Ntende (+ 2 dams)	516	East/ Gastibo	100	15/3/07	20/10/07	47 043	85 069	Works in phase 2
Cyunuzi dam	-	East/ Kirehe	100	10/2/07	30/9/07	13 848	25 042	Works in phase 2 (Marshland rehabilitated)
S/total	1534	-	-	-	-	692 369	1 252 024	-
2. Studies under implementation								
Kinnyogo II	150	East/Kirehe	70	1/4/07	30/11/07	18 467	33 394	Works in phase 2
S/total	150	-	-	-	-	18 467	33 394	-
3. Studies under procurement								
Study for development of Muvumba scheme N° 8	1,845	East/ Nyagatare	Bids opening on 15/11/07	20/12/ 07	30/6/08	220 000	400 000	-
Total studies	3,529	-		-	-	930 836	1 683 248	-
C. Training, maintenance and extension (in rice schemes)	-	-	Already started in Kanyonyomba, Kibaya-Cyunuzi, Ngenda, Cyarubare-Rusuli, Rwasave & Kinnyogo	16/9/05	30/6/08	200 000	361 664	Extension & maintenance ongoing in Kanyonyomba, Kinnyogo, Kibaya-Cyunuzi, Ngenda, Rusuli-Cyarubare and Rwasave
TOTAL MARSHLANDS						9 554 855	17 278 219	

Source: GASPRD RSSP status Marshlands Phase 1 on 31 October 2007

Annex 2: District Plan Maps



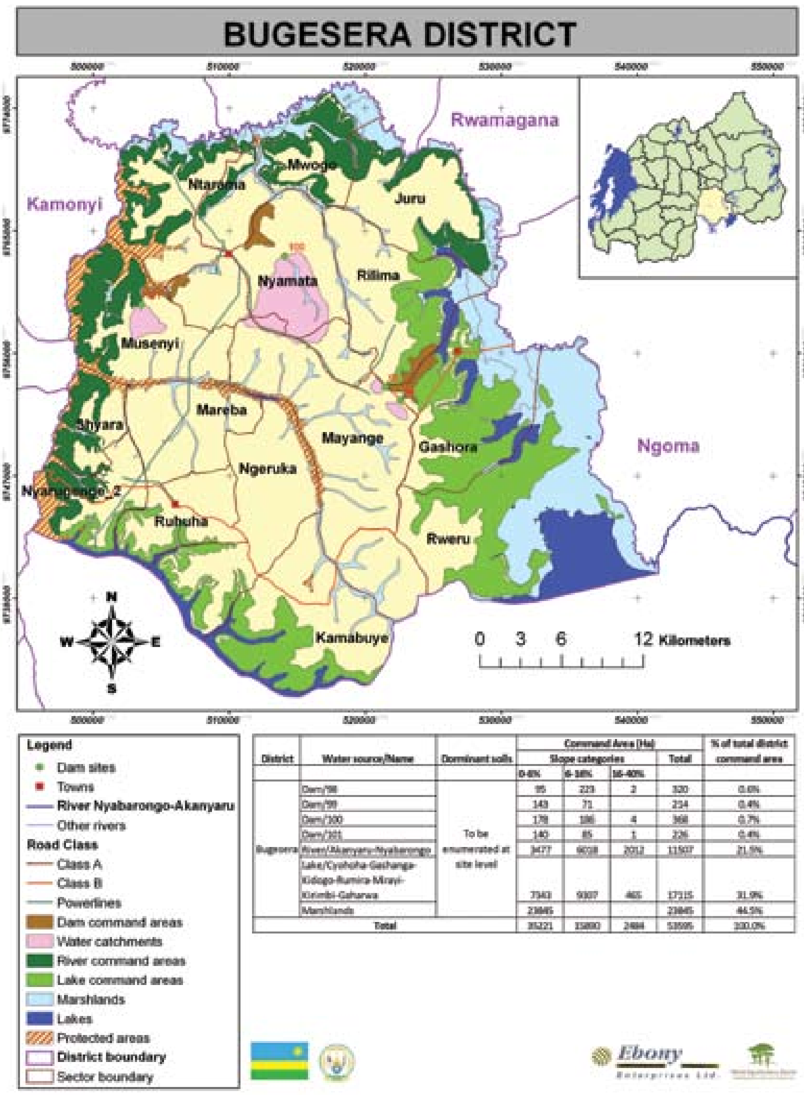
District	Water source/Name	Dorminant soils	Slope			Command Area (Ha)	% of total district command area
			0-6%	6-16%	16-40%		
Kirehe	Dam/26	To be enumerated at site level	123	24	0	147	0.4%
	Dam/27		47	128	184	379	0.9%
	Dam/28		104	96	32	232	0.6%
	Dam/29		103	226	55	384	0.9%
	Dam/30		57	90	20	167	0.4%
	River/Akagera		8041	8710	2578	19329	47.8%
	Lake /Nasho, Cyambwe, Rwampanga		3925	1266	200	5391	13.3%
	Marshlands		14436			14436	35.7%
Total			26856	10540	3069	40465	100.0%

EASTERN PROVINCE

Bugesera District Irrigation Plan

Bugesera district has command areas represented in lake, river, marshlands and dam domains. Riverine PIAs are all located along Akanyaru and Nyabarongo rivers while the lake PIAs would depend on lakes Cyohoha, Gashanga, Kidogo, Mirayi, Kirimbi and Gaharwa, leaving the marshlands evenly spread within the district.

The IMP study for Rwanda indicates that a total of 53 595 ha have good potential for conventional irrigation in Bugesera district. Of these, the marshlands, lake and river domains constitute the biggest portions with 23 845 ha (44.5%), 17 115 ha (31.9%) and 11 507 ha (21.5%), respectively. The rest of the command areas belong to the dam domain at 1 128 ha (2.1%). The total irrigation water requirement for Bugesera is about 461.6 Mm^3, partitioned into 238.5 Mm^3 for marshlands and 223.125 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

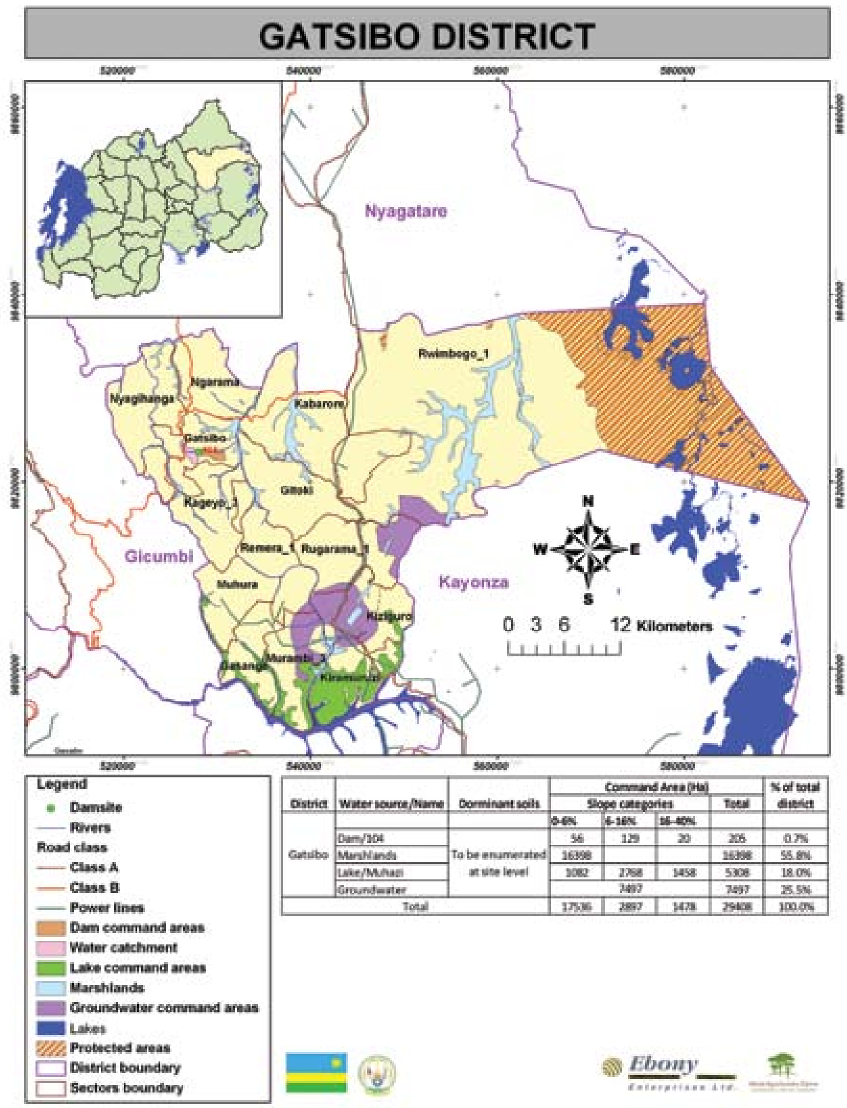


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories 0-6%	6-16%	16-40%	Total	% of total district command area
Bugesera	Dam/98	To be enumerated at site level	95	223	2	320	0.6%
	Dam/99		143	71		214	0.4%
	Dam/100		178	186	4	368	0.7%
	Dam/101		140	85	1	226	0.4%
	River/Akanyaru-Nyabarongo		3477	6018	2012	11507	21.5%
	Lake/Cyohoha-Gashanga-Kidogo-Rumira-Mirayi-Kirimbi-Gaharwa		7343	9307	465	17115	31.9%
	Marshlands		23845			23845	44.5%
Total			35221	15890	2484	53595	100.0%

Gatsibo District Irrigation Plan

Except for the eastern part which is protected as a national park, the PIAs of Gatsibo district are spread in the central, southern and western regions with good irrigation potential for dam, lake, groundwater and marshland irrigation development. The PIAs have a combined area of 29 408 ha as shown in the plan map. There is good road and electricity access.

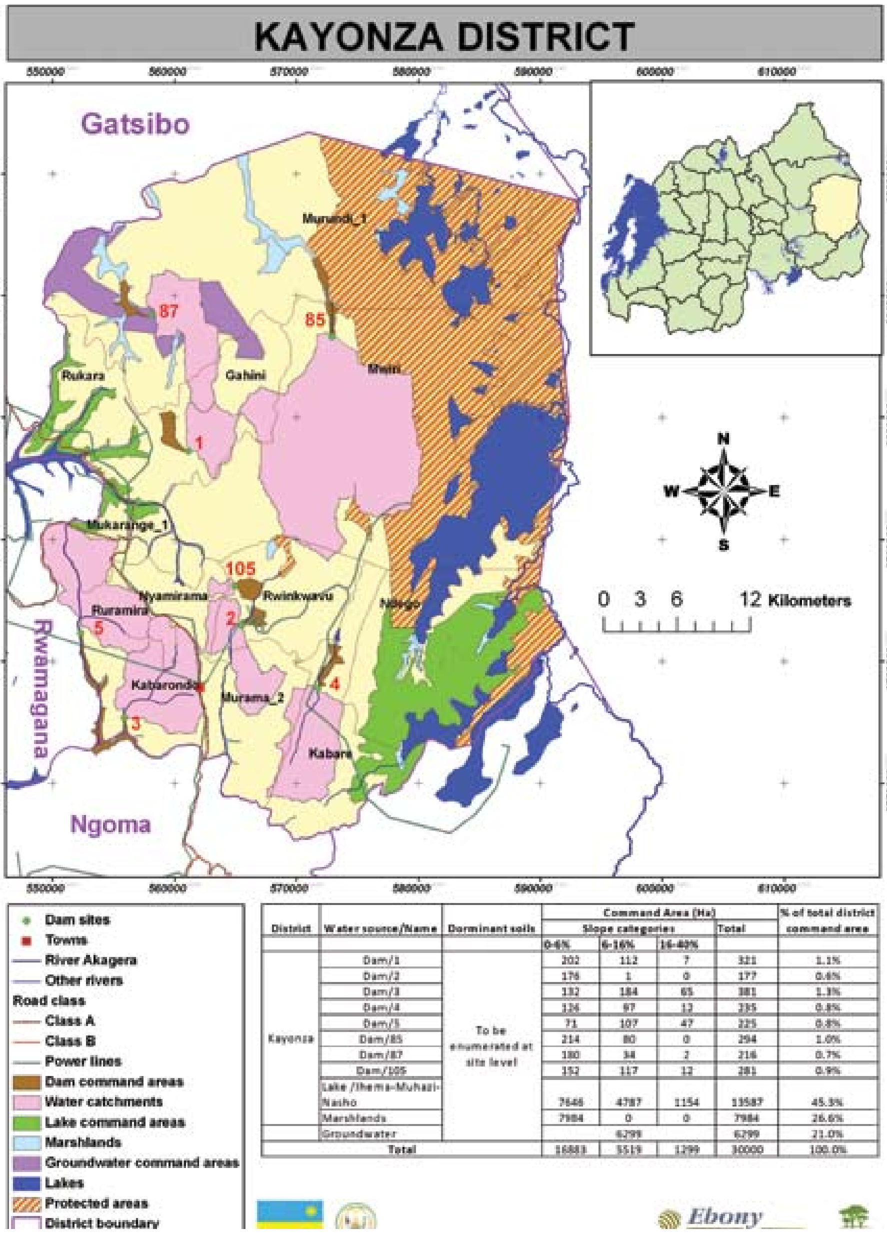
The irrigation water demand for these PIAs is approximately 220.6 Mm^3. The lake water has to be pumped from Lake Muhazi at no more that 100m static head. Conventional drip and sprinkler irrigation systems can be applied, depending on the location and morphology of landforms. However, centre pivot sprinkler irrigation can only be applied after investigations have verified that sufficient groundwater is available. The precise irrigation systems can be mapped out according to engineering designs at site level.



District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories 0-6%	6-16%	16-40%	Total	% of total district
Gatsibo	Dam/104	To be enumerated at site level	56	129	20	205	0.7%
	Marshlands		16398			16398	55.8%
	Lake/Muhazi		1082	2768	1458	5308	18.0%
	Groundwater		7497			7497	25.5%
Total			17536	2897	1478	29408	100.0%

Kayonza District Irrigation Plan

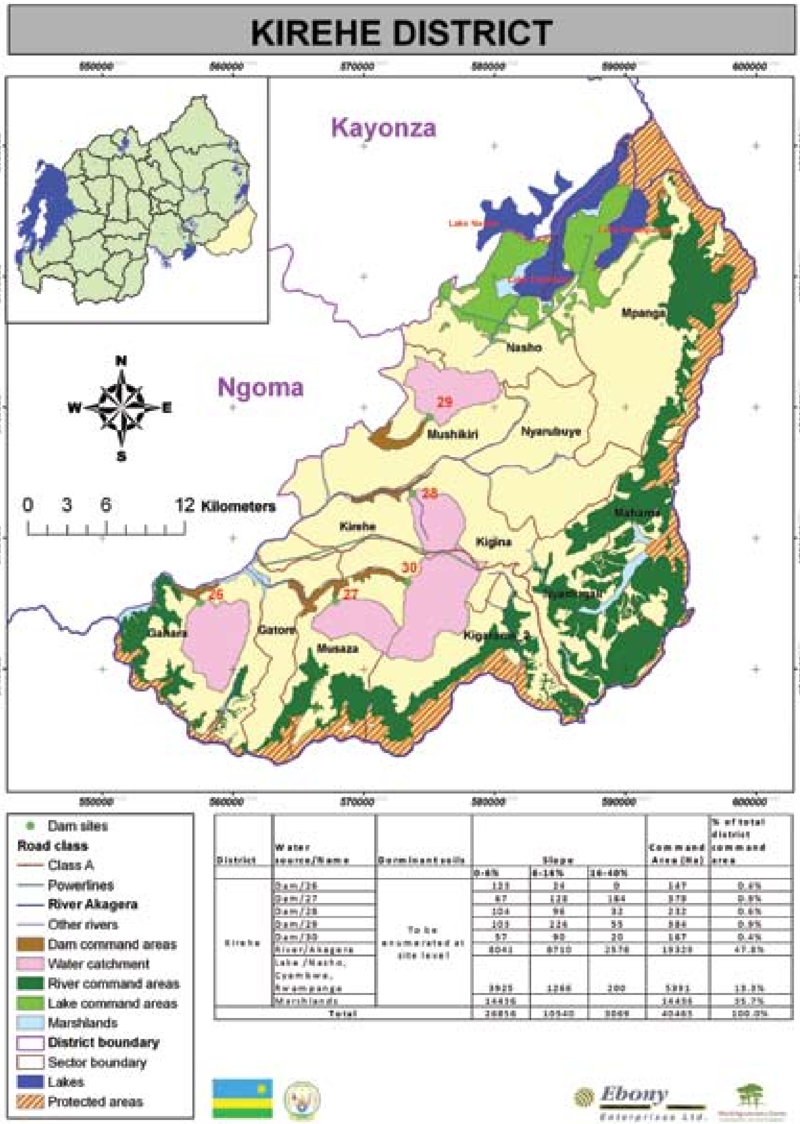
Kayonza district has command areas represented in groundwater, lake, marshlands and dam domains. A total of 30 000 ha has good potential for irrigation. Of these, the lake domain constitutes the largest area with 13 587 ha (45.3%), followed by the marshlands with 7 984 ha (26.6%) and groundwater with 6 299 ha (21%). The rest of the command areas belong to the dam domain constituting 2130 (7.1%) of the total irrigation potential for the district. The total irrigation water requirement for Kayonza is about 245 Mm^3 partitioned into 80 Mm^3 for marshlands and 165 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.



District	Water source/Name	Dominant soils	Command Area (Ha)				% of total district command area
			Slope categories			Total	
			0-6%	6-16%	16-40%		
Kayonza	Dam/1	To be enumerated at site level	202	112	7	321	1.1%
	Dam/2		176	1	0	177	0.6%
	Dam/3		132	184	65	381	1.3%
	Dam/4		126	97	12	235	0.8%
	Dam/5		71	107	47	225	0.8%
	Dam/85		214	80	0	294	1.0%
	Dam/87		180	34	2	216	0.7%
	Dam/105		152	117	12	281	0.9%
	Lake /Ihema-Muhazi-Nasho		7646	4787	1154	13587	45.3%
	Marshlands		7984	0	0	7984	26.6%
	Groundwater			6299		6299	21.0%
Total			16883	5519	1299	30000	100.0%

Kirehe District Irrigation Plan

The PIAs for Kirehe district are in dam, river, lake and marshland domains with a total command area of 40 465 ha and irrigation water demand of 303.5 Mm^3. The river domain PIAs draw their water from the Akagera river which has minimum flow rate of about 90m s^{-1} at the entry point of the district at Gahara sector, which increases to about 102m s^{-1} at the Northern tip of Mpanga sector as it exits the district. This gives a minimum average flow rate of about 96m s^{-1}, which translates to an annual supply of 2 986 Mm^3. The other sets of PIAs are from dam, marshland and lake domains. The PIAs from the lake domain draw water from lakes Nasho, Cyambwe and Rwampanga. The total irrigation water requirement for Kirehe is about 340 Mm^3 partitioned into 144 Mm^3 for marshlands and 195 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

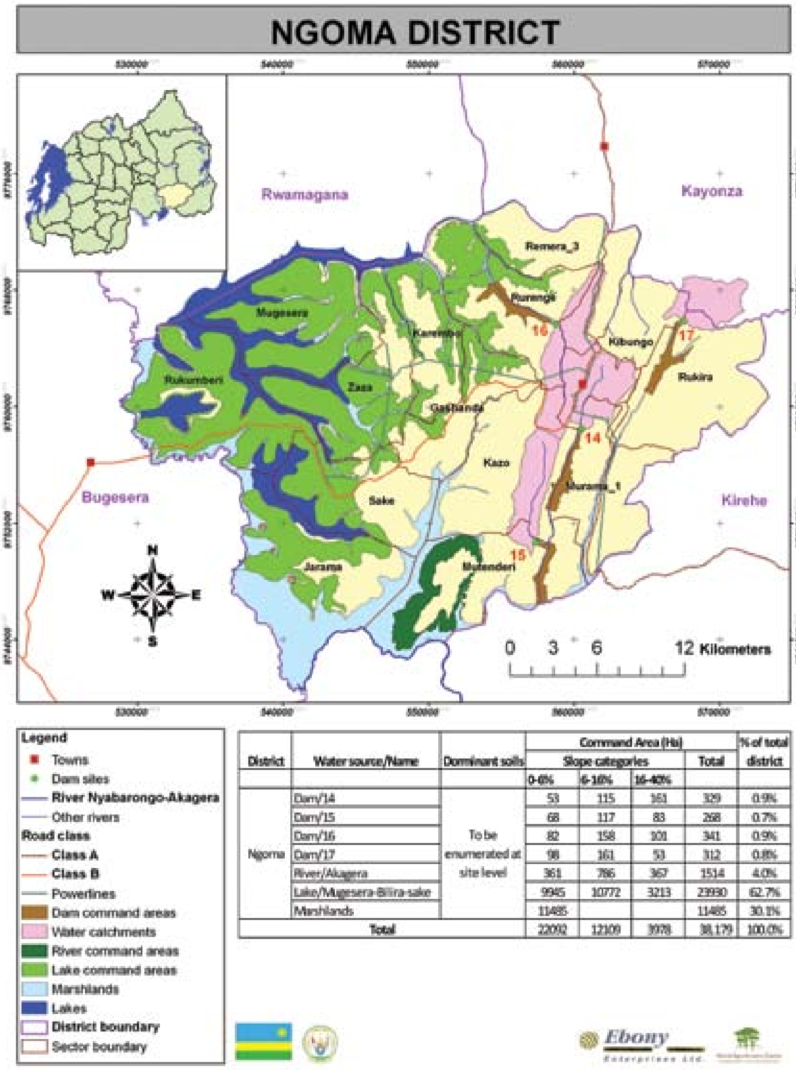


District	Water source/Name	Dominant soils	Slope			Command Area (Ha)	% of total district command area
			0-6%	6-16%	16-40%		
Kirehe	Dam/26	To be enumerated at site level	123	24	0	147	0.4%
	Dam/27		67	128	184	379	0.9%
	Dam/28		104	96	32	232	0.6%
	Dam/29		103	226	55	384	0.9%
	Dam/30		57	90	20	167	0.4%
	River/Akagera		8041	8710	2578	19329	47.8%
	Lake /Nasho, Cyambwe, Rwampanga		3925	1266	200	5391	13.3%
	Marshlands		14436			14436	35.7%
Total			26856	10540	3069	40465	100.0%

Ngoma District Irrigation Plan

Ngoma district falls into ACZs 10 and 11. It is mainly lowlands and middle altitudes with slopes predominantly ranging from 6% to 25%. The geomorphology of Ngoma is made up of round hills with pockets of old peneplain and angular hills. The soils are varied but predominantly clayey and loamy. Rainfall in this district ranges from 900mm to 1100mm. Temperatures are moderate, 18–21° C. Possibilities in land suitability vary widely from upland crops, which require careful management, to upland crops, which require very careful management, and valley crops. Irrigation of rice along marshlands of Ngoma district is ongoing.

The IMP study indicates that a total of 38 179 ha have good potential for conventional irrigation in Ngoma district, covering dam, river, lake and marshland domains. Of these, the lake domain occupies 23 930 ha (62.7%), marshland 11 485 ha (30.1%) and the remainder shared between dams and river PIAs. These sites would need approximately 315.1 Mm^3 of water (179.5 Mm^3 from lakes, 114.9 Mm^3 from marshlands and 20.1 Mm^3 from the other domains). Access to road and electrical power grid to these sites is good.

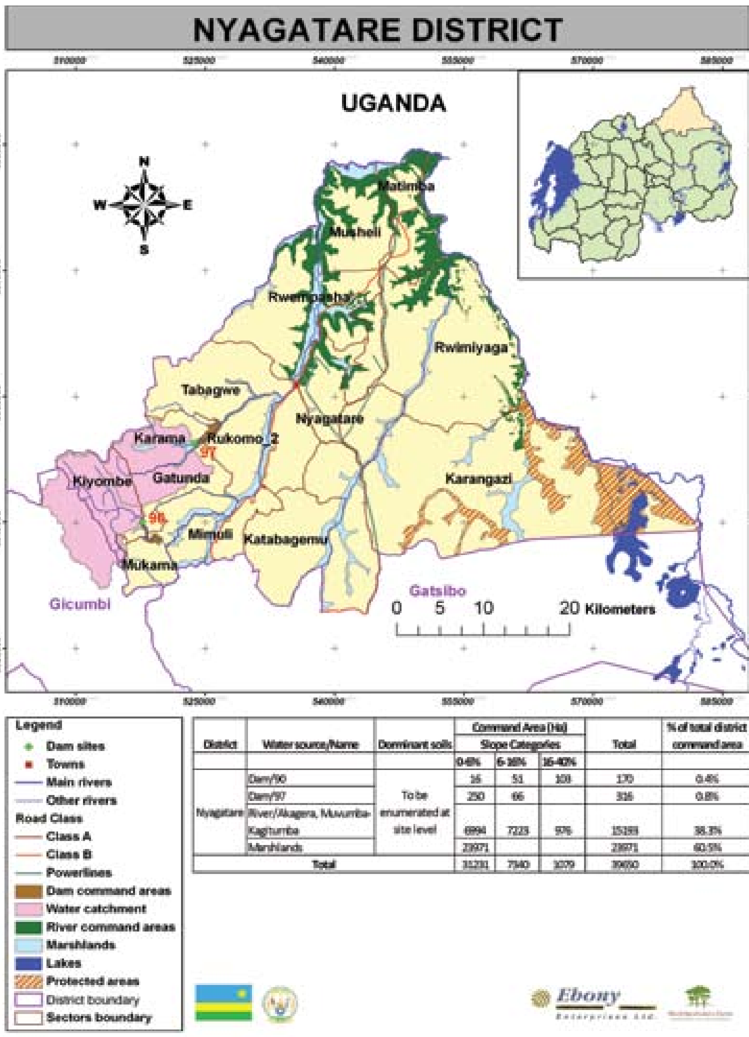


District	Water source/Name	Dominant soils	Command Area (Ha)				% of total district
			Slope categories			Total	
			0-6%	6-16%	16-40%		
Ngoma	Dam/14	To be enumerated at site level	53	115	161	329	0.9%
	Dam/15		68	117	83	268	0.7%
	Dam/16		82	158	101	341	0.9%
	Dam/17		98	161	53	312	0.8%
	River/Akagera		361	786	367	1514	4.0%
	Lake/Mugesera-Birira-sake		9945	10772	3213	23930	62.7%
	Marshlands		11485			11485	30.1%
Total			22092	12109	3978	38,179	100.0%

Nyagatare District Irrigation Plan

Nyagatare district has command areas represented in river, marshlands and dam domains. Riverine PIAs are all located along Akagera and Muvumba-Kagitumba rivers on the northern and upper eastern sections of the district. While the potential for dams is only possible in the southwestern zone of the district, the marshlands are evenly spread. There is ongoing irrigation of rice along the Muvumba valley, with marshland irrigation for hytCodervam 2&3 covering over 7km of canals and a further 7km of drainage works. Livestock production, a major priority, can be boosted through irrigation of fodder.

The IMP study indicates that a total of 39 650 ha have good potential for irrigation in this district. Of these, the marshlands and river domains constitute the largest portions, with 23 971 ha (60.5%) and 15 193 ha (38.3%), respectively. The rest of the command areas belong to the dam domain, covering an area of 486 ha (1.2%). The total irrigation water requirement for Nyagatare is about 357.3 Mm^3 partitioned into 239.7 Mm^3 for marshlands and 117.6 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

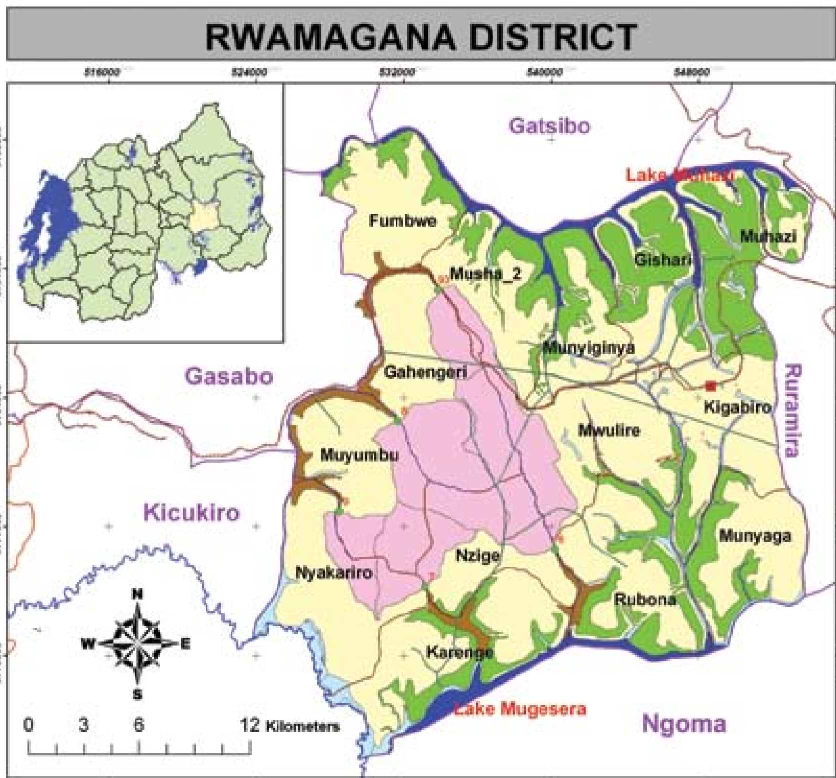


District	Water source/Name	Dominant soils	Command Area (Ha) Slope Categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Nyagatare	Dam/90	To be enumerated at site level	16	51	103	170	0.4%
	Dam/97		250	66		316	0.8%
	River/Akagera, Muvumba-Kagitumba		6994	7223	976	15193	38.3%
	Marshlands		23971			23971	60.5%
Total			31231	7340	1079	39650	100.0%

Rwamagana District Irrigation Plan

Rwamagana district has command areas represented in lake, river, marshlands and dam domains. These are evenly spread, giving an opportunity for different types of irrigation to be established within the district. A total of 20 276 ha have good potential for conventional irrigation in the district. Of these, the lake domain constitutes the largest area of 12 664 ha (62.9%), followed by the marshlands with a PIA of about 5 268 ha (26%). The command areas for dams in Rwamagana constitute 11% of the total irrigation potential.

The total irrigation water requirement for Rwamagana is about 165.3 Mm^3, partitioned into 52.7 Mm^3 for marshlands and 112.6 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.



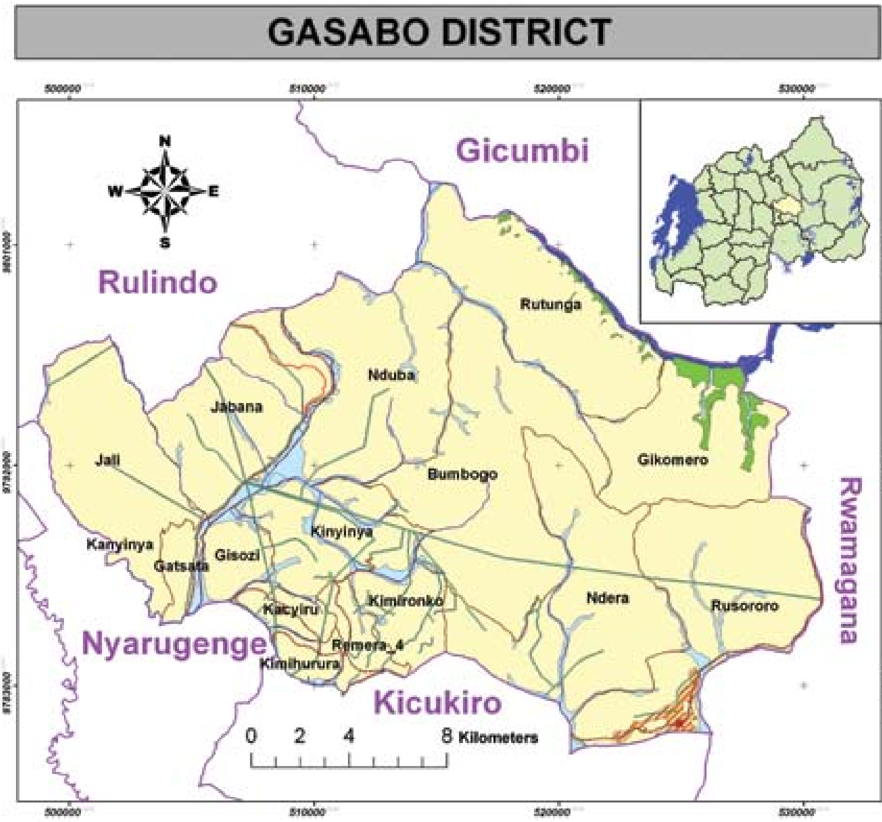
District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Rwamagana	Dam/6	To be enumerated at site level	99	111	23	233	1.1%
	Dam/7		98	131	57	286	1.4%
	Dam/8		172	151	71	394	1.9%
	Dam/9		176	124	38	338	1.7%
	Dam/93		48	147	68	263	1.3%
	Lake /Muhazi-Mugesera		2922	7028	2714	12664	62.5%
	River/Nyabarongo		103	384	343	830	4.1%
	Marshlands		5268			5268	26.0%
Total			8886	8076	3314	20276	100.0%

KIGALI PROVINCE

Gasabo District Irrigation Plan

Gasabo district has command areas represented in lake and marshlands domains. Lake PIAs depend on Lake Muhazi. Marshlands evenly spread throughout the district.

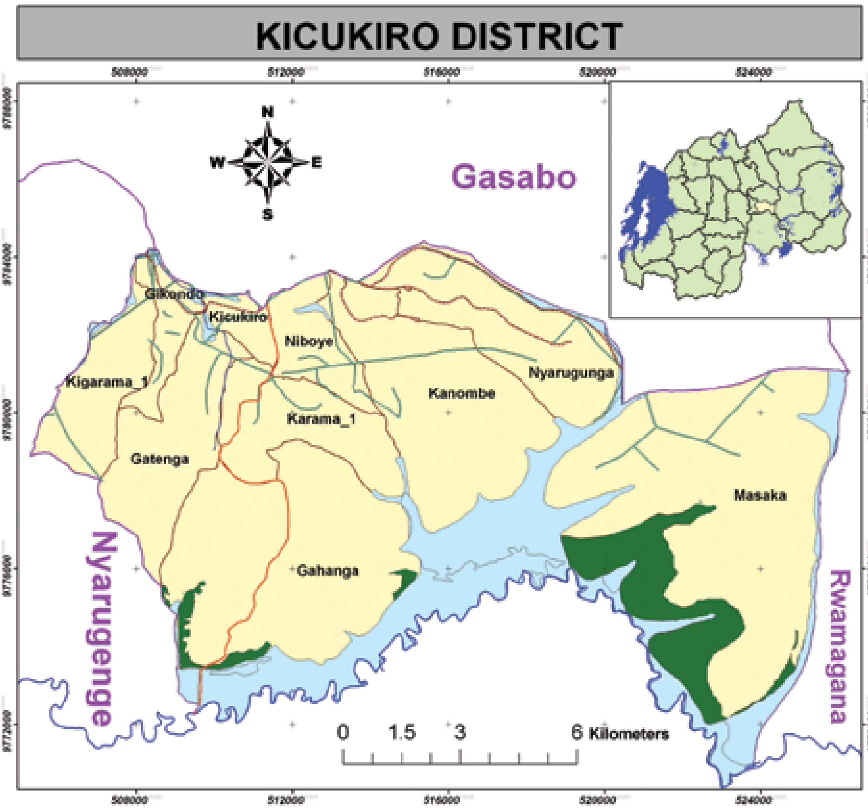
A total of 5 161 ha have good potential for conventional irrigation in the district. Of these, the marshlands constitute the biggest portion with 4 623 ha (89.6%) while the rest belong to the lake domain with 538 ha (10.4%). The total irrigation water requirement for Gasabo is about 50.26 Mm^3, partitioned into 46.23 Mm^3 for marshlands and 4.04 Mm^3 for lake command areas. Access to road and electrical power grid to these sites is good.

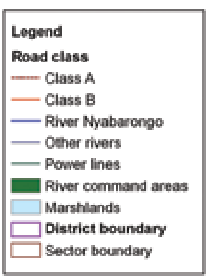


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories 0-6%	6-16%	16-40%	Total	% of total district command area
Gasabo	Lake/Muhazi	To be enumerated at site level	103	145	290	538	10.4%
	Marshlands		4623			4623	89.6%
Total			4726	145	290	5161	100.0%

Kicukiro District Irrigation Plan

Kicukiro district's command areas are constituted by river and marshlands domains. The river PIAs depend on the Nyabarongo river. The PIAs are located in the southern zone of the district. Kicukiro district has a total irrigation potential of 4 243 ha. Of these, 3 256 ha constitute the potential for marshlands, while the remaining 987 ha are suitable for conventional irrigation using water from the Nyabarongo. The irrigation water demand for both marshland and riverine command areas is approximately 31.82 Mm^3. The total irrigation water requirement for Kicukiro is about 40 Mm^3 partitioned into 32.6 Mm^3 for marshlands and 7.4 Mm^3 for riverine command areas. Access to road and electrical power grid to these sites is good.

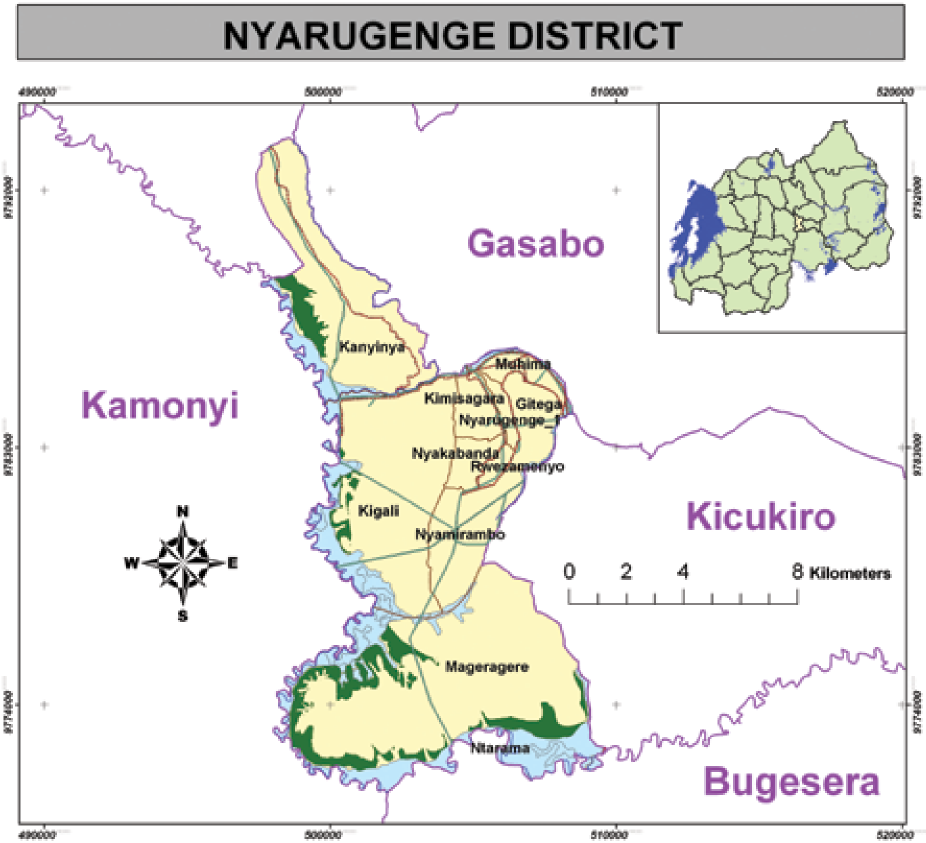




District	Water source/Name	Dominant soils	Command Area (Ha)				% of total district
			Slope categories			Total	
			0-6%	6-16%	16-40%	Total	
Kicukiro	River/Nyabarongo	To be enumerated at site level	338	584	65	987	23%
	Marshlands		3256			3256	76%
Total			3594	584	65	4243	99%

Nyarugenge District Irrigation Plan
Nyarugenge district has command areas represented in river and marshland domains. Riverine PIAs and marshlands are located along the Nyabarongo river.

A total of 3 393 ha have good potential for conventional irrigation in the district. Of these, the marshlands constitute the biggest portion with 2 370 ha (69.8%), while the rest belong to the river domain with 1 023 ha (30.2%). The total irrigation water requirement for Nyarugenge is about 31.37 Mm^3, partitioned into 23.7 Mm^3 for marshlands and 7.67 Mm^3 for riverine command areas. Access to road and electrical power grid to these sites is good.



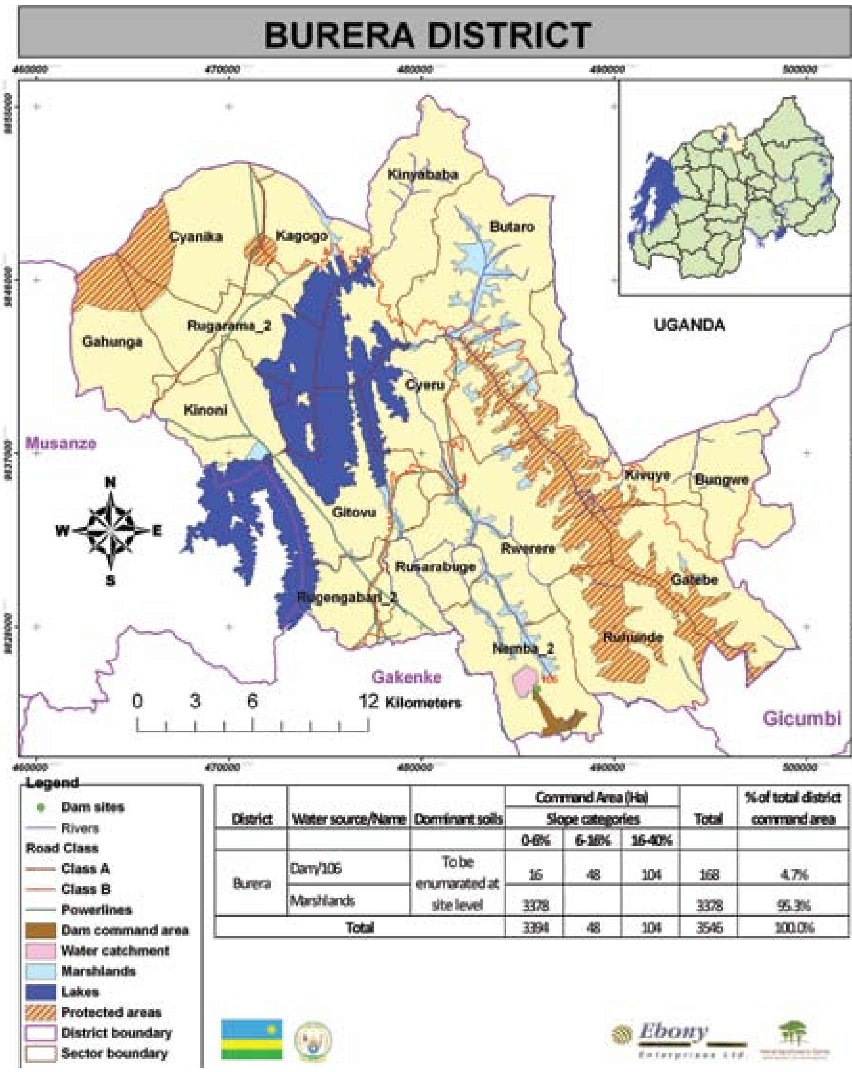
District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories 0-6%	6-16%	16-40%	Total	% of total district command area
Nyarugenge	River/Nyabarongo	To be enumarated at site level	136	464	423	1023	30.2%
	Marshlands		2370			2370	69.8%
Total			2506	464	423	3393	100.0%

NORTHERN PROVINCE

Burera District Irrigation Plan

The command areas of Burera district are constituted by marshlands and dam domains. The marshland PIAs spread centrally from the northern to the southern parts of the district.

A total of 3 546 ha have good potential for conventional irrigation in the district. Of these, the marshlands constitute the biggest portion with 3 378 ha (95.3%). The rest of the command areas belong to the dam domain with 168 ha (4.7%). The total irrigation water requirement for Burera is about 35.04 Mm^3 partitioned into 33.78 Mm^3 for marshlands and 1.26 Mm^3 for the dam command areas. Access to road and electrical power grid to these sites is good.

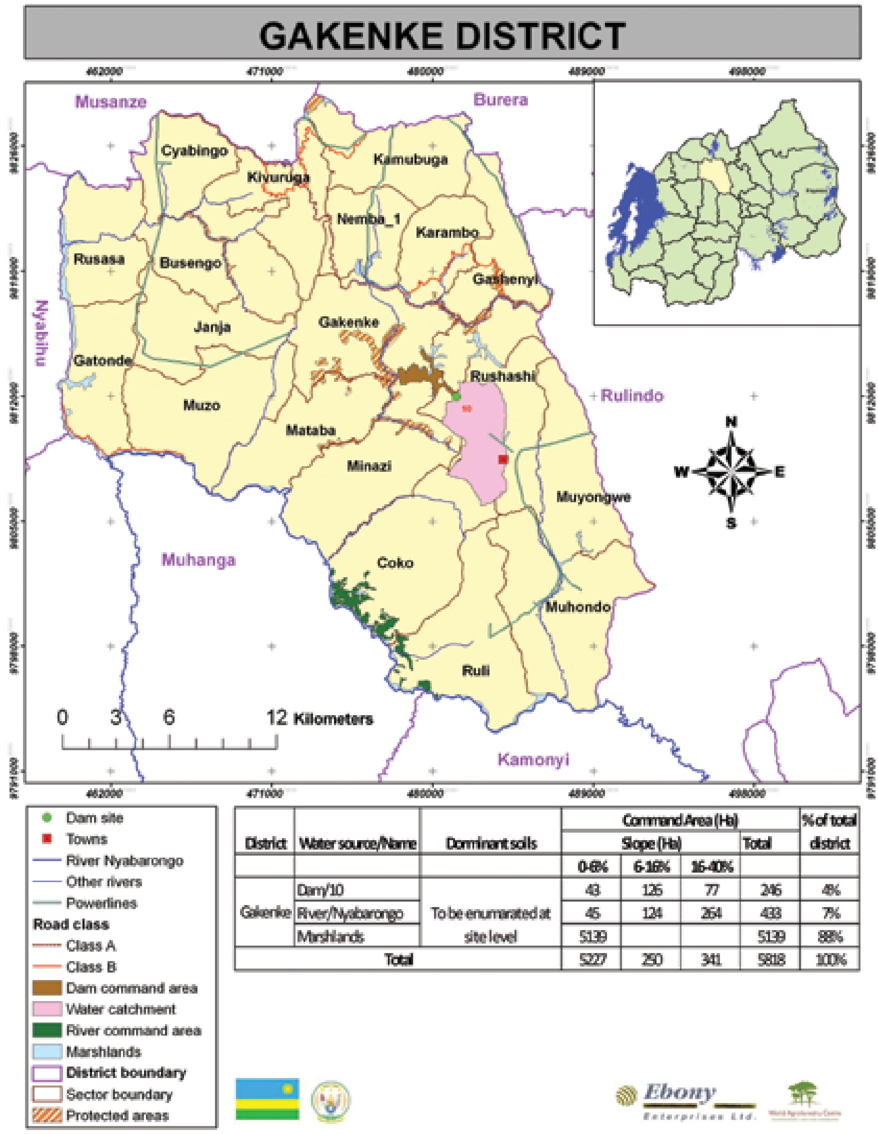


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories 0-6%	6-16%	16-40%	Total	% of total district command area
Burera	Dam/106	To be enumerated at site level	16	48	104	168	4.7%
	Marshlands		3378			3378	95.3%
Total			3394	48	104	3546	100.0%

Gakenke District Irrigation Plan

Gakenke district's command areas consist of marshlands, river and dam domains. The riverine command areas are located in the southwestern part of the district and depend on the Nyabarongo river for irrigation water.

A total of 5 818 ha have good potential for conventional irrigation in the district. The marshlands domain constitutes the biggest portion with 5 139 ha (88%). The rest of the command areas belong to the dam domain with 168 ha (4.7%). Total irrigation water requirement for Gakenke is about 56.5 Mm³, partitioned into 51.4 Mm³ for marshlands and 5.1 Mm³ for the dam command areas. Access to road and electrical power grid to these sites is good.

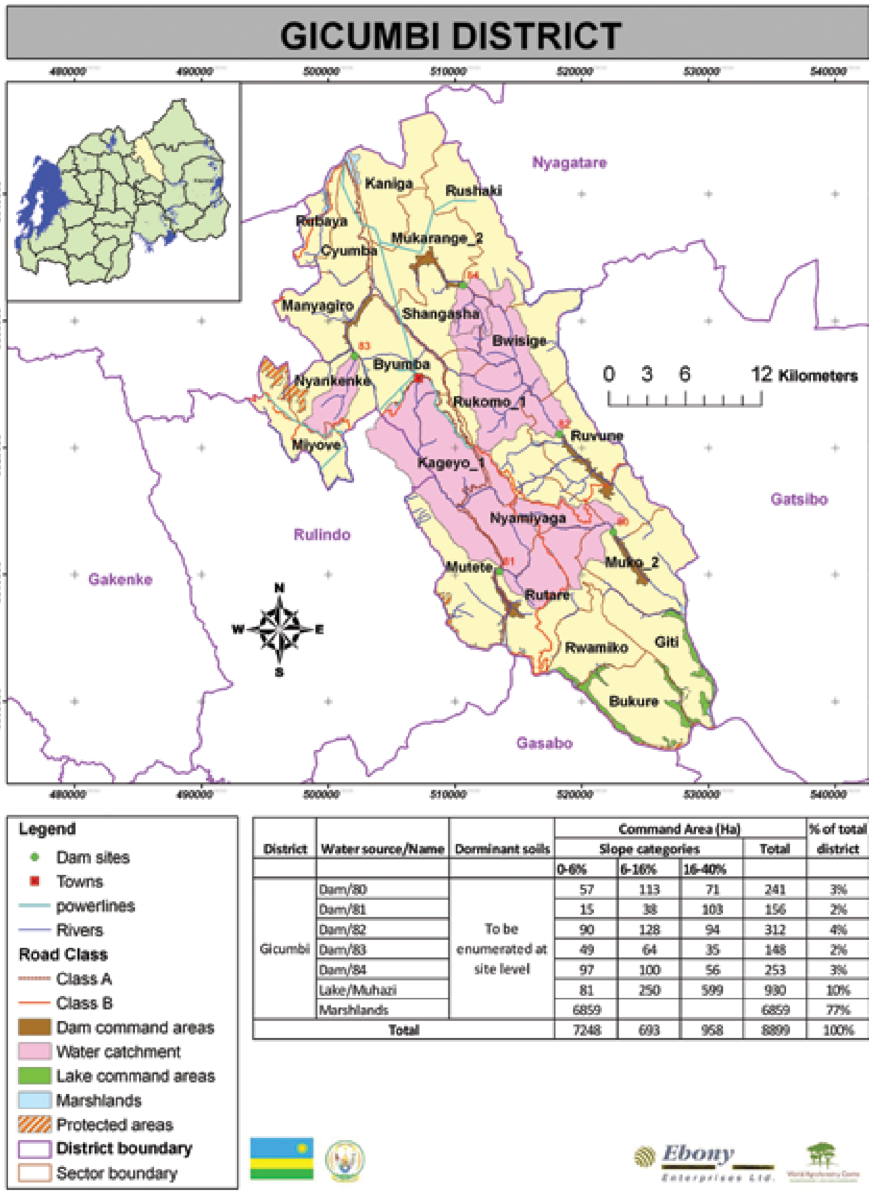


District	Water source/Name	Dominant soils	Command Area (Ha)				% of total district
			Slope (Ha)			Total	
			0-6%	6-16%	16-40%		
Gakenke	Dam/10	To be enumerated at site level	43	126	77	246	4%
	River/Nyabarongo		45	124	264	433	7%
	Marshlands		5139			5139	88%
Total			5227	250	341	5818	100%

Gicumbi District Irrigation Plan

Gicumbi district's command areas consist of marshlands, lake and dam domains. Whilst the dam PIAs are evenly spread in the district, the lake PIAs are located in the southern tip.

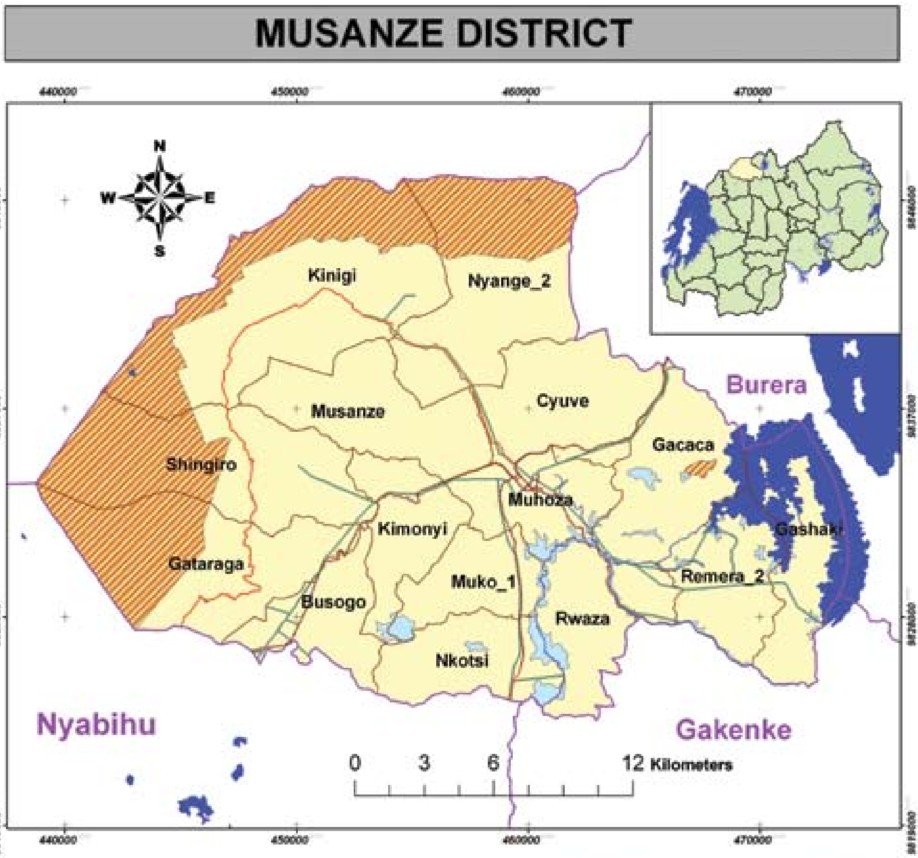
A total of 8 899 ha have good potential for conventional irrigation in the district, with marshlands occupying 8 659 ha (77%). The total irrigation water requirement for Gicumbi is about 86.6 Mm^3 for marshlands, with the rest claiming 15.3 Mm^3. Access to road and electrical power grid to these sites is good.



District	Water source/Name	Dominant soils	Command Area (Ha)				% of total district
			Slope categories			Total	
			0-6%	6-16%	16-40%		
Gicumbi	Dam/80	To be enumerated at site level	57	113	71	241	3%
	Dam/81		15	38	103	156	2%
	Dam/82		90	128	94	312	4%
	Dam/83		49	64	35	148	2%
	Dam/84		97	100	56	253	3%
	Lake/Muhazi		81	250	599	930	10%
	Marshlands		6859			6859	77%
Total			7248	693	958	8899	100%

Musanze District Irrigation Plan
Musanze district's command areas consist of marshlands domain. The marshlands are located in the eastern and southern parts of the district.

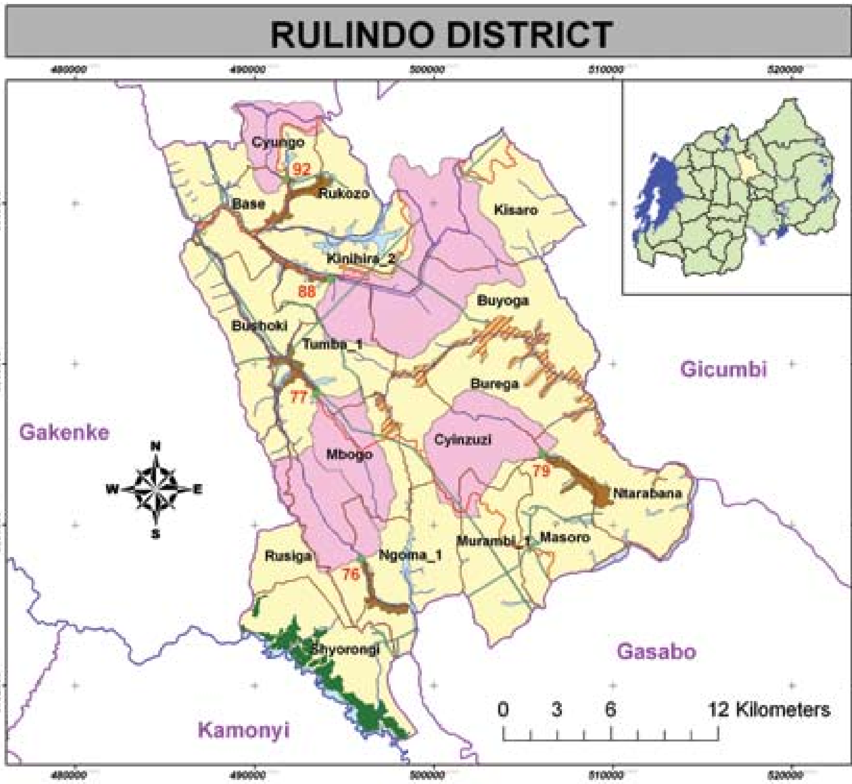
A total of 1 616 ha, all under the marshlands domain, have good potential for conventional irrigation in the district. The total irrigation water requirement for Musanze is about 16.16 Mm^3 for marshlands. Access to road and electrical power grid to these sites is good.



District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Musanze	Marshlands	To be enumarated at site level	1616			1616	100.0%
Total			1616	0	0	1616	100.0%

Rulindo District Irrigation Plan
Rulindo district's command areas consist of river, marshlands and dam domains. The riverine PIAs are all located on the southern border of the district adjacent to the Nyabarongo river. The rest of the PIAs are evenly spread throughout the district.

PIAs in Rulindo occupy an area of 8 947 ha with good potential for conventional irrigation. Of these, the marshlands domain occupy 7112 ha (79.5%). PIAs for the river and dam domains occupy 884 ha (9.9%) and 734 ha (8.2%), respectively. The total irrigation water requirement for Rulindo district is about 84.9 Mm^3, partitioned into 71.1 Mm^3 for marshlands and 13.8 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.



District	Water source/Name	Dorminant soils	Command Area (Ha) Slope categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Rulindo	Dam/76	To be enumarated at site level	44	62	62	168	1.9%
	Dam/77		88	80	19	187	2.1%
	Dam/79		57	99	134	290	3.2%
	Dam/88		48	39	2	89	1.0%
	Dam/92		45	67	105	217	2.4%
	River/Nyabarongo		150	377	357	884	9.9%
	Marshlands		7112			7112	79.5%
Total			7544	724	679	8947	100.0%

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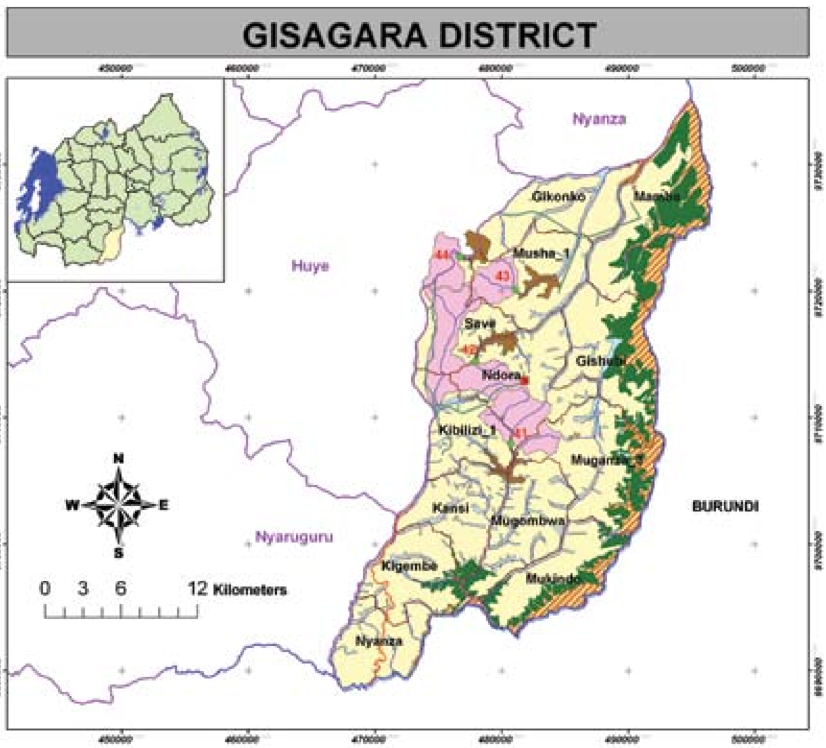
SOUTHERN PROVINCE

Gisagara District Irrigation Plan

Gisagara district has command areas represented in marshlands, river and dam domains. The riverine PIAs are all along the Akanyaru river, whilst the dam PIAs are mostly in the central and northwestern part of the district.

A total of 24 180 ha have good potential for conventional irrigation in the district, with marshlands occupying the largest portion with 15 324 ha (63%). The total irrigation water requirement for Gisagara is about 153.24 Mm^3 for marshlands, with the rest accounting for 66.42 Mm^3. Access to road and electrical power grid to these sites is good.

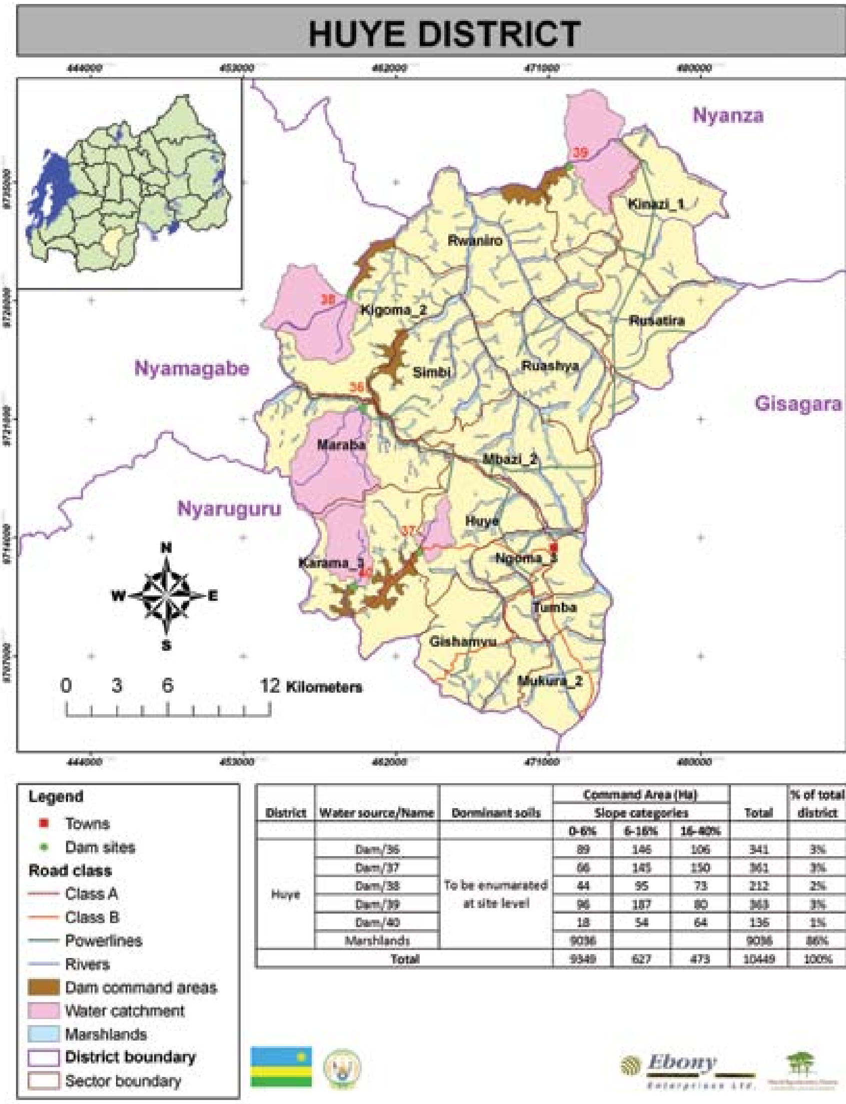


District	Water source/Name	Dominant soils	Command Area (Ha)				% of total district
			Slope categories			Total	
			0-6%	6-16%	16-40%		
Gisagara	Dam/41	To be enumerated at site level	83	144	86	313	1%
	Dam/42		64	121	115	300	1%
	Dam/43		53	121	152	326	1%
	Dam/44		28	107	198	333	1%
	River/Akanyaru		1258	2857	3469	7584	31%
	Marshlands		15324			15324	63%
Total			16810	3350	4020	24180	100%

Huye District Irrigation Plan

Huye district has dam and marshland irrigation domains with a total PIA of 10 449 ha. The marshlands PIA constitutes 86.5% of the area at 9 036 ha, with dams occupying the remaining 13.5% at 1 409 ha. These sites, which have good access to electricity and roads, will require about 78.4 Mm^3 of water to satisfy crop water demand.

A total of 24 180 ha have good potential for conventional irrigation in the district, with marshlands occupying the largest portion with 15 324 ha (63%). The total irrigation water requirement for Huye is about 101 Mm^3, with the marshlands requiring 90.4 and the rest 10.6 Mm^3. Access to road and electrical power grid to these sites is good.

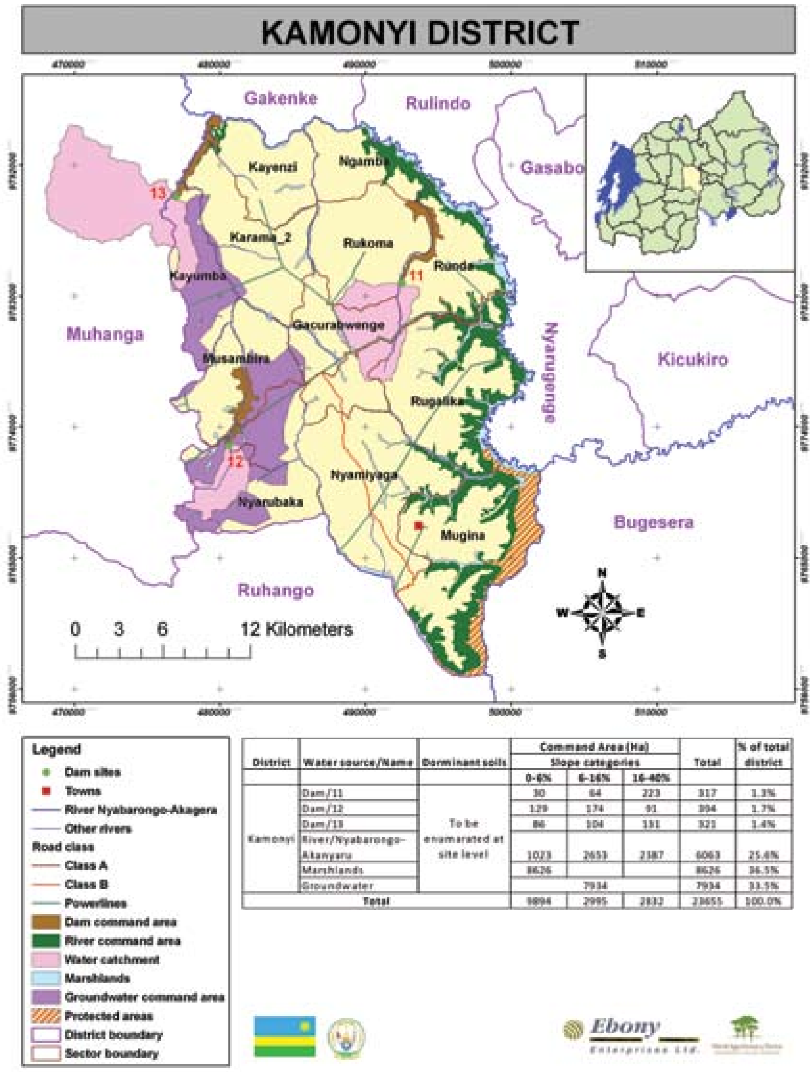


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district
			0-6%	6-16%	16-40%		
Huye	Dam/36	To be enumarated at site level	89	146	106	341	3%
	Dam/37		66	145	150	361	3%
	Dam/38		44	95	73	212	2%
	Dam/39		96	187	80	363	3%
	Dam/40		18	54	64	136	1%
	Marshlands		9036			9036	86%
Total			9349	627	473	10449	100%

Kamonyi District Irrigation Plan

Kamonyi district's command areas consist of groundwater, river, marshlands and dam domains. Riverine PIAs are all located on the eastern part of the district adjacent to Nyabarongo and Akanyaru rivers. Other than one dam PIA located in the eastern part of the district, the other domains are spread throughout the western boundaries of the district.

Kamonyi has a total of 23 655 ha of land with good potential for conventional irrigation. The marshlands, groundwater and river domains occupy 8 626 ha (36.5%), 7 934 (33.5%) and 6 063 ha (25.6%), respectively. The rest of the command areas belong to the dam domain with about 1 032 ha (4.4%). The total irrigation water requirement for Kamonyi district is about 199 Mm^3; partitioned into 86.3 Mm^3 for marshlands and 112.7 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

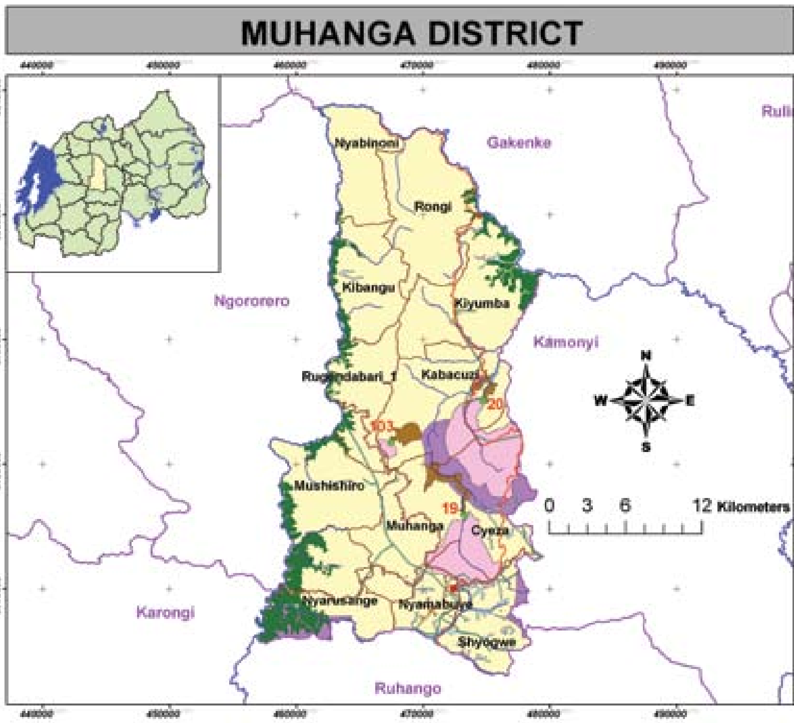


District	Water source/Name	Dorminant soils	Command Area (Ha) Slope categories			Total	% of total district
			0-6%	6-16%	16-40%		
Kamonyi	Dam/11	To be enumarated at site level	30	64	223	317	1.3%
	Dam/12		129	174	91	394	1.7%
	Dam/13		86	104	131	321	1.4%
	River/Nyabarongo-Akanyaru		1023	2653	2387	6063	25.6%
	Marshlands		8626			8626	36.5%
	Groundwater			7934		7934	33.5%
Total			9894	2995	2832	23655	100.0%

Muhanga District Irrigation Plan

Over 70% of Muhanga district falls into ACZ 7, with the remainder into ACZ 8. The larger portion of the district encompasses the Central Plateau with the rest forming part of the Granitic Ridge. It has varied slope ranges with a geomorphology of angular hills, rounded hills and headlands. The district generally has soils with depths greater than 1m consisting largely of clayey to fine clay formations.

The command areas for Muhanga district consist of river, marshlands, groundwater and dam domains. A total of 14 551 ha have good potential for irrigation in the district. Of these, the marshlands, groundwater and river domains have almost equal portions of 4 462 ha (30.7%), 4 747 ha (32.6%) and 4 575 ha (31.4%), respectively. The rest of the command areas belong to the dam domain, covering an area of 767 ha (5.3%). The total irrigation water requirement for Muhanga is about 120.3 Mm^3; partitioned into 44.6 Mm^3 for marshlands and 75.7 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

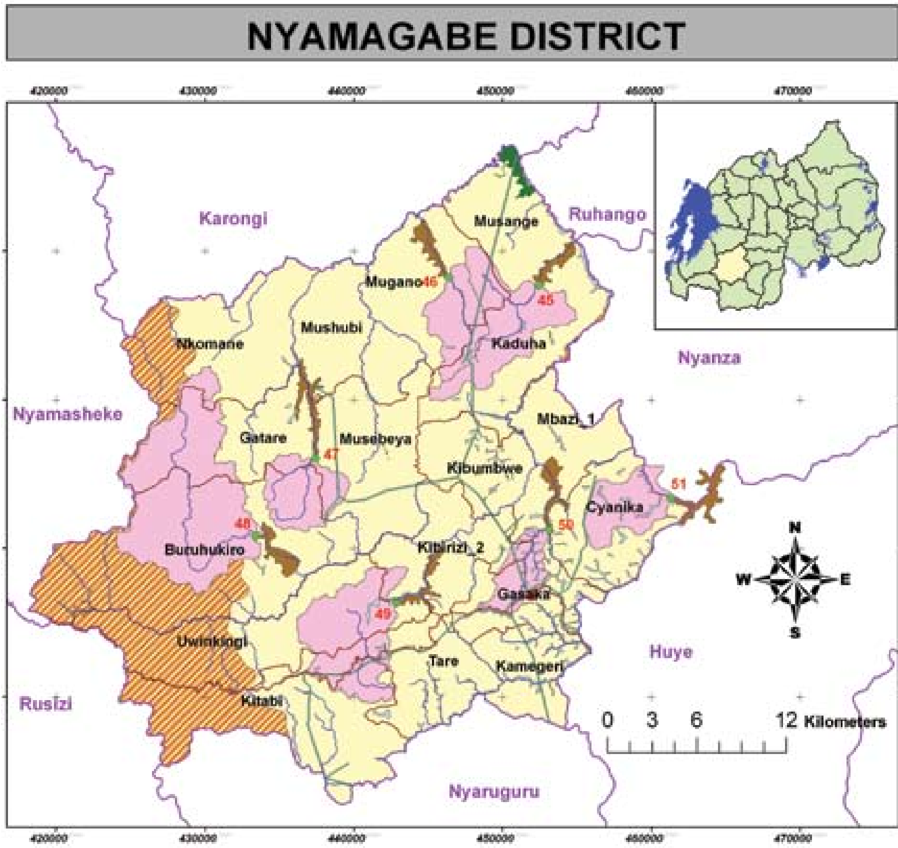


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories 0-6%	6-16%	16-40%	Total	% of total district command area
Muhanga	Dam/19	To be enumarated at site level	46	113	177	336	2.3%
	Dam/20		36	80	54	170	1.2%
	Dam/103		17	75	169	261	1.8%
	River/Nyabarongo		533	1341	2701	4575	31.4%
	Marshlands		4462			4462	30.7%
	Groundwater			4747		4747	32.6%
Total			5094	1609	3101	14551	100.0%

Nyamagabe District Irrigation Plan

Nyamagabe district's command areas consist of river, marshland and dam domains. These are evenly spread, presenting an opportunity for different types of irrigation to be established. A total of 6 845 ha of land has good potentials for conventional irrigation in the district. Of these, the marshlands constitute the largest area with 4 478 ha (65.4%). The remaining 34.6% of the area is shared by PIAs in dam and river domains.

The total irrigation water requirement for Nyamagabe is about 62.5 Mm^3, partitioned into 44.8 Mm^3 for marshlands and 17.7 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

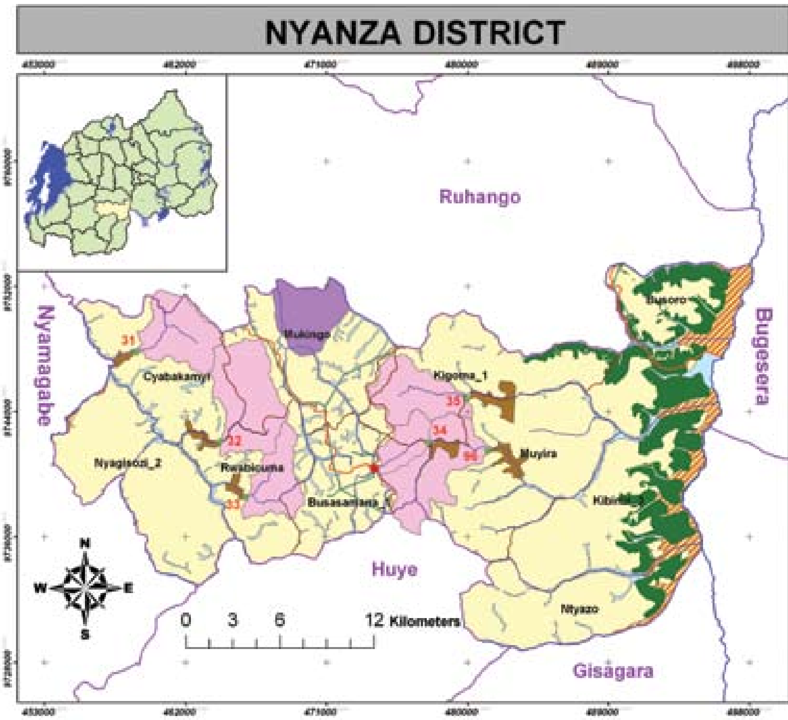


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories 0-6%	6-16%	16-40%	Total	% of total district command area
Nyamagabe	Dam/45	To be enumarated at site level	17	65	134	216	3.2%
	Dam/46		30	85	171	286	4.2%
	Dam/47		73	143	129	345	5.0%
	Dam/48		27	69	197	293	4.3%
	Dam/49		34	76	124	234	3.4%
	Dam/50		29	97	167	293	4.3%
	Dam/51		78	161	158	397	5.8%
	River/Nyabarongo		27	70	206	303	4.4%
	Marshlands		4478			4478	65.4%
Total			4793	766	1286	6845	100.0%

Nyanza District Irrigation Plan

Nyanza district has command areas consisting of groundwater, river, marshlands and dam domains. Riverine PIAs are located along the Akanyaru river with a minimum flow rate of about 7.5m s^{-1} at the entry point of the district in Ntyazo sector, increasing to 7.7m s^{-1} at the outlet in Busoro sector.

A total of 19 474 ha have good potential for conventional irrigation in the district. Of these, the marshlands constitute the largest area with 10 970 ha (56.1%),followed by the river and groundwater domains with 5 976 ha (30.6%) and 1 633 ha (8.4%), respectively. The rest of the command areas belong to the dam domain constituting 954 ha (4.6%) of the total irrigation potential for the district. The total irrigation water requirement for Nyanza is about 173.36 Mm^3, partitioned into 109.2 Mm^3 for marshlands and 64.2 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

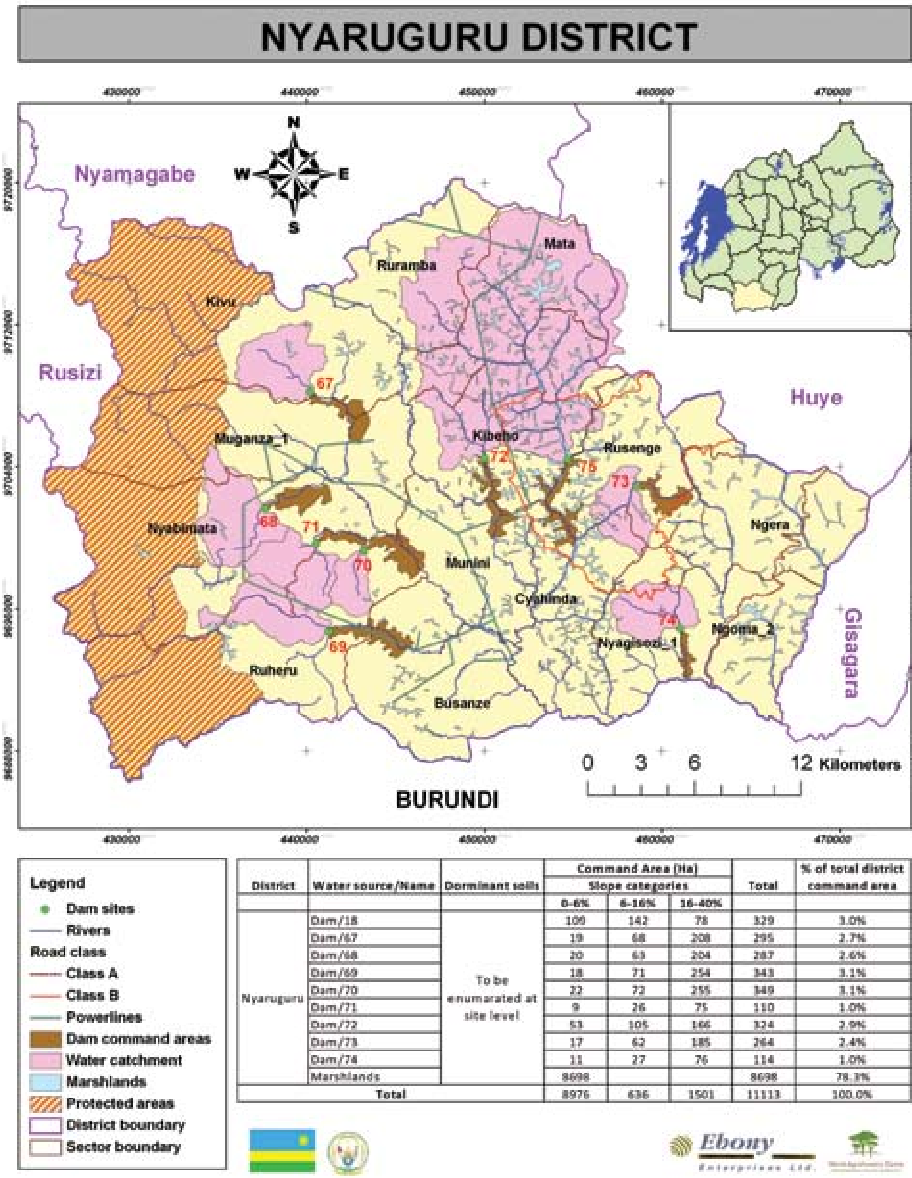


District	Water source/Name	Dominant soils	Command Area (Ha)				% of total district command area
			Slope categories			Total	
			0-6%	6-16%	16-40%		
Nyanza	Dam/31	To be enumerated at site level	10	26	30	66	0.3%
	Dam/32		18	58	51	127	0.7%
	Dam/33		19	45	30	94	0.5%
	Dam/34		24	62	44	130	0.7%
	Dam/35		79	185	46	310	1.6%
	Dam/96		64	127	36	227	1.2%
	River/Akanyaru		1310	3501	1156	5967	30.6%
	Marshlands		10920			10920	56.1%
	Groundwater			1633		1633	8.4%
Total			12444	4004	1393	19474	100.0%

Nyaruguru District Irrigation Plan

Nyaruguru district has an even distribution of command areas for marshlands and dam domains. According to the IMP study for Rwanda, PIAs in Nyaruguru occupy an area of 11 113 ha of the land with good potential for conventional irrigation. Of these, the marshlands domain has an area of 8 698 ha (78.3%), with the remainder in the dam domain.

The total irrigation water requirement for Nyaruguru district is 105.1 Mm^3, partitioned into 87 Mm^3 for marshlands and 18.1 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

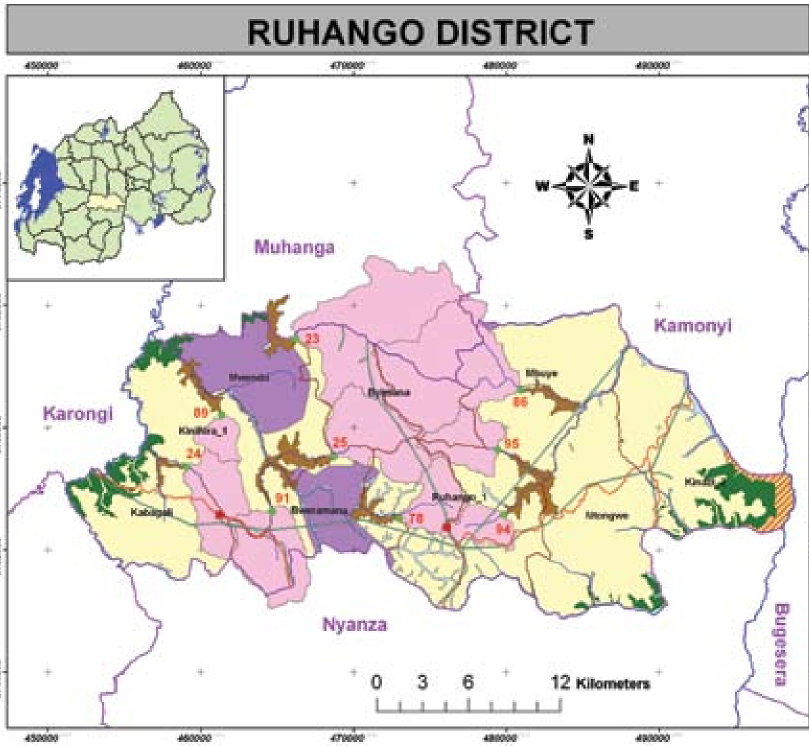


District	Water source/Name	Dorminant soils	Command Area (Ha) Slope categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Nyaruguru	Dam/18	To be enumarated at site level	109	142	78	329	3.0%
	Dam/67		19	68	208	295	2.7%
	Dam/68		20	63	204	287	2.6%
	Dam/69		18	71	254	343	3.1%
	Dam/70		22	72	255	349	3.1%
	Dam/71		9	26	75	110	1.0%
	Dam/72		53	105	166	324	2.9%
	Dam/73		17	62	185	264	2.4%
	Dam/74		11	27	76	114	1.0%
	Marshlands		8698			8698	78.3%
Total			8976	636	1501	11113	100.0%

Ruhango District Irrigation Plan

Ruhango district has command areas consisting of groundwater, river, marshland and dam domains. Riverine PIAs are located along the Akanyaru and Nyabarongo rivers on the eastern and western borderlines, leaving the dam and groundwater domains evenly spread throughout the district.

A total of 21 314 ha have good potential for conventional irrigation in the district. Of these, the marshland and groundwater domains constitute 9 130 ha (42.8%) and 8 322 ha (39%), respectively. The rest of the command areas belong to the river and dam domains. The total irrigation water requirement for Ruhango is about 182.7 Mm^3, partitioned into 91.4 Mm^3 for marshlands and 91.3 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.



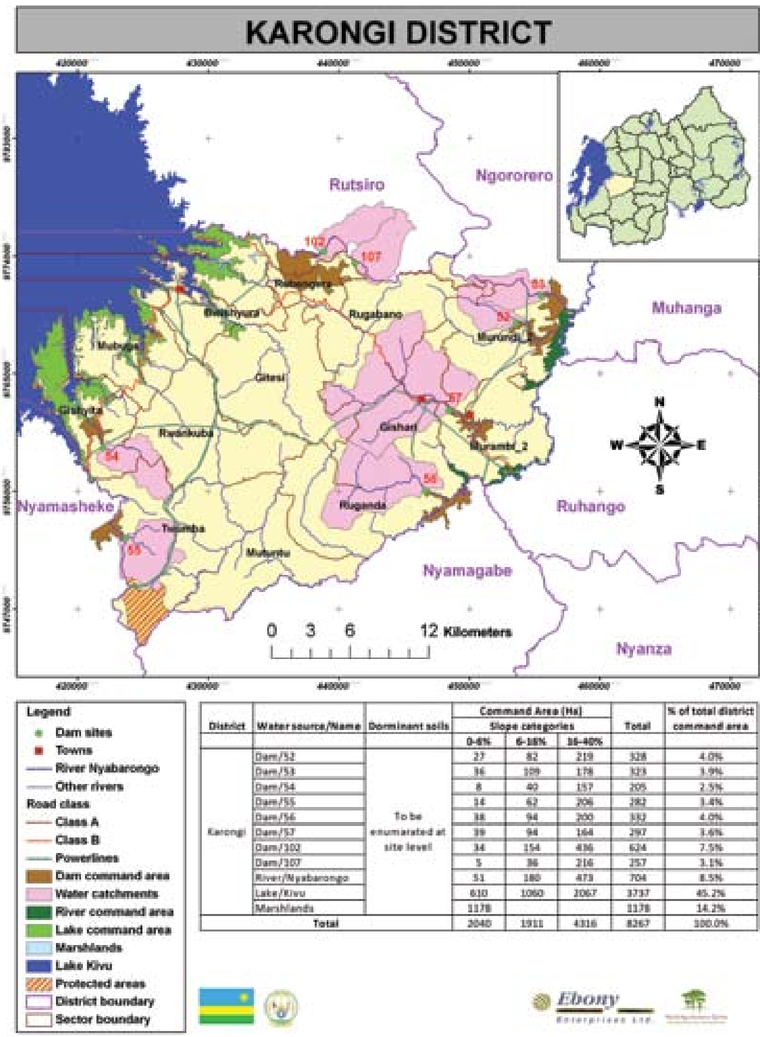
District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Ruhango	Dam/23	To be enumerated at site level	49	116	137	302	1.4%
	Dam/24		18	43	44	105	0.5%
	Dam/25		43	100	173	316	1.5%
	Dam/78		149	65	4	218	1.0%
	Dam/86		89	105	28	222	1.0%
	Dam/89		53	116	97	266	1.2%
	Dam/91		74	90	86	250	1.2%
	Dam/94		125	183	24	332	1.6%
	Dam/95		78	106	36	220	1.0%
	River/Nyabarongo-Akanyaru		359	119	1153	1631	7.7%
	Marshlands		9130			9130	42.8%
	Groundwater			8322		8322	39.0%
Total			10167	1043	1782	21314	100.0%

WESTERN PROVINCE

Karongi District Irrigation Plan

Karongi district's command areas consist of lake, river, marshland and dam domains. The riverine PIAs are located along the Nyabarongo River; while the lake PIAs depend on lake Kivu. The dam PIAs are all located along the border of the district with some of them having trans-boundary command areas sharing with Ngororero, Nyamashake and Nyamagabe districts.

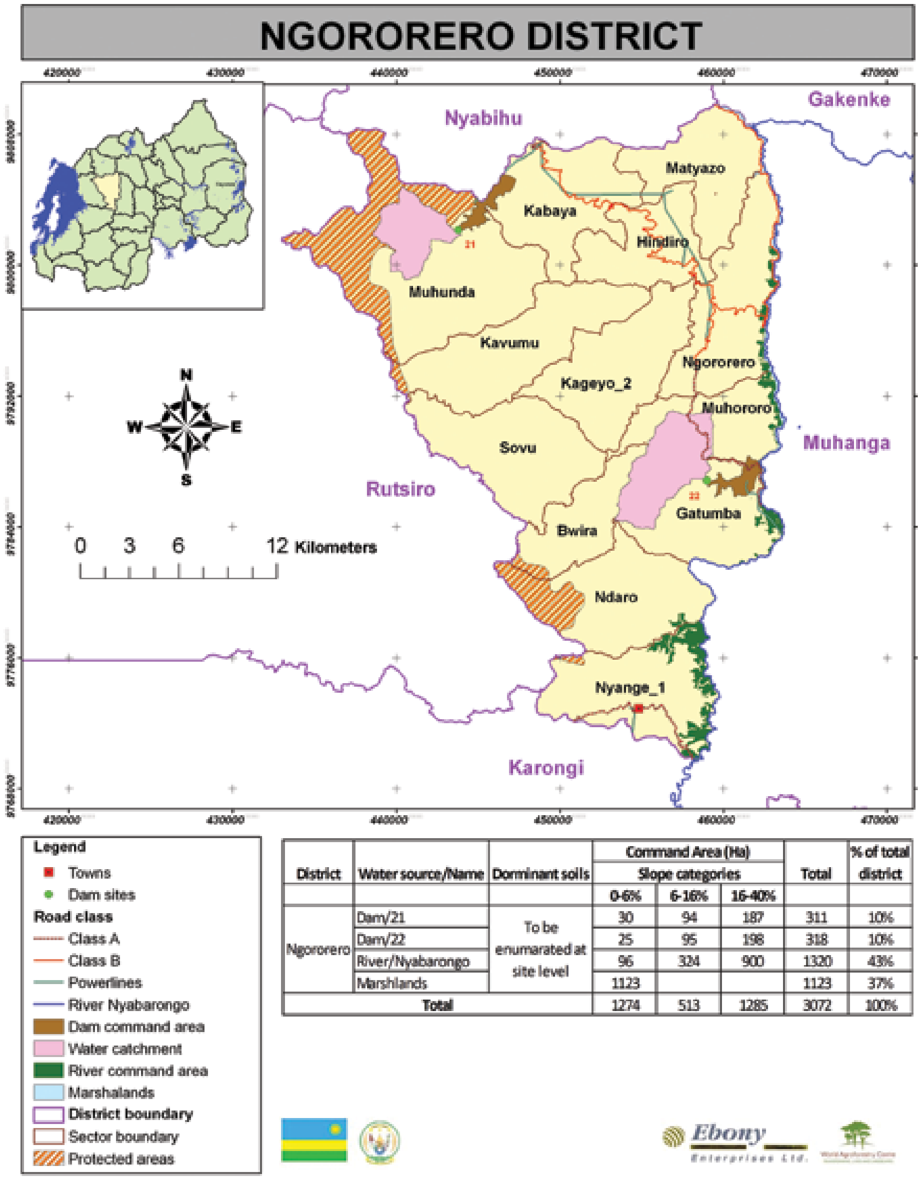
The IMP study for Rwanda indicates that a total of 8267 ha have good potential for conventional irrigation in the district. Of these, the lake domain constitutes the biggest percentage at 3737 ha (45.2%), followed by the dam domain at 2 648 ha (32%). The total irrigation water requirement for Karongi is about 65 Mm^3, partitioned into 11.8 Mm^3 for marshlands and 53.2 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.



District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Karongi	Dam/52	To be enumerated at site level	27	82	219	328	4.0%
	Dam/53		36	109	178	323	3.9%
	Dam/54		8	40	157	205	2.5%
	Dam/55		14	62	206	282	3.4%
	Dam/56		38	94	200	332	4.0%
	Dam/57		39	94	164	297	3.6%
	Dam/102		34	154	436	624	7.5%
	Dam/107		5	36	216	257	3.1%
	River/Nyabarongo		51	180	473	704	8.5%
	Lake/Kivu		610	1060	2067	3737	45.2%
	Marshlands		1178			1178	14.2%
Total			2040	1911	4316	8267	100.0%

Ngororero District Irrigation Plan

Ngororero district has dam, river and marshland irrigation domains, and a total PIA of 3 072 ha partitioned as 629 ha, 1 320 ha and 1 123 ha respectively. The river and dam command areas are all located along border of the district with the latter to depend on river Nyabarongo. These sites, which have good access to electricity and roads will require about 18.3 Mm^3 of water to satisfy crop water demand. Of this, the marshlands will require 2.7 Mm^3, with the rest going to the dams and river command areas.

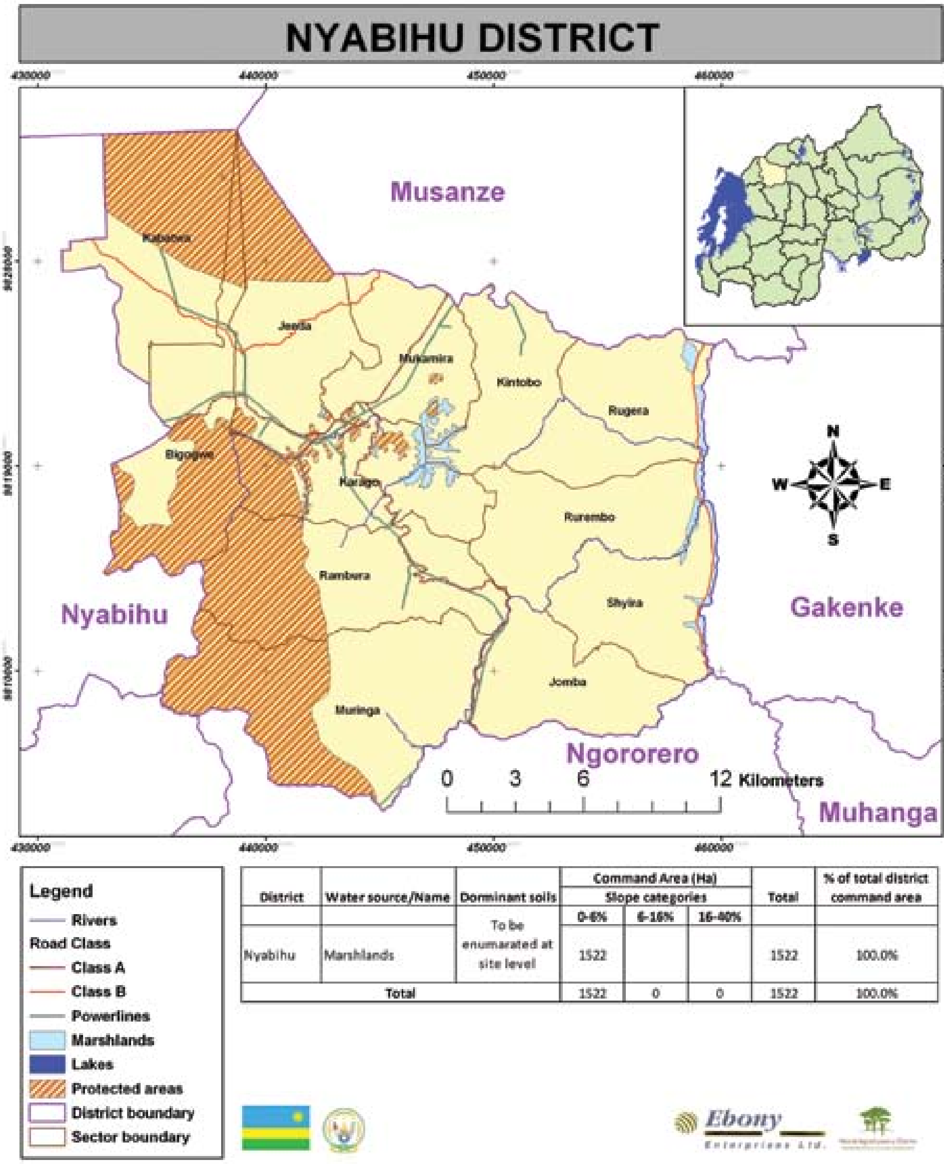


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district
			0-6%	6-16%	16-40%		
Ngororero	Dam/21	To be enumarated at site level	30	94	187	311	10%
	Dam/22		25	95	198	318	10%
	River/Nyabarongo		96	324	900	1320	43%
	Marshlands		1123			1123	37%
Total			1274	513	1285	3072	100%

Nyabihu District Irrigation Plan

Nyabihu district's command areas consist chiefly of marshland domain. Marshland PIAs are all located in the central and eastern parts of the district.

A total of 1 522 ha of land have good potential for conventional irrigation under the marshlands domain in the district. The total irrigation water requirement for Nyabihu is about 15.22 Mm^3 for marshlands. Access to road and electrical power grid to these sites is good.

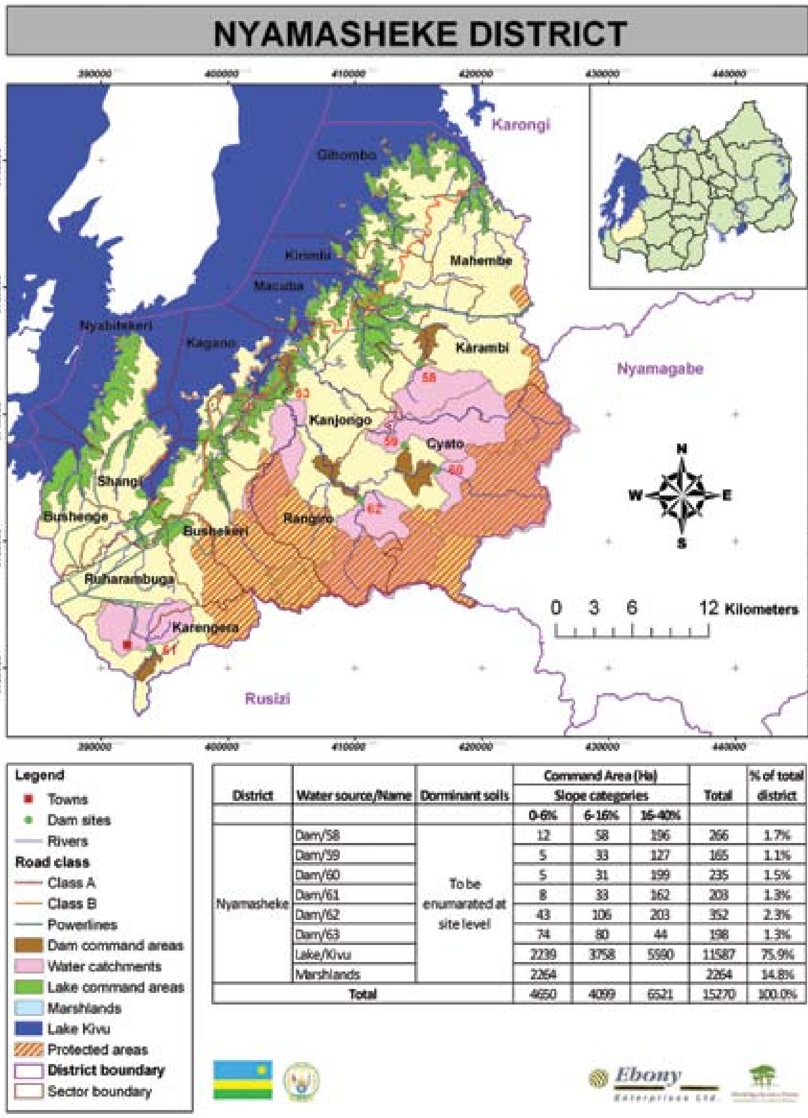


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Nyabihu	Marshlands	To be enumarated at site level	1522			1522	100.0%
Total			1522	0	0	1522	100.0%

Ramasheke District Irrigation Plan

Ramasheke district's command areas consist of lake, marshlands and dam domains. These areas are evenly spread along the corridor adjoining Lake Kivu. A major portion of the district is already designated as a protected area. A total of 15 270 ha have good potential for conventional irrigation in the district. Of these, the lake domain constitutes the largest area with 11 587 ha (75.9%), followed by the marshlands with a PIA of about 2 264 ha (14.8%). The rest of the command areas belong to the dam domain, constituting 1 419 (9.3%) of the total irrigation potential.

The total irrigation water requirement for Ramasheke is about 120.1 Mm^3, partitioned into 22.6 Mm^3 for marshlands and 97.5 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

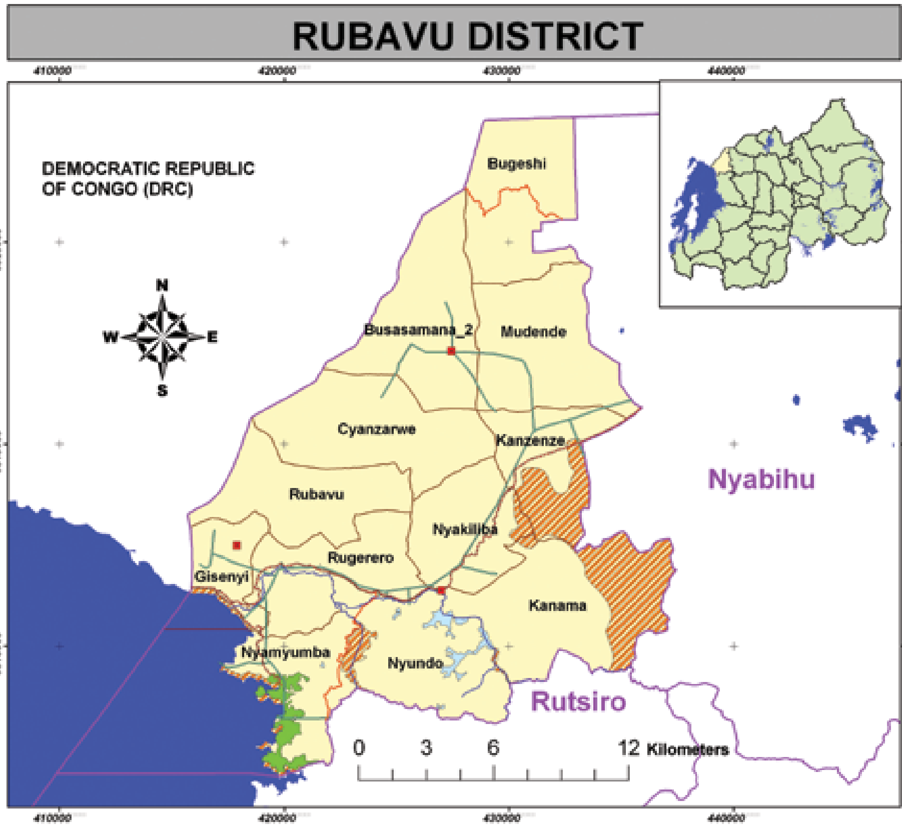


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district
			0-6%	6-16%	16-40%		
Nyamasheke	Dam/58	To be enumarated at site level	12	58	196	266	1.7%
	Dam/59		5	33	127	165	1.1%
	Dam/60		5	31	199	235	1.5%
	Dam/61		8	33	162	203	1.3%
	Dam/62		43	106	203	352	2.3%
	Dam/63		74	80	44	198	1.3%
	Lake/Kivu		2239	3758	5590	11587	75.9%
	Marshlands		2264			2264	14.8%
Total			4650	4099	6521	15270	100.0%

Rubavu District Irrigation Plan

Rubavu district's command areas consist only of lake and marshland domains. Both are located in the southern part of the district with the lake domains bordering Lake Kivu.

A total of 750 ha have good potential for conventional irrigation in Rubavu district. The marshlands constitute 367 ha (48.9%) while the lake domain constitutes 383 ha (51%). The total irrigation water requirement for Rubavu is about 6.54 Mm^3, partitioned into 3.67 Mm^3 for marshlands and 2.88 Mm^3 for the lake command areas. Access to road and electrical power grid to these sites is good.



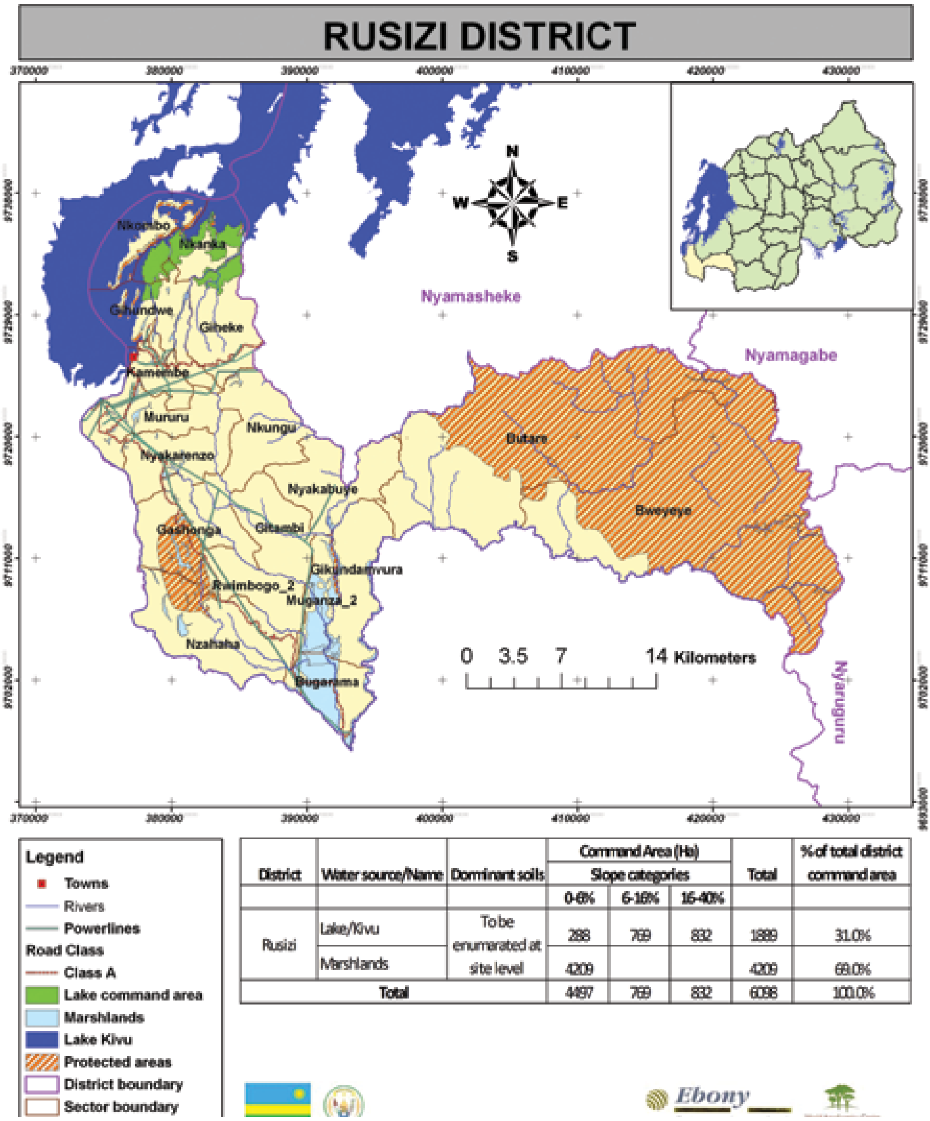
District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories 0-6%	6-16%	16-40%	Total	% of total district command area
Rubavu	Lake/Kivu	To be enumarated at site level	52	86	245	383	51.1%
	Marshlands		367			367	48.9%
Total			419	86	245	750	100.0%

Rusizi District Irrigation Plan

Rusizi district's command areas consist only of lake and marshlands domains. The marshland PIAs are located at the south central part of the district, while the lake PIAs depend on Lake Kivu.

A total of 6 098 have good potential for conventional irrigation in Rusizi district. Of these, the marshland domain constitutes the biggest percentage with 4 209 ha (69%) and the dam domain occupies the remaining 1 889 ha (31%).

The total irrigation water requirement for Rusizi is about 56.1 Mm^3, partitioned into 42.1 Mm^3 for marshlands and 14.2 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.

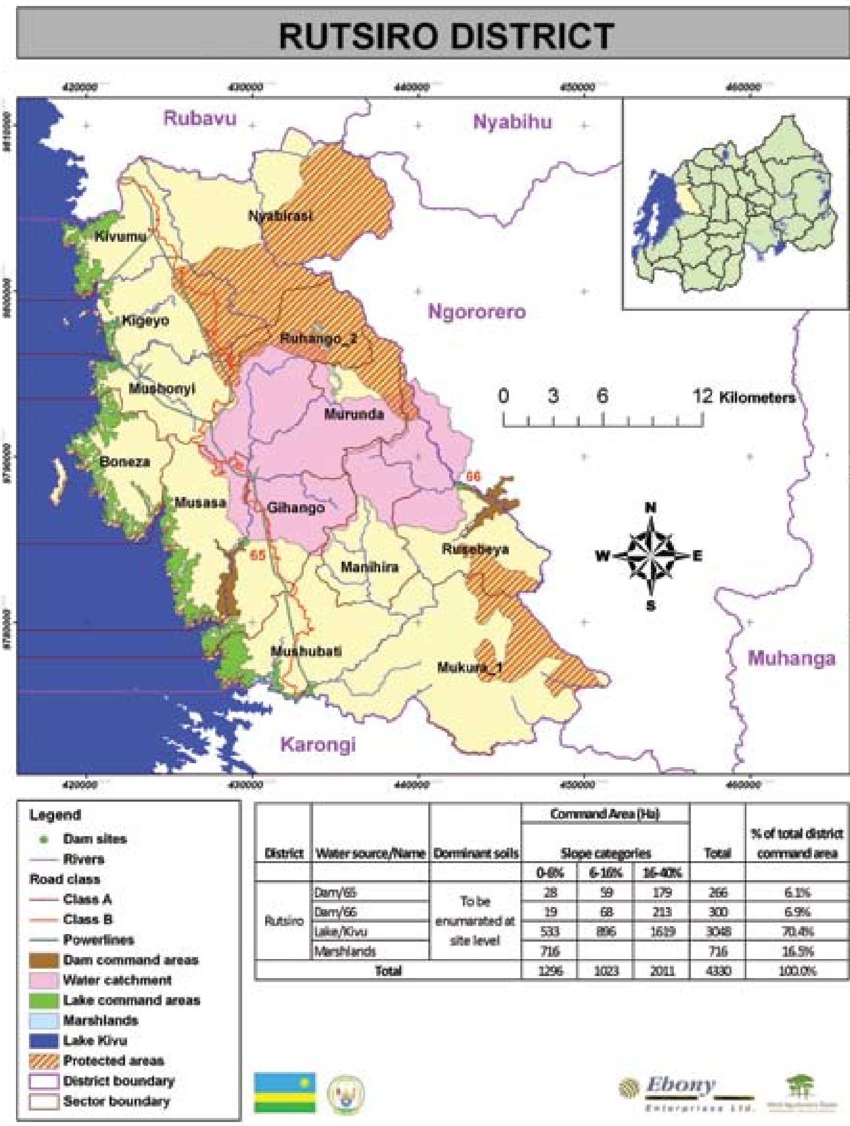


District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories			Total	% of total district command area
			0-6%	6-16%	16-40%		
Rusizi	Lake/Kivu	To be enumerated at site level	288	769	832	1889	31.0%
	Marshlands		4209			4209	69.0%
Total			4497	769	832	6098	100.0%

Rutsiro District Irrigation Plan

Rutsiro district's command areas consist of lake, marshlands and dam domains. PIAs within the lake domain occupy the largest area with 3 048 ha (70%). Water for irrigation for these PIAs will be abstracted from Lake Kivu. The marshlands account for 716 ha (17%) and the remaining 566 ha (13%) are occupied by PIAs in the dam domain.

The total irrigation water requirement for Rutsiro is about 34.3 Mm^3, partitioned into 7.16 Mm^3 for marshlands and 27.1 Mm^3 for the rest of the command areas. Access to road and electrical power grid to these sites is good.



District	Water source/Name	Dominant soils	Command Area (Ha) Slope categories 0-6%	6-16%	16-40%	Total	% of total district command area
Rutsiro	Dam/65	To be enumerated at site level	28	59	179	266	6.1%
	Dam/66		19	68	213	300	6.9%
	Lake/Kivu		533	896	1619	3048	70.4%
	Marshlands		716			716	16.5%
Total			1296	1023	2011	4330	100.0%

Annex 3: Potential command areas linked to water sources

ID	District	Water source/name	Command Area (ha) Slope categories			Total
			0-6%	6-16%	16-40%	
1	Burera	Dam/106	16	48	104	168
		Marshlands	3378	-	-	3378
2	Kicukiro	River/Nyabarongo	338	584	65	987
		Marshlands	3256	-	-	3256
3	Karongi	Dam/52	27	82	219	328
		Dam/53	36	109	178	323
		Dam/54	8	40	157	205
		Dam/55	14	62	206	282
		Dam/56	38	94	200	332
		Dam/57	39	94	164	297
		Dam/102	34	154	436	624
		Dam/107	5	36	216	257
		River/Nyabarongo	51	180	473	704
		Lake/Kivu	610	1060	2067	3737
		Marshlands	1178	-	-	1178
4	Rusizi	Lake/Kivu	288	769	832	1889
		Marshlands	4209	-	-	4209
5	Nyabihu	Marshlands	1522	-	-	1522
6	Rubavu	Lake/Kivu	52	86	245	383
		Marshlands	367	-	-	367
7	Gakenke	Dam/10	43	126	77	246
		River/Nyabarongo	45	124	264	433
		Marshlands	5139	-	-	5139
8	Ngororero	Dam/21	30	94	187	311
		Dam/22	25	95	198	318
		River/Nyabarongo	96	324	900	1320
		Marshlands	1123	-	-	1123
9	Nyarugenge	River/Nyabarongo	136	464	423	1023
		Marshlands	2370	-	-	2370

ID	District	Water source/name	Command Area (ha) Slope categories			Total
			0-6%	6-16%	16-40%	
10	Kirehe	Dam/26	123	24	0	147
		Dam/27	67	128	184	379
		Dam/28	104	96	32	232
		Dam/29	103	226	55	384
		Dam/30	57	90	20	167
		River/Akagera	8041	8710	2578	19 329
		Lake /Nasho, Cy-ambwe, Rwampanga	3925	1266	200	5391
		Marshlands	14 436	-	-	14 436
11	Ngoma	Dam/14	53	115	161	329
		Dam/15	68	117	83	268
		Dam/16	82	158	101	341
		Dam/17	98	161	53	312
		River/Akagera	361	786	367	1514
		Lake/Mugesera-Bili-ra-sake	9945	10 772	3213	23 930
		Marshlands	11 485	-	-	11 485
12	Nyamasheke	Dam/58	12	58	196	266
		Dam/59	5	33	127	165
		Dam/60	5	31	199	235
		Dam/61	8	33	162	203
		Dam/62	43	106	203	352
		Dam/63	74	80	44	198
		Lake/Kivu	2239	3758	5590	11 587
		Marshlands	2264	-	-	2264
13	Huye	Dam/36	89	146	106	341
		Dam/37	66	145	150	361
		Dam/38	44	95	73	212
		Dam/39	96	187	80	363
		Dam/40	18	54	64	136
		Marshlands	9036	-	-	9036

ID	District	Water source/name	Command Area (ha) Slope categories			Total
			0-6%	6-16%	16-40%	
14	Gisagara	Dam/41	83	144	86	313
		Dam/42	64	121	115	300
		Dam/43	53	121	152	326
		Dam/44	28	107	198	333
		River/Akanyaru	1258	2857	3469	7584
		Marshlands	15324	-	-	15324
15	Rwamagana	Dam/6	99	111	23	233
		Dam/7	98	131	57	286
		Dam/8	172	151	71	394
		Dam/9	176	124	38	338
		Dam/93	48	147	68	263
		Lake /Muhazi-Mugesera	2922	7028	2714	12 664
		River/Nyabarongo	103	384	343	830
		Marshlands	5268	-	-	5268
16	Kayonza	Dam/1	202	112	7	321
		Dam/2	176	1	0	177
		Dam/3	132	184	65	381
		Dam/4	126	97	12	235
		Dam/5	71	107	47	225
		Dam/85	214	80	0	294
		Dam/87	180	34	2	216
		Dam/105	152	117	12	281
		Lake /Ihema-Muhazi-Nasho	7646	4787	1154	13 587
		Marshlands	7984	-	-	7984
		Groundwater	6299			6299
17	Nyanza	Dam/31	10	26	30	66
		Dam/32	18	58	51	127
		Dam/33	19	45	30	94
		Dam/34	24	62	44	130
		Dam/35	79	185	46	310
		Dam/96	64	127	36	227
		River/Akanyaru	1310	3501	1156	5967
		Marshlands	10 920	-	-	10 920
		Groundwater	1633			1633

ID	District	Water source/name	Command Area (ha) Slope categories			Total
			0-6%	6-16%	16-40%	
18	Ruhango	Dam/23	49	116	137	302
		Dam/24	18	43	44	105
		Dam/25	43	100	173	316
		Dam/78	149	65	4	218
		Dam/86	89	105	28	222
		Dam/89	53	116	97	266
		Dam/91	74	90	86	250
		Dam/94	125	183	24	332
		Dam/95	78	106	36	220
		River/Nyabarongo-Akanyaru	359	119	1153	1631
		Marshlands	9130	-	-	9130
		Groundwater	8322			8322
19	Muhanga	Dam/19	46	113	177	336
		Dam/20	36	80	54	170
		Dam/103	17	75	169	261
		River/Nyabarongo	533	1341	2701	4575
		Marshlands	4462	-	-	4462
		Groundwater	4747			4747
20	Kamonyi	Dam/11	30	64	223	317
		Dam/12	129	174	91	394
		Dam/13	86	104	131	321
		River/Nyabarongo-Akanyaru	1023	2653	2387	6063
		Marshlands	8626	-	-	8626
		Groundwater	7934			7934
21	Gicumbi	Dam/80	57	113	71	241
		Dam/81	15	38	103	156
		Dam/82	90	128	94	312
		Dam/83	49	64	35	148
		Dam/84	97	100	56	253
		Lake/Muhazi	81	250	599	930
		Marshlands	6859	-	-	6859

ID	District	Water source/name	Command Area (ha) Slope categories			Total
			0-6%	6-16%	16-40%	
22	Rulindo	Dam/76	44	62	62	168
		Dam/77	88	80	19	187
		Dam/79	57	99	134	290
		Dam/88	48	39	2	89
		Dam/92	45	67	105	217
		River/Nyabarongo	150	377	357	884
		Marshlands	7112	-	-	7112
23	Nyaruguru	Dam/18	109	142	78	329
		Dam/67	19	68	208	295
		Dam/68	20	63	204	287
		Dam/69	18	71	254	343
		Dam/70	22	72	255	349
		Dam/71	9	26	75	110
		Dam/72	53	105	166	324
		Dam/73	17	62	185	264
		Dam/74	11	27	76	114
		Marshlands	8698	-	-	8698
24	Gatsibo	Dam/104	56	129	20	205
		Marshlands	16 398	-	-	16 398
		Lake/Muhazi	1082	2768	1458	5308
		Groundwater	7497			7497
25	Nyagatare	Dam/90	16	51	103	170
		Dam/97	250	66	-	316
		River/Akagera, Mu-vumba-Kagitumba	6994	7223	976	15193
		Marshlands	23 971	-	-	23 971
26	Nyamagabe	Dam/45	17	65	134	216
		Dam/46	30	85	171	286
		Dam/47	73	143	129	345
		Dam/48	27	69	197	293
		Dam/49	34	76	124	234
		Dam/50	29	97	167	293
		Dam/51	78	161	158	397
		River/Nyabarongo	27	70	206	303
		Marshlands	4478	-	-	4478

ID	District	Water source/name	Command Area (ha) Slope categories			Total
			0-6%	6-16%	16-40%	
27	Rutsiro	Dam/65	28	59	179	266
		Dam/66	19	68	213	300
		Lake/Kivu	533	896	1619	3048
		Marshlands	716	-	-	716
28	Musanze	Marshlands	1616	-	-	1616
29	Bugesera	Dam/98	95	223	2	320
		Dam/99	143	71		214
		Dam/100	178	186	4	368
		Dam/101	140	85	1	226
		River/Akanyaru-Nyabarongo	3477	6018	2012	11 507
		Lake/Cyohoha-Gashanga-Kidogo-Rumira-Mirayi-Kirimbi-Gaharwa	7343	9307	465	17 115
		Marshlands	23 845	-	-	23 845
30	Gasabo	Lake/Muhazi	103	145	290	538
		Marshlands	4623	-	-	4623
Total less small reservoirs		**464 086**				
Small reservoirs		125 626.7				
Grand total		**589 712.7**				

Annex 4: Potential dam points

Dam ID	X coordinate	Y ccordinate	Water catchment areas	Potential command area
1	561141.26	9797275.30	1757	321
2	565503.15	9782976.25	11543	177
3	555920.51	9775366.14	4817	381
4	571798.89	9777766.54	3986	234
5	552336.35	9782295.28	5281	225
6	540202.77	9775769.25	3445	233
7	533172.88	9773730.41	1826	287
8	531682.88	9782733.13	3233	394
9	528498.68	9777816.09	1116	337
10	481343.96	9811961.48	1739	248
11	492501.70	9783892.86	2655	378
12	480637.07	9772746.71	1123	394
13	476979.42	9789792.61	5307	324
14	560540.54	9758450.84	1352	328
15	557380.56	9750682.19	1610	269
16	558766.64	9765631.37	2689	341
17	567552.02	9765884.74	1408	312
18	454794.39	9704459.28	11681	330
19	473331.66	9775882.40	2067	356
20	474730.51	9785087.79	2960	170
21	443797.77	9802163.78	1497	333
22	459006.69	9786850.46	2440	325
23	466254.21	9765813.76	5088	303
24	459107.74	9757409.32	1948	105
25	468739.70	9758088.68	2606	318
26	557504.28	9745090.56	2564	147
27	567839.61	9745195.57	1705	378
28	573738.63	9753425.53	1577	232
29	575058.26	9759251.74	2190	384
30	573364.25	9746641.06	3593	166
31	458870.84	9747790.63	1786	67
32	464166.23	9742092.08	2598	126
33	465820.85	9738563.97	1364	95
34	477504.53	9742045.69	804	130
35	479964.34	9744826.34	1777	310

Dam ID	X coordinate	Y ccordinate	Water catchment areas	Potential command area
36	460062.34	9721634.69	2436	341
37	463409.67	9713129.44	472	361
38	459272.26	9728376.55	2045	212
39	472201.13	9736119.45	2037	362
40	459550.42	9711092.34	1073	136
41	480739.11	9707941.70	2063	314
42	477956.68	9714428.80	3377	300
43	481106.85	9720114.57	1013	327
44	476717.93	9722715.60	1013	334
45	452450.73	9747691.55	3484	220
46	446396.46	9748222.25	1902	290
47	437462.08	9736057.62	2173	345
48	433375.81	9730834.53	8365	320
49	442874.40	9726338.03	4182	253
50	453147.69	9731224.04	1490	305
51	461314.80	9733517.22	2018	396
52	453606.12	9768935.73	981	337
53	455504.66	9770979.82	1136	324
54	421960.96	9759307.03	1589	211
55	423672.52	9752374.18	1835	300
56	446641.30	9756009.51	3436	347
57	448463.42	9762202.27	6828	299
58	415112.69	9743993.10	1810	309
59	413923.42	9737565.56	6086	201
60	416465.77	9735580.16	5052	364
61	393897.83	9721580.60	2316	234
62	410426.92	9733247.47	5631	376
63	404446.17	9741240.02	2652	198
65	429611.01	9784887.27	9664	342
66	442503.08	9788202.06	4084	354
67	440209.61	9708227.57	1561	327
68	437651.39	9701650.96	1859	321
69	441269.78	9694722.65	1464	367
70	443214.14	9699276.73	640	387
71	440539.44	9699671.01	1361	124
72	450016.23	9704480.75	1527	324

Dam ID	X coordinate	Y ccordinate	Water catchment areas	Potential command area
73	458588.69	9702873.70	1080	267
74	461024.36	9694911.25	1190	123
76	495948.00	9799124.00	2372	168
77	493428.00	9808366.00	1995	187
78	473005.11	9754057.75	1284	218
79	506055.00	9805017.00	2918	291
80	522509.00	9813354.00	3033	244
81	513528.00	9810247.00	10523	205
82	518232.00	9821071.00	6261	313
83	502109.00	9827234.00	1323	149
84	510646.00	9832803.00	1143	254
85	572924.00	9806652.00	16767	295
86	480982.00	9762476.00	5077	222
87	558140.00	9808424.00	3570	216
88	494213.00	9814744.00	6233	88
89	461388.00	9760826.00	594	265
90	517727.00	9840018.00	10459	192
91	464688.00	9754513.00	2400	249
92	491738.00	9820377.51	1279	238
93	533849.00	9789858.00	1238	273
94	479853.97	9754307.07	892	332
95	479442.68	9758546.91	1475	219
96	481301.00	9741524.07	2391	227
97	523828.93	9849419.00	8041	316
98	521483.00	9753502.97	198	320
99	522618.84	9752554.28	123	214
100	514098.35	9763147.92	2671	369
101	503567.00	9759588.00	427	226
102	438867.68	9774328.25	1253	689
103	467484.51	9781737.56	148	270
104	528044.93	9823146.70	246	206
105	564944.03	9786234.17	252	281
106	486003.00	9824760.00	148	198
107	441260.42	9773470.40	1411	316

Annex 5: A comparative analysis for the selection of an organizational structure for irrigation management

Major criteria

1. Water resources – natural location and distribution policy			
	Central	Regional	Local
Grade	**	***	*

The distribution and natural location and supply of water throughout Rwanda is one of the major factors determining the proposed organizational structure. Factors to be considered: location, amount and quality available for irrigation, distribution over space and time.

Water resources in Rwanda are diverse—they include rivers, lakes, aquifers and wells. Data on water amounts, quality and consumption are limited in availability and scattered in time, but in general Rwanda has very large unexploited reserves of both surface and groundwater. These resources exceed the expected demand and bode well for the future development of irrigated agriculture. Anthropogenic pollution, however, threatens the use of these resources. The irregular distribution of water resources influences decisions on locating and managing irrigation projects. Moreover, destruction of vegetative cover, soil erosion and inappropriate drainage have contributed to a reduction in water availability with springs and lakes drying up.

2. PIAs – distribution and character			
	Central	Regional	Local
Grade	**	***	*

Rwanda's topographic structure for the most part consists of small, scattered farms only suited decentralised projects. However, if policy makers focus on larger projects over larger areas, the tendency will lead to concentrating efforts on the drier, eastern regions where better topographic conditions prevail, permitting larger contiguous plots more centralised management. Other factors such as soil types, water availability, land use and vegetation, type of potential crops to be grown in the area and their economic value, climatic conditions and rainfall patterns are also crucial in determining the potential areas. Social and cultural conditions should not be ignored as factors that can influence PIAs.

3. Water usage policy			
	Central	Regional	Local
Grade	***	**	*

Water resources are the public domain in Rwanda and controlled by the government, which encourages water users to coordinate and jointly manage water usage through WUAs. These associations must play a pivotal role in promoting efficient use of water sources.

4. Alternative organizational structures and controls			
4a. Plan, establish, supervise, monitor and maintain irrigation water supply projects			
	Central	**Regional**	**Local**
Grade	**	***	*
Comprehensive action regarding water management organization is best handled within a regional framework because regional incentives are highest. Acquaintance with the regional land and water layout as well as familiarity with the regional inhabitants and leaders will facilitate operations.			
4b. Manage natural water resources for irrigation in an environmentally sustainable manner			
	Central	**Regional**	**Local**
Grade	***	***	*
Environmental issues can be administered at a central or regional level. In most cases, environmental policy is best directed at the central level. However, action and maintenance should be managed regionally. Village or other small political entities are rarely in a position to manage environmental issues.			
4c. Ensure long-term reliable water supply for irrigation			
	Central	**Regional**	**Local**
Grade	***	***	*
Strict planning, including professional assessment of water source capacity and sustainability, are imperative to ensure long-term water supply. This can best be achieved through high-level, coordinated analysis of water sources combined with ongoing monitoring and periodical re-assessment. Central or regional agencies coordinated by a central regulatory and planning entity are required to fulfill this objective. Small localised water organizations are unsuitable for administering and monitoring long-term supply.			

Organizational objectives

5. Manage water supply in a cost-effective manner to ensure long-term economic stability of the supply mechanism			
	Central	**Regional**	**Local**
Grade	**	***	**
Cost effectiveness will be ensured by combining the functions of operating the water supply system and managing its financial aspects. Strong operational management is best managed by regional authorities, whereas fund-raising (from central organizations and NGOs) is best administered centrally. Ultimately, water will be supplied at a cost. Fee collection at a regional level will require local or regional administration for efficient collection.			

6. Provide agricultural and technical know-how regarding crop irrigation and irrigated agricultural production			
	Central	**Regional**	**Local**
Grade	**	***	*
Provision of technical know-how and extension requires intimate understanding of the local and regional practices. Although central organizations—both government offices and universities—will be involved in the generation of new knowledge, dissemination and knowledge transfer will be optimised on the regional level. Personal acquaintance with local growers by professional extensionists is imperative for efficient implementation of knowledge.			

7. Ensure high water use efficiency and prevent water loss and waste			
	Central	Regional	Local
Grade	*	***	***

Control and monitoring of water usage, including metering, can be conducted most efficiently at the regional and local levels. It is unrealistic to expect central authorities to successfully monitor loss prevention and inefficiency. A high level of control requires local presence.

8. Collaborate with adjacent authorities and agencies such as government offices engaged in agriculture, infrastructure, industry and environment			
	Central	Regional	Local
Grade	***	***	*

Because the agencies involved in water issues represent a variety of disciplines—agriculture, technology, environment, human resources, industry and more—high levels of coordination are required. Central and strong regional agencies are mandatory for the efficient coordination and optimal fulfillment of interests. Local agencies are too small to handle multidisciplinary issues. The capabilities and leadership of regional entities are needed to coordinate combined development efforts.

9. Collaborate, liaise and develop fruitful relationships with local government authorities at different levels and farmer associations			
	Central	Regional	Local
Grade	*	***	***

Development plans and ultimate allocation of water supply infrastructure and water to end users requires coordination and agreement with local government and local organizations. Regional and local organizational structure is best suited for managing discussions and reaching agreement with end users.

10. Collaborate with different offices, agencies, NGOs and other organizations on co-development of agricultural enterprises			
	Central	Regional	Local
Grade	***	**	*

Central funding and NGO contributions are leading sources of finance for irrigation projects. Central government offices are ideally positioned to negotiate and manage such funding. In many cases, these offices are the only formal entities entitled to enter discussion regarding such funds. However, strong regional organizations could nevertheless be instrumental in coordinating utilisation of funds, and in some cases initiating such funding. Local organizations would probably be ineffective in this function.

11. Develop and expand irrigation water enterprise			
	Central	Regional	Local
Grade	***	***	*

Development of new irrigation enterprises and expansion of existing ones are significant duties of water organizations. While initiation of new enterprises should be led by a central authority, existing enterprises are best developed by regional authorities with first-hand acquaintance with the project.

12. Manage the finances of the irrigation enterprise, including collection of national and local funds, and efficiently mobilise funds for maintenance and development			
	Central	Regional	Local
Grade	***	***	*
Water enterprises are expected to become financially self-sufficient over the long term. Although initial funding will originate from central sources, collection of fees from end users will ultimately become the responsibility of regional organizations. Regional authorities are in the best position to ensure ongoing maintenance and operation of existing enterprises. Similarly, these authorities can ensure sustainable financial management due to their ability to collect user fees effectively.			

13. Build and develop capabilities and competence within the organization			
	Central	Regional	Local
Grade	**	***	**
Capacity building largely depends on the character of the organization and its leaders. However, regional organizations with a positive level of strength may possess an advantage over cumbersome central agencies on one hand and small local organizations on the other.			

14. Handle legal and regulatory issues regarding water policy			
	Central	Regional	Local
Grade	***	**	*
The legal and regulatory framework governing water utilisation and conservation constitute the basis of all water development activity. A central organization is in the best position to determine law making in a coordinated and unbiased manner. On the other hand, recommendations, including proposals of regional by-laws, can and should be determined at a regional level. Regional authorities are also best suited to handle implementation.			

Organizational activity requirements

15. Demonstrate the initiative and professional competence required to conceive and design water enterprises			
	Central	Regional	Local
Grade	***	***	*
In-depth understanding of regional requirements for water, as well as the potential and capacity for irrigated agricultural production, are mandatory for initiating irrigation projects. At the same time, central funding and planning for national water usage are also imperative. A central organization is typically required to take the lead in regulating and authorising new water installations.			

16. Perform ongoing monitoring of water—both quantity and quality— at the source			
	Central	Regional	Local
Grade	***	***	*
The need monitoring for water at the source for both quality and quantity is essential from any perspective. Regular monitoring is necessary for early warning of supply problems and for the sustainable management of water resources. All monitored parameters should be set on a national level, whereas operations will be performed regionally.			

17. Devise long-term and seasonal supply schedule			
	Central	Regional	Local
Grade	**	***	*
Scheduling water supply timing and amounts depends on climatic conditions, soil type and crop at the specific area. This is part of the professional planning of the irrigation project. Supply of water at this level should be provided by the regional level organization.			

18. Establish water supply facilities and infrastructure			
	Central	Regional	Local
Grade	***	***	*
Moving from traditional to advanced agriculture requires professional guidance. Projects should be set up with competent technical guidance and inspection. Guidelines and infrastructure should be supplied by a central organization and end user facilities by local organizations.			

19. Maintain water supply at the required capacity, quality and pressure			
	Central	Regional	Local
Grade	*	***	***
These functions are strictly the responsibility of regional and local water authorities at the operational level. Ongoing certainty of supplies at this level cannot be guaranteed from afar.			

20. Manage outlets, including maintenance, metering, leakage monitoring and billing			
	Central	Regional	Local
Grade	*	**	***
Close monitoring and maintenance of irrigation systems are best performed by local and regional authorities. The involvement of local users in water organizations is facilitated by linking growers who live in close proximity. Payment charging for water supply is best handled locally. The perception of participation in irrigation supply by local growers is important.			

Other evaluation criteria

21. Consider sociological implications (demography, skilled vs non-skilled worker availability)			
	Central	Regional	Local
Grade	**	***	**
Changes in agricultural production during the colonial period resulted in a reduction of the land available for food production. These changes, together with demographic pressure and environmental damage, have contributed to land degradation. Activities that coordinate water use, disease and weed control, cultivation and quality management can most efficiently be managed as a group. This type of development also requires investment in skilled and experienced staff as well as training programmes for the farmers.			

22. Consider economic implications of irrigation, cost of installation and investment capacity			
	Central	Regional	Local
Grade	***	***	*

The contributions of irrigation to agriculture and economic growth are not in dispute. Rough economic estimates for installing irrigation systems, particularly for high-value crops, demonstrate profitability. However, required investments in irrigation infrastructure are high and payback periods are lengthy. Central financing and regional implementation require a high level of collaboration between central and regional organizations. The importance of the active participation of both levels of organization cannot be overstated.

23. Consider environmental implications of over-utilisation risks, surface drainage and runoff			
	Central	Regional	Local
Grade	***	**	*

The main factors influencing environmental impact are soil conservation and erosion control, anthropogenic water pollution, the effect of fertilizers and herbicides on water quality and environment and conflicting water demands (i.e. consumption for irrigation vs recharge amounts and other demands). These considerations dictate an emphasis on centralised orientation for managing, regulating, monitoring and inspecting water use and consumption.

Summary and grading for organizational level

Criterion	Alternative organizational structure and control			
	Relative weight for grading	Central	Regional	Local
1	3	2	3	1
2	3	2	3	1
3	3	3	2	1
4	3	2	3	1
5	3	3	3	1
6	3	3	3	1
7	2	2	3	2
8	2	2	3	1
9	2	1	3	3
10	1	3	3	1
11	1	1	3	3
12	2	3	2	1
13	3	3	3	1
14	2	3	3	1
15	2	2	3	2
16	2	3	2	1
17	2	3	3	1
18	3	3	3	1
19	2	2	3	1
20	3	3	3	1
21	2	1	3	3
22	1	1	2	3
23	3	2	3	2
24	2	3	3	1
25	3	3	2	1
Total	**-**	**142**	**163**	**77**
Percent	**-**	**37**	**43**	**20**

The World Agroforestry Centre (ICRAF) is part of the Alliance of 15 Centres supported by the Consultative Group on International Agricultural Research (CGIAR). We are an autonomous, not-for-profit research for development institution supported by over 50 different governments, private foundations, regional development banks and the World Bank. The Centre was founded in 1978, initially as the International Council for Research in Agroforestry (ICRAF), to promote the exchange of information on agroforestry research in the tropics. The Council was created in response to a visionary study led by Canada's International Development Research Centre (IDRC), which coined the term 'agroforestry'.

In 1992, ICRAF joined CGIAR and, in the years since then, has transformed itself into a world-class international agricultural research centre. In order to more fully reflect our global reach, as well as our more balanced research for development agenda, w adopted a new brand name in 2002 – 'World Agroforestry Centre'. Our legal name – International Centre for Research in Agroforestry – remains unchanged.

The ICRAF vision is an agroforestry transformation in the developing world – a massive increase in the use of working trees on working landscapes by smallholder rural households that helps ensure security in food, nutrition, health, fodder, shelter and energy, income and a regenerated environment. Our mission is to use science to generate knowledge on the complex role of trees in livelihoods and the environment, and foster use of this knowledge to improve decisions and practices on the poor.

About this book

This Irrigation Master Plan (IMP) highlights on how both surface (runoff, rivers and lakes) and underground water resources can be fully, efficiently and sustainably exploited by promoting irrigation in its various forms using a scientific tool developed by ICRAF in a GIS environment.

The IMP thus provides Rwanda with a planning tool for rational exploitation of its soil and water resources intended to trigger an increase in crop production of both staple foods for local consumption and high-value products for export.

The IMP supports decision making for the following: Identification of the most favourable areas to establish irrigation infrastructure; Estimation of irrigation water stock; Prioritization of irrigation water distribution; Recommendation of abstraction mechanisms; Identification of irrigation water conveyance mechanisms to the command areas; Establishment of irrigated agriculture in small, medium and large-scale projects on hillsides, marshlands and other topographically suitable areas; Identification of options for upgrading the agricultural value chain; Recommendations of options for water harvesting and storage; Production of district irrigation plan maps for the potential irrigation areas (PIAs) that could be irrigated by the different kinds of water resources by agroclimatic zone (ACZ) or even province level; and Articulation of the national policy options concerning the distribution of irrigation water.

In so doing, the IMP targets Rwanda's various practitioners and stakeholders in government, local and external support agencies and communities – to ensure sustainable production of food, cash, export and industrial crops.

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