Consolidated Hydrological Year Book for Uganda 1978-2014

Foreword

In front of you is the Consolidated Hydrological Year Book for Uganda 1978-2014, which has been prepared by the Directorate of Water Resources Management of the Ministry of Water & Environment. The report presents a comprehensive review of the hydrological data collected in Uganda in the 1978-2014 timeframe, and emphasizes the need for high-quality water data to foster sustainable socio-economic development in the country.

This work is based on a collection of all available hydrological and meteorological time-series data from the current database systems at DWRM, which has been migrated into the data management software package Aquarius. The data also includes meta-data on stations and equipment, as well as discrete discharge measurements and rating curve parameters.

The Hydrological Yearbook describes and illustrates the climatic zones in Uganda and also features maps that provide information about the water resources, drainage system, and land cover followed by the layout of the monitoring network. It also contains overviews describing the hydrological processes in the country per major hydrological basin, together with representative hydrographs of river flow and groundwater levels with supporting summary statistics. Also included is a commentary which examines notable hydrological events and summarizes both the present national hydrological status and the future water resources outlook.

This publication clearly shows that the demand for water in Uganda is rising rapidly; the situation is not critical but shortages can be experienced at local level at some points in time. Proper water resources planning and management based on accurate water data is therefore critical. It is recognized that water data are expensive, but the absence of water data leads to lost potential and possible water conflicts. While it is apparent that the monitoring network has grown significantly in the last 20 years to cover almost every major river system in the country a lot more investment is still required to gauge many tributaries to these rivers.

Currently, the Ministry is preparing for anticipated changes in environmental monitoring by introducing a Water Information System covering all databases in the Water and Environment Sector, including the Aquarius Data Management System that was used to prepare this publication. Moreover, the Ministry is preparing for a gradual implementation of real-time data transmission of all monitoring stations.

It is my sincere hope that you will find this report an invaluable source of information, whether as a hydrologist, politician, researcher, government official, or any other citizen of Uganda for achieving Uganda's Vision 2040. My Ministry will continue to support activities and initiatives that contribute to the fulfilment of its overall mandate of sound management and sustainable utilization of Uganda's natural resources for the present and future generations.

Finally, let me use this opportunity to thank the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) for funding the preparation of this document.

For God and my country,

Hon. Sam Cheptoris
Minister for Water and Environment
Republic of Uganda

Executive Summary

This publication presents a comprehensive review of the hydrological data collected in Uganda in the 1978-2014 timeframe, and emphasizes the need for high-quality water data to foster sustainable socio-economic development in the country. The publication of this report was supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

The performance of key economic sectors in Uganda depends on timely access to adequate quantities of water of suitable quality. It is evident that pressure on finite water resources is increasing because of socio-economic development and population growth, while climate change is making the availability of water resources more unpredictable.

The demand for water is projected to increase by over 400% in the period 2010-2030 (NWRA 2009) while the overall water utilization rate could reach 14.9% by 2030. The changes are more dramatic for several basins —such as Albert Nile, Lake Kyoga, and Lake Victoria—where the water utilization rate may rise above 30%.

The situation is not critical but shortages can be experienced at local level at some points in time. Hence proper planning and manage-ment of the existing water resources will be crucial.

The DWRM has been tasked to ensure that the productive sectors are supplied with adequate quantities of water while preventing water shortages and conflicting water use at local, regional, and even international level. At the same time, DWRM is tasked to minimize adverse impacts of water resources on the livelihood and security of Uganda's people—such as floods and water-borne diseases. Other tasks are related to maintaining sufficient flows to preserve the environment.

To perform these duties, water managers need to know where Uganda's water resources are—in what volume and quality. They need this information for the present situation, but also for the short and mid-term future. It requires a diverse set of hydro-logic tools that are based on accurate and timely data about all components of the hydrological cycle.

DWRM is Uganda's focal point for river flow, lake level, groundwater, and water quality data, and has been collecting water data for over a century now. It has resulted in a large database that has proved invaluable for analyzing and describing the diverse hydrologic and climatic regime in the country. The monitoring network covers all major river systems in Uganda despite the vast distances, the inaccessibility of the terrain, and the operational difficulties.

Nevertheless, historic data alone are not sufficient for understanding the current and future hydrological processes. Large parts of the river basin are constantly changing: forests are being transformed into agricultural lands, wetlands converted to irrigated areas, while areas adjacent to cities are being paved or covered with houses because of urbanization. For those parts of the river basin subject to land-use change, the response to a rain-event has changed and historic rainfall-runoff relations no longer describe the hydrology of the river. Furthermore, the hydrological processes in Uganda are very sensitive to the impacts of climate change. It implies that hydrologic monitoring and the collection of water data is—and will be—an ongoing activity.

It is recognized that water data are expensive. Nevertheless, it can be argued that the total costs of collecting water data are much lower than the ensuing benefits.

Indeed, the absence of adequate understanding of the hydro-logical processes because of inaccurate or insufficient water data typically leads to lost potential, overly conservative decisions, and even to possible resource conflicts. Water data are crucial for Uganda to meet its mid and long-term development objectives.

Given the costs to maintain an effective hydro-logical monitoring network, it is essential that water data are used to increase socio-economic and

environmental benefits. Thus, rather than just collecting hydro-logical data, DWRM aims to provide hydrological services that support economic growth, food security, safety of citizens and households, maintaining a healthy environment, and other societal benefits.

There are several trends that affect the acquisition of water data. One is related to changing expectations of data clients. Data consumers and data end-users will increasingly expect to have access to real-time data of high quality. These data feed into operational models to optimize power production, forecast floods, or finetune water supply to irrigation systems.

Other anticipated trends in environmental monitoring are related to mass adoption of cheap electronic sensors and real-time communication technology, which will result in large volumes of complex data. Data management systems, river basin models, and related water information tools should be able to handle these new types of data.

DWRM is preparing for these changes. It has recently established the state-of-the art Aquarius Data Management System that will enable real-time data access. DWRM is also setting up a sophisticated Water Information System, which brings together a fast array of climatic information and other water data. Further, DWRM is currently developing a suite of tools for optimizing power production of the cascade of hydropower facilities along the Victoria and Kyoga Nile, as well as elsewhere in the country. These advanced systems and tools will make it easier for DWRM to accomplish its various tasks, and to provide the high quality hydrological data and services that its clients have become accustomed to.

The second part of this publication presents the accomplishments by DWRM in the 1978-2014 timeframe in the field of water monitoring. It is recognized that the climatic conditions and hydrologic parameters in Uganda are subject to very considerable spatial variation. The water data have therefore been presented separately for each main river basin.

Because of the political situation in the late 1970s and early 1980s, there are data gaps in the 1978-2014 timeframe. Most data gaps are concentrated in the late 1980s and early 1990s. Continuous records exist since the late 1990s, providing time series of reasonable length. The existing records have made it possible to calculate seasonal patterns, flow reliability, and key statistics for key tributaries in each major river basin—apart from Kidepo—and to provide a description and trend analysis of the surface and groundwater hydrology in the major basins. Nevertheless, several important tributaries in each major river basin are not monitored, and it is evident that the current network in insufficient to fully understand the hydrological processes in Uganda. It may require future expansion provided sufficient resources can be made available.

It is evident that accurate and timely water data is essential for fact-based management, development, and protection of the country's water resources for the benefit of the people of Uganda. DWRM is well positioned to provide these data in the years to come. It is clear, though, that this will require ongoing investments in modernizing data acquisition systems and hydrological services.

Contents

1 - Introduction

The Directorate of Water Resources Management (DWRM) is Uganda's focal point for river flow, lake level, and groundwater data. The Directorate monitors, collates, quality controls, and archives hydrometric data from a gauging station network across the country.

Until 1978, DWRM published Annual Yearbooks as part of the Hydrological Data Series, bringing together the principal datasets relating to river flows, lake and groundwater levels, and water quality throughout Uganda, and featuring a comprehensive hydrological review of the year. Water data acquisition activities came to a virtual standstill in the 1980s due to the politically unstable situation. From 1994 onwards, the surface water monitoring network was gradually restored but DWRM did not resume the publication of annual data books. With the introduction of Personal Computers and electronic database systems, the storage and dissemination of water data had changed fundamentally. Electronic data files had replaced hard-copy Yearbooks as the medium for data dissemination.

With the introduction of the internet, data management has once again been subjected to fundamental changes. Rather than publishing water data at the end of each calendar year, many data users are increasingly expecting near real-time access to accurate hydrological information. To meet this expectation, automated data processing, analysis, and dissemination will be required.

Uganda is responding to these developments by introducing a comprehensive Water Information System (WIS). It comprises an official repository and information system for all hydrological, climatic, watershed, infrastructure, and water related data. As part of WIS, DWRM has recently introduced Aquarius Time Series (in short, Aquarius) as its data management system for hydrological time series. Aquarius includes the full set of functionality required by a modern water monitoring and management institute, and represents an effective solution for water data management for the mid-term future and beyond.

In addition, Aquarius provides an audit trail function which keeps track of all edits done to the data, as quality control measure. In conjunction with the database development in Aquarius, rating curves were updated for 20 selected stations, which were subject to field visits to this purpose. The 20 selected stations are Ruizi, Nyakijumba, Sio, Namatale, Mpologoma, Namalu, Greek/Selim, Sironko, Simu, Sipi, Kafu, Tochi II, Mpanga, Chambura, Mitano, Nkusi, Waki II, Anyau, Ora II and Nyagak. A separate report was published detailing the work done on these stations, which functions as quality control. For the remaining stations, MWE is in charge of gradually updating the remaining set of rating curves.

What has not changed in the years since the last Hydrological Yearbook was published, is the importance of water data. In fact, with increasing pressure on natural resources due to demographic growth and economic development, it has become more and more important to base effective water resources management on a good understanding of the hydrological processes, and on sound knowledge of where Uganda's water resources are, in what quality and quantity. It is evident that this requires a broad range of data and information.

It is recognized that water data are expensive, yet the benefits are widespread. Water is an essential and growing input for many socio-economic activities, and accurate hydrological information is indispensable for energy planning, irrigation development, Nile water allocation, integrated catchment planning, hydraulic designs of bridges and water retention structures, flood management, and climate proofing, to name but a few. It can be argued that the total costs of water data collection activities are much lower than the ensuing benefits.

Indeed, the absence of an adequate understanding of the hydrological processes because of inaccurate or insufficient water data typically leads to lost potential, overly conservative decisions, and even to possible resource conflicts. Water data are crucial for Uganda to meets its mid and long-term development objectives.

This publication reports on the important achievements by the DWRM in the field of hydrological monitoring in the period 1978-2014. Despite considerable operational difficulties, the Directorate has maintained a country-wide monitoring network that covers all important rivers. These efforts have resulted in long time series of river flow data, facilitating meaningful statis-

tical analysis of droughts, floods, and safe water yields.

Chapter 2 of this publication outlines the water resources context in Uganda. It describes the climatic conditions and the main hydrologic characteristics of the surface and groundwater resources in the country. Next, the chapter presents the transboundary context, and assesses how climate change may affect the water resources of Uganda. Chapter 2 continues with an in-depth discussion of the role of water in national development, and the role and mandate of the DWRM in developing, managing, and protecting the nation's water resources.

In Chapter 3, a discussion of the hydrological services in Uganda is provided. Arguments are brought forward that water data are essential and a review of the costs associated with hydrological data acquisition is made. After an overview of the available water data in the country, the chapter describes how water data are used for various productive purposes in Uganda.

Chapter 4 is concerned with the practical aspects of hydrological monitoring in the country. The text describes the history and extent of the data acquisition activities, and provides an overview of past and current hydrological practices. Next is a discussion of the comprehensive Water Information System, and the role of the recently introduced Aquarius system for time series management. Chapter 4 concludes with a brief examination of trends in environmental monitoring, and assesses how it may affect the future work of DWRM.

Chapter 5 presents a comprehensive hydrological review for the time frame 1978-2014. Data from this period are used to illustrate the spatial and temporal distribution of the water resources in the country, and to describe the specific surface and groundwater hydrology of the eight main river basins. For each main basin, the chapter also presents a water balance and trend analysis.

Chapter 6 provides closing comments. It reiterates the importance of accurate and reliable data for evidence-based decision-making to achieve effective management and sustainable development of Uganda's water resources.

2 - Water Resources Management

This chapter outlines the main features of the water resources of Uganda, the transboundary context, and the possible implications of climate change. It examines the role of water in national development and the role and mandate of the DWRM in developing, managing, and protecting the nation's water resources.

The Water Resources of Uganda

Climate

Most of Uganda experiences two rainy seasons, with heavy rains from March to May, and lighter rains from October to December. Only the North experiences a single rainy season – from May to October – which is more pronounced. Mean annual rainfall over Uganda is about 1,200 mm, but is subject to pronounced temporal and spatial variability. Some variations occur within specific catchments, particularly some of the larger ones. The mean annual rainfall masks the pronounced seasonal variation of rainfall in many areas of the country, caused by different weather patterns. The general north-easterly or south-easterly wind systems are occasionally intruded by moisture-laden westerly winds which pass over the Congo rain forest and have significant effects on the weather. Average annual rainfall ranges from 1,800 mm around the shores of Lake Victoria to below 600 mm in some parts of the Karamoja region (figure 2.1).

High evaporation rates have a marked effect on Uganda's hydrology and use of its water resources. Potential evaporation exceeds rainfall in about 90% of the country (figure 2.2). High rates of evaporation reduce runoff, groundwater recharge, and dry season flows, while they increase drought risks.

The climate of Uganda ranges from arid to humid, demonstrating the climatic variability of the country (Thornthwaite Climate Classification, based on data from 1960 – 1990) (figure 2.3). Most of Uganda (67%) is classified as 'dry sub-humid' and is characterized by a moderate water surplus during the rainy seasons, while water deficits occur during the dry season. About 20% of the country – mostly in the North-East and parts of the Rift Valley – is classified as 'semi-arid' while a few small and isolated spots in Karamoja are classified as 'arid.' Arid and semi-arid zones are generally more suited as rangelands. The remaining 13% of Uganda is classified as either 'humid' or 'moist sub-humid.' These conditions prevail around the shores of Lake Victoria, in the mountainous regions in the country (Mt. Elgon and the Rwenzori), in the Kabale region, and close to the Democratic Republic of Congo's border in West-Nile Region.

Table 2.1. Main characteristics of the lakes in Uganda

	Area (km^2)	Volume (km^3)	Maximum depth (m)	Mean depth (m)
Lake Victoria	69,000	2,700	79	31
Lake Kyoga	6,300	16	8	6
Lake Albert	5,300	140	58	25
Lake Edward	2,300	78	117	34
Lake George	250	0.7	3.0	2.5

Surface Water

Uganda is situated on a continental plateau between the eastern and western arms of the African Rift Valley. High mountains rise on both the eastern and western borders. The plateau has an average altitude of 1,300 m above sea level and has a relatively flat topography, characterized by flat-topped hills and broad swamp-filled valleys. These extensive wetland areas in the country (11% of total land surface) have a marked effect on Uganda's hydrology.

Uganda exhibits a high variation in specific runoff. Very low values are reported in the Lake Kyoga area, in the Katonga and Bukora catchments, and in the Albert Nile valley. High runoff coefficients are only observed in south-western Uganda, West Nile, and the Mt. Elgon region.

The low average specific runoff in a large part of Uganda is a determining factor in the country's hydrology. It is partly attributed to the high evaporation losses from the extensive wetland areas, the close balance between rainfall and evaporation losses, and annual rain deficit in large parts of the country. In Uganda, rainfall is quite substantial but most of it evaporates; thus, rainfall that is available for productive purposes (the 'balance') is surprisingly small. The monthly potential evapotranspiration and precipitation charts are presented in figures 2.4 and 2.5 for a slightly different study period spanning 1961-1990.

The equatorial lakes have an important influence on the surface water hydrology in Uganda. Lake Victoria is the largest of the lakes with a surface area of approximately 69,000 km² (table 2.1) and by far the most important of the equatorial lakes. It is also the only one with a regulated outflow, thanks to the Kiira and Nalubaale hydro facilities

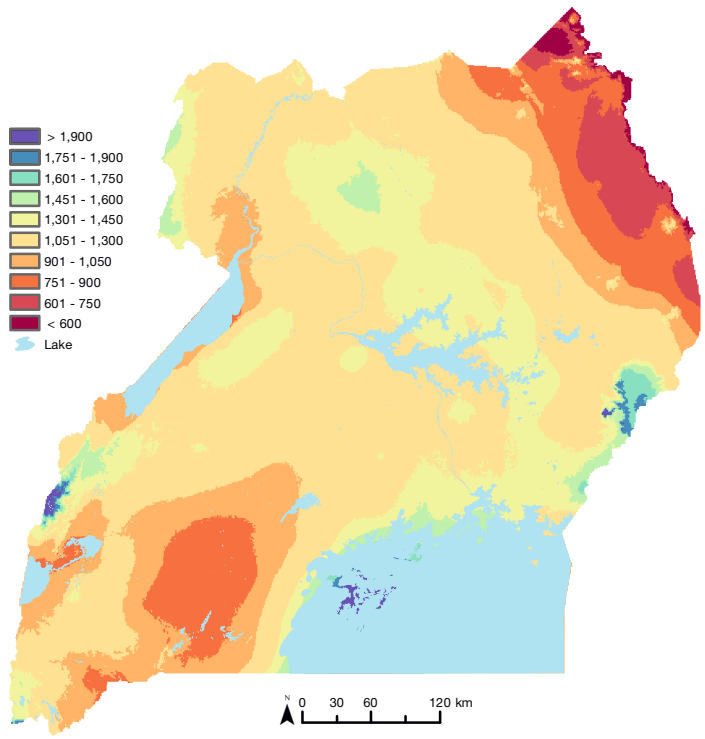


Figure 2.1: Mean annual rainfall

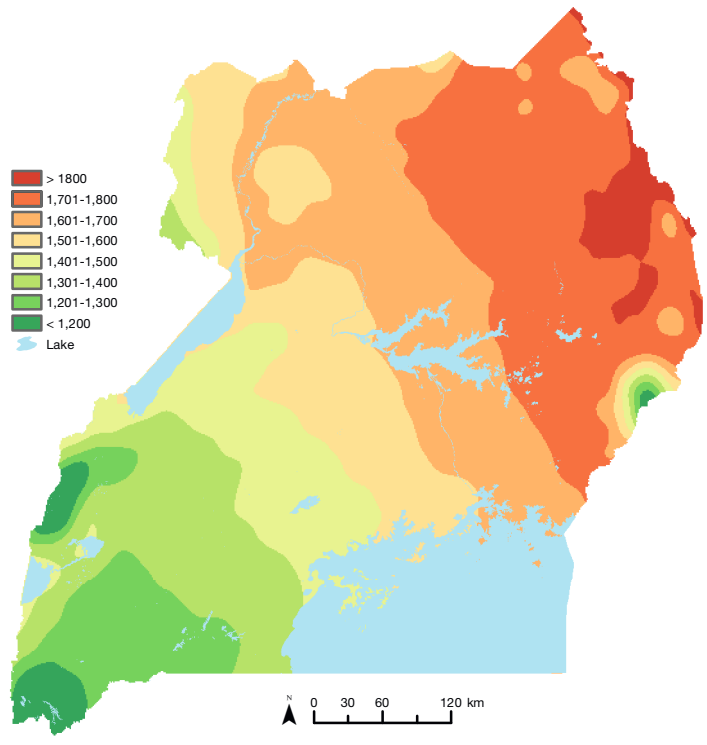


Figure 2.2: Main annual rain surplus/deficit

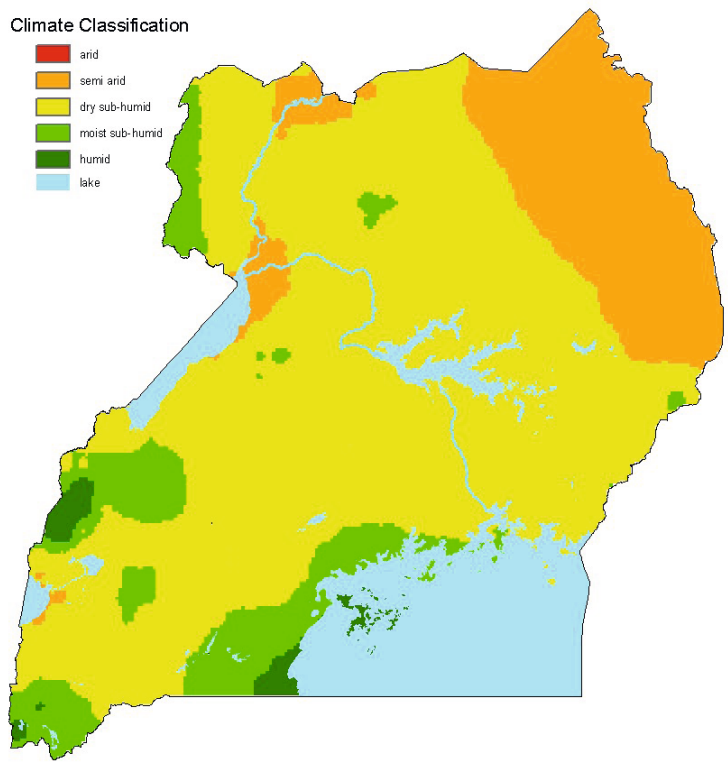


Figure 2.3: Climates of Uganda according to the Thornthwaite Classification

Figure 2.4: Monthly potential Evapotranspiration of Uganda (1961-1990)

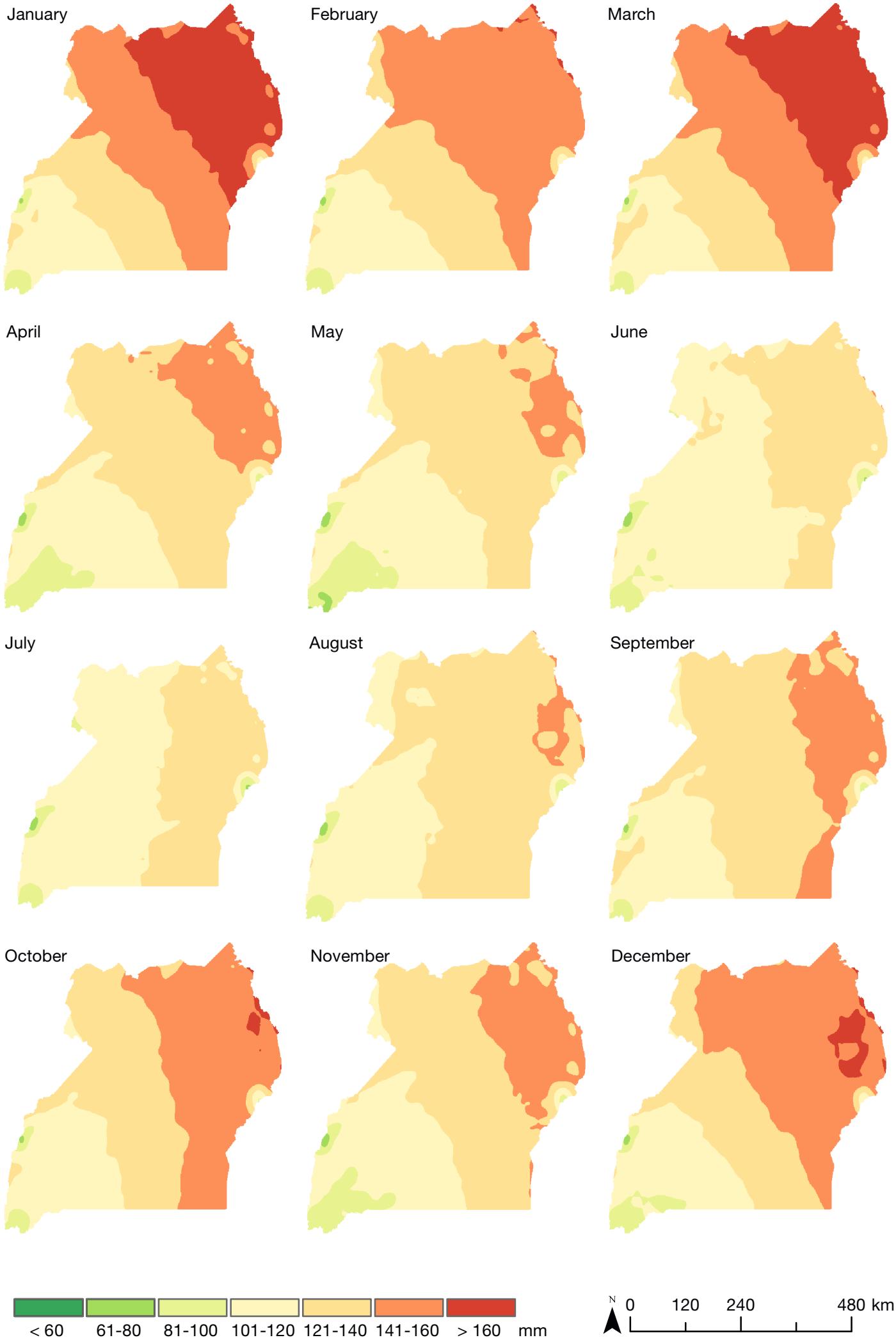


Figure 2.5: Monthly Precipitation of Uganda (1961-1990)

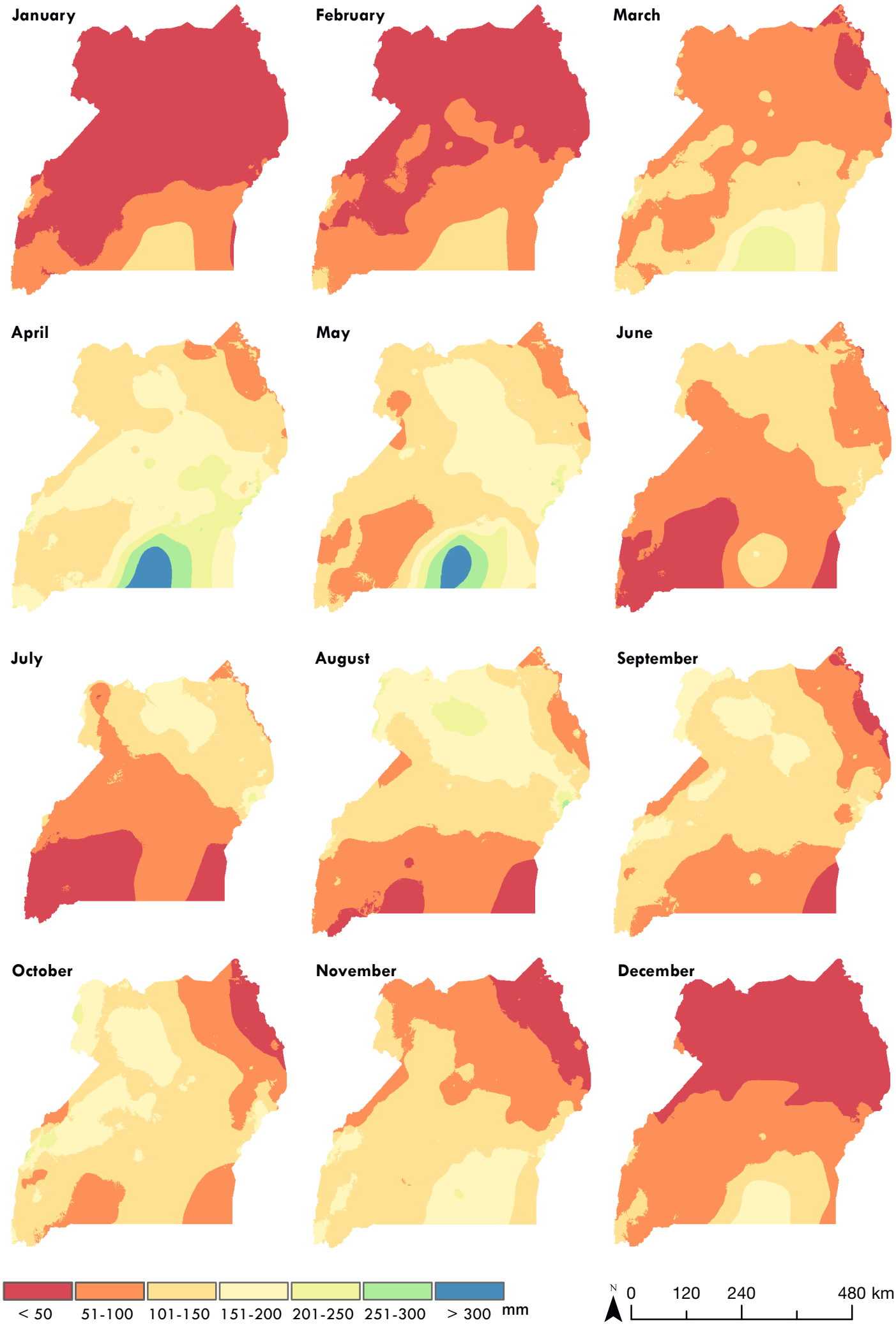
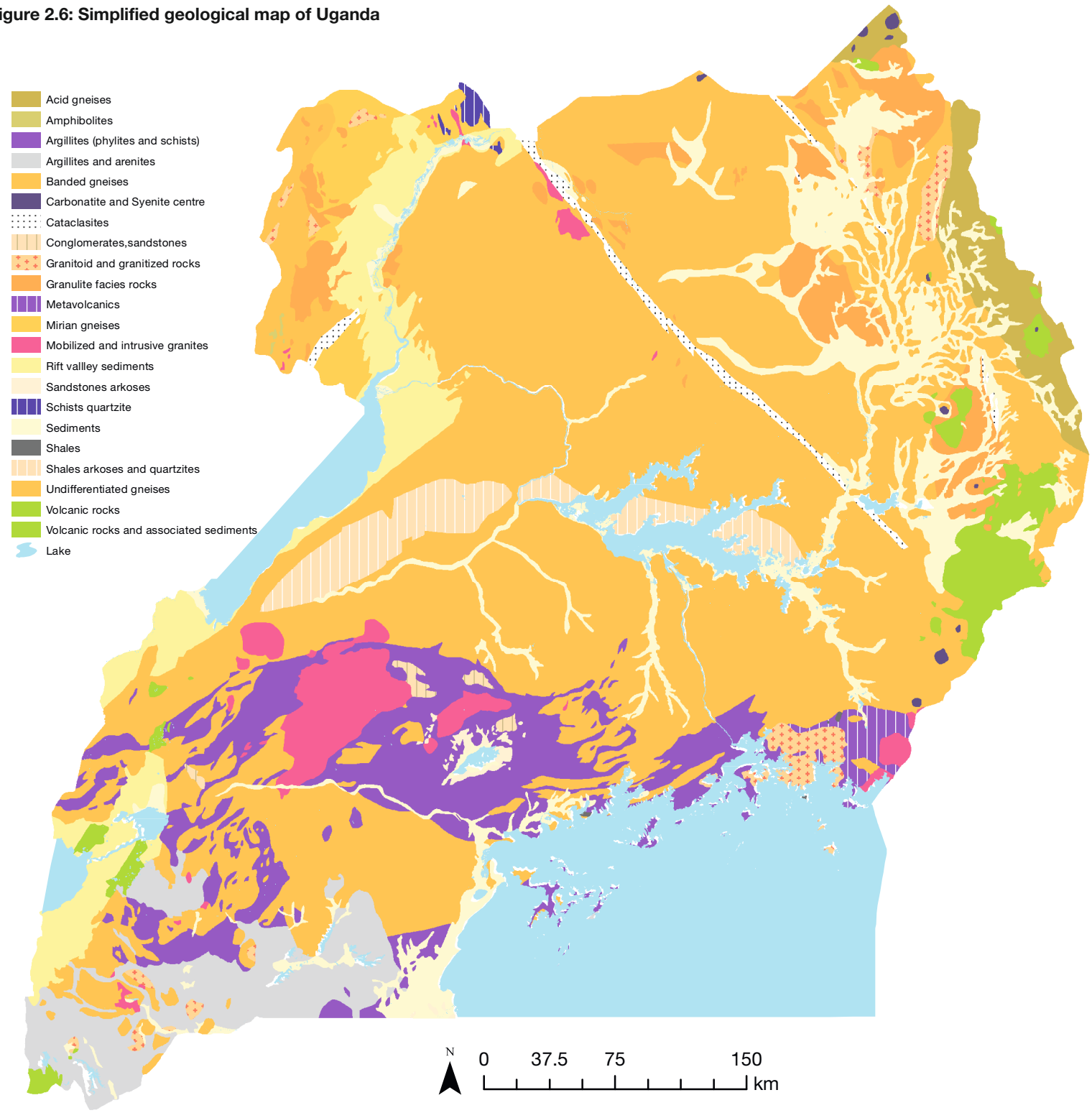


Figure 2.6: Simplified geological map of Uganda



on the Victoria Nile at Jinja. The outflow from Lake Victoria constitutes the main input into the water balances of Lakes Kyoga and Albert.

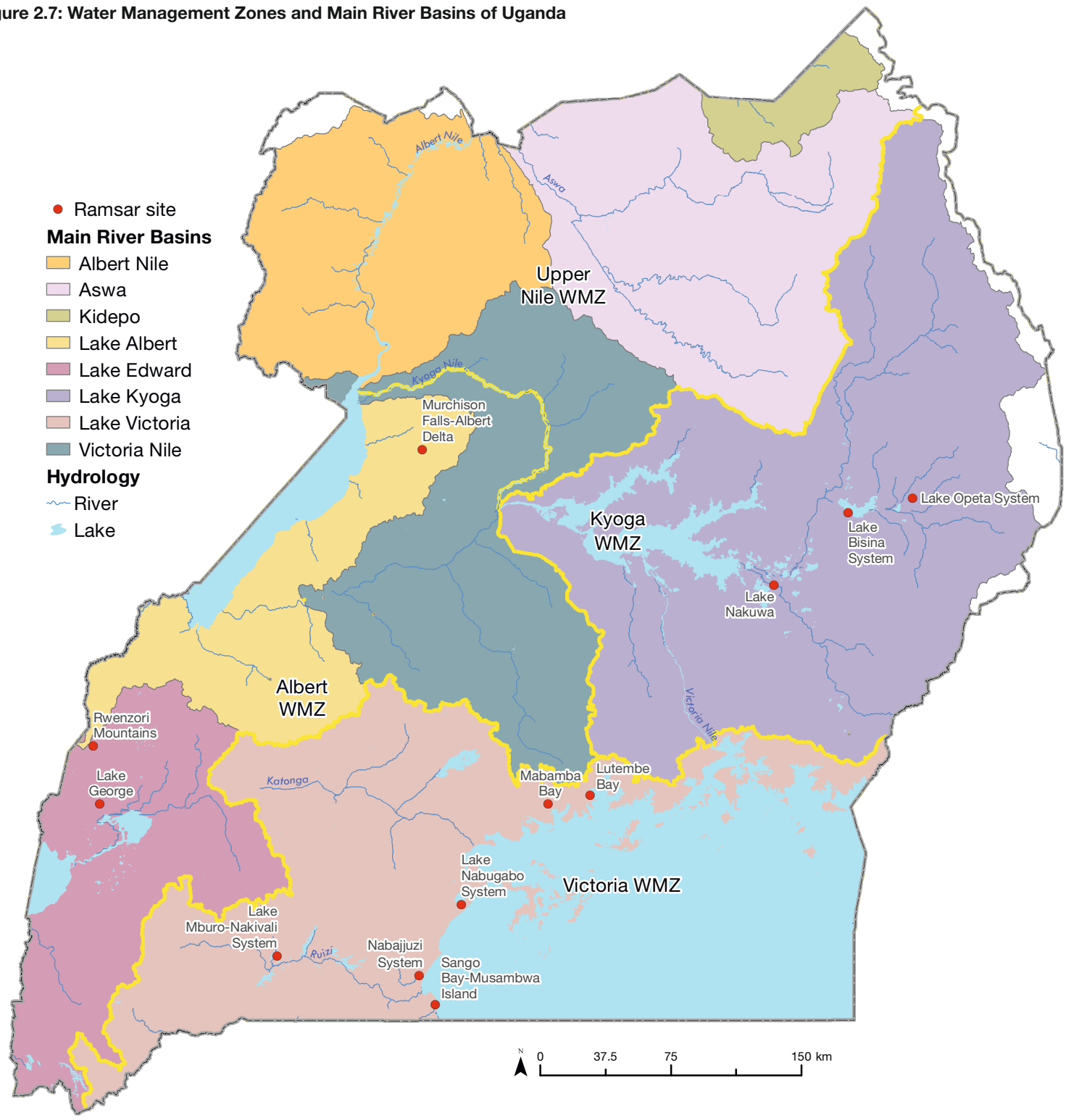
The Nile dominates Uganda's hydrology. Lake Victoria is the single largest contributor to the Nile flow and runoff from the catchments downstream of the lake is relatively small compared to the outflow from Lake Victoria. Evaporation losses from Lake Kyoga, Lake Albert, Lake Edward, and Lake George are significant and exceed direct rainfall on their surfaces, resulting in a substantial combined net loss of water from the Nile system.

Groundwater

Uganda's groundwater resources are substantial in comparison to the available surface water (if Victoria Nile flows are not considered).

Uganda is mainly underlain by pre-Cambrian rocks consisting of granites, gneisses, migmatites, meta-sediments, mudstones, and argillites. Some volcanic rocks are found in the South-West, in Kisoro District (Mgahinga and Muhavura mountains) and in the south-east of the country (east of Mbale). The Rift Valley area itself consists of sedimentary formations with thicknesses exceeding 2 km. Other fluviatile formations occur near the lakes and in paleo-channels throughout the country. A simplified map of the geol-

Figure 2.7: Water Management Zones and Main River Basins of Uganda



ogy of Uganda is presented in figure 2.6.

There are roughly four types of aquifers in Uganda: those formed 1) in the fractured bedrock, 2) in weathered bedrock, 3) in sedimentary formations, and 4) in volcanic formations. It is noted that groundwater potential in Uganda is highly variable, and that a difference between high potential and poor potential can occur within the same hydrogeological unit.

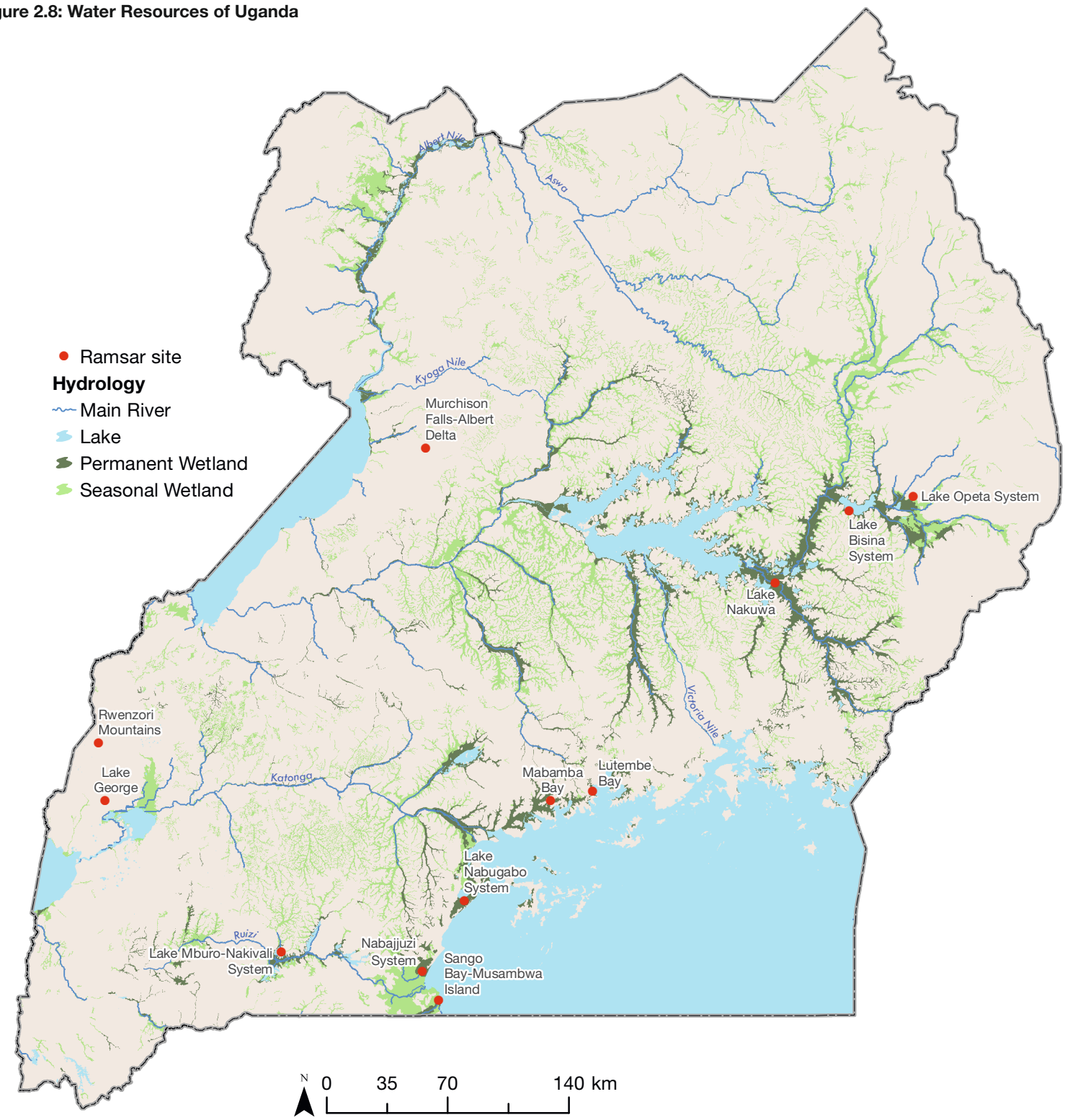
Most boreholes in the country tap water from the weathered and fractured basement rocks. The yield and the depth of the boreholes depend on the origin of the parent rock, the degree of weathering, and the degree of fracturation. The yields of these boreholes vary between 0.5 and 50-80 m^3/hour, while boreholes drilled for water supply can be as deep as 200 m, though they are commonly below 80 m depth.

Sedimentary aquifers are generally found along current river channels or paleo-channels in which fluvial/alluvial gravel, sand and silt have been deposited, as well as in the Rift Valley in the westernmost part of the country. These unconsolidated aquifers in Uganda are generally unconfined or semi-confined. They can be more than 50 m thick where there are significant paleo-channel deposits.

Very few boreholes have been drilled in the volcanic rock hence little is known about the characteristics of these aquifers.

The estimated annual groundwater recharge rates in Uganda are highly variable and range from approximately 10 percent of the annual rainfall in the deep weathering zone of Central Uganda (Taylor and Howard, 1996; Tindimugaya, 2000), to approximately 1 percent of the annual rainfall in the zone of stripping in western Uganda (Taylor and Howard, 1999). It is noted, however, that estimation of groundwater recharge rates can be complicated by preferential flow paths in the unsaturated zone, as well as by temporal and spatial

Figure 2.8: Water Resources of Uganda

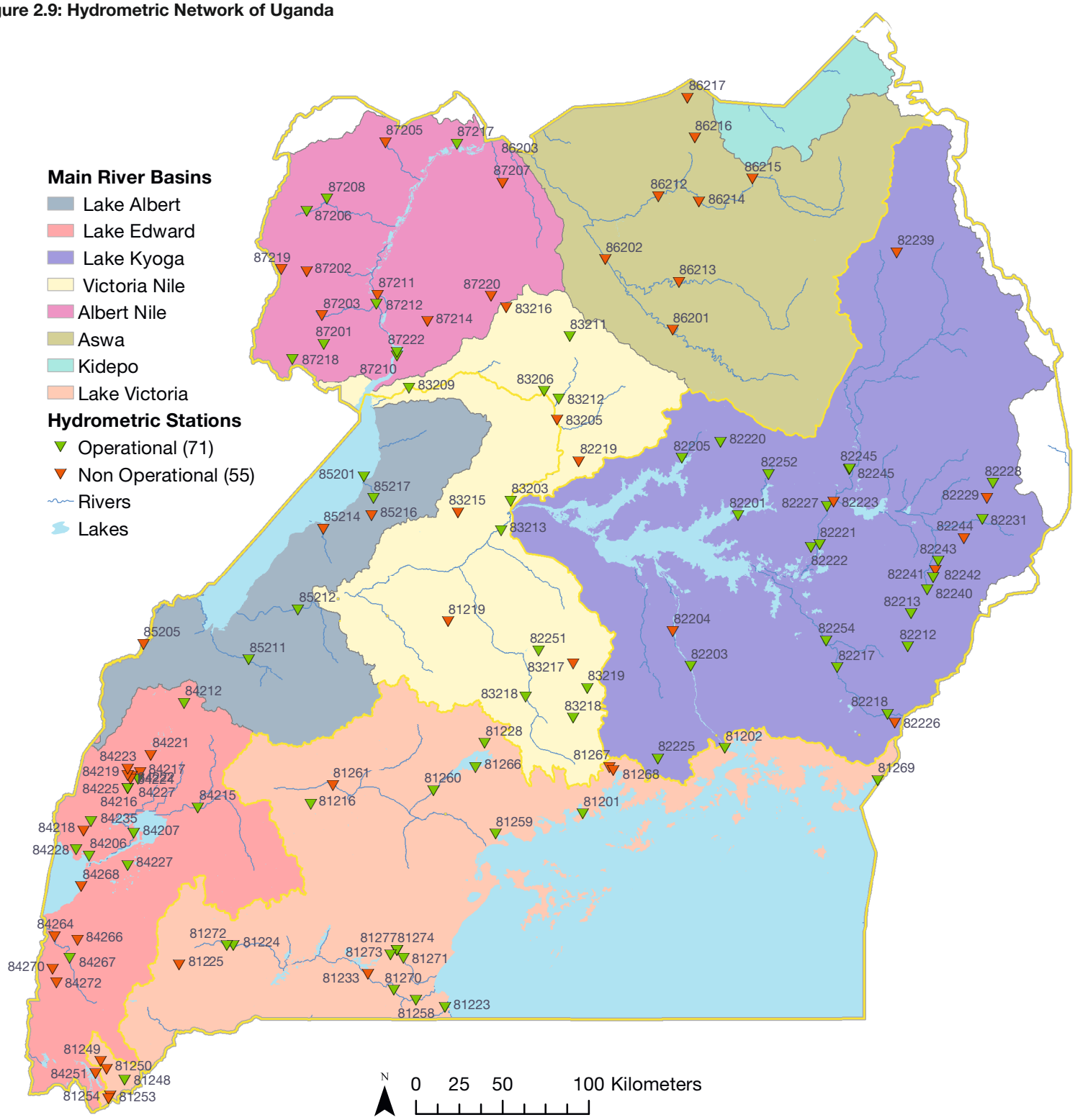


variability of the parameters involved. Hence multiple techniques are recommended in view of the uncertainties inherent in each method. Distribution of recharge in Uganda has been assessed based on the mean annual rainfall and overburden thickness. The mean annual groundwater recharge in Uganda is estimated to be 120 mm.

Water Quality

In their natural state, the quality of surface and groundwater in Uganda is generally good. However, poor sanitation has led to bacterial contamination of both groundwater and surface water. Further, eutrophication resulting from excessive quantities of nutrients reaching water bodies can cause algal blooms in all lakes that may lead to oxygen deficits and fish kills, or promote the excessive growth of weeds such as water hyacinth.

Figure 2.9: Hydrometric Network of Uganda



The Transboundary Context

Virtually all of Uganda lies within the Nile drainage area. Only a small part of Karamoja drains into the Lake Turkana basin. Uganda is both an upstream and downstream riparian, and several Nile tributaries and lakes are shared with neighbouring countries. These include Kagera, Semliki, Sio-Malaba-Malakisi, Albert Nile, and the lakes Victoria, Edward, and Albert. In fact, most of the water in Uganda comes from outside our borders.

Lake Victoria is shared by Kenya (6%), Tanzania (49%), and Uganda (45%) and its drainage basin also includes parts of Burundi and Rwanda. There are concerns about eutrophication and pollution in the Lake. The key features that determine the hydrology of Lake Victoria include the high contribution (85%) of over-lake rainfall to total lake inflow. However, this rainfall is balanced out by an almost equal amount of evaporation, such that net rainfall is only a small factor of actual received inflow to the lake. This suggests that lake levels and the long-term outflow will be highly sensitive to climatic change. Lake level fluctuation is limited to a relatively narrow band of some 3 m (figure 2.10), giving Lake Victoria a life storage volume of over 200 km^3; this attenuates seasonal and annual variability in lake outflows and has led to relatively stable Victoria Nile flows. The Nile flows are modified by their passage through Lakes Kyoga and Albert, but remain steady with little seasonal variation. Just south of the South Sudanese border, the river is joined by the Aswa, a seasonal river, which basin is almost exclusively in Uganda, and other streams known as The Torrents. They provide a seasonal component to the steady flow of the Bahr el Jebel, as the White Nile is known in South Sudan.

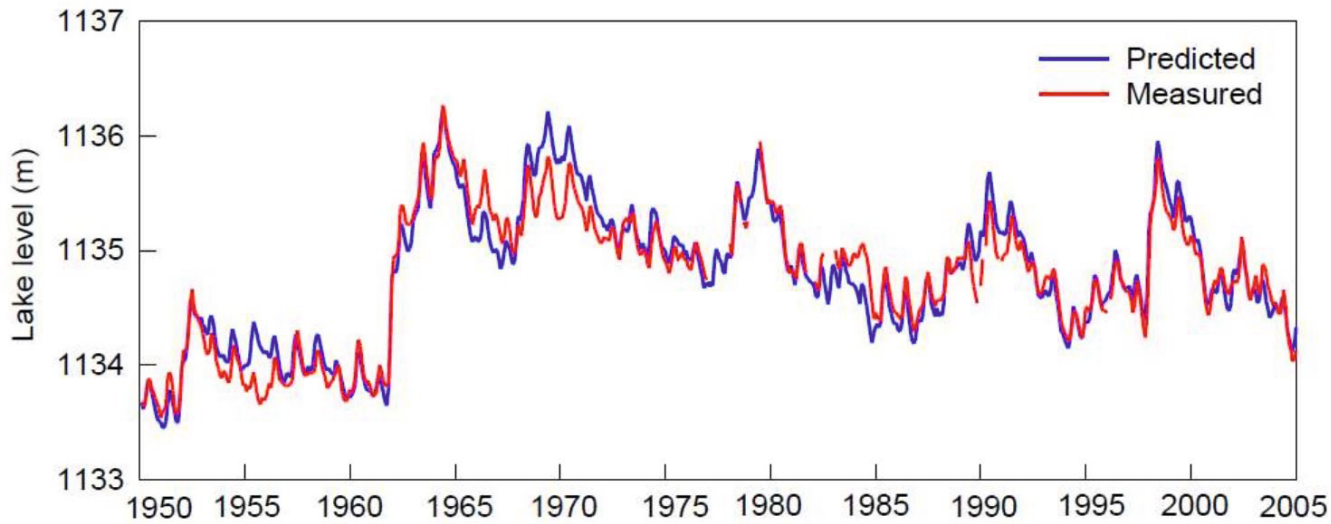


Figure 2.10: A comparison of estimated (blue line) and observed (red line) water levels in Lake Victoria.

The Prospect of Climate Change

There is overwhelming scientific evidence of a warming trend in the earth's temperature, and consensus about the movement towards intensified extreme events such as floods and droughts.

Many efforts have been made at understanding and predicting the future climate over the Equatorial plateau. The climate models give contradicting and wide-ranging results. While a warming trend is common in all models, some predict a drier and others a wetter climate, depending on which global circulation model (GCM) is used. The low resolution of the GCMs makes it difficult to predict regional and local weather patterns.

While the direction and magnitude of change in rainfall is yet unclear, anecdotal evidence suggests an increase in the temporal variability of rainfall in Uganda in recent years. It has been reported that the rainy season has become shorter and more intense, and subject to erratic onset and cessation, making it very difficult for farmers to plan the farming calendar. It has not been possible, however, to verify these reports and determine significant long-term trends in rainfall patterns in Uganda because of insufficient data.

Likely impacts of the continuing warming trend because of climate change include:

- Higher evaporation and consequent increased losses from reservoirs and lakes;
- Higher evapotranspiration rates and rising crop water requirements;
- A consequent increase in demand for irrigation water, and an increased vulnerability of rainfed agriculture to drought;
- An exacerbation of desertification in drier regions such as Karamoja, which are apt to lose more moisture if the weather is hotter; it will possibly increase wind erosion, lead to further land degradation, and pose a threat to the pastoralist lifestyle that dominates the semi-arid zones;
- Hotter and longer dry periods which will increase drought risks, especially in drier regions;
- Increased variation in precipitation and risk of moisture deficit at critical stages of crop growth; this could jeopardize agricultural production in rainfed areas, with subsequent consequences for food security and standards of living in rural areas;
- Higher frequency and intensity of severe rainstorms that will lead to increased flood risk and storm damage, also in urban areas;
- Higher water temperatures, which increase algal productivity and reduce oxygen dissolution, among other effects.

Further, Lake Victoria water levels and White Nile flows are particularly sensitive to climate change. The principal components of the Lake Victoria water balance are over-lake rainfall (82-85% of total inflow) and lake evaporation (75-78% of total outflow). This makes Lake Victoria very sensitive to changes in precipitation and temperature. While the general warming trend of the global climate would lead to an increase of the evaporation rate, its possible impact on the rain regime on the Equatorial plateau is uncertain. Thus, the impact of climate change on lake levels and the resulting Victoria Nile flows is uncertain. This applies both to the magnitude and direction of a possible change. Changes in Lake Victoria outflow will impact hydropower production on the Victoria and Kyoga Nile.

The Directorate of Water Resources Management

The overall mandate of the Directorate of Water Resources Management (DWRM) is "to promote and ensure rational and sustainable utilization, effective management, and safeguard of water resources so that there is water of adequate quantity and quality to meet the social welfare and economic development needs of Uganda". The Directorate is responsible for monitoring and assessing the state of the water resources of Uganda – both in terms of water quality and quantity – and for allocating and regulating their use through the issuance of water abstraction and waste water discharge permits. The strategic objective is to maximize the beneficial use of Uganda's water resources by supporting the productive sectors to achieve their respective objectives, while ensuring environmental integrity and taking into account the transboundary context.

DWRM comprises four departments namely: Department of Water Resources Monitoring and Assessment, Department of Water Quality Management, Department of Water Resources Regulation, and the Transboundary Water Resources Management Department. The latter promotes transboundary regional cooperation and equitable utilization of the shared Nile and Lake Victoria waters.

Some of the water resources management functions have been de-concentrated to Water Management Zones (WMZ) as a way of moving closer to the stakeholders. The country has been divided into four WMZs (Victoria, Albert, Kyoga and Upper Nile) based on hydrological basins (figure 2.7). Figure 2.7 also shows the 8 main river basins.

The Water Resources Monitoring and Assessment Department (WRMA) of the DWRM is responsible for the collection, interpretation, and dissemination of standardized water resources data and information in Uganda. It traces its beginning to the late 19th century when the first hydrometric stations were established to determine the extent of the Nation's water resources. The Department provides real-time, current year, and historic information for a network of over a hundred active and about 50 discontinued environmental monitoring sites.

Uganda recognizes the need for comprehensive water resources information to safeguard the supply of potable water to a growing population, to determine and optimize its hydropower potential, to protect the country's unique aquatic environment, to assess its irrigation potential and achieve food security, to support the development of the mining and oil and gas sector, and to protect the country's sovereignty over its water resources.

The WRMA data underpin most of the water resources development and management activities in Uganda, including recent projects such as the construction of Bujagali and Karuma dams, Kampala City water supply, municipal water supply for Masaka, Masindi, Mbarara, and Hoima, and many others. The Department provides the only central database of hydrological information in the country, but also promotes best practices in hydrometric monitoring and data validation. Most hydrological research in Uganda is based on data provided by the Department.

Apart from its monitoring program, the WRMA also provides authoritative commentary on current hydrological conditions and the status of Uganda's water resources.

Table 2.2: Water for production in Uganda

SECTOR	SECTOR DESCRIPTION
Irrigation	Agricultural droughts occur frequently in Uganda and periodic moisture deficits are among the principal reasons for low crop yields. Irrigation provides reliable water supply for crop production and is key to increasing agricultural yields. The total acreage under consolidated irrigation is currently small but the potential irrigated area exceeds 500,000 ha (National Irrigation Master Plan 2010 – 2035). The subsector, therefore, has the potential to make an important contribution to food security, rural development, and economic growth.
Livestock	Uganda's natural environment provides good grazing areas for livestock. The sector contributes some 15% to the agricultural economy and has high potential for domestic and export marketing of dairy, meat, hides, skins, and leather. The performance of the sector is negatively affected by multiple factors, such as insufficient facilities for drinking water for the animals during the dry season and periodic droughts. Increasing sector productivity will support rural development and contribute to food security.
Fisheries	Fish production in Uganda peaked at 330,000 ton per annum but has seen a gradual decline since 2008. Revenue from fish export is significant. Fishery represents a non-consumptive water use. Key sector requirements include maintaining aquatic habitats, maintaining surface area of shallow lakes, and sustaining river flows to keep ecosystems healthy and abate upstream pollution.
Aquaculture	Aquaculture production in Uganda has grown exponentially over the last 10 years, with an annual growth rate of over 300%. With high demand for fish – both for local markets and for export – production growth is expected to continue. The vast majority of aquaculture production comes from low and semi-intensive ponds, minor lakes, and communal dams. Water pollution is a main concern.
Hydropower	Hydropower potential in Uganda is estimated at 4,500 MW, mainly through large facilities on the Nile system. Only 630 MW is currently operational. Water use is non-consumptive.
Industry	Uganda is pursuing a strategy of industrialization that will require dependable water supply and adequate pollution control. There is currently no reliable data on water used by individual industries, but industrial water demand is currently small (NWRA, 2012). Sector demand is expected to increase substantially with economic growth.
Tourism	Game parks and wildlife reserves are among the most important tourist destinations in Uganda. Requirements in terms of water resources are mainly non-consumptive and concerned with preservation of natural scenic spots such as lake shores, rivers, and water falls (e.g. Murchison Falls). There are a number of specific water-related tourist attractions including white-water rafting along the Victoria Nile, and sport fishing on the major lakes and rivers.
Mining	Commercially viable reserves of over 27 types of minerals have been found and will be developed. Water is mainly used for drilling and processing. Consumptive water use is distributed and most probably small. Water quality concerns are more pertinent and potentially large.
Oil production	Commercially viable oil deposits have been discovered in the Albertine Graben in western Uganda. Peak production is estimated at 180,000 barrels per day. A refinery of the same capacity is planned in Hoima. Fresh water plays an integral part in many operating processes in the petroleum industry. Water is widely used in cooling systems, for heating and crude washing, and to maintain pressure in oil reservoirs. Although water is typically recycled and used multiple times, most water eventually returns to the environment and needs to be treated and cleaned before discharge so as not to pollute the environment.

The Role of Water in National Development

Water for People

Access to clean and safe water is a prerequisite for a healthy population and has a direct impact on the quality of life, labour productivity, and economic development of the country. The National Water Policy gives first priority to domestic water supply. The national targets for water supply and sanitation coverage in urban areas are 100% safe water coverage and 95% sanitation coverage by 2020, with 80-90% effective use and functionality of facilities. In rural areas the targets are 79% safe water coverage and 95% sanitation coverage by 2020, with 80-90% effective use and functionality of facilities.

Water for Productive Purposes

Water is an essential input into many production processes and for agricultural activities. The role of water in the development of the principal economic sectors in discussed in table 2.2.

Water for the Environment

Uganda has many unique aquatic and terrestrial ecosystems, and water resources are an integral part of a complex and varied landscape that comprises 1) large wetland areas that cover some 11% of Uganda's land area, 2) the Nile system that includes the equatorial lakes Victoria, Kyoga, Albert, Edward, and George, 3) some 160 minor lakes, and 4) extensive river systems draining into the Nile.

The following environmental goods and services accrue from water resources:

- Aquatic ecosystems (lakes, rivers, ponds) are important habitats for aquatic biodiversity.
- Water and/or hydrological cycles play an important role in climate modulation.
- Aquatic habitats, especially wetlands, play an important role in flood control, pollution control and purifying waste water, maintaining dry season flows, and groundwater replenishment.

In addition, economic development in Uganda is closely linked to the ability of the environmental and natural resource base to provide a variety of goods and services, and sustain these into the future. Environmental degradation entails high economic costs such as declining fish catch and expenditures for water treatment and curative health care, resettlement of environmental refugees, flood control, and restoration of degraded ecosystems; it would also adversely impact on the important tourism sector in the country.

While many factors – such as water quality, sediments, food-supply, and biotic interactions – are important determinants of healthy aquatic ecosystems, an overarching master variable is the flow regime. For rivers, a residual flow has to be guaranteed (ecological flow, environmental flow). Its purpose is to preserve the ecological functions of the river and its embankment zones comprising flora, fauna, morphological river characteristics and recharge of groundwater. In addition, the residual flow allows the maintenance of the existing water quality. In particular, a decrease of oxygen content and the increase of algae growth shall be prevented. Thus, the required residual flow depends on the morphological, biological, physical and chemical characteristics of the river. Therefore, it has to be identified separately for each specific river (Design Guidelines for Water Supply Infrastructure in Uganda, Rev 02; MWE 2013).

3 - Hydrological Services

In this chapter the hydrological services in Uganda are discussed. Arguments are brought forward that water data are essential and a review of the costs associated with hydrological data acquisition is made. An overview of the available water data follows, as well as a description how water data are used for various productive purposes in Uganda.

Introduction

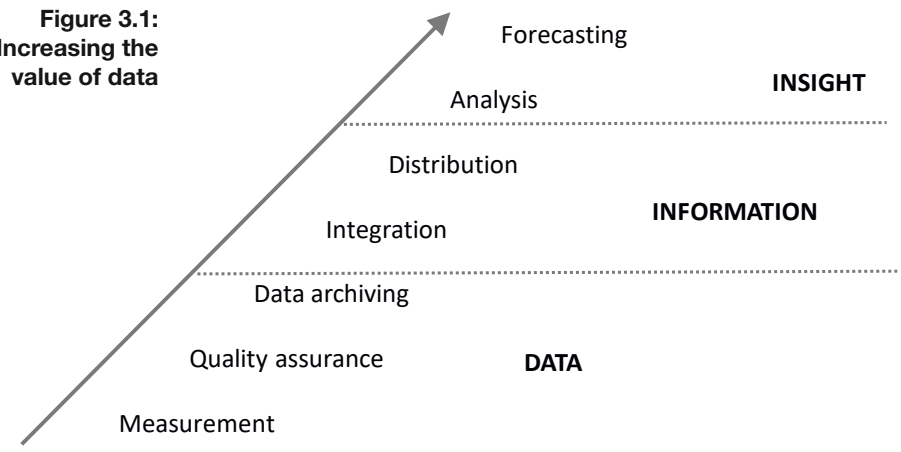
It is obvious that water resources cannot be managed unless we know where they are, in what quantity and quality. More broadly, effective water resources management needs to be based on a good understanding of the hydrological processes, the socio-economic development potential and objectives, and the implications and trade-offs of possible water resources management and development scenarios. It requires a broad range of data and information. Indeed, the prominent WMO/UNESCO Report on Water Resources Assessment, p. 16 states:

"Accurate information on the condition and trends of a country's water resource – surface and groundwater; quantity and quality – is required as a basis for economic and social development, and for maintenance of environmental quality through a proper perception of the physical processes controlling the hydrological cycle in time and space.... almost every sector of a nation's economy has some requirement for water information, for planning, development, or operational purposes."

It is recognized that the collection of water data is expensive. Given the high costs to maintain an effective hydrological monitoring network, it is essential that water data are used to increase socio-economic and environmental benefits. Data in themselves have little value. Only when data are used to produce information and insights that directly benefit public services and society in general do they justify public funding. Figure 3.1 presents the data value chain. Value is added by tailoring data and information to more specialized applications or decisions.

Thus, rather than just collecting hydrological data, the aim of the DWRM is to enable the provision of hydrological services that support economic growth, food security, safety of citizens and households, maintaining a healthy environment, and other societal benefits.

Figure 3.1: Increasing the value of data



(adapted from Bruce Stewart, 2015)

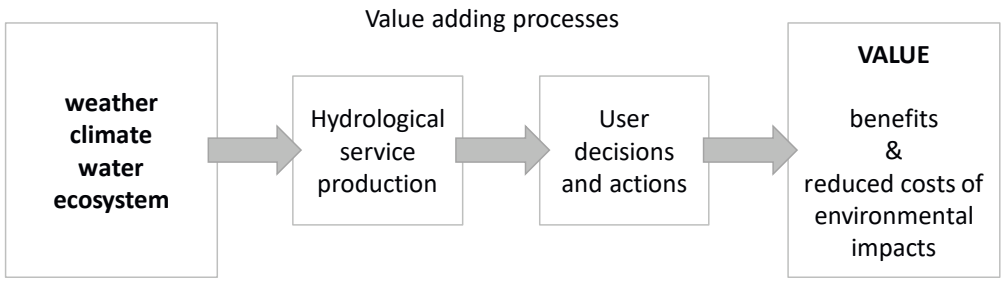


Figure 3.2: Value of Hydrological Services

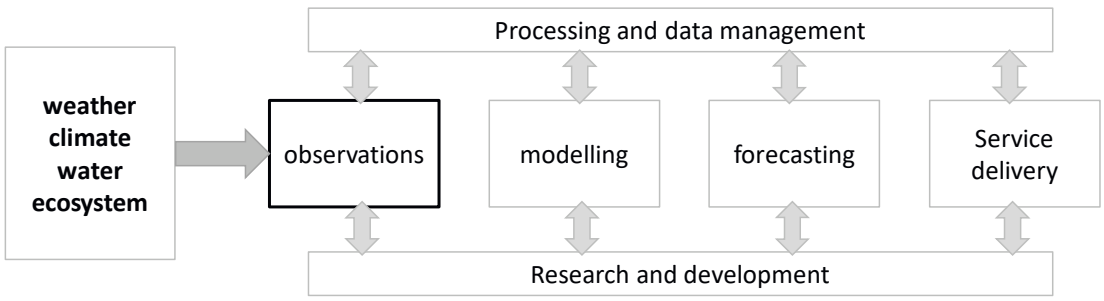


Figure 3.3: Generating hydrological services

Hydrological services are defined as the provision of information and advice on the past, present, and future state of rivers, lakes, and groundwater resources. Hydrological services focus primarily on water resources, although other components of the hydrological cycle – such as rainfall, evaporation, and soil moisture storage – are commonly taken into consideration.

It is noted that the actual benefits of hydrological data and services depends on their role in the decision-making process. This is illustrated in figure 3.2. Decisions are broad in scope indeed. It could concern a private engineering firm designing a bridge, a government agency delineating a flood plain, a regulator issuing a water permit, or a catchment management organization mediating between conflicting water uses. It implies that data – and in particular the derived hydrological services and products – need to be easily accessible to all stakeholders in the decision-making process. It is evident that the value of data and derived products increase by encouraging their broad use.

Hydrological services require reliable water data and a sound understanding of the hydrological processes, as depicted in figure 3.3. While data are the obvious starting point, virtually all hydrological services – and the benefits they provide – depend on the availability of reliable data in combination with an integrated system of data management, modeling, forecasting, and information dissemination.

Availability of Hydrological Data

Streamflow Data

Since the 1940s, flow data has been recorded at 104 stations. Some stations have been discontinued and at present a total of 64 hydro-stations are operational. Figures 3.4 and 3.5 presents the data completeness for the historic discharge measurement network for the periods 1947-2016 and 1978-2014 respectively.

Because of the political situation in the late 1970s and early 1980s, there are significant data gaps in the 1978-2014 timeframe. Out of the 89 stations analyzed within the period 1978-2014, only 11 stations have over 60% records, while 24 stations have between 40% and 60% records. It is noted that 41 stations have less than 20% records for the 1978-2014 period. It implies that time-series analysis (for instance, statistical analysis of floods and droughts) is effectively not possible for these stations. Nevertheless, the existing records may be useful for various hydrological and water resources analyses, and they have therefore been maintained in the database. Similarly, comparing hydrological and hydrometeorological processes during the period under review, 1978-2014, against the long-term pattern outside of this period is not relevant because of the data gaps before 1978.

Figure 3.6 presents the data coverage for the 11 stations with over 60% data record for the 1978-2014 timeframe. Most data gaps are concentrated in the late 1980s and early 1990s. Continuous records exist since the late 1990s, providing time series of reasonable length.

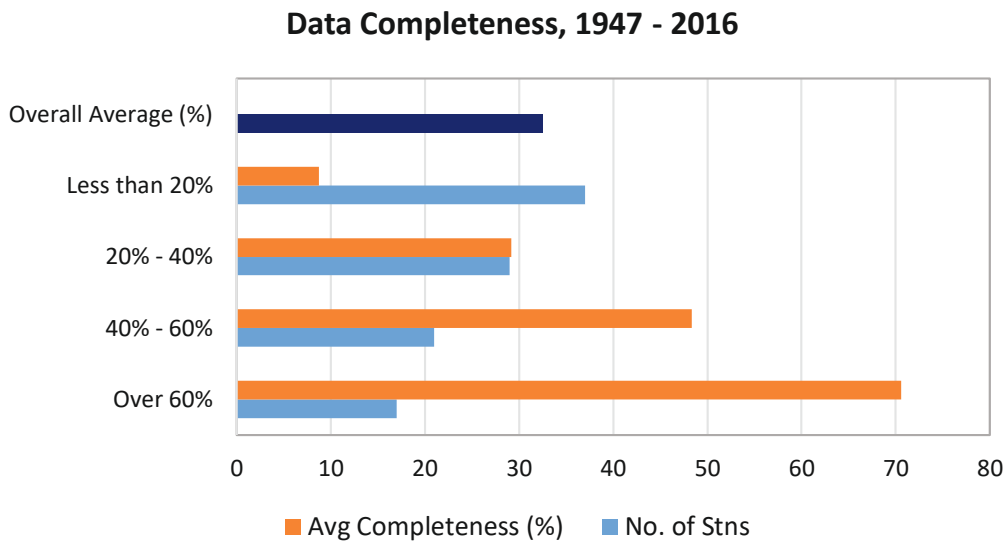


Figure 3.4: Data completeness for the historic discharge measurement network for the period 1947-2016

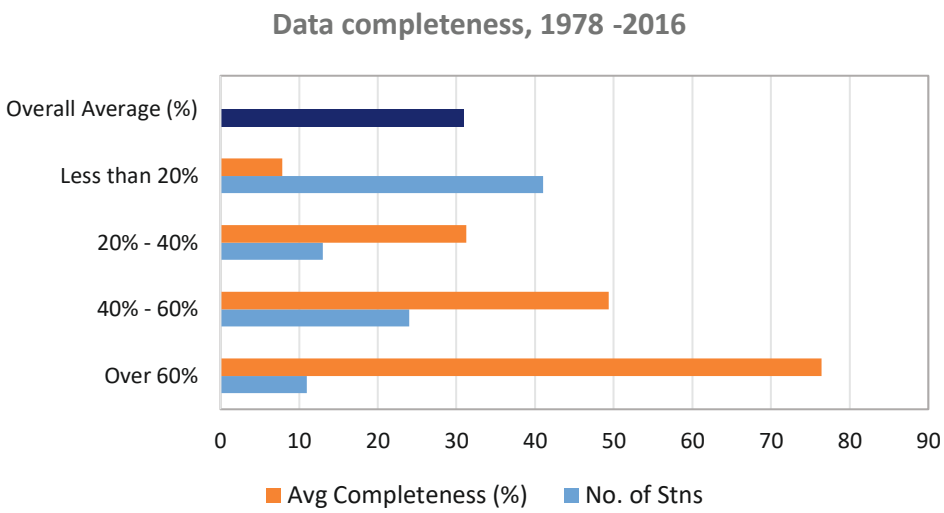


Figure 3.5: Data completeness for the historic discharge measurement network for the period 1978-2014

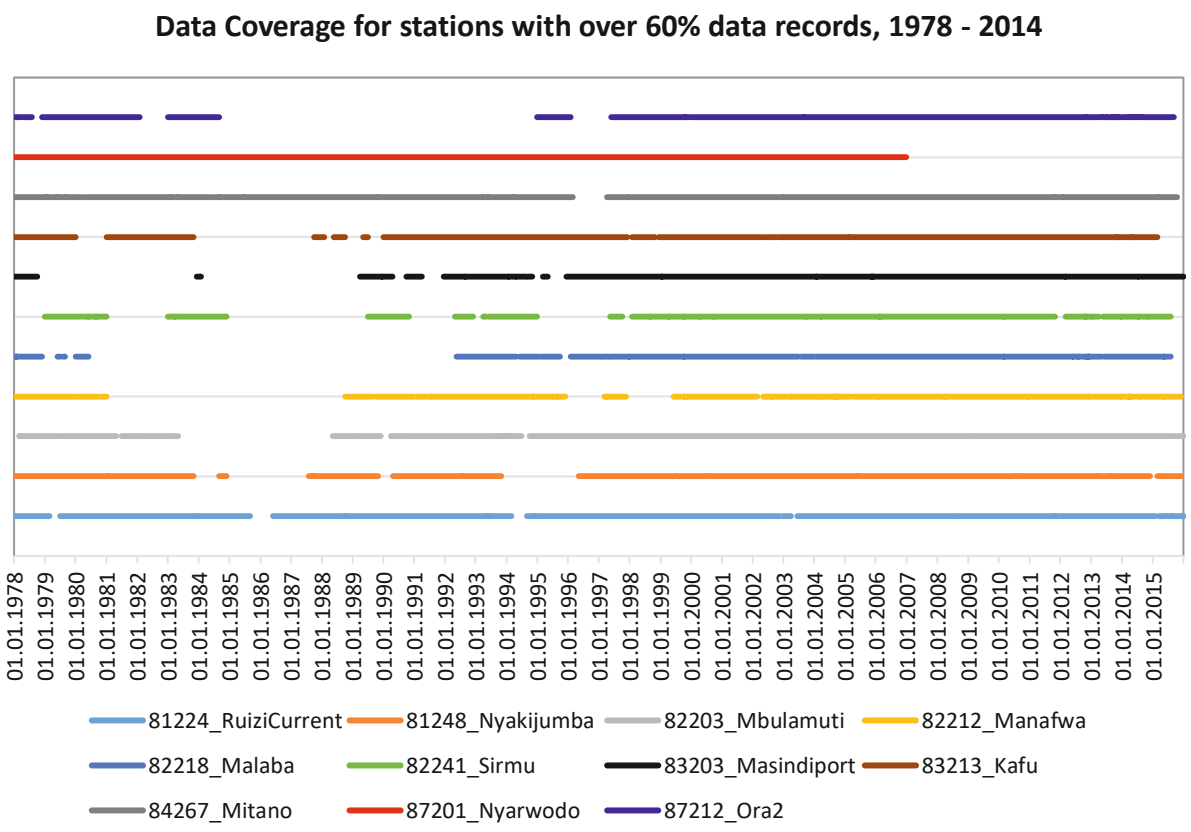


Figure 3.6: Data coverage for stations with over 60% data record for the period 1978-2014

Climate Data

Since the late 1990s and early 2000s, DWRM has operated 10 Automatic Weather Stations, manufactured by Campbell Scientific, across the country. It is noted that two of these stations are located on islands in Lake Victoria (Lolui and Bukasa). The following variables have been measured: rainfall, incoming solar radiation, wind speed, wind direction, relative humidity, temperature (daily average, daily minimum, daily maximum). The daily records are mostly complete.

Groundwater Data

The Directorate of Water Resources Management collects several types of groundwater data items that are processed, quality-checked, stored in databases, and then prepared for dissemination. Generally, there are two types of information currently collected, being:

1. Technical information on boreholes. These comprise borehole construction information (borehole depth, depth to bedrock, water strikes, casing / screen depths and numbers, geological formations penetrated) and aquifer characteristics like yields, transmissitvity (based on pumping test results) and water quality. The technical data are supplied to DWRM by the licensed drilling contractors in the country, who are obliged to fill and submit standard Borehole Completion Forms for each borehole they drill as part of their licensing requirements. This information is stored in the National Ground Water Data Base.
2. Information on water levels in boreholes and rainfall measurements. This information is being collected, processed, and analyzed by DWRM. The groundwater level monitoring data are entered in an excel sheet on a standalone computer.

The National Ground Water Database (NGWDB) has been set up to serve as a management support tool for DWRM to assure cost-effective management and development of groundwater resources. The groundwater database was set up in 1994. In mid-1998 – after being out of operation for more than a year – the groundwater database was transferred from Paradox software (with Atlas GIS facilities) to Visual Dbase v.5 (with ArcView GIS facilities). In 2012, the database was transferred again to MS Access and cleaned and updated during the EU funded groundwater mapping project.

The NWGDB contains approximately 40,000 records on boreholes and shallow wells. Database users include staff of the technical unit itself, as well as contractors, consultants, NGOs, and DWD projects.

The DWRM also issues the national ID number for boreholes. A separate excel database is kept for the allocations of borehole numbers to drilling contractors. The drilling contractors receive these numbers before they construct the boreholes but will "account" for the numbers through the submission of the borehole completion forms.

The Use of Hydrological Data

In Uganda, information about water quantity and quality is used by water resources planners, energy planners, policy-makers at national and local levels, design engineers, research scientists, officials responsible for climate proofing, agronomists, the general public, etc. Specific examples include:

Energy Planning

Designing effective water release policies to optimize electricity production of the series of hydropower facilities on the Nile system is highly data intensive. Lake Victoria serves as the principal reservoir for the cascade of hydropower facilities along the Nile. They are essentially operated on a run-of-the-river basis, which means that water releases have to be timed carefully to maximize power generation. Integrated water and energy planning is achieved by using a dedicated Decision Support System (DSS). It includes: i) a long-term planning tool with a horizon of two years or more to determine mid- and long-term Lake Victoria release policies based on a long-lead climate outlook, ii) a short term release model to forecast the implications of the proposed lake release volumes for the coming 12-month period, which supports DWRM in negotiations with national stakeholders and international partners, iii) a general hydraulic modeling tool for the Nile for analyzing routing times and possible impacts from hydropower development on daily flows and water levels, which supports DWRM in short-term operational decisions and impact assessment, and iv) a short-term power generation optimization tool, which plans hourly dam releases and power production. It is evident that the model suite is highly data intensive and that valuable electricity is lost in the absence of adequate water data.

Irrigation Development

Implementation of the National Irrigation Master Plan 2010-2035 will need to take into account the local water resources context and priorities. Allocation of finite water resources for irrigation based on inadequate data may lead to localized water deficits and conflicts between water using sectors.

While the total area under consolidated irrigation in Uganda is currently small – estimated as some 10,000 ha – the country's irrigation potential exceeds 500,000 ha (National Irrigation Master Plan 2010–2035). Development of this potential does not significantly conflict with hydropower production along the Nile (NWRA 2012), but it may have major adverse impacts on local wetlands, local ecosystem functions, the hydrologic regime of nearby rivers, and associated fisheries and tourism. Assessing the implications of irrigation development is based on a sound understanding of the local hydrological processes, and requires data on water level, flow, pollution, and sediment for the rivers that provide scheme water supply.

Nile Water Allocation

Virtually all of Uganda lies within the Nile Basin, emphasizing the transboundary context of water resources management in the country. It is noted that Uganda is both an upstream and downstream Nile riparian, and that the majority (69%) of Uganda's renewable water resources originates outside the country. Negotiations with Nile partners on equitable use of the Nile waters and their benefits are ongoing. The outcome of these discussions will determine the agreed-upon consumptive water use of the country, and could impose rules on the operation of water control infrastructure on the Nile system. The talks should also ensure that water abstractions in upstream riparian countries are reasonable and take into account Uganda's interest. Negotiations are preferably fact-based and supported with adequate data on water availability – taking into account potential climate change – and current and future water use.

Hydraulic Design

Estimates of flood discharge with various risks of exceedance are needed for a wide range of engineering problems. Industries and residential areas need to be located above maximum expected flood levels, while maximum discharge estimates are needed for hydraulic designs of bridges, culverts, and water retention structures. Design floods are typically derived through statistical analysis of historic flood records. In view of the very high variability of

annual floods in Uganda, long records are needed to provide reliable flood estimates. Alternatively, flood estimates need to be based on rainfall frequencies and rainfall-runoff relations. It is evident that water data provide essential input in computing design flows.

Catchment Planning

Most water resources issues in Uganda are local. The catchment, therefore, has been adopted as the framework for water resources management in the country. This approach also reflects the high spatial variability of rainfall and water resources availability. Water demand in Uganda is set to increase significantly as a result of ongoing population growth, socio-economic development including industrialization, irrigation development, and specific local issues such as oil production.

Catchment management plans will allocate the finite water resources in accordance with the national water policy and strategy, and the respective sector objectives. The plans aim to achieve equitable use of local water resources and their protection. Adequate and detailed local water data are vital to ensure that the local context and priorities are taken into account, and that over-extraction of water resources and environmental stress are prevented.

Regulating Water Abstraction

All water use and abstractions in Uganda above a certain threshold are regulated. The issuing of permits is DWRM's principal tool to control water depletion and pollution, in order to ensure the rational and sustainable utilization of the nation's water resources.

Issuing water permits is based on a sound understanding of the local hydrological processes as well as catchment management plans. Detailed local water data are essential to provide the factual basis for water regulation at catchment and local level. Observational water records are also used as input into hydrological models that evaluate the implications and trade-offs of the proposed water abstractions.

Effective Flood Management

Flood risks and flood damage will likely increase because of the anticipated increase in extreme rain events due to climate change. In Uganda, the areas most affected by floods are the low-lying areas at the foothills of Mount Elgon and the Rwenzori's that are part of the original floodplain. Floodplains in Uganda are generally attractive sites for agricultural activities and various types of development, and include significant and growing human settlements.

In the Ugandan socio-economic and climatic context, it is not realistic to protect the large floodplains against the maximum possible flood that will occur. Hence the aim should not be to prevent flooding from an extreme event, but to mitigate its consequences and ensure that human life is not brought in jeopardy.

Flood risk mapping is concerned with specifying the probability of inundation and flood depth in the floodplain and adjacent areas. It is a highly data intensive activity. The inundation maps provide key input into advance flood planning and proper regulation and zoning of flood prone areas.

Climate Proofing

There is overwhelming scientific evidence of a warming trend of the Earth's atmosphere and a gradual increase of temperature in Uganda is anticipated in the coming decades. Uncertainties remain over the magnitude and speed of future temperature increase. Climate change may change rainfall on the catchments, increase the hydrological variability of the river and lake systems, and lead to higher water demand.

Uganda is highly vulnerable to the impacts of a warming climate owing to a multiplicity of factors, such as the generally high potential evaporation rates that accentuate the impacts of periodic moisture shortages to crop production, combined with the large rural popu-

lation that depend for its livelihood on rainfed agriculture or semi-pastoralism. The rural poor have generally limited possibilities to diversify into less-climate sensitive livelihoods, and therefore have low resilience to climate shocks.

The preparation of climate change vulnerability and risk maps – both at national and catchment level – needs to be based on accurate and detailed water and climate data.

Data Access Policy

DWRM is the owner of the hydrological data collected by the Directorate in Uganda. Data from the following databases can be made available to the public for professional, research, educational, and other purposes:

1. Surface water database; developed in Aquarius software, it contains mostly daily water levels of rivers and lakes at specific stations. Water levels are converted to discharge using rating curves based on periodic discharge measurements. The database has recently been quality-controlled.
2. Groundwater monitoring database, which provides daily groundwater levels of the monitoring boreholes.
3. Borehole/groundwater database, which provides data on well logs, yields, handpump installation, and water quality at the time of drilling for a large number of boreholes in the country.
4. GIS database, which provides data layers of water resources related information. Examples of shape files include country-wide surface water runoff and groundwater potential.
5. Water quality database, which contains information on the water quality of surface water, groundwater, waste water, and drinking water.

Data access is subject to paying a fee, as follows:

- Surface water and groundwater levels are available at a cost of UGX30,000 per station year.
- Borehole data are available at a cost of UGX 5,000 per borehole.
- GIS layers are sold at a cost of UGX500,000 per layer, or UGX50,000 per map (either hard or soft copy is possible). GIS maps of the groundwater mapping projects are available free of charge.
- The cost for water quality from water quality monitoring stations is not fixed, it depends on the amount of data and time series, as well as amounts of parameters.
- Government agencies, District Local Governments, and students of Makerere University do not pay for data records; the latter need to submit a copy of their reports to the Director of DWRM.

The procedure for data collection from all databases of DWRM is the same, and involves:

1. Write a hard copy letter to the Director, DWRM requesting for the specific data;
2. The director, through the commissioner in charge, replies to approve the supply of data;
3. DWRM prepares the invoice and a Bank Advice Form;
4. The applicant pays the Uganda Revenue Authority at the bank using the Bank Advice Form;
5. Upon confirmation of payment the data are issued in soft copy on a CD brought by applicant, or by email.

BOX 3.1: Catchments without data

Hydrology is an inexact science. The parameters that determine the hydrological response to a rain event – such soil type and depth, land use, relief, vegetation cover, agricultural practices, presence of bedrock fracture, antecedent rainfall and soil moisture, etc. – all vary at micro-scale and are thus subject to high spatial variability. Hydrology practitioners, therefore, have relied on empirical relations derived through regression analysis rather than on theoretical formulas. Regarding ungauged catchments – i.e. catchments without data – using parameter values estimated without any measurement to provide an indication of their validity has proven inadequate. Without any observational data, the accurate assessment of the hydrology of a catchment remains an unsolved challenge.

The absence of a sound understanding of the hydrological processes because of inaccurate, insufficient, or no data typically leads to overly conservative decisions, lost potential, and possible resource conflicts. It will probably also result in mistakes, which will need to be rectified at a later point in time, typically at considerable costs.

Costs and Benefits of Hydrological Services

Hydrological data collection and service provision is not cheap. Yet, the benefits are widespread, as discussed in the previous paragraph. Nevertheless, since hydrological services are a public good that has to be provided by Government – and is funded through taxation – it is important to find the right balance between the level of service provision and derived benefits.

Although Uganda has collected hydrological information for more than a century now and operates close to 75 stations, one can argue that the current water data collection activities are insufficient. Furthermore, the total costs of the data collection activities are arguably much lower than the ensuing benefits. This is because:

- Pressure on natural resources – including water resources – is increasing to unprecedented levels because of ongoing population growth, food security concerns, and socio-economic development; consensual management of water resources – through an IWRM process and relying on DWRM's permitting tool – only works in practice when based on facts and a solid understanding of the regional and local hydrological regime;
- Rapid urbanization is increasing pollution that will effectively reduce the available water resources; water pollution needs to be measured in order to be managed;
- Climate change has shown to be a reality, which could further reduce the effective availability of water resources; increasing climate resilience has to be informed by a factual understanding of the weather and hydrological processes;
- Water is an essential and growing input for many socio-economic activities; the use of water data to optimize the benefit of Uganda's land and water resources is increasing rapidly – as discussed in paragraph "The Use of Hydrological Data"; it is evident that the benefits to society of water data are also growing quickly;
- The expectations of data clients – including many in the general public – are subject to rapid change because of innovations in information technology; data clients will increasingly expect real-time data and information available through the web or on their smartphone;
- There are still a large number of catchments without any data.

To summarize: given the socio-economic and water resources trends in Uganda, there will inevitably be mistakes – i.e. unnecessary costs, conflicts and/or benefits forfeited – if water resources are managed without sufficient data, information, and insights in the hydrological processes.

4 - Hydrometry

This chapter gives an overview of the history and extent of data acquisition activities and hydrological practices. It includes a discussion of the comprehensive Water Information System and a brief examination of trends in environmental monitoring and how these may affect the future work of DWRM.

The Hydrometric Network

Hydrometry in the widest sense is the measurement of all components of the hydrological cycle including rainfall, evaporation, infiltration, groundwater flow and storage, river flows, and freshwater storage in lakes. Hydrometry also includes monitoring the quality of the various water bodies. Nevertheless, the term is primarily applied to the measurement of river flows, lake level fluctuations, and groundwater levels.

Surface Water

In Uganda, hydrological monitoring started in 1889 with one station in Entebbe that recorded the water level changes of Lake Victoria. From then on until 1978, the network was gradually expanded to 140 operational stations that covered most of the country. The period 1979 up to 1990 witnessed political instability and the hydrological monitoring network virtually collapsed with nearly all equipment vandalized and most data lost.

From 1994 onwards, the surface water monitoring network was partly restored and rehabilitated. By 1997 the number of operational stations had reached 37, covering almost all important rivers in the country. Subsequent reviews of surface water monitoring activities recommended network strengthening based on local, national, and transboundary priorities. In response to these recommendations, the number of monitoring sites was gradually increased to 71 (see figure 2.9). While there are recognized data gaps – note that the network still does not cover parts of north-eastern Uganda – it is recognized that sustainability considerations and budgetary constraints may limit further expansion of the network.

As discussed in paragraph "Costs and Benefits of Hydrological Services", hydrological data collection is expensive. The principal factors that make water data costly are associated with equipment costs and periodic field visits to check station performance and conduct stream gauging. Further, incidences of vandalism make it necessary to occasionally replace expensive equipment. However, modern technology may reduce operating expenses and facilitate further expansion of the network.

DWRM also operates a national water quality monitoring network that includes 119 stations. Sampling of suspended sediments is being carried out periodically.

Groundwater

A national groundwater monitoring network has been set up to get an idea on the background water levels for areas that are not disturbed by groundwater abstraction. In a few cases, monitoring stations have been set up near areas where groundwater abstractions are taking place with the aim to monitor the impact of these abstractions. In many cases, the stations are also equipped with a rain gauge. A typical output of the processed information is given in figure 4.1, while full hydrographs of 14 stations are included in Appendix A.

There are 55 groundwater monitoring wells of which 29 (53%) are currently operational and 23 (42%) are newly drilled ready for installation. The groundwater monitoring network is presented in figure 2.9. 21 sites also include rain gauges.

Given the anticipated role of groundwater for productive purposes, a further expansion of the groundwater network is probably necessary.

Hydrometric Practices

Stream discharge is arguably the most important variable required for effective water management. It is, however, one of the most difficult variables to measure on a continuous basis.

In practice, therefore, discharge is derived from stage measurements. River level is measured on a (semi) continuous basis by a recorder installed in the river or by manual observations, and is then used to calculate discharge by using the "rating curve". The rating curve is the unique relationship between river stage and discharge at the control section.

However, morphological processes such as erosion or sedimentation can lead to shifts in the stage-discharge relation, and the rating curve may require frequent adjustments for unstable station controls.

Thus, measuring river flow generally involves:

1. Measuring water levels on a regular interval in order to obtain a continuous record of stage – which is the height of the water surface relative to a benchmark at a location along the river;
2. Conducting periodic measurements of the river discharge;
3. Developing a relation between the stage and the discharge;
4. Using the stage-discharge relations – the rating curve – to convert the continuous stage record into a continuous record of stream flow estimates.

Measuring Stage

Stage – sometimes called gauge height or water level – can be measured using a variety of methods. A typical monitoring station in Uganda is equipped with staff gauges mounted on gauge pillars (figure 4.3). Local observers take two readings per day from which the daily average is established. The water levels are recorded in a Gauge Register, which is periodically collected by Water Resources Inspectors who add the record set to an electronic database after manually checking for measurement errors. This process is well-established but data are not 'real-time', and data processing involves several manual steps that are potentially error prone.

An alternative approach is to measure water levels automatically, either with a pressure transducer, a float-operated shaft encoder, or a radar sensor (which is a 'non-contact' sensor). The measured stage value is stored in an electronic data logger on a regular interval, usually every 15 minutes. Automatic quality control routines check the validity of the measurement. Data are transferred to the central or zonal database by means of a data storage device, or through real-time communication using the mobile phone network. The latter method has been successfully tested and is promising.

Stage must be measured with respect to a constant reference elevation, known as a datum. This is a permanent

Figure 4.1: Groundwater level and conjunctive rainfall monitoring of Soroti Otucopii Network Station

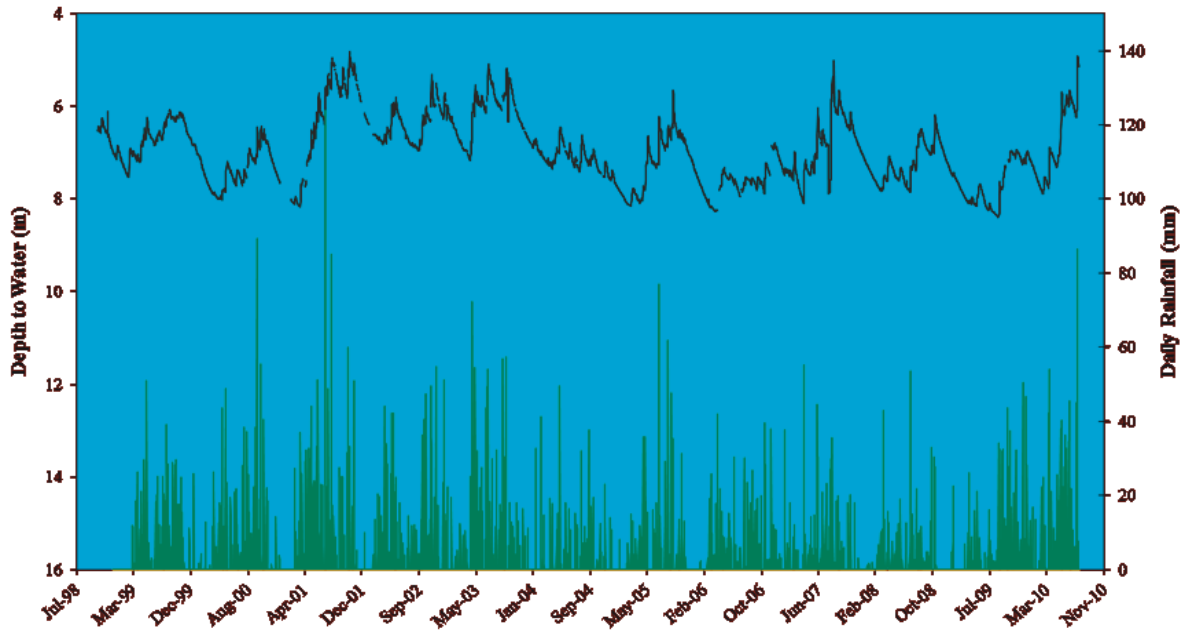
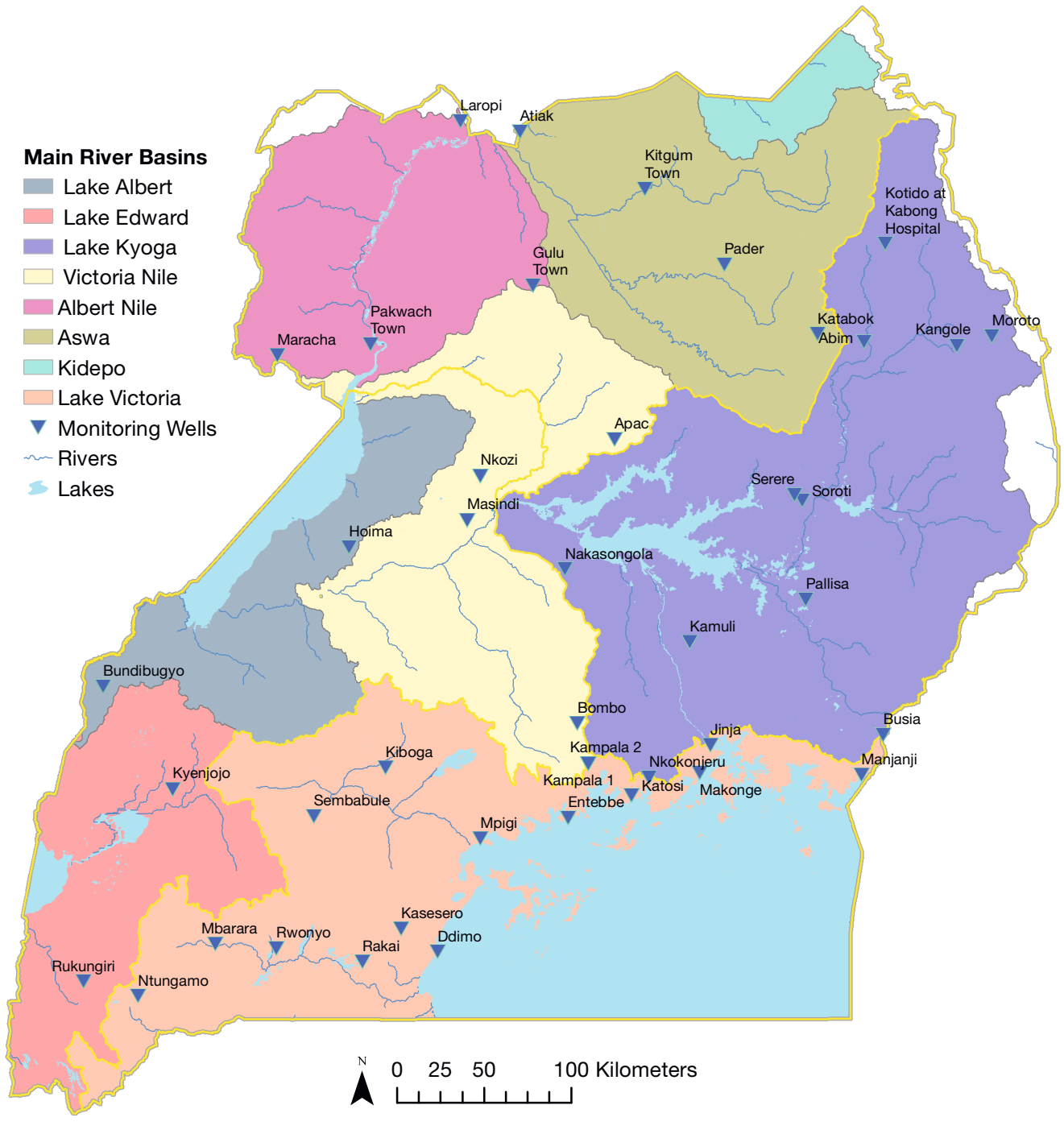


Figure 4.2: Location map of all groundwater stations



benchmark that serves to maintain station accuracy in case the staff gauges or other measurement equipment are damaged by floods.

River Discharge

In order to establish the rating curve – i.e. the relation between river stage and discharge – river flow needs to be measured for a wide range of water levels.

The DWRM uses two methods for flow measurement: 1) the conventional mechanic current meter, and 2) the Acoustic Doppler Current Profiler (ADCP).

The conventional current meter is mainly used for small rivers. In this method, the river cross-section is divided into several vertical subsections for which the water velocity is determined using a propeller-based current meter. Discharge in each subsection is computed by multiplying the subsection area by the measured velocity. Total discharge is computed by aggregating the discharge for each sub section. This method is well established but time-consuming.

The ADCP is a hydro-acoustic instrument that measures flow velocities by sending out sound waves that are scattered back from particles within the water column. The instrument was introduced in Uganda in 2001. It is operated from a tethered boat (see figure 4.4 and 4.5) and can be used for a wide range of river conditions. An ADCP measurement takes little time and is instantly processed, and several transects can therefore be made under steady flow conditions. Figure 4.6 shows the output of a typical ADCP measurement.

The quality of the discharge record depends to a considerable extent on the stability and hydraulic conditions at the measurement site. In practice, it has proven difficult to find locations that combine uniform flow conditions and a stable control section with tactical considerations such as site access and security of equipment. A compromise

Figure 4.3: Staff gauges

Figure 4.4: Measuring discharge of river Ruizi at Mbabara Old Water Works in February 2016

Figure 4.5: Measuring discharge of river Ruizi at Mbabara Old Water Works in February 2016

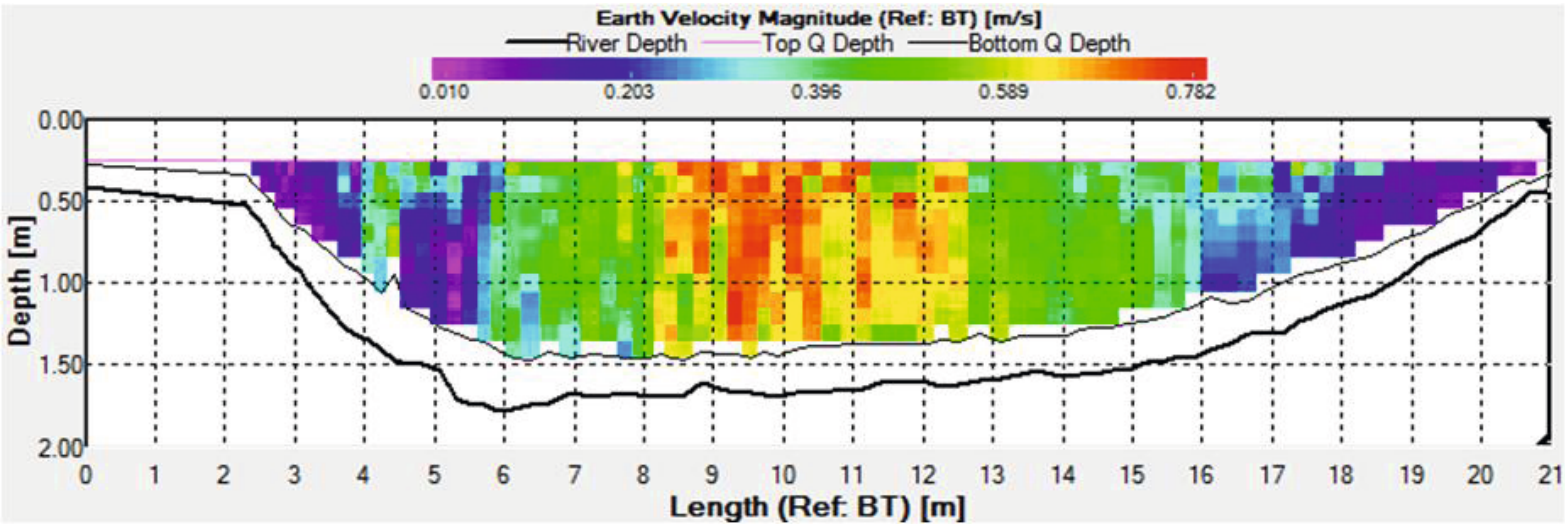


Figure 4.6: Output of an ADCP measurement on River Kafu.

is often required. The introduction of the ADCP has substantially increased the accuracy of river flow measurement in Uganda, since this instrument is far better able to cope with irregular velocity distributions than the conventional mechanic current meter.

Groundwater Monitoring

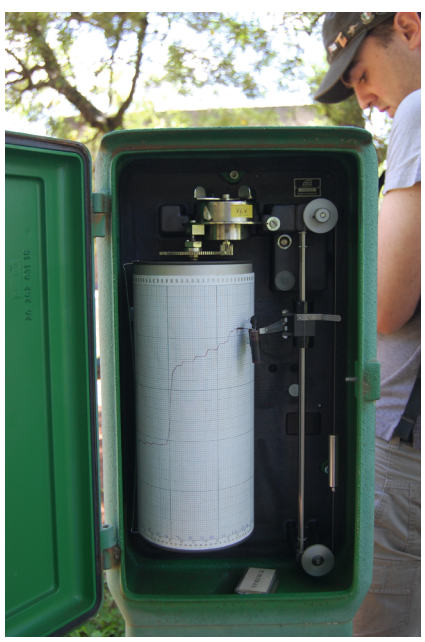
Groundwater levels are observed once a day, by a water level meter or automatic water level recorder. The field data is collected by Inspectors, entered in Excel sheets at the groundwater data processing center; validated against rainfall record by senior hydrogeologists, flagged when doubtful, and stored in the station specific excel files.

Sediment Monitoring

Depth integrated sampling techniques are used for measuring suspended sediment transport. Generally, sediment measurements are only conducted at stations with a reliable rating curve, since flow volume is needed to calculate the total amount of sediment in the river. The frequency of sediment measurement occasionally differs from the frequency of discharge measurements.

Figure 4.7 (left): Semi automatic recording of groundwater levels

Figure 4.8 (right): Manual recording of groundwater levels using water level dipper



Data Management Practices

Established Practices

Most hydrometric activities in Uganda are still based on manual observations that involve hard-copy data processing with several manual steps. A few automatic stations are operational, some of which with real-time data transmission. Historic surface water data were stored in HYDATA – a system designed in the 1990s that has proved reliable and effective. Nevertheless, HYDATA exhibited several limitations. For instance, it does not include a map-navigation tool and has no facilities to connect real-time to the monitoring network.

Real-time water data were stored in the proprietary software provided by the respective equipment manufacturers – for instance HYDRAS 3 for OTT instruments, or DEMASdb for SEBA equipment. While these applications include a broad range of functionality for storing and manipulating hydrological time-series, they do not support the loggers and sensors of many other companies in the water monitoring industry.

Groundwater data were archived in MS Excel whereas meteorological data were stored in MS Access.

Thus, different data management systems were used in parallel, and error-prone processing steps were needed to integrate the various data sources into a single database.

It is noted that neither HYDATA, HYDRAS 3, or DEMASdb includes auditing tools that track data processing and quality control steps ("who did what, when, and why"). The value of hydrological data increases significantly if the end-user – even decades from now – can assess the accuracy and reliability of the data. It requires information on the station characteristics, the methodology and instruments used, the experience of the hydrographers, and the data processing steps and quality control procedures.

Given the above, it was clear that an overhaul of the data management system and practices was required. After completing a thorough evaluation process, DWRM recently introduced Aquarius Time Series, which is a modern Data Management System (DMS) for hydrological time-series data.

Aquarius Time Series

Aquarius is an advanced and complete water data management system that offers an effective solution for environmental data management. The application includes the full set of functionality required by a modern water monitoring and management agency. Aquarius stores surface water data, groundwater observations, meteorological data, and meta data in a single system. Data can be made available in real-time.

While conventional hydrometric networks are based on manual observations and hard-copy data processing and publication, modern networks aim for continuous monitoring and real-time data communication, processing, quality control, and web-publishing. They focus on data flow while aiming for zero percent downtime. Data, in principle, should enter the system only once – preferably at the monitoring site – after which it is processed to the final product in an uninterrupted chain of processing, quality control, and dissemination steps. Data flow and the data management process is schematically depicted in figure 4.9. The practical setup of such system at DWRM is presented in figure 4.10.

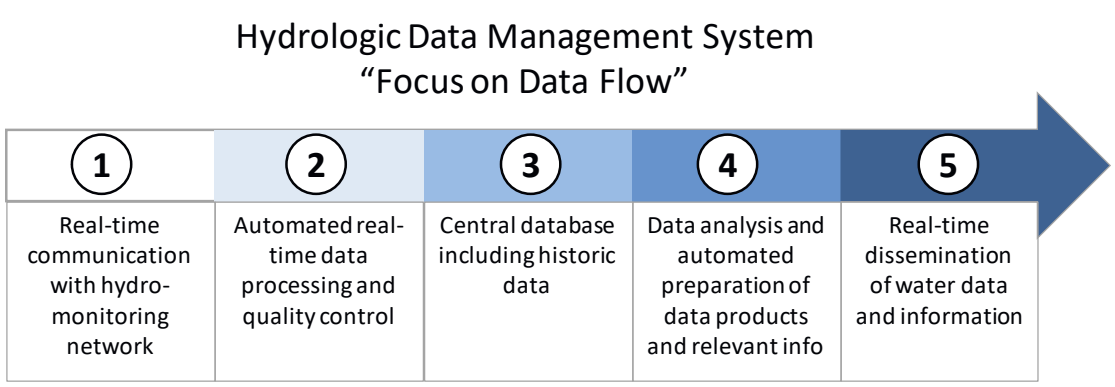
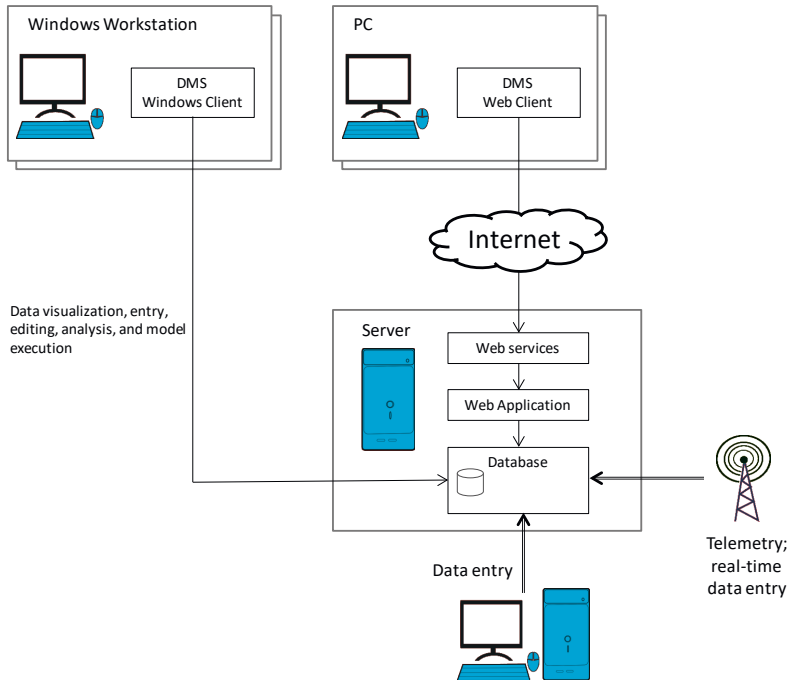


Figure 4.9: data flow in a modern hydrological time-series data management system

Figure 4.10: structure of a typical modern hydrometric data system



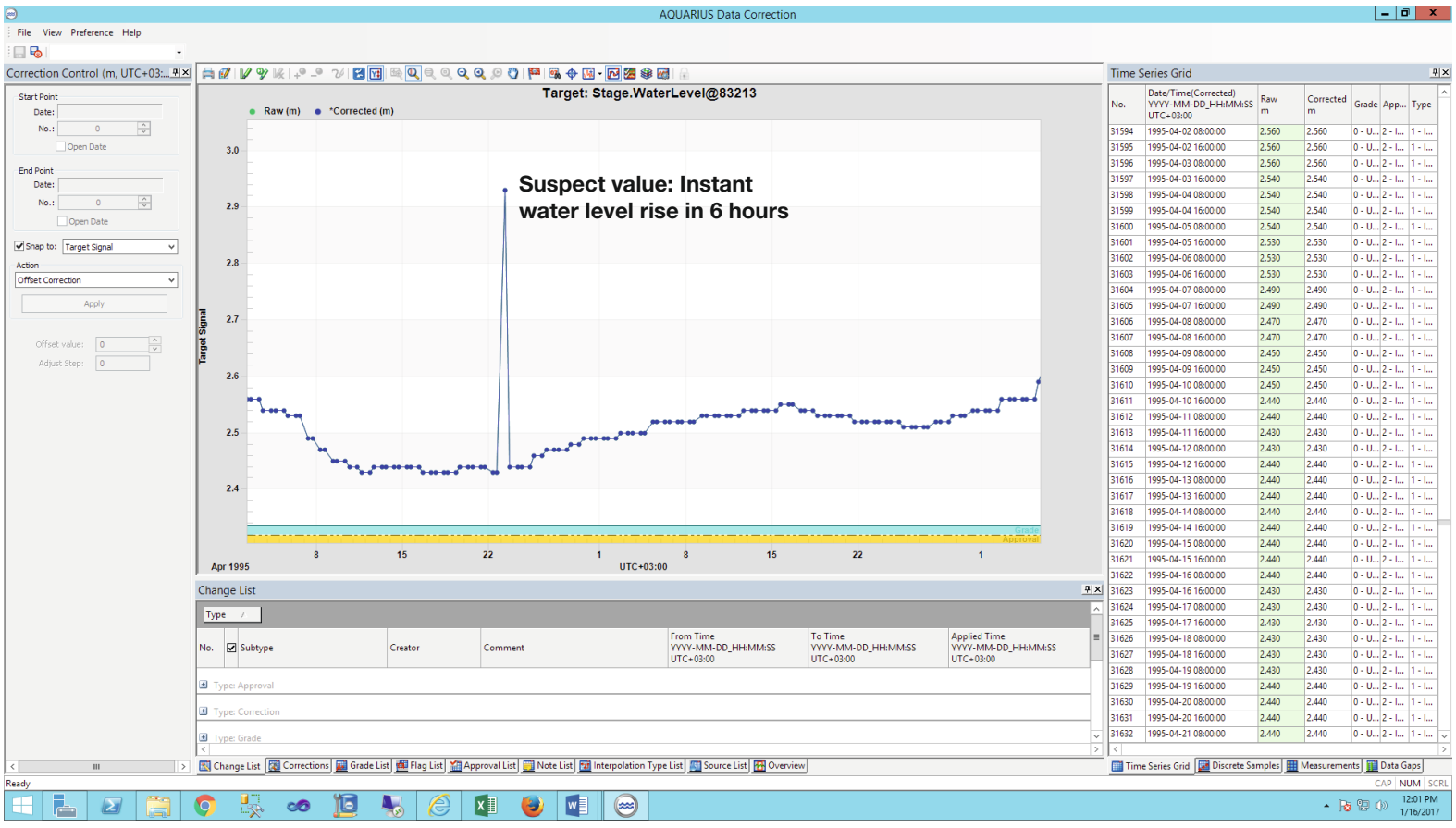


Figure 4.11: Suspect Data Point

Components of a modern data management system include automatic stations, communication system, database, models that produce diverse data products for various purposes, publication system, and data dissemination system. Aquarius supports the above setup.

Data Quality Control

Erroneous or anomalous data evidently compromise the value of the data set and need to be identified and corrected, or deleted. Common data errors include ambiguous records, duplicate records, empty records that are confused with zero values, missing data, incorrect units, unexplained outliers, truncation of peak flow, scale issues, anomalous peaks, sensor drift, etc. It is noted that data quality control in many instances requires a manual approach and is therefore a time-consuming activity.

The data quality control program at DWRM includes three components:

1. Quality control of the raw data using the in-built functionality of Aquarius or HYDATA;
2. Systematic and thorough review of the rating curve;

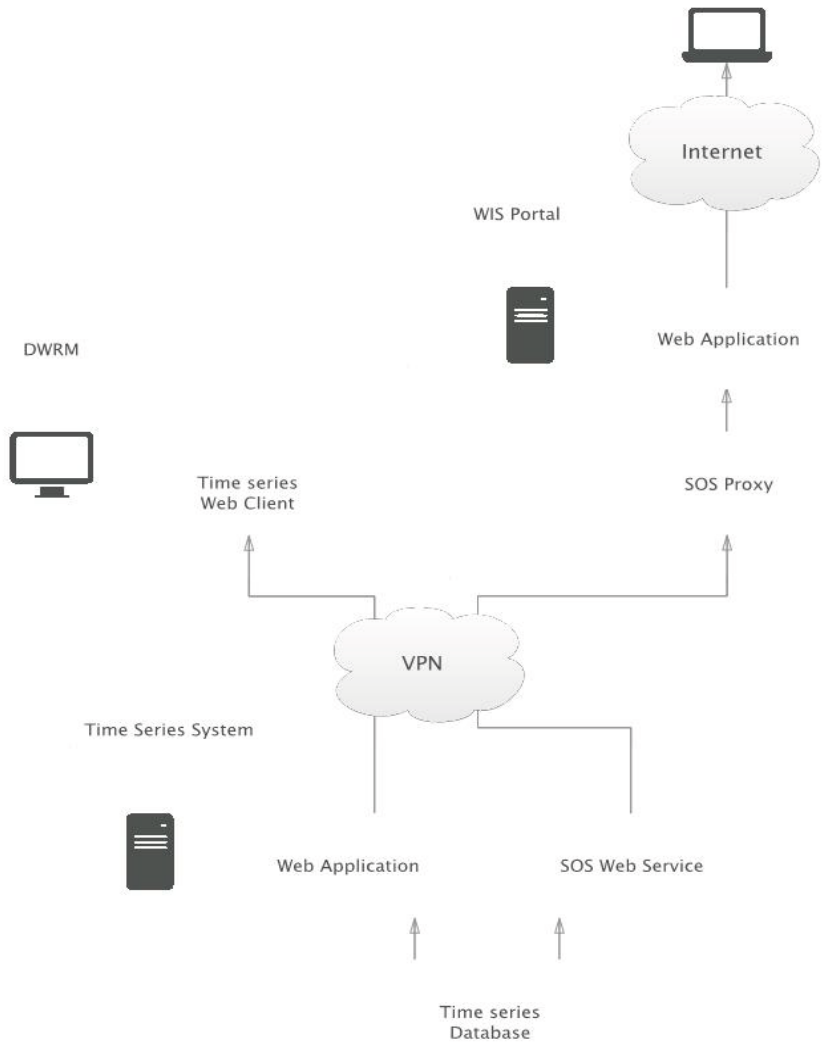


Figure 4.12: Deployment of Components at WMZ and National Level

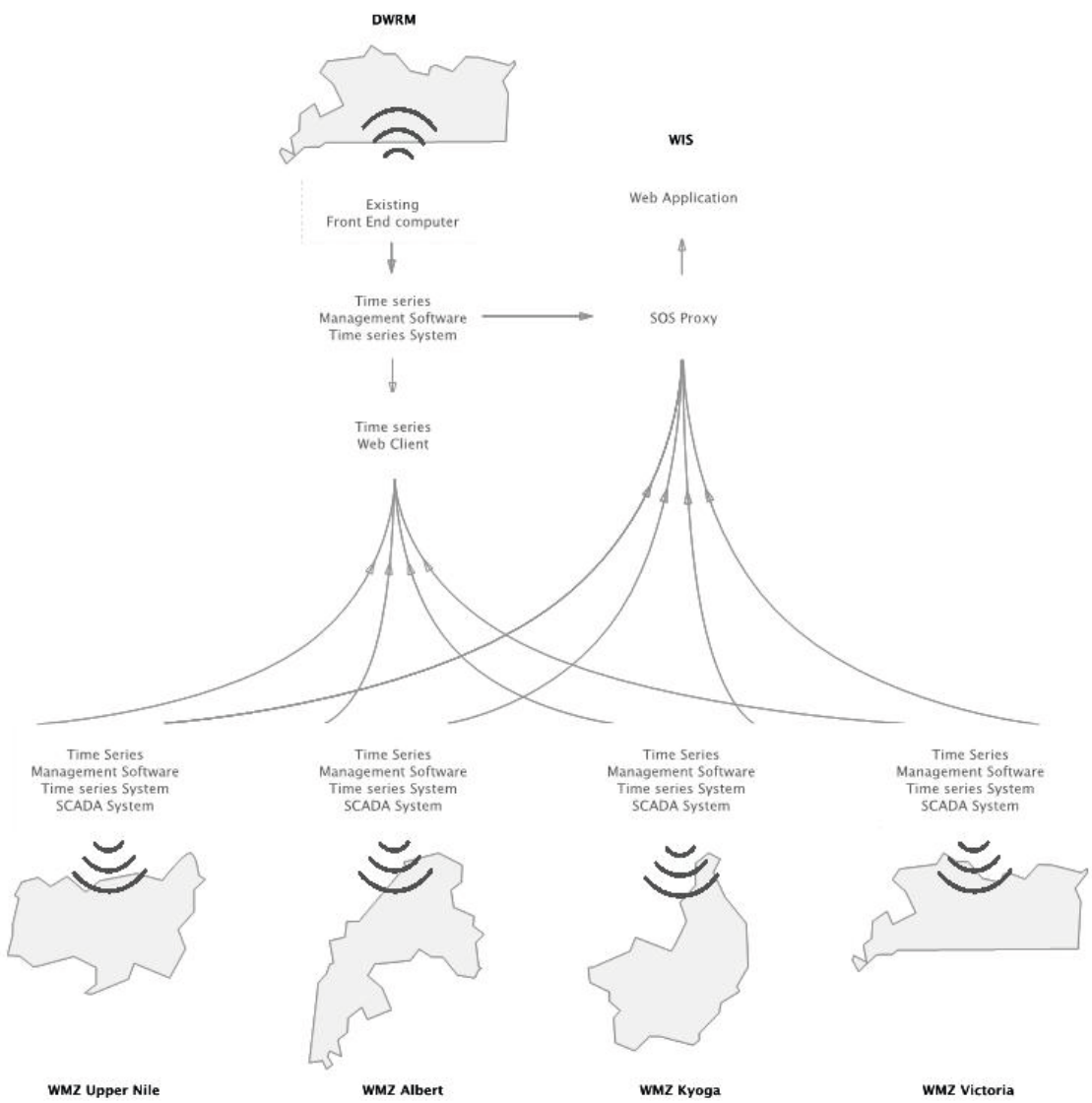


Figure 4.13: Components of WIS at national level

3. Gap filling (it is to be noted that this applies to short gaps only).

Typical tools in Data Management Software such as Aquarius or HYDATA include threshold and rate-of-change based flagging, as well as basic data point corrections such as specific value replacement, re-sampling, small gap interpolation, and collaborative flagging where data can be corrected based on data from nearby stations. Figure 4.11 presents an example of a suspected data point.

The second element of the quality control process pertains to improving rating curves. The rating curve is the unique relationship between river stage and discharge at the control section of a hydrometric station. Because streamflow is one of the most difficult variables to measure on a continuous basis, discharge is commonly derived from level recordings – which are converted into discharge by using the rating curve. Improving the accuracy of the rating curve is obviously the single most effective way to improve the quality of the historic streamflow data set.

The third component of the quality control program is concerned with gap filling. Hydrologic datasets frequently contain data gaps, ranging from several days to several months or longer. For data gaps that are limited to a few days, the gap filling routines included in the Data Management Software can be used. However, for longer gaps – those exceeding a few weeks or even longer – the DMS tools are not suitable. Only by developing predictive rainfall-runoff models – that establish the relation between the climatic conditions and the hydrologic variables – and then running these models for the periods without data, short data gaps can be "filled". However, when data are not available for longer periods – those exceeding months – parameter value estimation becomes increasingly inadequate. It is noted that WMO regulations on data processing and quality control explicitly discourage gap filling in the primary dataset.

Data Analysis

While a typical DMS includes some data analysis tools, their primary role is to integrate all components of the 'data flow chain'. The systems are designed to seamlessly provide real-time data to independent analysis tools, models, and forecasting tools. The scope of potential tools is broad indeed and depends on what the data are used for. Tools could include design tools for infrastructure, rainfall-runoff models, floodplain inundation assessment tools, calibration modules for earth-observation products, etc. A number of analysis tools exist at DWRM. The Nile DSS established by the Nile Basin Initiative (NBI) is operational and well-supported, and evaluates the basin-wide response to alternative water allocation and management policies at Nile basin scale. At national level, a complete MIKEBASIN setup has been developed that covers the entire country. A number of catchment models are also available, for instance for Ruizi river.

Water Information System

Uganda is introducing a comprehensive Water Information System (WIS). It comprises an official repository and information system for all hydrologic, climatic, watershed, infrastructure, and water related data. The WIS allows for a review of information by all stakeholders, including basin planners, decision makers, data users, and water users at various levels.

The components of the WIS under control of the DWRM aim to improve national water resources monitoring and hydrological information processing and dissemination. It includes integrated database systems for surface water, groundwater, water quality, and permits.

WIS will be a distributed system. This implies that independent hydrological databases will be developed for each Water Management Zone (WMZ). Each WMZ will operate: 1) time series management software, 2) time series storage system, and 3) a SCADA system for data acquisition that includes telemetry options for real-time data transfer. Aquarius will perform the above three functions. WMZs are responsible for all primary data acquisition and processing steps including monitoring, quality control, editing, conversion, validation, and reporting. The physical storage of data is at the WMZ.

At a national level, the four WMZ systems will be connected through a secured and private network to a central web application which synchronizes the respective data sets. This ensures that all users are accessing the latest data, and enables seamless use of the WMZ data by multiple clients including third parties and third party applications.

The above set-up is illustrated in figures 4.11 and 4.12.

Trends in Environmental Monitoring

There is a confluence of trends in environmental monitoring:

1. Ongoing innovation and cost reductions may lead to mass adoption of affordable electronic environmental sensors, digital data loggers, and real-time communication technology; one way to capitalize on this development is through a 'citizen science' initiative;
2. Continuous monitoring and real-time data communication – in combination with the trend identified above – results in large volumes of complex data; the data management system needs to be able to handle this;
3. Data consumers and data end-users are increasingly expecting the availability of high quality data in (near) real-time; it is noted that client expectations are changing rapidly (e.g. to use apps on smart phone);
4. In response to client expectations for (near) real-time data and data products, there is an obvious drive towards automated data processing, analysis, and dissemination.
5. The demand for water data is growing rapidly because of increasing pressure on water resources and concerns about climate change, which are initiating the development of fact-based climate change adaptation and resilience plans;
6. Earth observation using drones will increasingly provide useful data with adequate resolution at river basin and sub-catchment scale.

Modern electronic monitoring technology – such as digital multi-channel data loggers, solid state electronic sensors, GPRS modems, automated sample collection and multi-parameter water quality sensors, and hydro-acoustic instruments for flow measurement – offers the possibility to substantially reduce the costs of hydro-metrological data acquisition. The emerging techonology is also characterised by the following: 1) low maintenance, 2) low risk of vandalism, 3) low frequency of regular field visits and absence of unscheduled field visits, and 4) automated data processing. The emerging monitoring technology also facilities the second trend: real-time data.

5 - Comprehensive Water Resources Review 1978-2014

This chapter presents a comprehensive hydrological review for the time frame 1978-2014. For each of the eight main river basins, the spatial and temporal distribution of the surface and groundwater hydrology are described. A description of hydrological monitoring activities and a water balance and trend analysis are also presented.

Albert Nile

Surface Water

The Albert Nile starts at the northern tip of Lake Albert and flows over a distance of some 200 km to the South Sudanese border at Nimule. The Albert Nile catchment comprises two distinct geographical elements: 1) the wide and very flat Nile valley – which is an extension of the Western Rift valley – that features large seasonal and permanent wetlands, and 2) the adjacent hills at much higher elevations, with a rugged terrain and relatively small catchments. Over a dozen small and parallel tributaries – sometimes referred to as 'the Torrents' – flow into the Albert Nile (see figure 5.2).

The area has a unimodal rainfall regime, at least on average. Rains are sparse from November to March, while the period April – October is generally wet. It is noted that the Albert Nile valley is much drier and warmer than the adjacent hills. Comparison with Penman estimates of potential transpiration shows that a Basin-wide moisture surplus only happens in the months of August to October, although pockets of moisture surplus occur in the hills in other rainy months as well.

It is evident that the river Nile dominates the hydrology of the Albert Nile catchment. The large storage volume of Lake Victoria attenuates Nile flows, which are modified by their passage through Lakes Kyoga and Albert, but remain more or less steady throughout the year. A seasonal component is added by the tributary inflow. Because of the parallel arrangement of the tributaries, their hydrologic regimes are, in fact, synchronized. All tributaries experience peak flows at almost the same time in the wet season, while all their flows are negligible in the dry season. It has a distinct impact on the hydrology of the area.

Because of the large wetland areas and generally semi-arid conditions in the Lake Albert valley, net evaporation losses of the Albert Nile are substantial. In previous studies, these losses have been estimated at 5% of dry season flows, although it is evident that this figure represents a rough estimate.

While soils are diverse in the Albert Nile Basin (see figure 5.3), a substantial part of the Basin is covered with Leptosols. These shallow soils are characterized by low soil moisture storage capacity and hence a quick response to a rain event.

Figures 5.4 and 5.5 present land-cover and geology of the Albert Nile catchment, respectively.

Groundwater Regime

The groundwater regime of the Albert Nile Basin is determined by the Nile River, which forms the regional drainage base. Regional groundwater flow is towards the Nile River, which is underlain by sedimentary, usually non-consolidated, rocks. These sediments have been deposited in the Rift Valley's graben structure (a depressed block of the Earth's crust bordered by parallel faults). The Nile is flowing in the eastern part of the Graben structure where it is close to the escarpment formed by highly fractured Basement rocks. The degree of fracturation of the Basement rock reduces with the distance from the Graben structure. The graben structure is 20 – 40 km wide. The hydraulic gradient of the piezometric levels is high near the borders of the Graben structure. The groundwater levels drop from 1,200 -1,550 m amsl along the DRC border to approximately 620 m amsl near the River Nile. Along the boundary with the Aswa River Basin the piezometric level is 700-1,000 m amsl in the North and 1050 m amsl in the South.

The water quality is usually good in the Basin although some areas with high iron concentrations are reported.

The groundwater recharge is highly variable (between 0 and 250 mm per year). in the south of the Basin, the recharge is generally increasing with distance from the river Nile, but along the Nile the recharge increases in a northerly direction then decreases with distances from the Nile.

Water Demand [mcm]	2012	2030 (projected)
Urban Domestic	0.5	15.8
Rural Domestic	7.8	33.8
Industrial	0.3	0.3
Livestock	15.6	15.6
Irrigation	0	214
Total	24.2	279.5
IRWR	450	450
Exploitation Index (%)	5.4	62.0

Source: National Water Resources Assessment 2012

Table 5.1: Current and projected water use in the Albert Nile Basin

Figure 5.1: River Anyau in the Albert Nile Basin

Water Balances and Trends

The current water utilization rate for the Basin is estimated at 5.4% (table 5.1). The projected utilization rate for 2030 stands at 62.0%. Water availability is based on Internal Renewable Water Resources (IRWR), which represents the annual flow of rivers and recharge of aquifers generated from precipitation over the Basin's land area. The External Renewable Water Resources (ERWR) – which originate outside the Basin – have not been considered. It is noted that in the specific case of the Albert Nile Basin, the ERWR vastly exceeds the IRWR.

The jump in the utilization rate from 5.4% to 62.0% is fully attributed to the introduction of irrigated agriculture along the Albert Nile. The rather alarming figure of 62% needs to be treated with some caution. Most of the new ir-

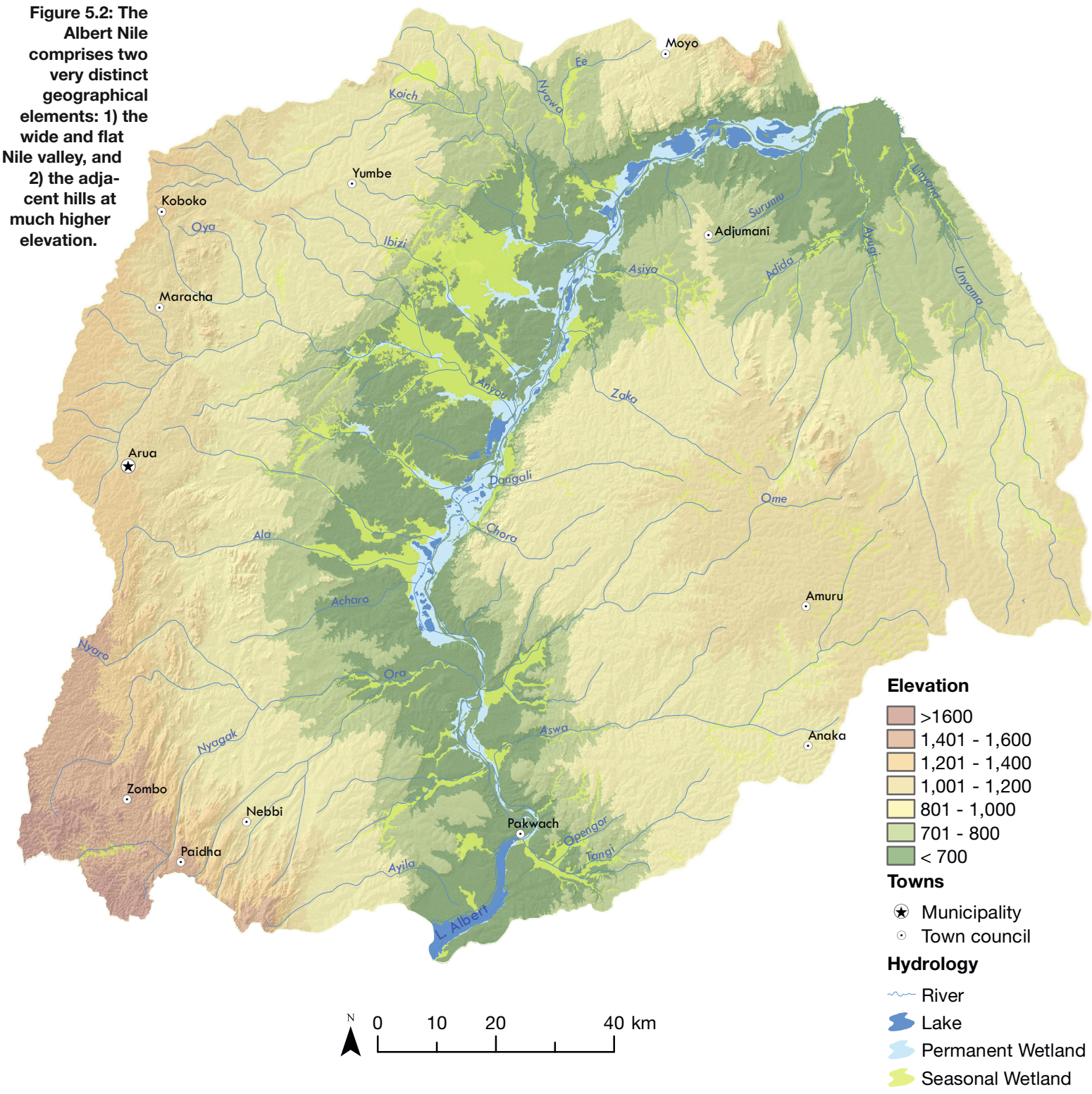


Figure 5.2: The Albert Nile comprises two very distinct geographical elements: 1) the wide and flat Nile valley, and 2) the adjacent hills at much higher elevation.

rigation areas in the Basin are planned in existing wetland areas, which already have high evaporation rates. These existing water losses have not been considered when calculating irrigation water use. Furthermore, there is still sufficient fresh water to fully satisfy the Basin's anticipated water use with internally generated resources. Nevertheless, it emphasizes that water conservation measures are best focused on increasing irrigation efficiencies and water productivity in agriculture.

It is noted that the calculations reflect the average situation in the Basin and that water deficits can be experienced in local areas and at certain times of the year as a result of both seasonal and annual variations in the availability and demand of water.

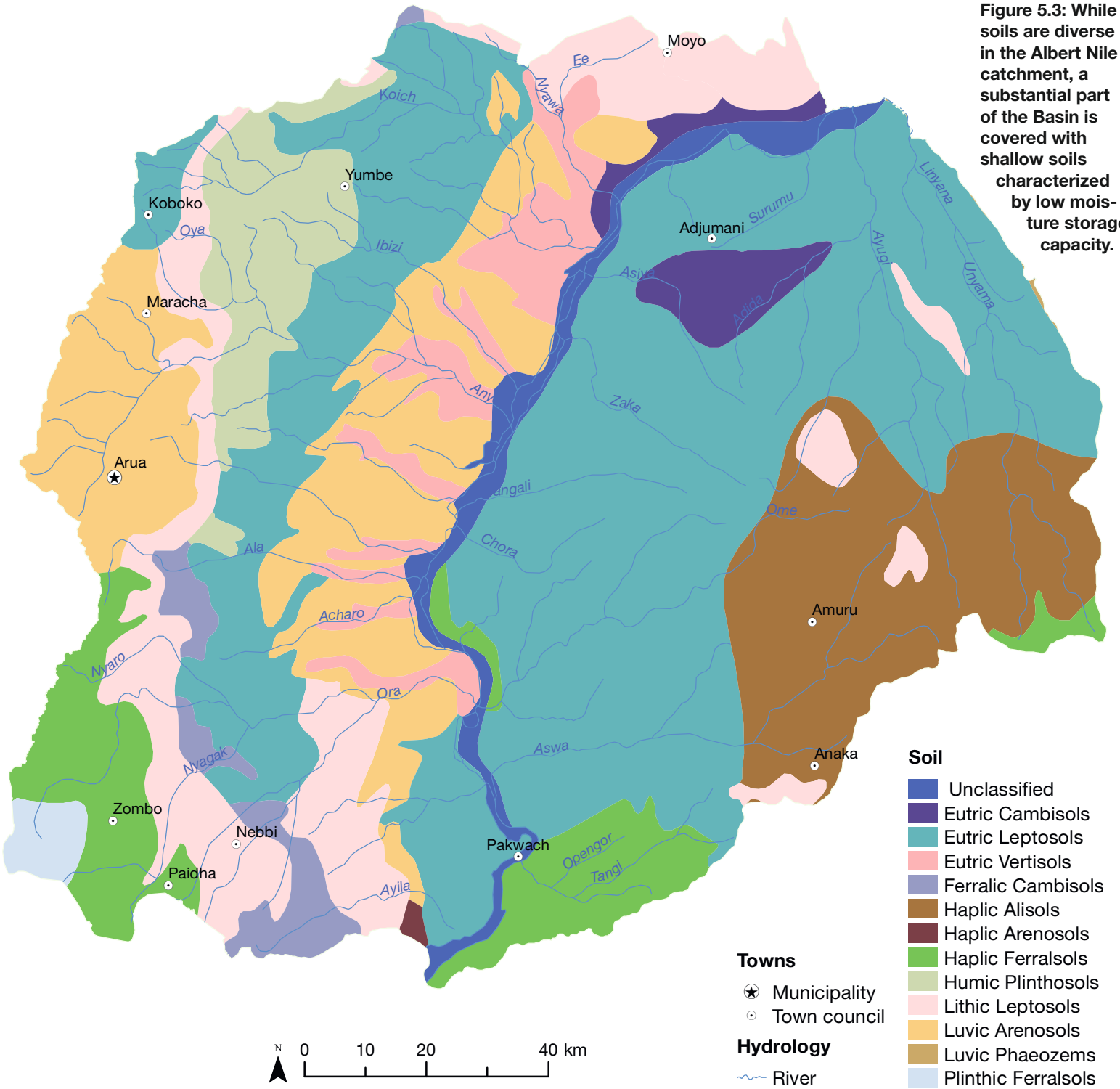


Figure 5.3: While soils are diverse in the Albert Nile catchment, a substantial part of the Basin is covered with shallow soils characterized by low moisture storage capacity.

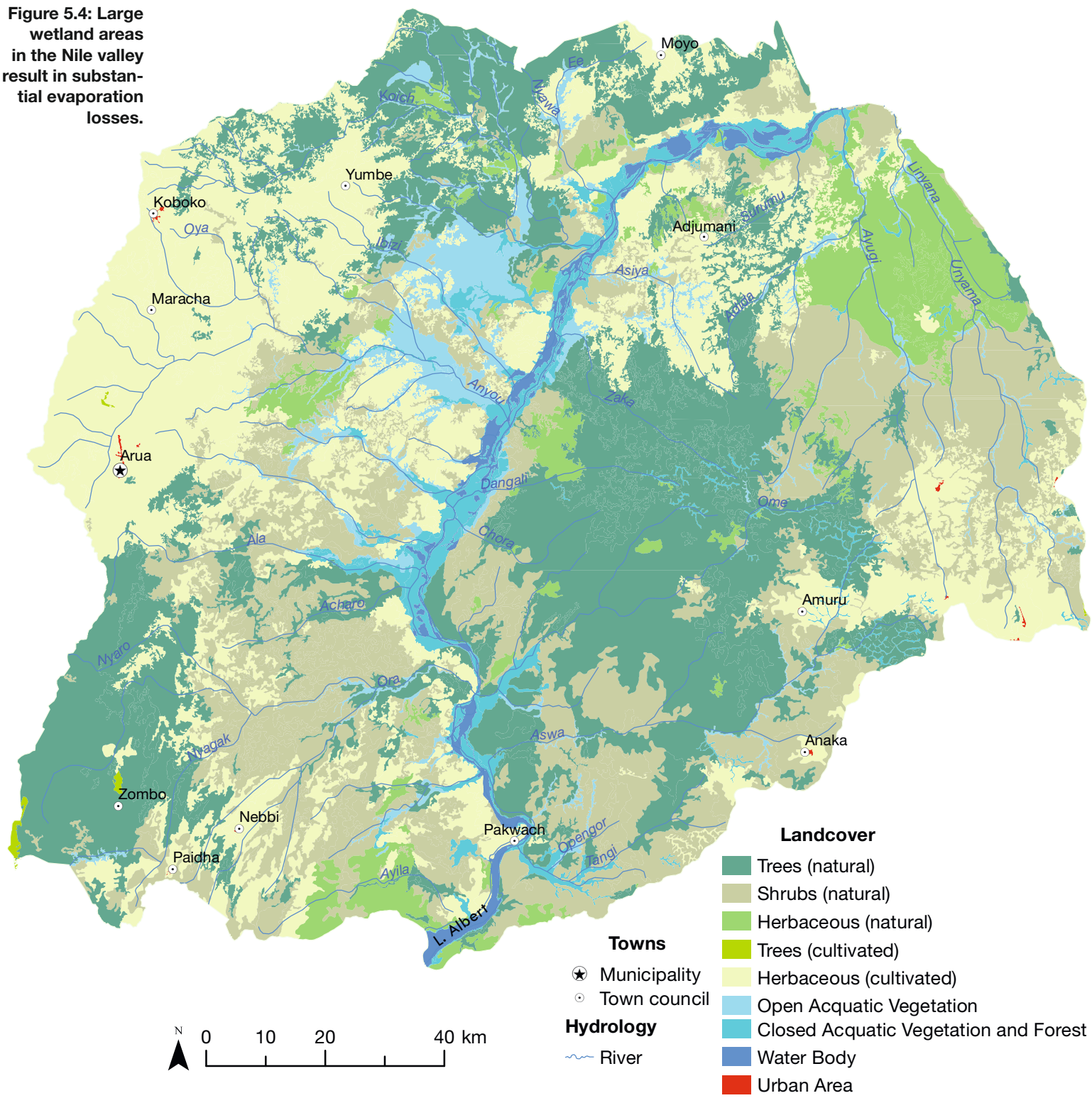
Hydrological Monitoring

Figure 5.6 presents the monitoring network in the Albert Nile Basin. Several tributaries on the west bank are monitored but none on the east bank. It is evident that this network is not sufficient to understand the hydrological processes in this basin.

The Monthly Flow Distribution graph on page 41 provides an indication of the seasonality of the flow regime. The graph plots mean monthly flow values together with the associated standard deviation. The latter is a measure of how the seasonal patterns vary over the years.

The graph with Monthly Flow Statistics is intended to show the variability of the historic flow observations, and hence the extent to which the flow regime is dominated by extreme events (either low or high flow). The lines extending from the mean values indicate the spread in observations. A stretched line points to high variability, while

Figure 5.4: Large wetland areas in the Nile valley result in substantial evaporation losses.



a squeezed line is evidence of more steady flow.

The Flow Duration Curve (FDC) visualizes the range of flows in a river. For each observed discharge, the curve shows the percentage of time that this specific discharge was exceeded. A steep curve implies a 'flashy' flow regime, while a flat curve points to a river with less seasonal or inter-annual variation.

The figures clearly show the very different flow regimes of the Nile and the catchment tributaries. Nile flows are effectively steady throughout the year, as indicated by the flat shape of the Flow Duration Curve and the very regular seasonal distribution. By contrast, catchment flow reflects the unimodal rainfall pattern that dominates the Albert Nile basin and is flashy, with a quick response to a rain event in the rainy season and with very low flows during the dry season. In fact, river Ora at station 87208 is dry for about 15% of the time.

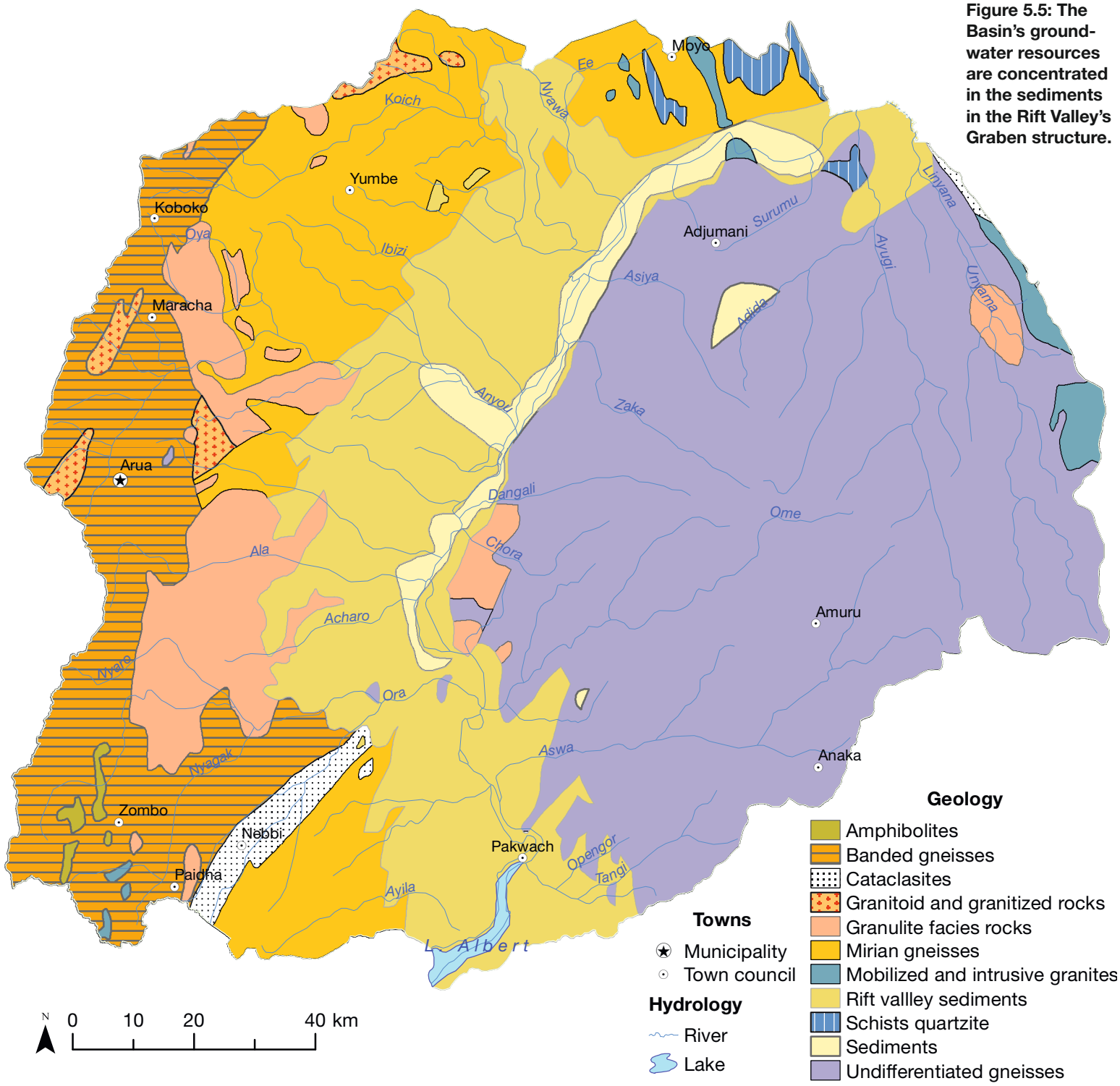


Figure 5.5: The Basin's groundwater resources are concentrated in the sediments in the Rift Valley's Graben structure.

Figure 5.6: Hydrometric network in the Albert Nile Basin. No tributaries on the eastern Nile bank are monitored.

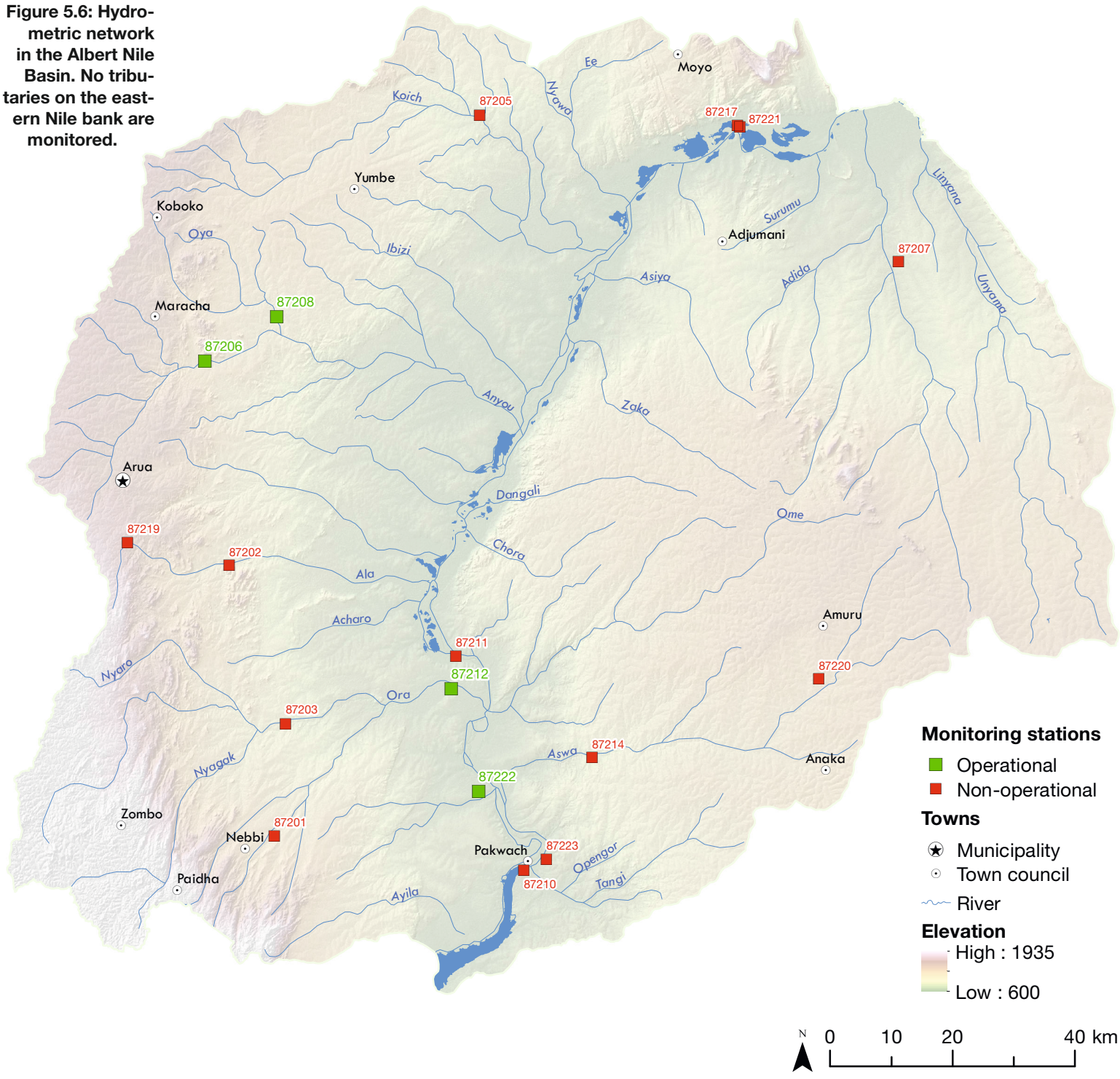


Table 5.2: Monitoring stations in the Albert Nile Basin

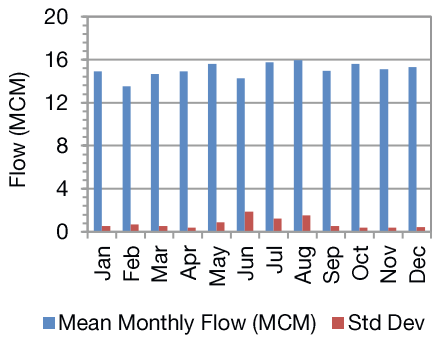
STATION	NAME
87201	R. Nyarwodo at Angal - Okollo Road
87202	R. Ala at Arua - Mutir Road
87203	R. Ora at Okollo
87205	R. Kochi at Yumbe - Moyo Road
87206	R. Anyau at Arua - Moyo Road
87207	R. Ayugi at Atiak - Laropi Road
87208	R. Oru at Arua - Yumbe Road
87210	R. Albert Nile at Pakwach. (87210)
87211	R. Albert Nile at Mutir

STATION	NAME
87212	R. Ora at Inde - Pakwach Road
87214	R. Achwa at Arua - Rhino Camp Road
87217	R. Albert Nile at Laropi (87217)
87219	R. Ala at Oliva Falls
87220	R. Aswa at Kilak County
87221	R. Albert Nile at Laropi (87221)
87222	R. Albert Nile at Panyango. (87222)
87223	R. Albert Nile at Pakwach D/S (Ne

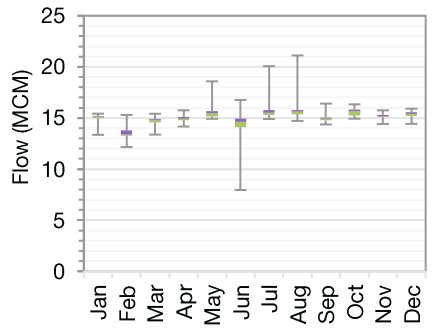
Hydrological Review

This paragraph presents the seasonal pattern, key statistics, and flow reliability of selected stations within the Albert Nile Basin.

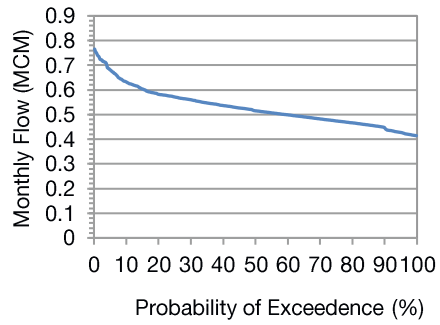
87201_Nyarwodo
Monthly Flow Distribution



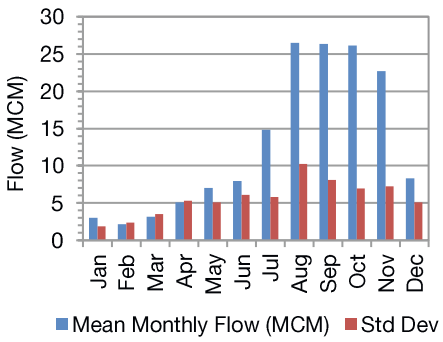
87201_Nyarwodo
Monthly Flow Statistics



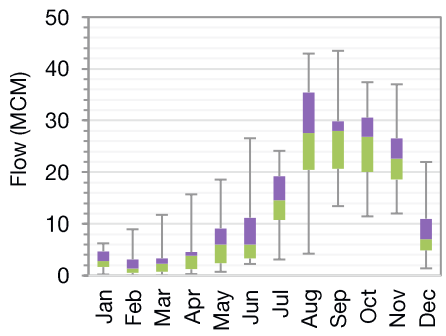
87201_Nyarwodo
Flow Duration Curve



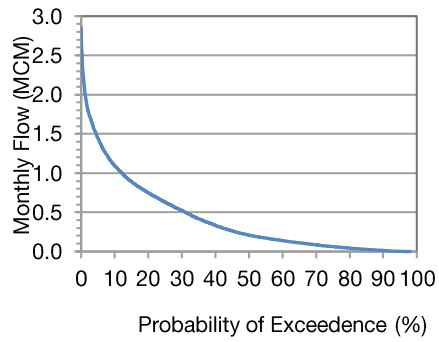
87206_Anyua
Monthly Flow Distribution



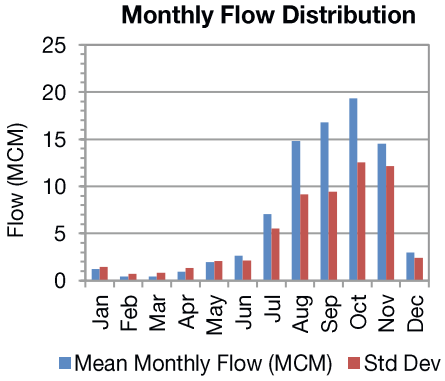
87206_Anyua
Monthly Flow Statistics



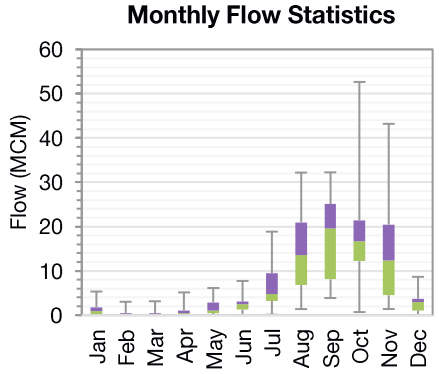
87206_Anyua
Flow Duration Curve



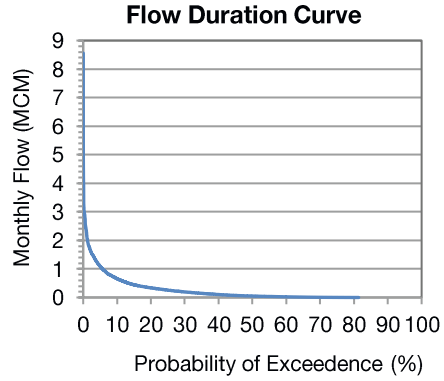
87208_Oru
Monthly Flow Distribution



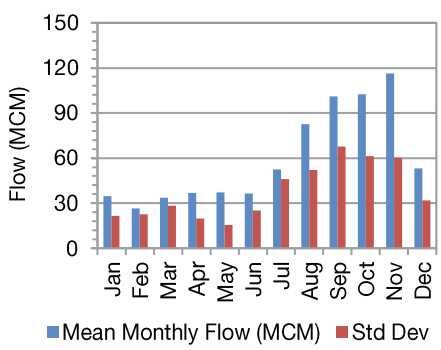
87208_Oru
Monthly Flow Statistics



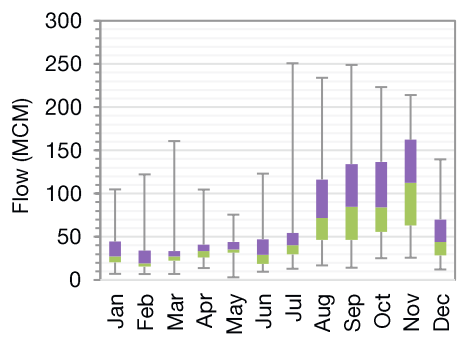
87208_Oru
Flow Duration Curve



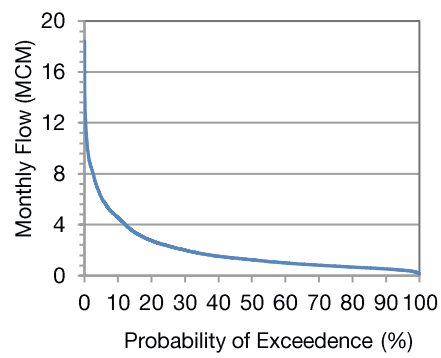
87212_Ora2
Monthly Flow Distribution



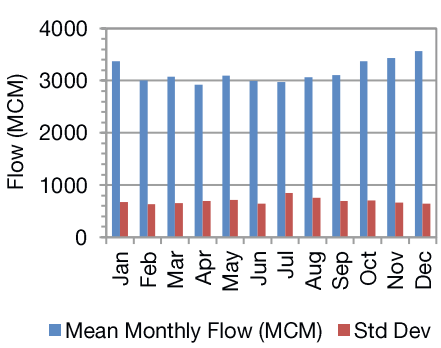
87212_Ora2
Monthly Flow Statistics



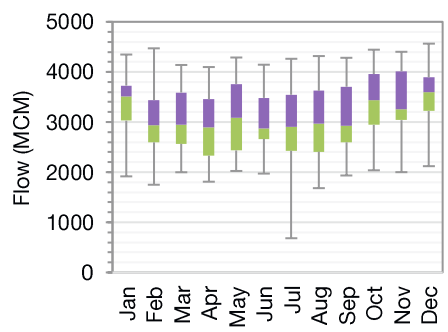
87212_Ora2
Flow Duration Curve



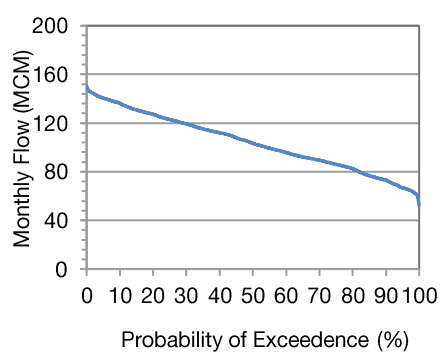
87222_Panyango
Monthly Flow Distribution



87222_Panyango
Monthly Flow Statistics



87222_Panyango
Flow Duration Curve



Aswa Basin

Surface Water

The Aswa drains the north-western part of the equatorial plateau and the Basin is almost entirely sitted in Uganda. Nevertheless, river flows into the Bahr el Je– as the Albert Nile is called in South Sudan – immediately downstream of the border with South Sudan. The Basin's most distinct feature is the Aswa shear zone. This northwest to south-east trending, and almost straight discontinuity in the earth's surface is anchoring the Aswa river for a stretch of almost 300 km, during which the river drops some 300 m. Several run-of-the-river hydropower projects have been planned along this stretch.

Several main tributaries join the Aswa, notably the Pager and Agago. They exhibit a classic dendritic drainage pattern. The runoff coefficient of Aswa at Puranga is estimated at 8.5 %, which is high for Uganda but quite common for a river of this size and without extensive wetland areas.

The Aswa Basin itself is rather flat apart from the mountainous area at the eastern edge (figure 5.7). The Basin receives on average some 1,200 mm of rainfall per year. The period December to March is generally dry, while September records the highest monthly rainfall. The rainfall regime is unimodal although August is drier than the other rainy months. Aswa – as well as the Pager and Agago – is a seasonal river that experiences prolonged periods of zero flow. By contrast, peak flows of Aswa are high and can exceed 1,000 m^3/s. It provides an indication of the seasonal variability of the rivers and streams in the Aswa Basin.

Figures 5.8, 5.9, and 5.10 present soils, land-cover, and geology of the Aswa catchment respectively.

Hydrological Monitoring

Figure 5.11 presents the hydrometric network in the Aswa basin. Only two stations were operational in the 1978-2014 timeframe. Monitoring activities were adversely affected by the pollical situation in North Uganda in this period. It is evident that current water monitoring activities are not adequate to understand the hydrological process in Aswa Basin.

The discharge regime of river Aswa (station Aswa 2) reflects the bi-modal rainfall regime of the region with peak flows in April and August. The standard deviation is high. It implies that river flow is dominated by extreme values and that predicting floods – or calculating design floods – will be difficult. Flows in the lean season are approaching zero.

Table 5.3: Current and projected water use in the Aswa Basin

Water Demand [mcm]	2012	2030 (projected)
Urban Domestic		15.2
Rural Domestic	5.1	3.9
Industrial		
Livestock	14.2	14.2
Irrigation		26.0
Total	19.3	79.3
IRWR	1,770	1,770
Exploitation Index (%)	1.1	4.5

National Water Resources Assessment 2012

Groundwater Regime

The Basin is mainly underlain by gneisses, granites and granitoid gneisses.

The groundwater in the Aswa Basin drains towards the Aswa River and its tributaries and generally drains in a west to northwest direction. The piezometric levels vary between 1,250 m amsl in the North-East and 1,050 amsl in the South to 700 m amsl near the outlet of the Basin in the North-western corner.

Groundwater recharge in the Basin varies between 100-150 mm per year in the Southwest to 25-50 mm in the far Northeast.

The quality of the groundwater is usually good but some spots with high iron concentrations are reported.

Water Balances and Trends

The current and projected water utilization rates for the Aswa Basin are presented in table 5.2. The utilization rates are low and Aswa Basin arguably has enough water to meet anticipated demand in the mid-term future and beyond. While some local shortages may be experienced, large scale competition over water resources are not expected.

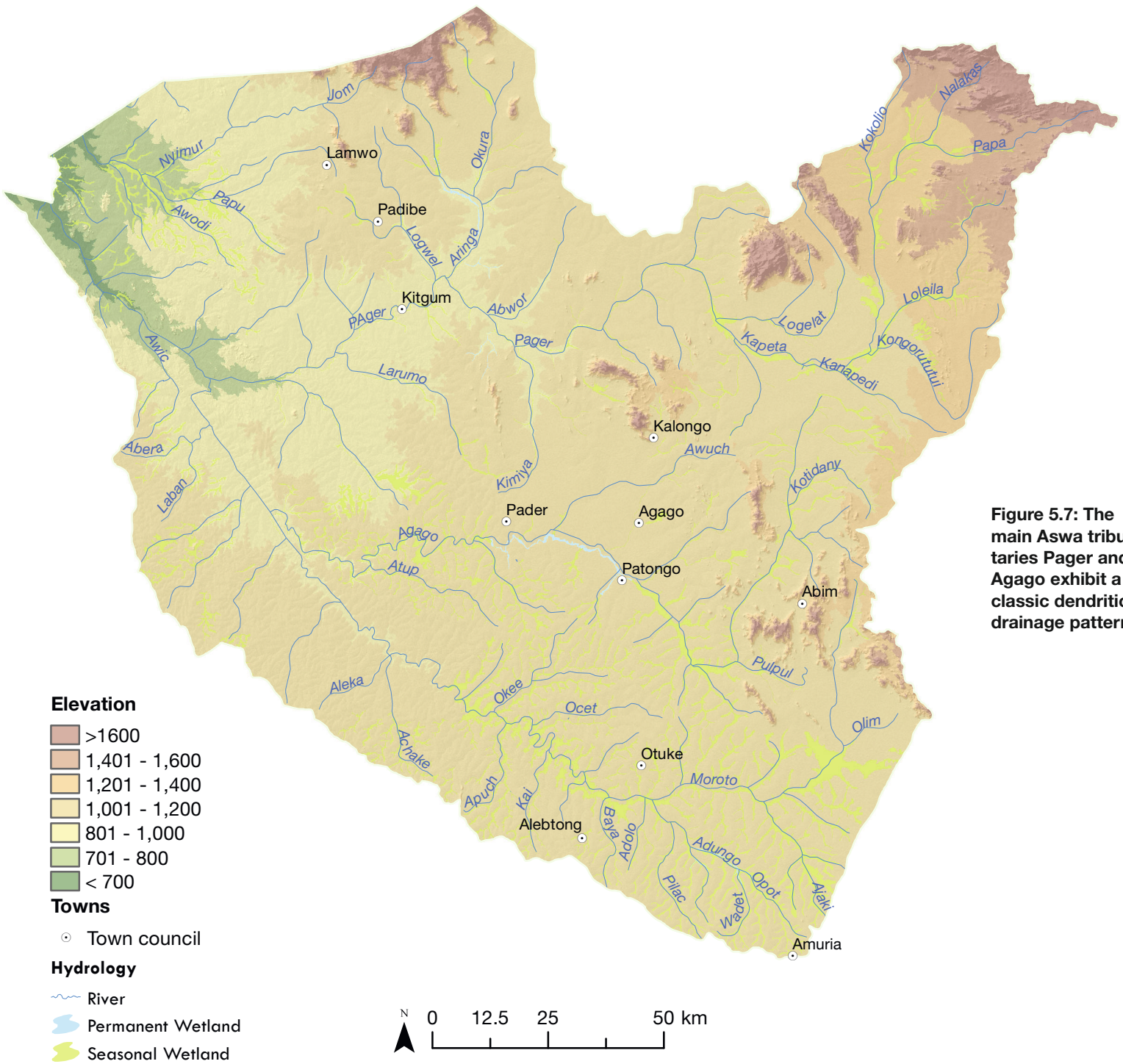
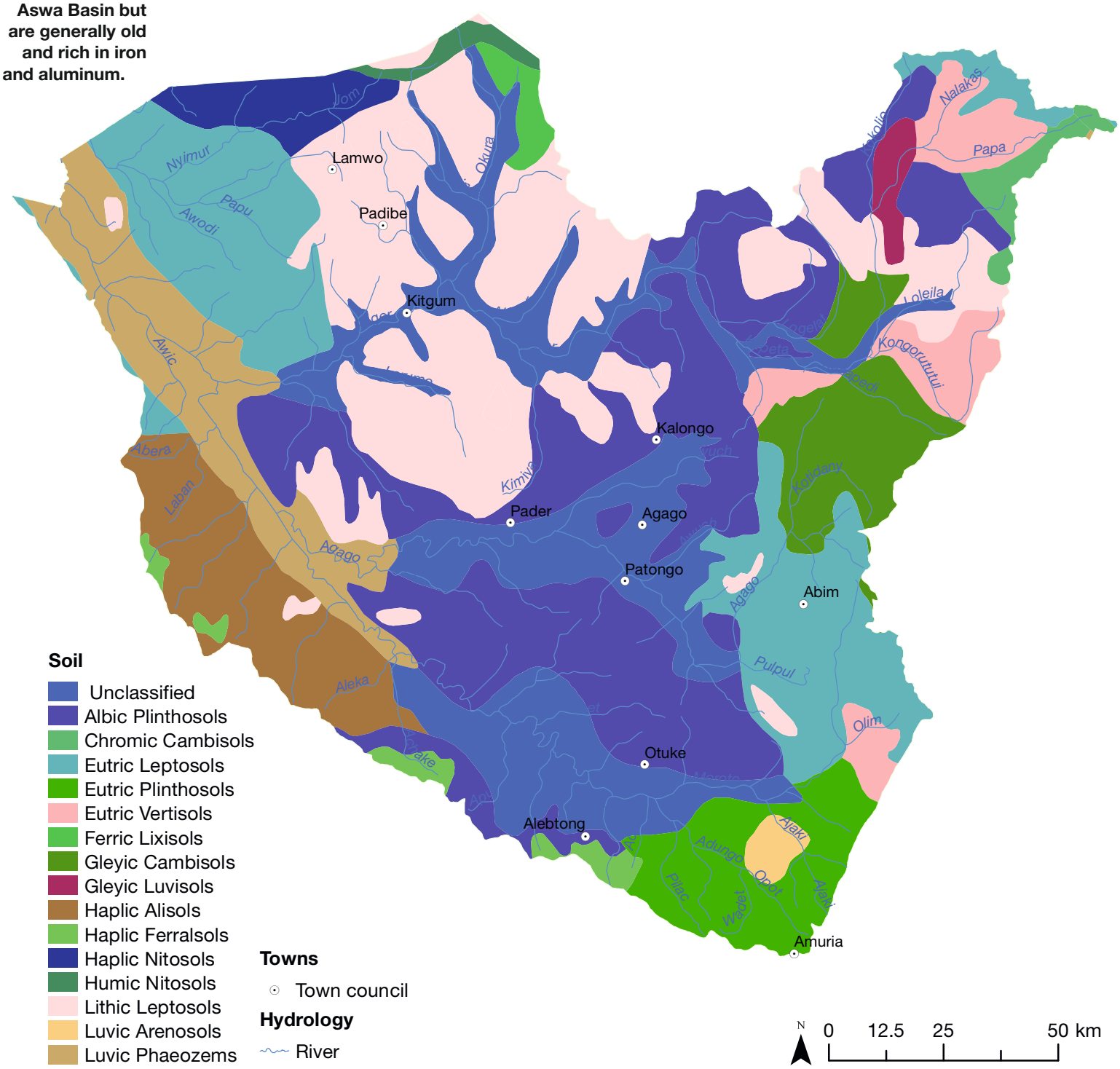


Figure 5.7: The main Aswa tributaries Pager and Agago exhibit a classic dendritic drainage pattern.

Figure 5.8: Soils are diverse in the Aswa Basin but are generally old and rich in iron and aluminum.



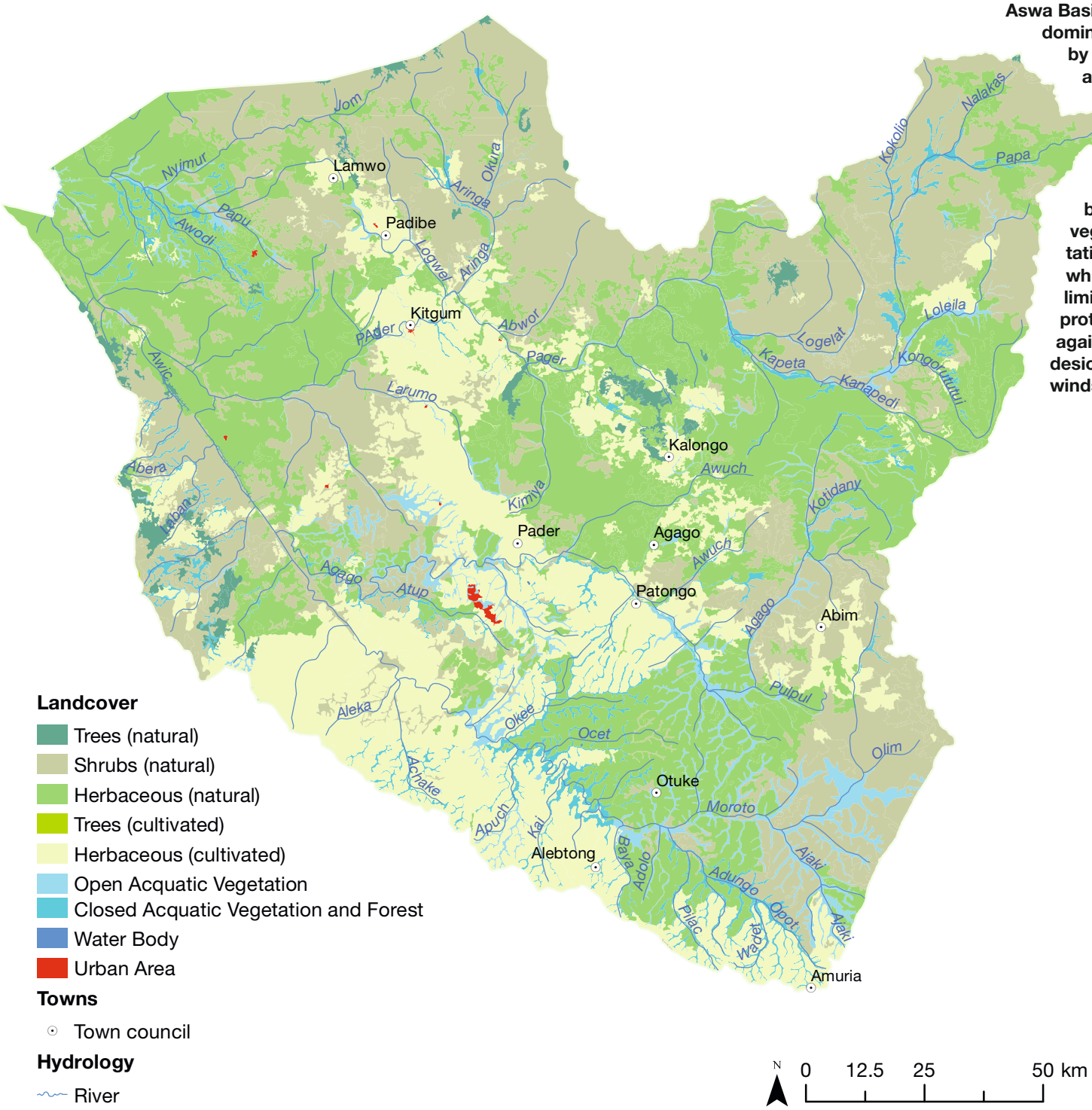


Figure 5.9: Land cover in the Aswa Basin is dominated by shrubs and herbaceous vegetation, which offer limited protection against desiccating winds.

Figure 5.10: The most distinct feature of the Basin is the north-east trending Aswa shear zone.

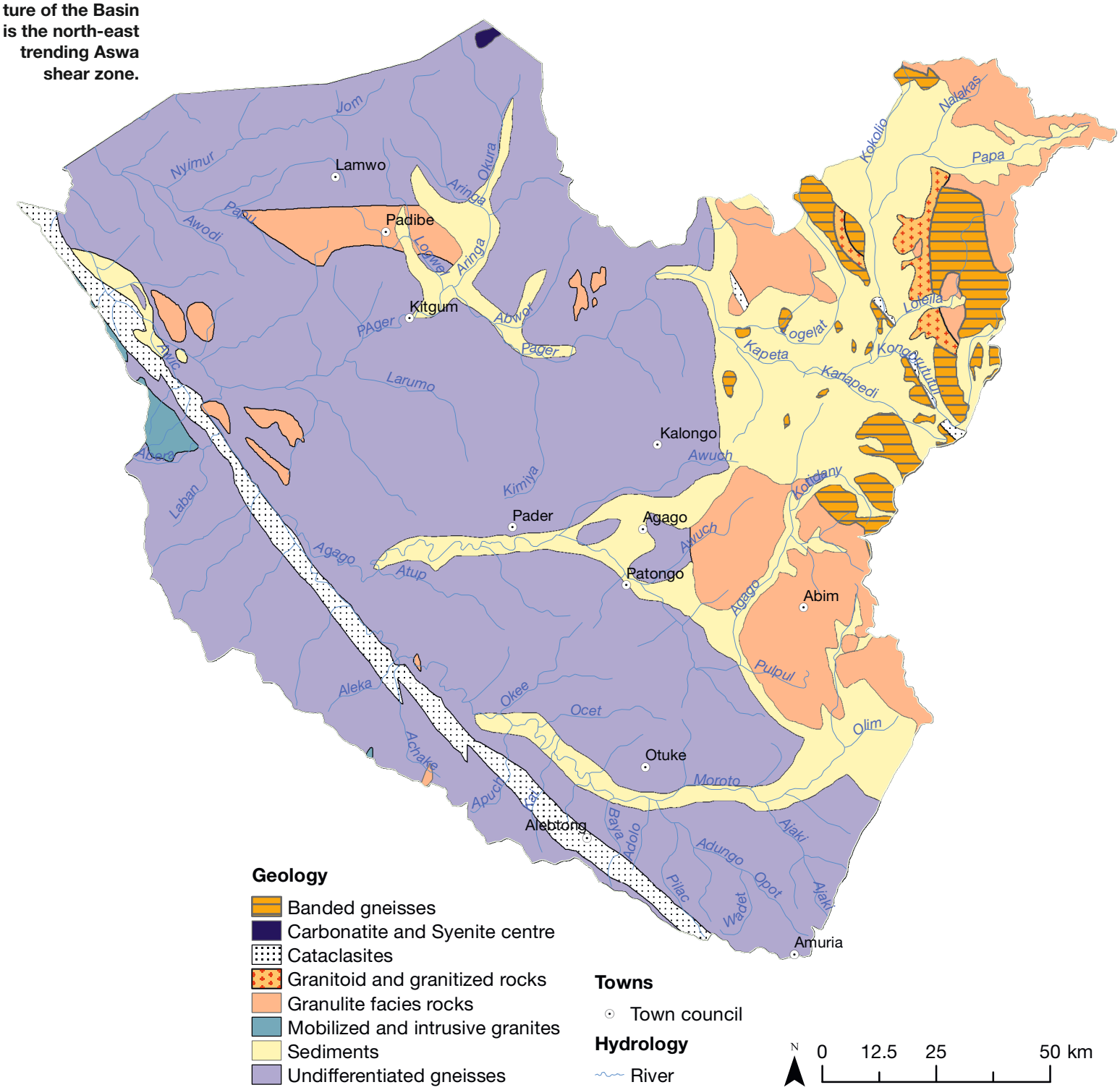
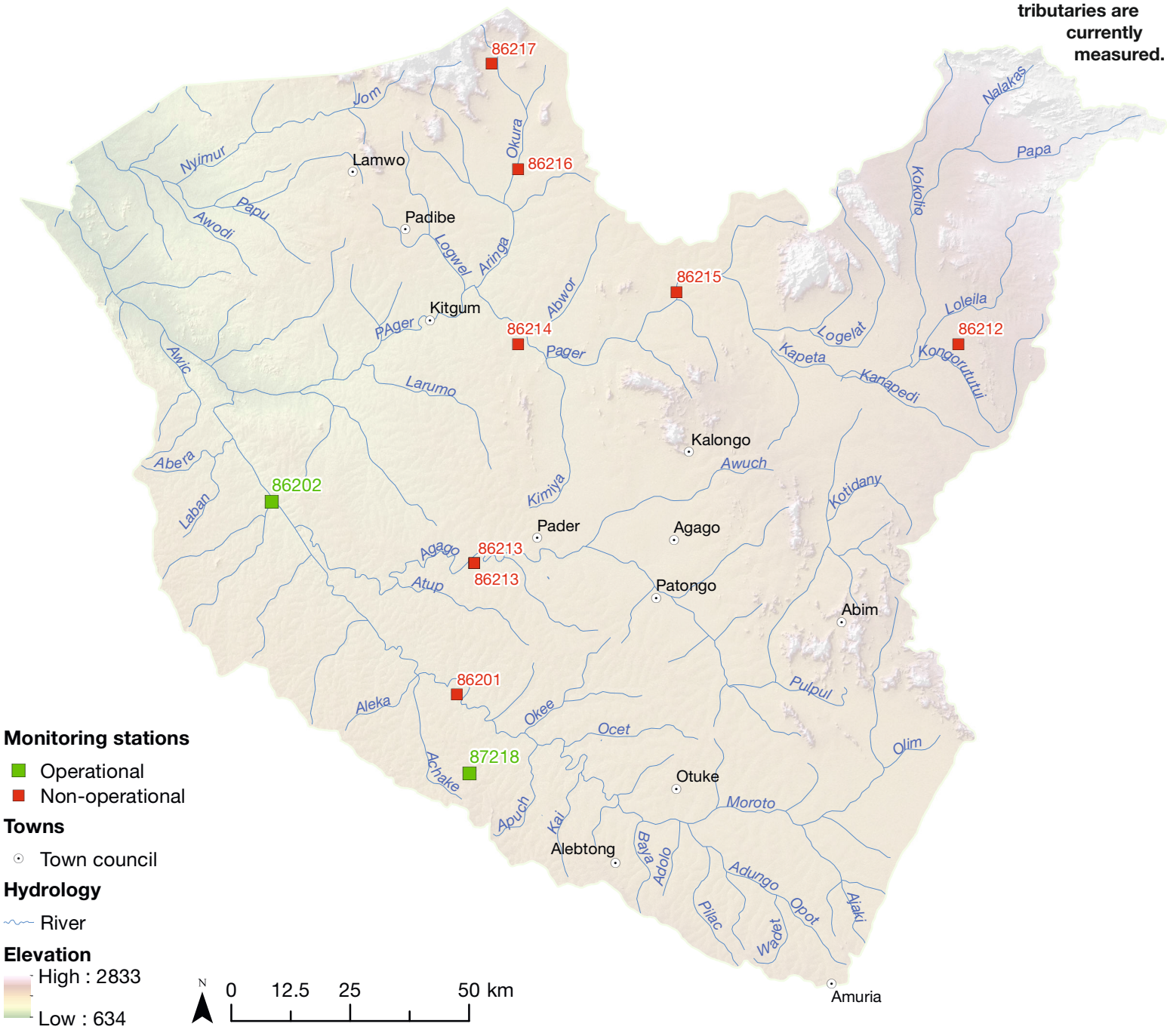


Figure 5.11: Hydrometric network in the Aswa Basin. No Aswa tributaries are currently measured.



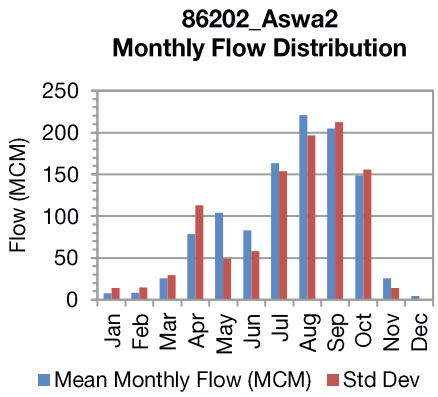
STATION	NAME
86201	R. Aswa I at Puranga
86202	R. Aswa II at Gulu - Kitgum Road
86212	R. Pager at Kitgum
86213	R. Agago at Kitgum - Lira Road
86214	R. Pager at Kitgum - Matidi Road

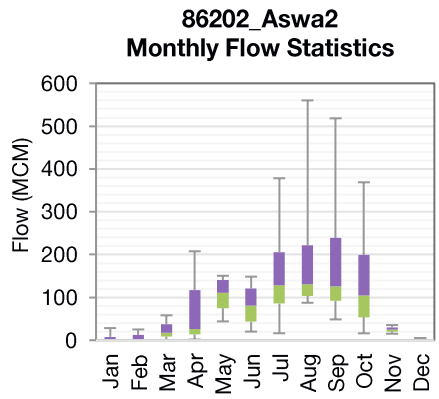
STATION	NAME
86215	R. Pager at Naam Okora
86216	R. Aringa at Kitgum - Mucwini Road
86217	R. Okura at Ogora
87218	R. Nyagak at Nyapea

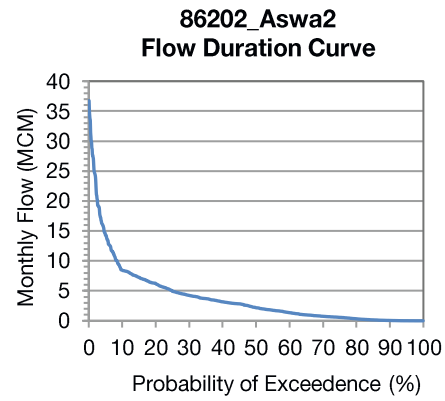
Table 5.4: Monitoring stations in the Aswa Basin

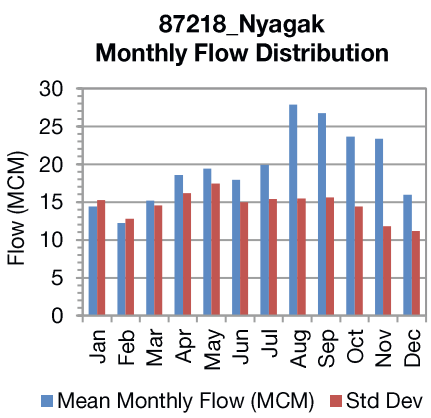
Hydrological Review

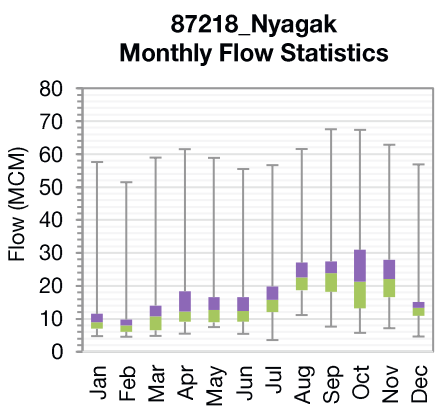
This paragraph presents the seasonal pattern, key statistics, and flow reliability of selected stations within the Aswa Basin.

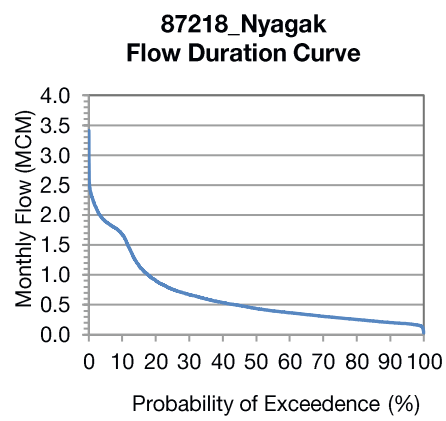












Kidepo Basin

Surface Water

Kidepo is the smallest of Uganda's main drainage Basins. It is situated in the semi-arid zone in north-eastern Uganda. While most of the Basin has a rather flat savannah landscape, mountains rise on all sides except the north. Mount Morungole is the highest at some 2,750 m while Mount Zulia is over 2,000 m in altitude (figure 5.12). Kidepo Valley National Park covers a large part of the Kidepo Basin and represents important environmental value.

Kidepo Basin drains into the Pibor-Akabo complex, and eventually via the Sobat into the White Nile just upstream of Malakal. However, due to the flat terrain, the high evaporation rates, the low runoff volume, and the extensive wetland areas in this part of South Sudan, the contribution of the Kidepo Basin to the Nile flows will be very limited.

Kidepo has a unimodal rainfall regime and flow in the two main rivers in the Basin – Narus and Kidepo – is seasonal. Many streams in the Basins are ephemeral with only sporadic flow after a rain event. Given the steep mountain slopes on the Basin's periphery, flash floods occur frequently. Droughts are common in this semi-arid region and lead to high pressure on scarce water resources. It is noted that ephemeral rivers are critically important for the vegetation and biota that they support. Altering flows could negatively affect the fragile riverine ecosystems in these dryland areas.

Figures 5.13, 5.14, and 5.15 present soils, land-cover, and geology of the Kidepo catchment, respectively.

Hydrological Monitoring

There were no hydrometric activities in the Kidepo Basin in the 1978-2014 timeframe because of the remoteness of the terrain and the political situation in North Uganda in that period.

Hydrological Review

In the absence of hydrometric activities in the Kidepo Basin in the 1978-2014 period, no hydrological review has been conducted.

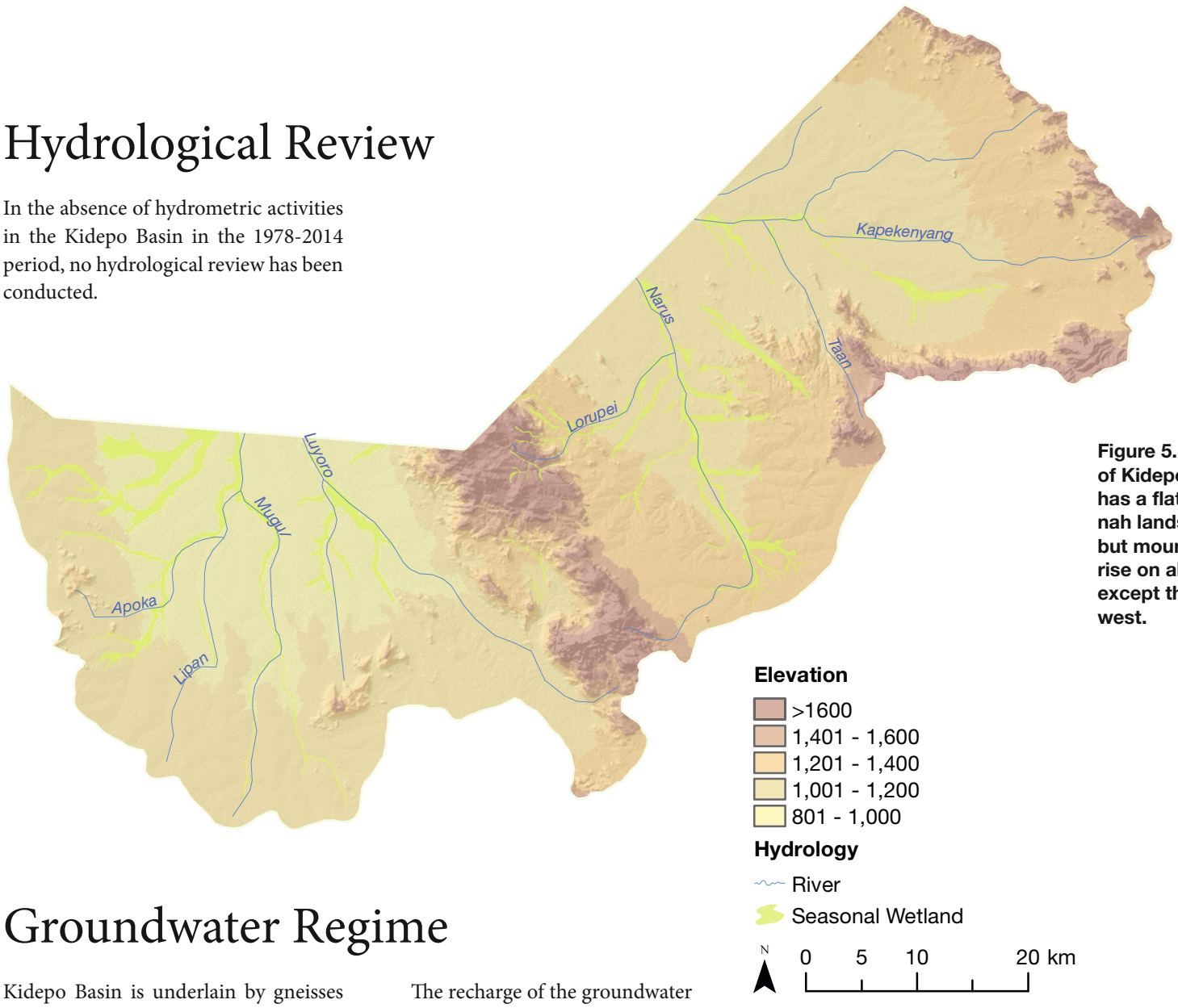


Figure 5.12: Most of Kidepo Basin has a flat savannah landscape but mountains rise on all sides except the northwest.

Groundwater Regime

Kidepo Basin is underlain by gneisses and amfibolites. The regional groundwater flow is towards South Sudan in the North but local drainage is towards the Kidepo, Narus, Lipan and Luyoro Rivers. The piezometric levels are 1,600 m amsl near the Kenyan border to 1,000 m near the South-Sudanese border.

The recharge of the groundwater is very low with less than 25 mm in the East to 25-50 mm in the West of the Basin.

The water quality is generally good but boreholes in the central part of the Basin often have iron concentrations.

Water Balances and Trends

Water utilization rates – both current and projected – are low (table 5.5). The National Park covers a large part of the Basin, and land and water use practices are focused on conservation rather than development. Structural water deficits, therefore, are not anticipated in Kidepo.

Water Demand [mcm]	2012	2030 (projected)
Urban Domestic		
Rural Domestic	0.3	2.7
Industrial		
Livestock	2.6	2.6
Irrigation		
Total	2.9	5.3
IRWR	210	210
Exploitation Index (%)	1.4	2.5

National Water Resources Assessment 2012

Table 5.5: Current and projected water use in the Kidepo Basin

Figure 5.13: Vertisols are common and fertile, but difficult to cultivate.

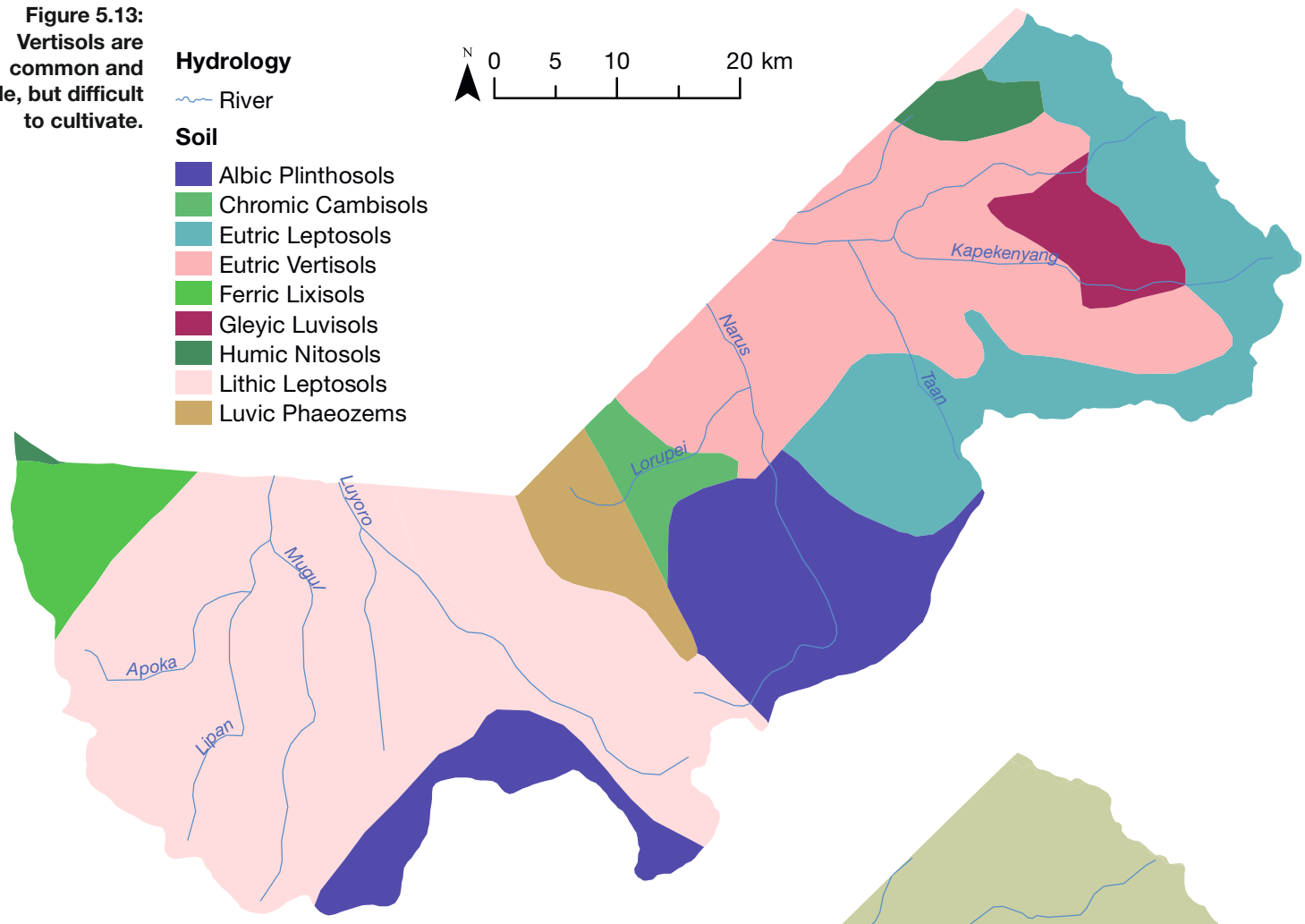
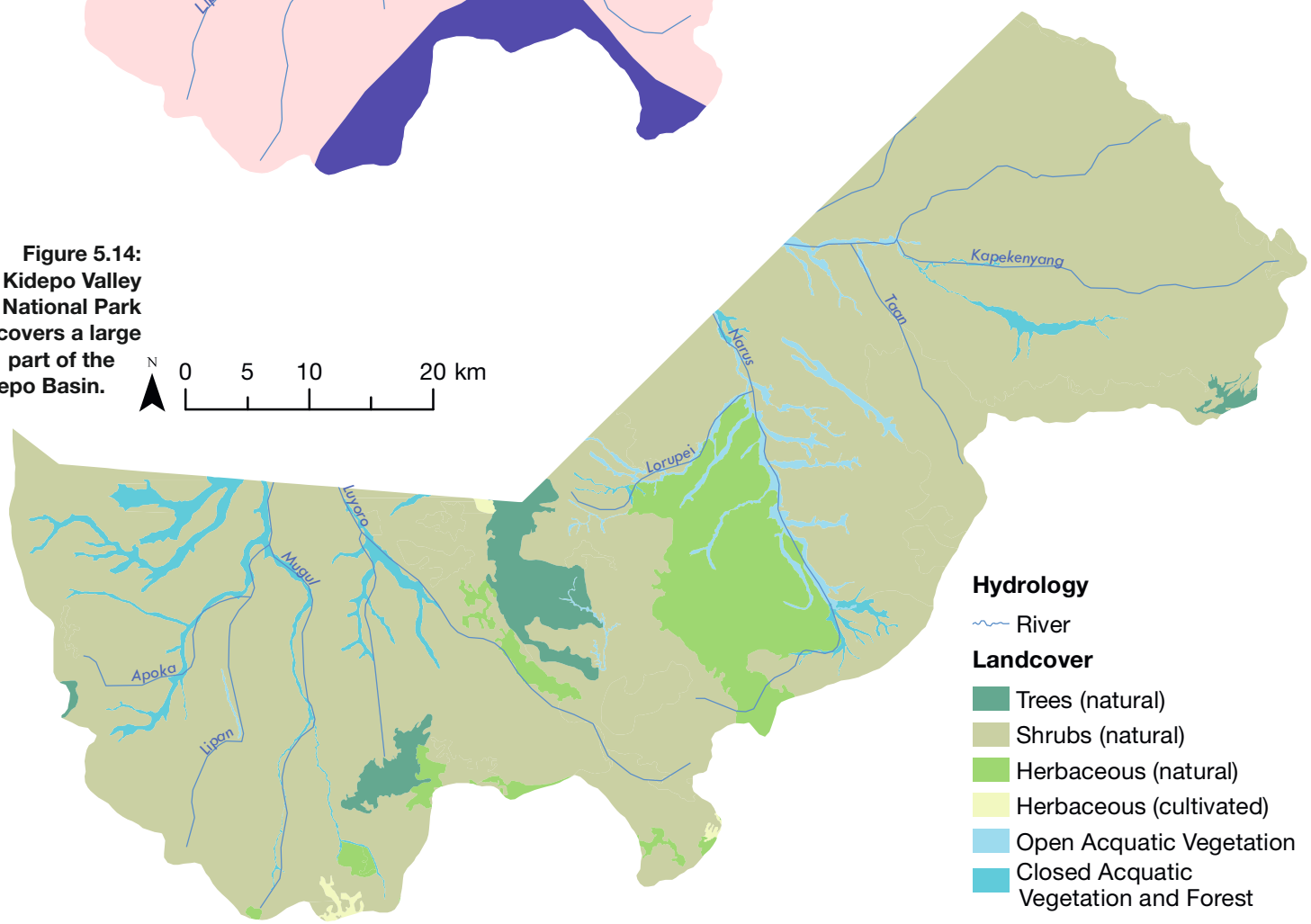


Figure 5.14: Kidepo Valley National Park covers a large part of the Kidepo Basin.



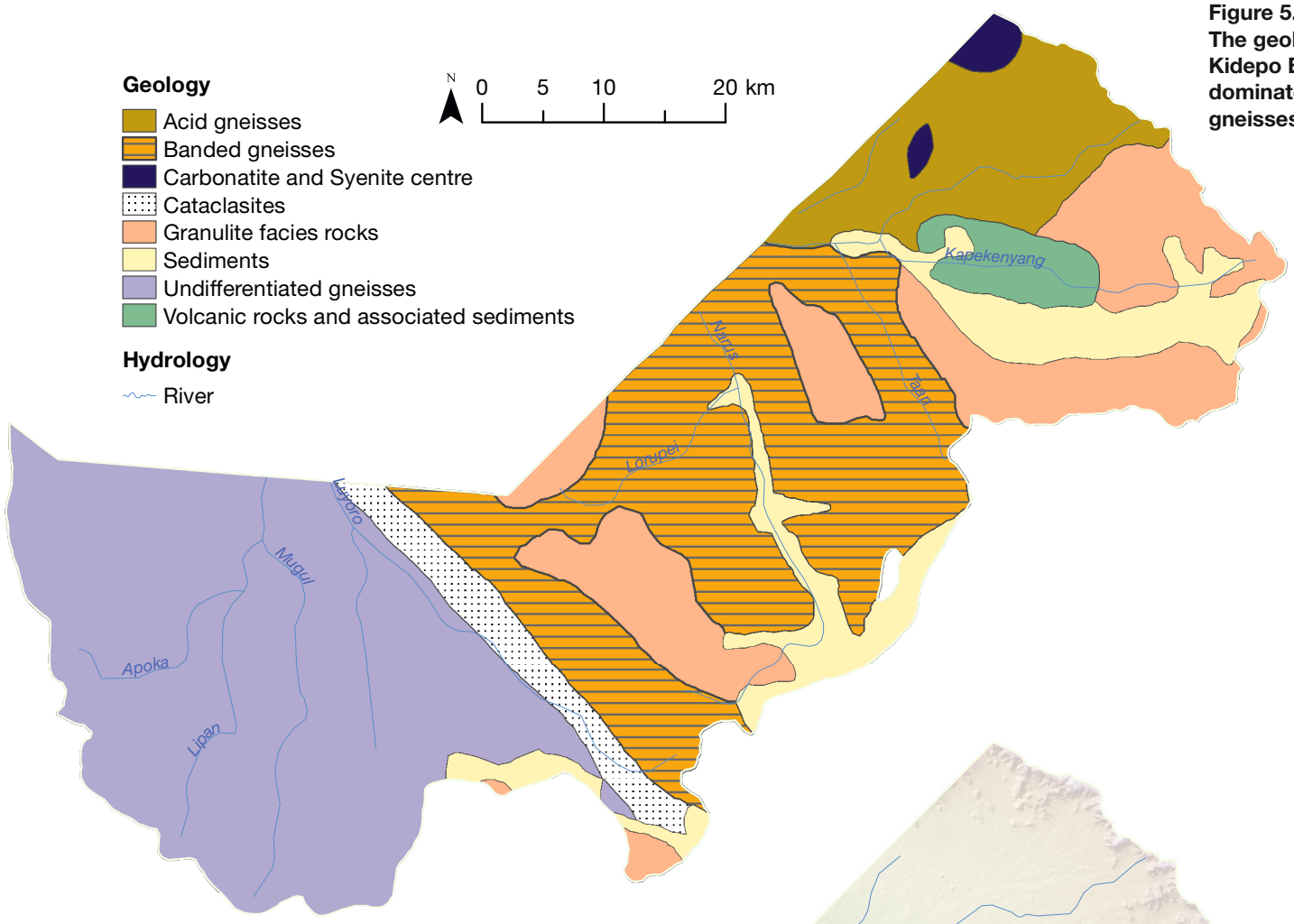


Figure 5.15: The geology of Kidepo Basin is dominated by gneisses.

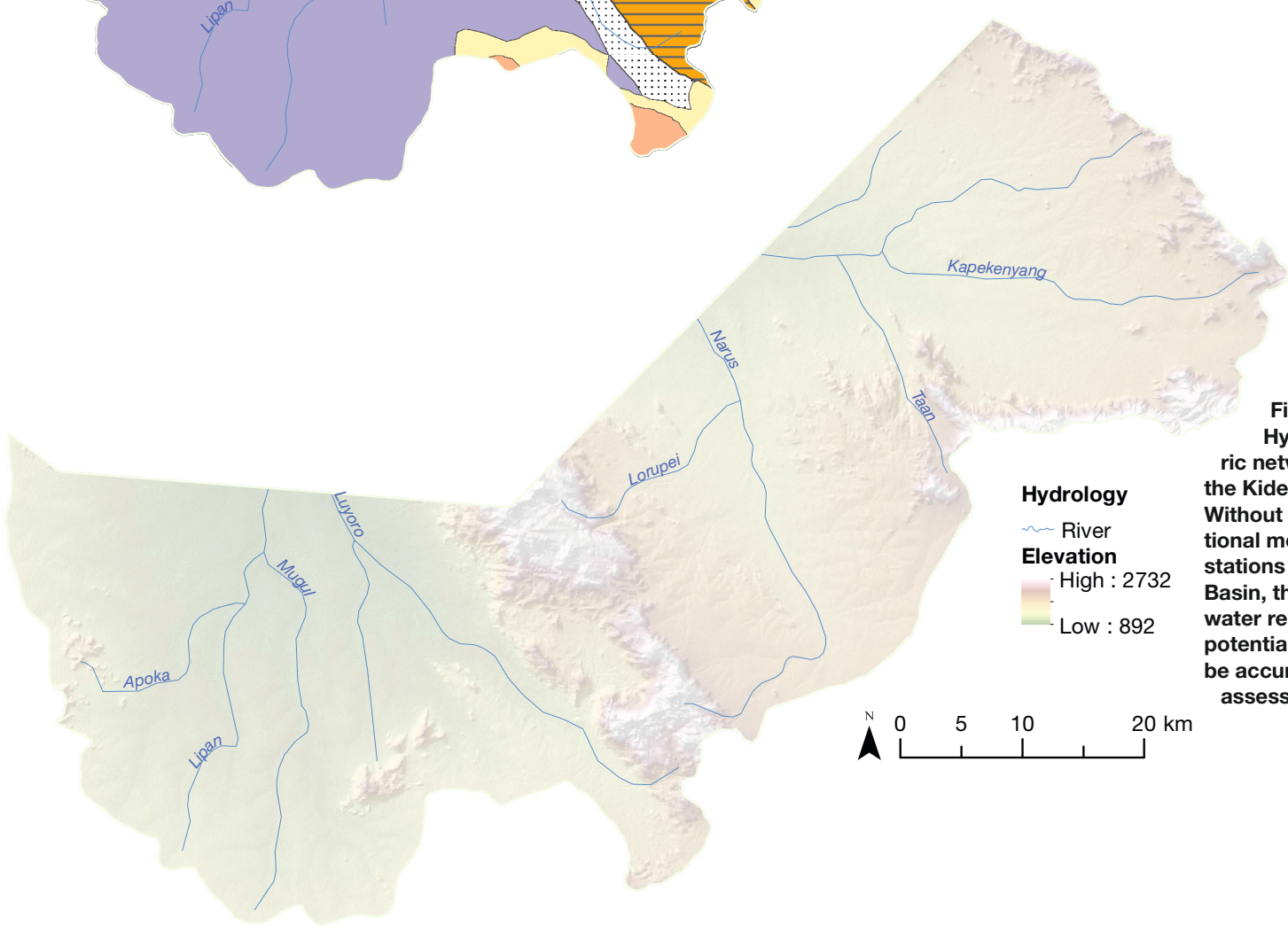


Figure 5.16: Hydrometric network in the Kidepo Basin. Without operational monitoring stations in Kidepo Basin, the Basin's water resources potential cannot be accurately assessed.

Lake Kyoga

Surface Water

From a hydrological perspective, the Lake Kyoga Basin is a one-of-a-kind. The Basin covers about a quarter of Uganda and encompasses distinct hydrological, climatological, and geographic elements.

Lake Kyoga itself is effectively a submerged valley that is directly connected to the Victoria and Kyoga Nile. Although the lake is rather large – with a surface area of some 1,720 km^2 – it is also very shallow with a maximum depth of not more than 5.7 m. The average depth is about 4 m and much of the shallower parts of the lake are covered with papyrus and water hyacinth. Because the inflow of the various tributaries is small relative to the Nile flows, lake level is a function of the flow of the Victoria Nile. The level of Lake Kyoga, therefore, is by and large determined by the operation of the hydro facilities at the outlet of Lake Victoria. Although Lake Kyoga is part of the Great Lakes system, it is not itself considered a great lake because of its small storage volume.

The spatial and temporal variability of rainfall over the basis is high. The north-eastern region is semi-arid with a unimodal rainfall regime. By contrast, the zones closer to Lake Victoria are much wetter and are experiencing a bi-modal regime with peaks in April and October/November. Rainfall on the slopes of Mount Elgon and the other mountains in the Basins is high due to orographic effects.

Most of the Lake Kyoga catchment has a relatively flat topology (figure 5.18) but high mountains rise on the eastern periphery. Mount Elgon reaches 4,321 m above mean sea level. It is the highest of a small group of extinct volcanoes along the eastern rim of the Basin on the border with Kenya. High rainfall and steep slopes cause a rapid runoff response to a rain event, despite the high infiltration capacity of the volcanic soils. When entering the flat plains, the flood volumes quickly exceed the drainage capacity of the rivers, whereas the sudden change in gradient causes deposition of sediment in the shallow valleys. These phenomena, together with back-water effect of Lake Kyoga and very shallow gradients, have created an extensive system of seasonal and permanent wetlands. Because of their capacity to buffer floods and their high evaporation rates, the wetlands have a marked influence on the hydrology of Lake Kyoga. Some seasonal wetlands have been earmarked for irrigated agriculture.

The semi-arid zone in the north-eastern part of the Basin is mostly used for raising livestock. Dry spells and significant grazing pressure causes stress to the eco-system. The resulting poor vegetation cover provides only limited protection during the seasonal rains, and could result in land degradation and high erosion rates.

Figures 5.19, 5.20, and 5.21 present soils, land-cover, and geology of the Lake Kyoga catchment respectively.

Figure 5.22 presents the hydrometric network in the Lake Kyoga Basin. In the 1978-2014 period, there were 15 operational stations in the basin. Station quality ranges from fair to excellent. Although the network is rather comprehensive, the Lake Kyoga Basin exhibits highly complex hydrology in particular because of the large wetland areas that interact with the river flows. Selected extension of the network is required.

Table 5.6: Current and projected water use in the Lake Kyoga Basin

Water Demand [mcm]	2012	2030 (projected)
Urban Domestic	2.6	49.7
Rural Domestic	27.1	129.3
Industrial	1.3	1.3
Livestock	75.7	75.7
Irrigation	11.1	678.0
Total	117.8	934.0
IRWR	2,320	2,320
Exploitation Index (%)	5.1	40.3

National Water Resources Assessment 2012

Hydrological Monitoring

The flow regime of rivers in the Lake Kyoga Basin is diverse. Mbalamuti Nile flows are more or less steady throughout the years and seasons. By contrast, rivers originating on the slopes of Mount Elgon exhibit a flashy regime dominated by extreme values. It implies that predicting floods – or calculating design floods – is very difficult.

Wetlands have a major impact on several rivers – for instance Agu, Abuket, and Mpologoma – by substantially increasing baseflow. Nevertheless, the variability of extreme floods remains high, as indicated by the high values of the standard deviation. This is somewhat surprising, as one would expect that the wetlands would play a bigger role in attenuating peak flow because of their buffering capacity.

Figure 5.17: River Mpologoma in the Lake Kyoga Basin

Groundwater Regime

Mount Elgon in the eastern corner of the Lake Kyoga Basin is made up of volcanics rocks of Tertiary origin. No boreholes have been drilled in this area, resulting in a lack of information on groundwater availability. The larger part of the Kyoga Basin is made up of undifferentiated gneisses of the Precambrian Basement System. The rocks in the Karamoja area are also of Precambrian origin, and have, next to the gneisses, also formations with granulite facies, as well as acid gneisses, amphibolites, quartzites and marbles of the Karasuk Series forming the North-Eastern boundary of the country. Aquifers in all mentioned Precambrian metamorphic formations are found in fractures, and to a lesser extent in the overburden.

Groundwater drains generally to Lake Victoria, with inferred groundwater levels over 2,100 m amsl around Mount Elgon to 1,050 m amsl around Lake Kyoga. Groundwater recharge is generally relatively high, over 125 mm per year, apart from specifically the north-eastern part of the Lake Kyoga Basin – Okok and Okere Sub-Basin, where annual recharge is between 0 and 50 mm per year.

A groundwater quality analysis carried out by JICA in 2010 for the Lake Kyoga Basin, based on 95 deep boreholes, 20 shallow wells and 36 springs, revealed that pH levels indicate generally acidic conditions, with half of the samples having a pH of less than 6.5, and high iron contents. The areas near the shores of Lake Victoria and Lake Kyoga have saline groundwater, above the guideline value in Uganda of 1,000 mg/l or acceptable maximum of 1,500 mg/l. The aquifers near the shores of Lake Kyoga contain water with high Total Dissolved Solids values. In the rest of the catchment the water is generally of good quality.

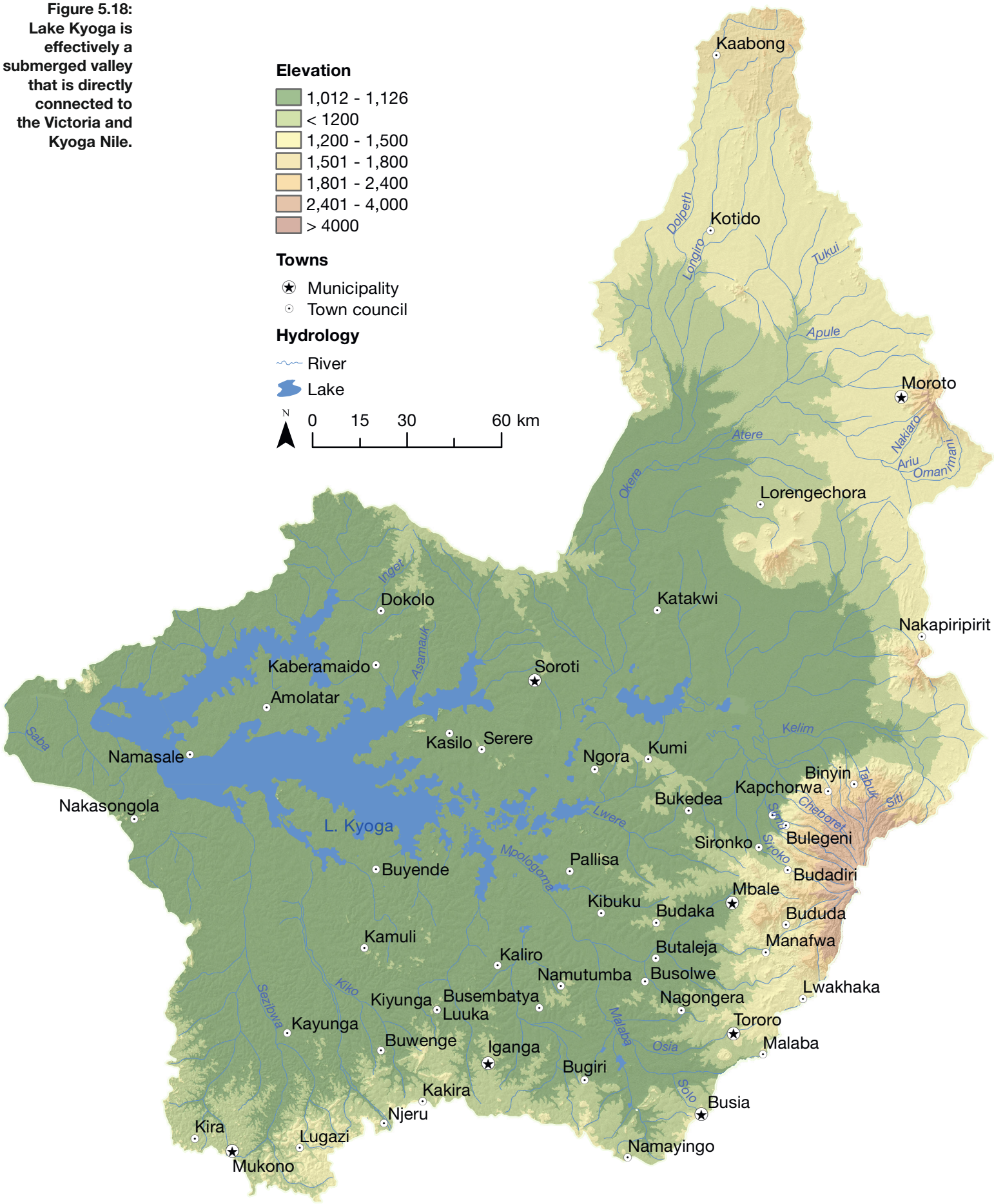
Water Balances and Trends

The current water utilization rate for the Basin is modest at 5.1% (table 5.6). The projected utilization rate for 2030 stands at 40.3%. Water availability is based on Internal Renewable Water Resources (IRWR), which represents the annual flow of rivers and recharge of aquifers generated from precipitation over the Basin's land area. It is noted that Nile flows have not been considered in these calculations. The Lake Kyoga Basin, therefore, is treated as an upstream catchment without external inflow.

The leap of the water utilization rate from 5.1% to 40.3% is by and large caused by the planned expansion of the irrigated area in the Lake Kyoga Basin. Several remarks need to be made: 1) although the exploitation index of 40.3% in 2030 is high, there is still sufficient water to satisfy the Basin's water demand, 2) it is quite likely that the effective water demand of irrigated agriculture in the wetland areas is lower than calculated, since there are also significant water losses in swamps, and 3) measures to increase water efficiency are best focused on improving water productivity in irrigated agriculture.

While some caution is warranted in the Lake Kyoga Basin, the situation is not at all alarming. It is noted that water deficits can be experienced in local areas and at certain times of the year. The figures presented in table 5.6 present average values.

Figure 5.18: Lake Kyoga is effectively a submerged valley that is directly connected to the Victoria and Kyoga Nile.



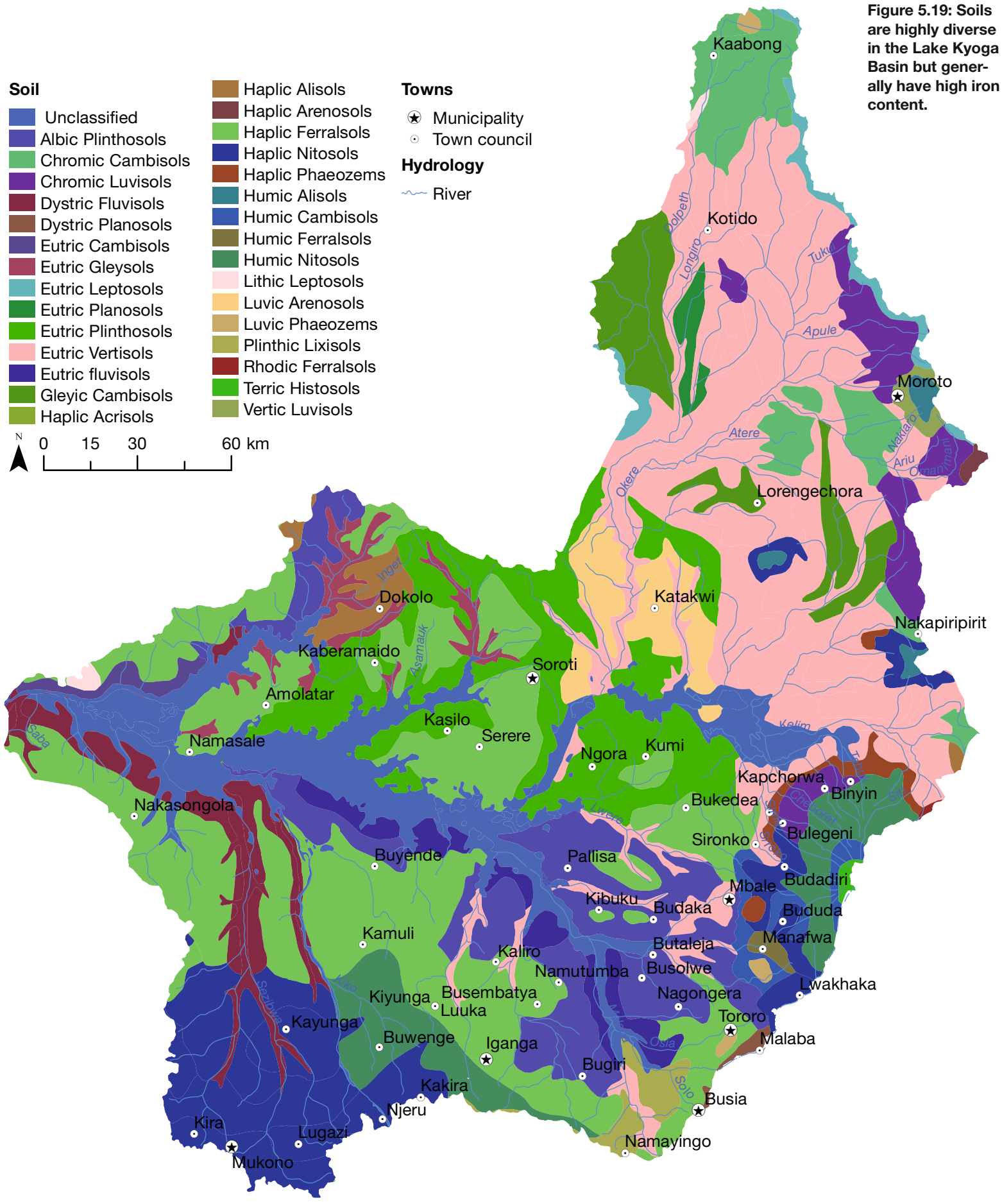


Figure 5.19: Soils are highly diverse in the Lake Kyoga Basin but generally have high iron content.

Figure 5.20: The large wetland areas have a marked influence on the hydrology of Lake Kyoga.

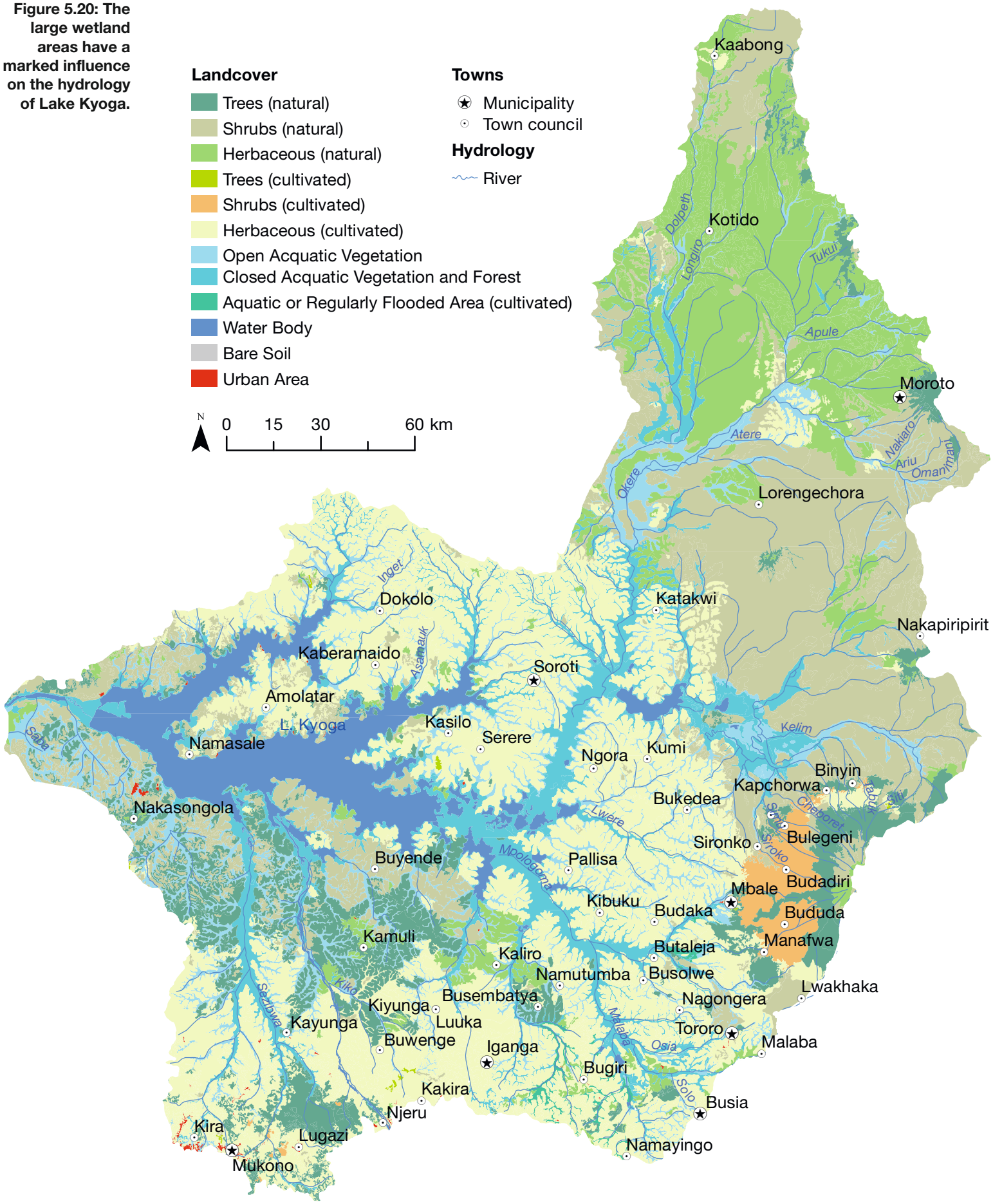
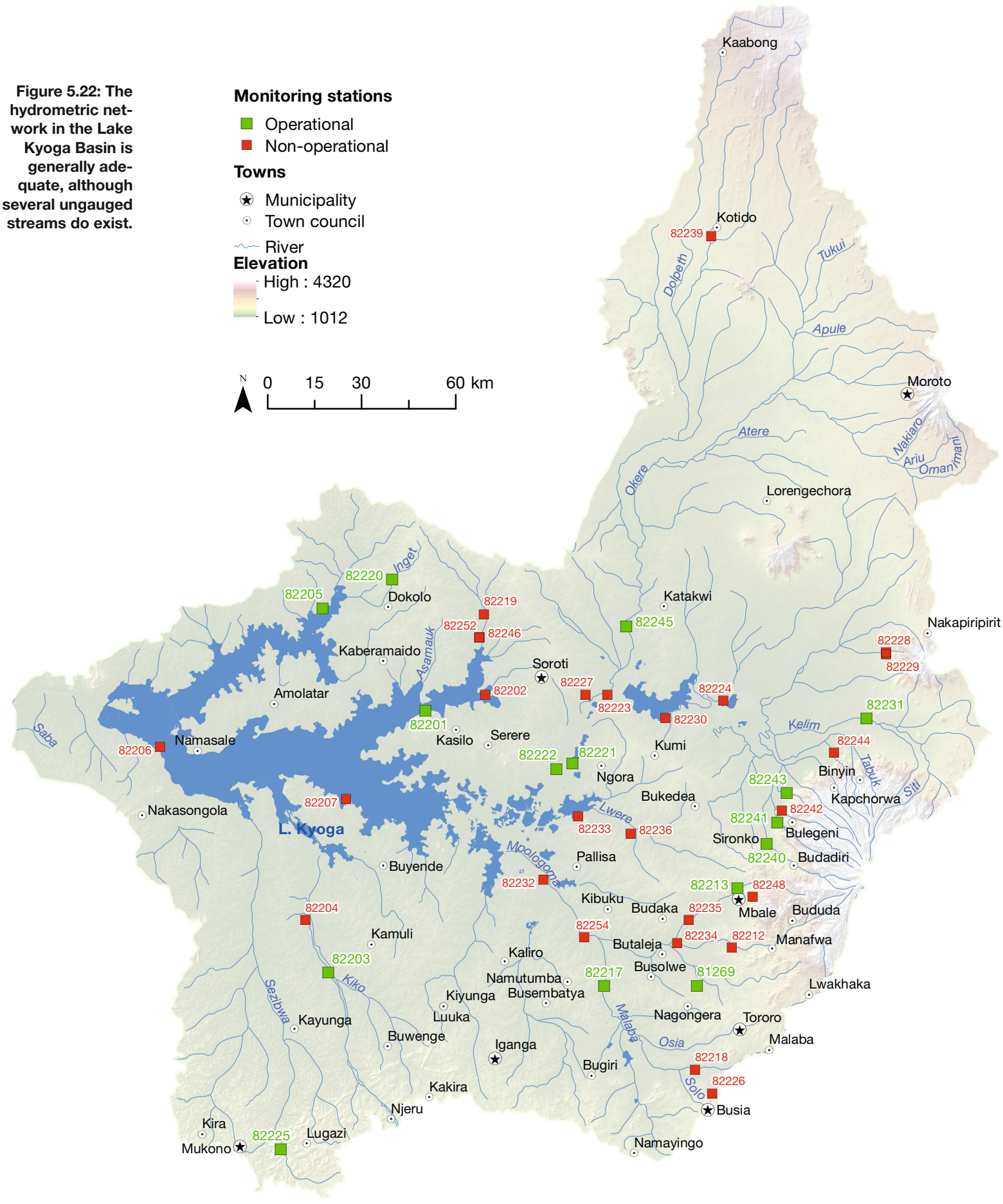


Figure 5.21: Most of the surfaces are old—mid to end Tertiary—except for the volcanic areas around Mount Elgon.

Figure 5.22: The hydrometric network in the Lake Kyoga Basin is generally adequate, although several ungauged streams do exist.

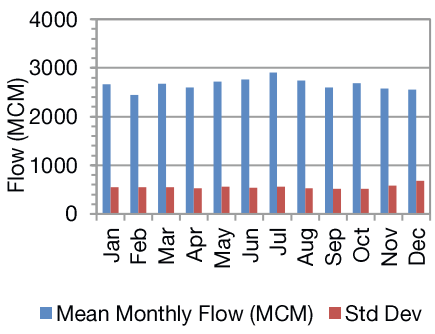


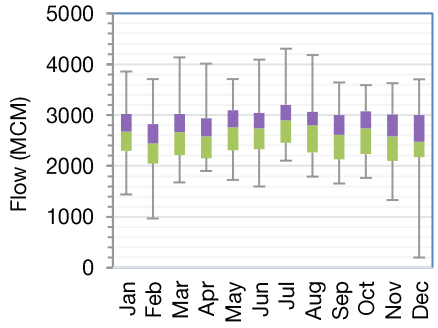
STATION	NAME
81269	R. Sio at Luhalali near Bunadeti
82201	L. Kyoga at Bugondo Pier
82202	L. Kyoga at Lale Port
82203	R. Victoria Nile at Mbulamuti
82204	R. Victoria Nile at Namasagali
82205	L. Kwania at Kachung
82206	L. Kyoga at Lwampanga
82207	L. Kyoga at Kigingi
82212	R. Manafwa at Mbale - Tororo Road
82213	R. Namatala at Mbale - Soroti Road
82217	R. Mpologoma at Budumba
82218	R. Malaba at Jinja - Tororo Road
82219	R. Omunyal Upper at Soroti - Doko
82220	R. Enget at Bata - Dokolo Road
82221	R. Agu at Kumi - Serere Road
82222	R. Abuket at Kumi - Serere Road
82223	R. Kapiri I at Railway Bridge
82224	L. Bisina at Opeta
82225	R. Sezibwa at Falls
82226	R. Kami at Tororo - Busia Road
82227	R. Kapiri at Kumi - Soroti Road

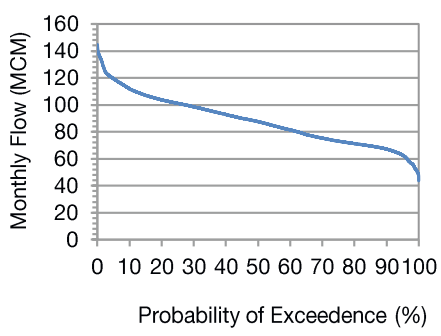
STATION	NAME
82228	R. Namalu at Mbale - Moroto Rd
82229	R. Amaler at Mbale - Moroto Road
82230	L. Bisina at Osera
82231	R. Kelim (Greek) at Mbale - Moroto Road
82232	R. Mpologoma at Kasodo
82233	L. Nyaguo at Agule
82234	R. Manafwa at Butaleja
82235	R. Namatala South at Naboa (Kaiti)
82236	R. Lwere at Kanyum
82239	R. Longiro - Near Kotido
82240	R. Sironko at Mbale - Moroto Road
82241	R. Simu at Mbale - Moroto Road
82242	R. Muyembe at Mbale - Moroto Road
82243	R. Sipi at Mbale - Moroto Road
82244	R. Atari at Mbale - Moroto Road
82245	R. Akokorio at Soroti - Katakwi Road
82246	R. Omunyal Lower at Soroti - Kabe
82248	R. Nabiyonga at Busamaga
82252	R. Omunyal Upper at Tiririri - Ot
82254	R. Mpologoma at Tirinyi-Mbale rd

Table 5.7: Monitoring stations in the Lake Kyoga Basin

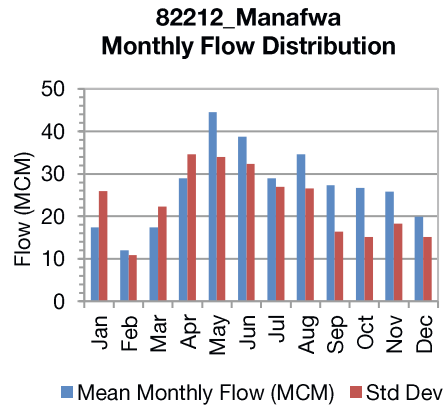
Hydrological Review

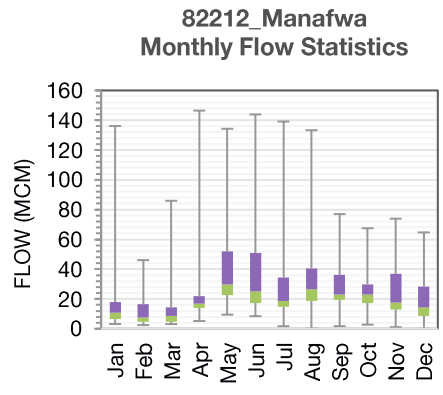


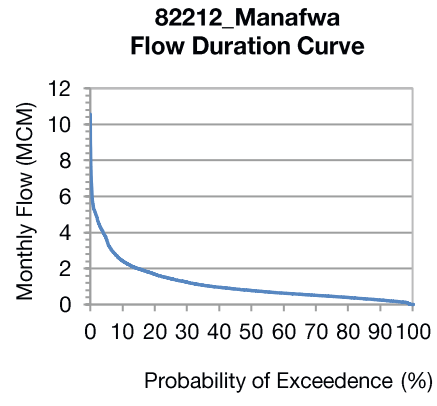




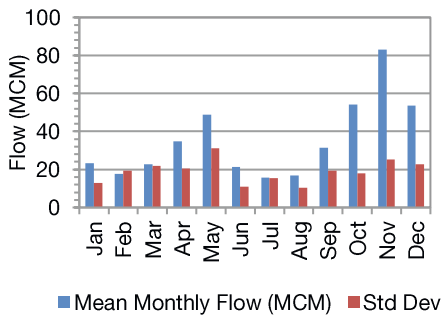
This paragraph presents the seasonal pattern, key statistics, and flow reliability of selected stations within the Lake Kyoga Basin.







82215_Mpanga
Monthly Flow Distribution



82215_Mpanga
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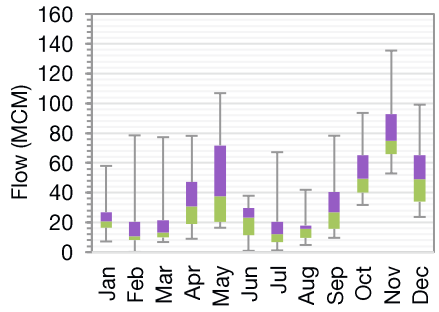
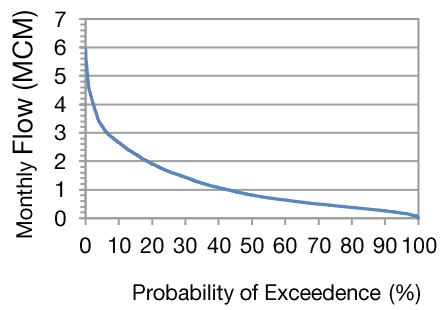
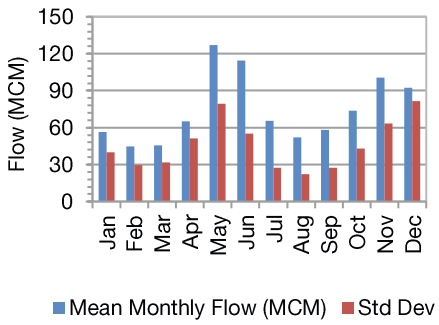


82215_Mpanga
Flow Duration Curve



82217_Mpologoma
Monthly Flow Distribution



82217_Mpologoma
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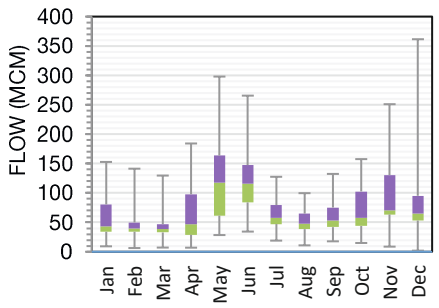
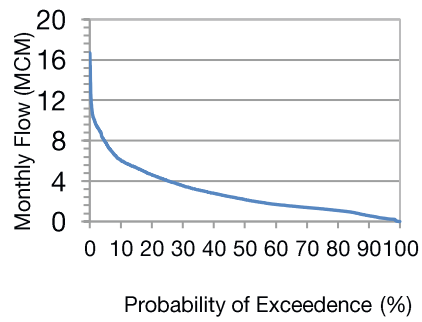
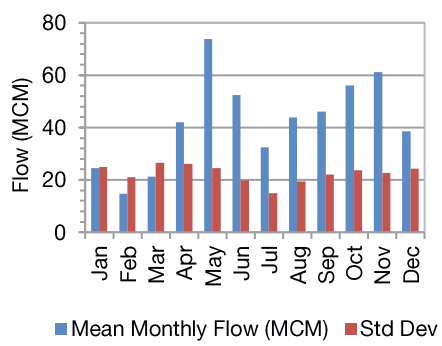


82217_Mpologoma
Flow Duration Curve



82218_Malaba
Monthly Flow Distribution



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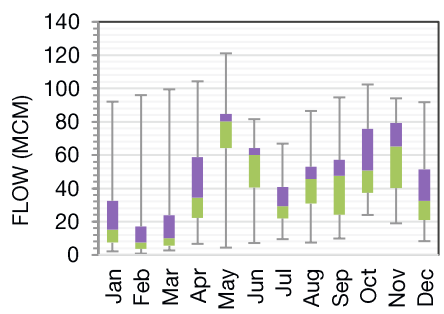
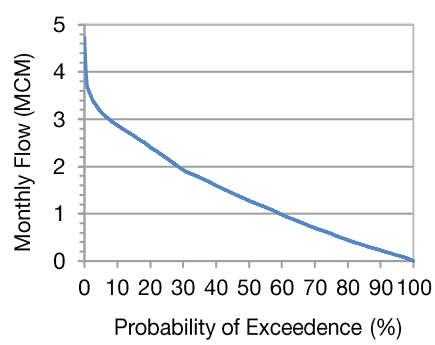
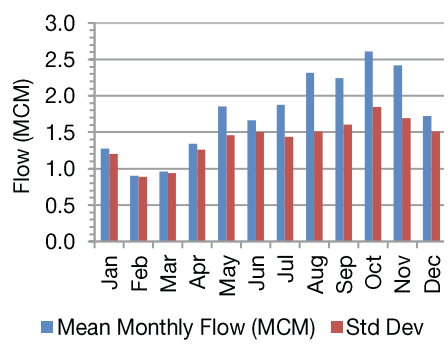
Monthly Flow Statistics



82218_Malaba
Flow Duration Curve



82220_Enget
Monthly Flow Distribution



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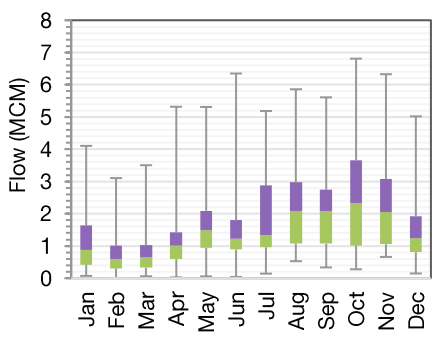
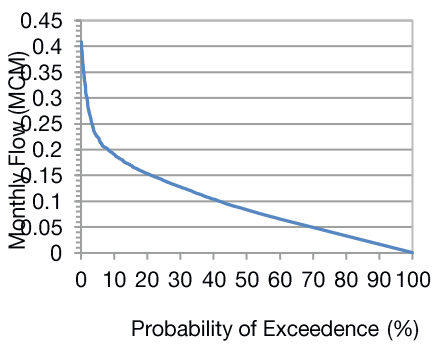
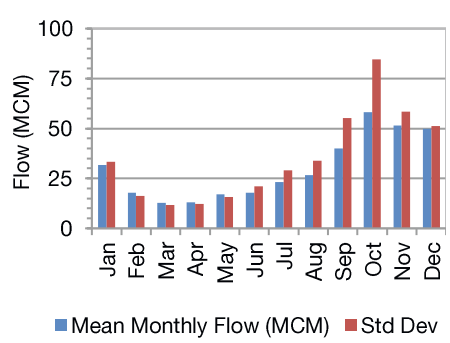
Monthly Flow Statistics



82220_Enget
Flow Duration Curve



82221_Agu
Monthly Flow Distribution



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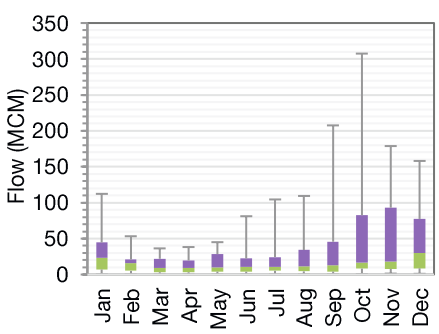
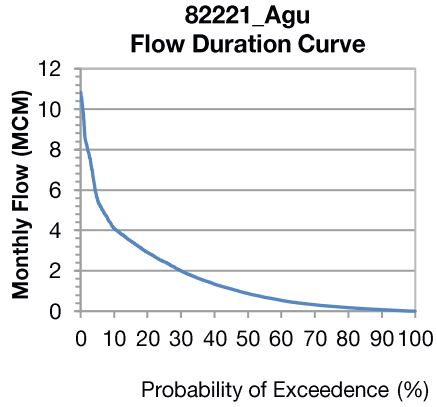
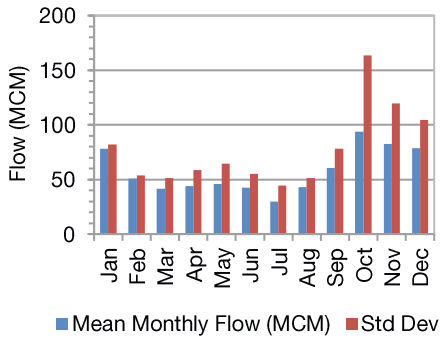


82221_Agu
Flow Duration Curve



82222_Abuket
Monthly Flow Distribution



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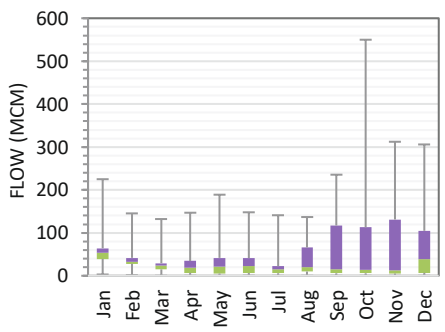
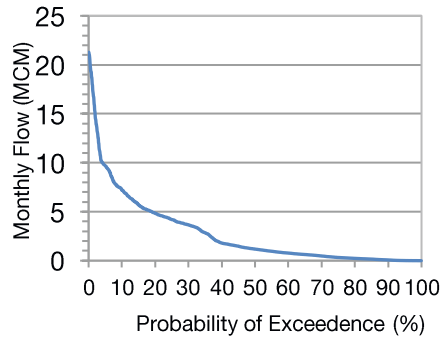
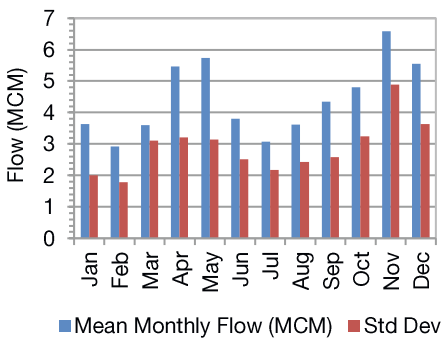
Monthly Flow Statistics



82222_Abuket
Flow Duration Curve



82225_Sezibwa
Monthly Flow Distribution



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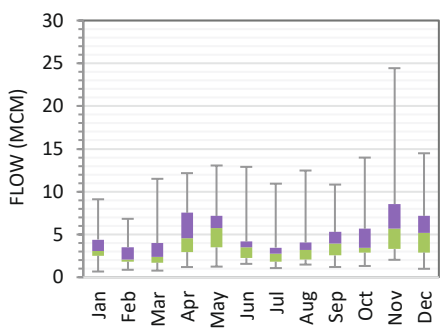
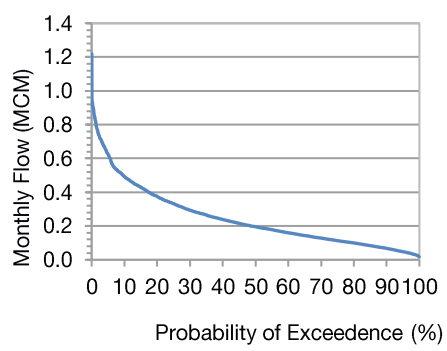
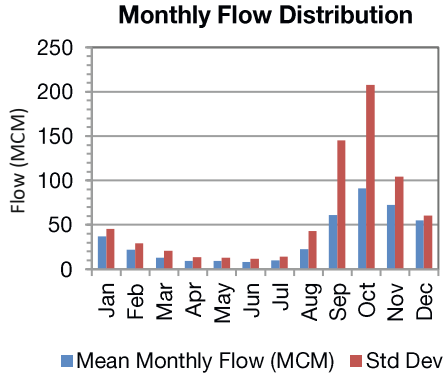


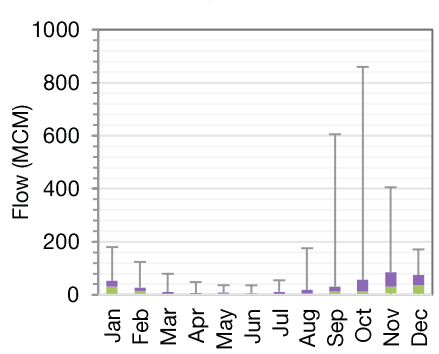
82225_Sezibwa
Flow Duration Curve



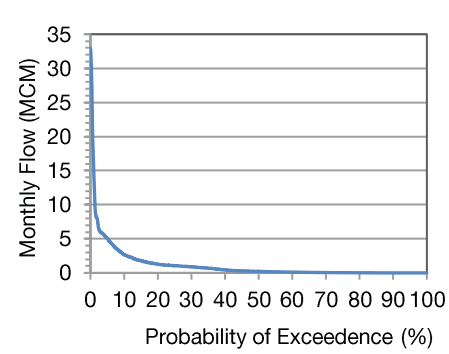
82227_Kapiri
Monthly Flow Distribution



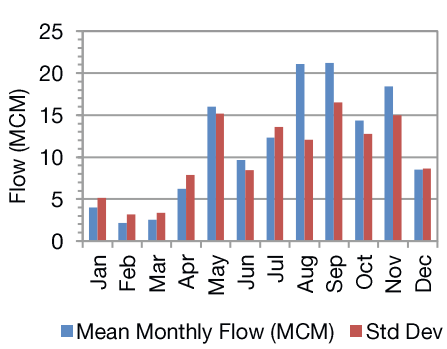
82227_Kapiri
Monthly Flow Statistics



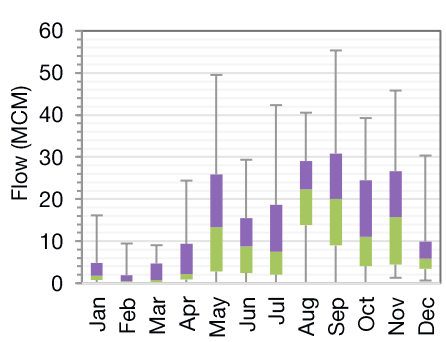
82227_Kapiri
Flow Duration Curve



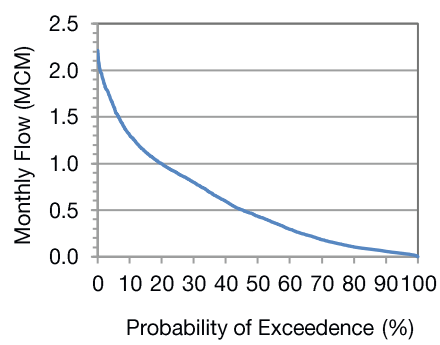
82231_Kelim
Monthly Flow distribution



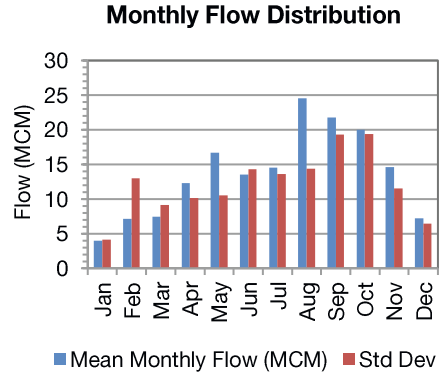
82231_Kelim
Monthly Flow Statistics



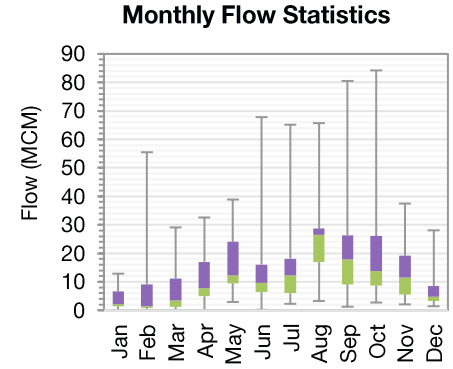
82231_Kelim
Flow Duration Curve



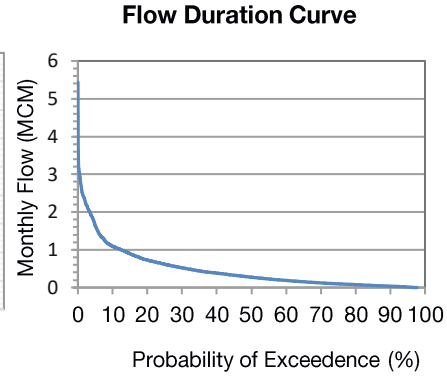
82240_Sironko
Monthly Flow Distribution

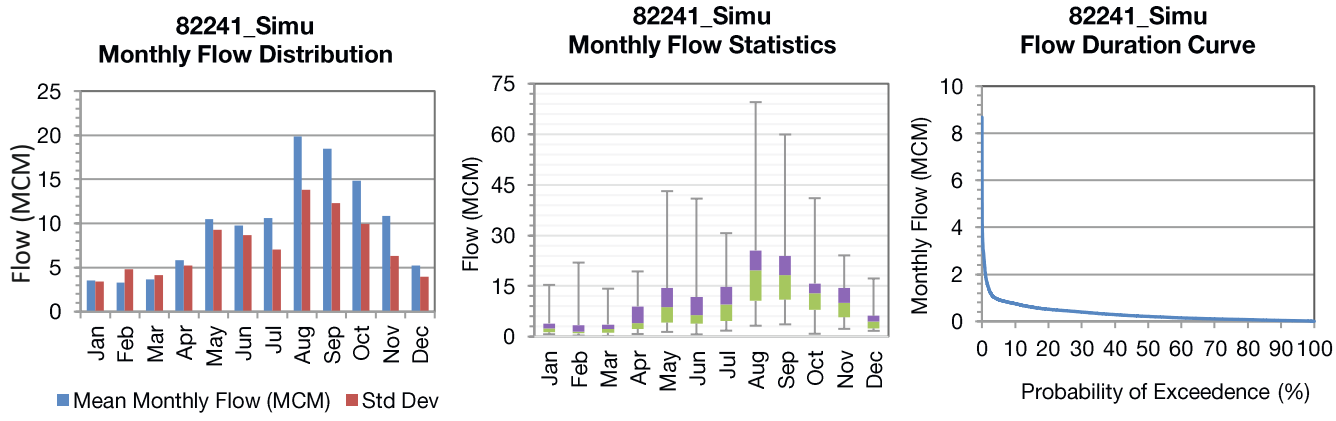


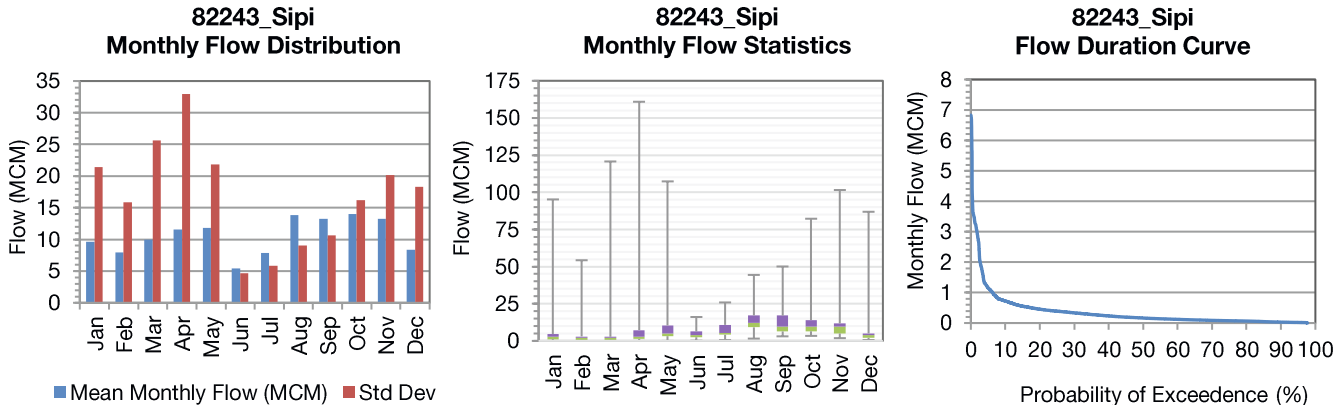
82240_Sironko
Monthly Flow Statistics

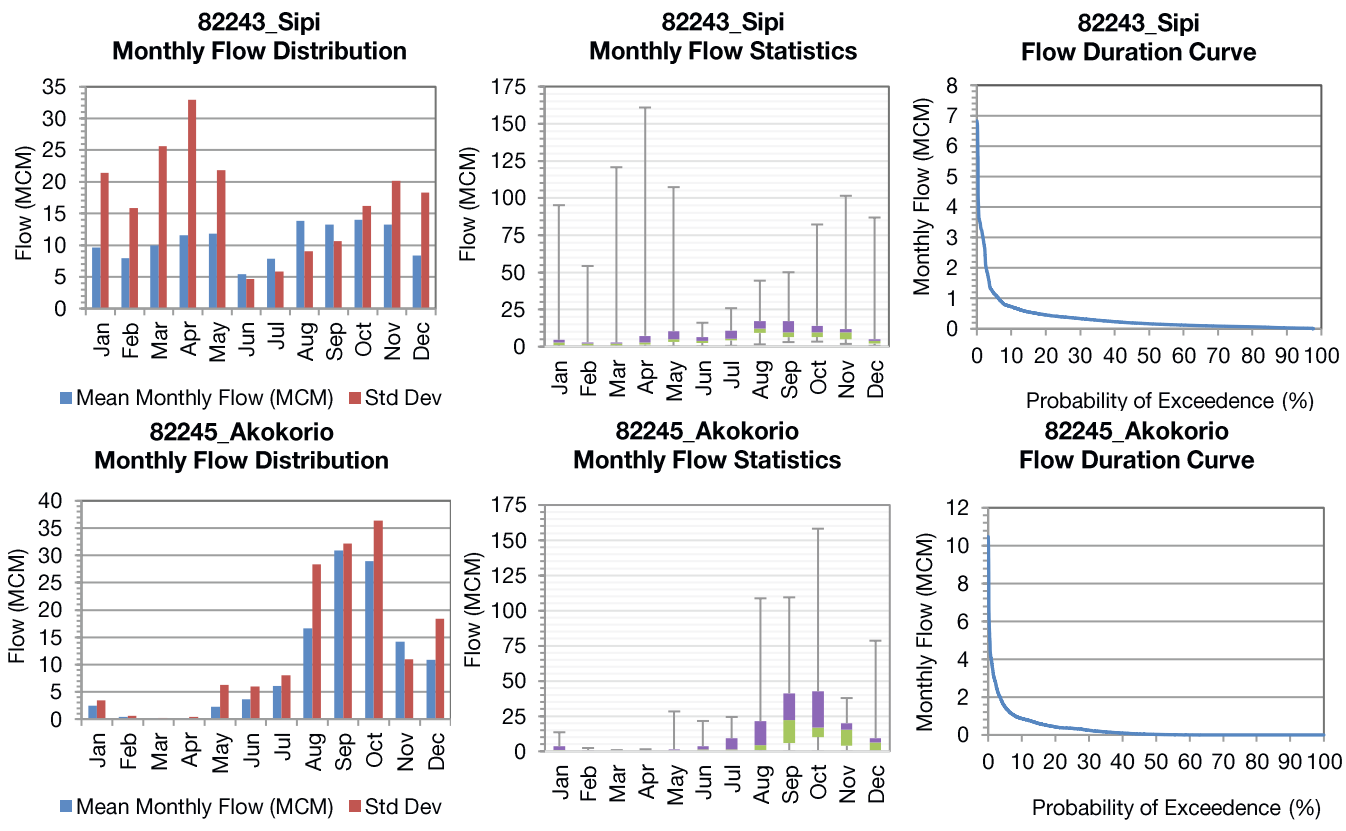


82240_Sironko
Flow Duration Curve




82241_Simu
Monthly Flow Distribution
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Mean Monthly Flow (MCM)
Std Dev
82241_Simu
Monthly Flow Statistics
Flow (MCM)
82241_Simu
Flow Duration Curve
Monthly Flow (MCM)
Probability of Exceedence (%)


82243_Sipi
Monthly Flow Distribution
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Mean Monthly Flow (MCM)
Std Dev
82243_Sipi
Monthly Flow Statistics
Flow (MCM)
82243_Sipi
Flow Duration Curve
Monthly Flow (MCM)
Probability of Exceedence (%)


82243_Sipi
Monthly Flow Distribution
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Mean Monthly Flow (MCM)
Std Dev
82243_Sipi
Monthly Flow Statistics
Flow (MCM)
82243_Sipi
Flow Duration Curve
Monthly Flow (MCM)
Probability of Exceedence (%)
82245_Akokorio
Monthly Flow Distribution
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Mean Monthly Flow (MCM)
Std Dev
82245_Akokorio
Monthly Flow Statistics
Flow (MCM)
82245_Akokorio
Flow Duration Curve
Monthly Flow (MCM)
Probability of Exceedence (%)

Victoria Nile

Surface Water

The Victoria Nile Basin encompasses three distinct and very different elements: 1) the Kyoga Nile, 2) the Kafu Basin, and 3) the northern tributaries of the Kyoga Nile.

The Kyoga Nile starts at the outlet of Lake Kyoga and empties into Lake Albert. The river drops some 400 m along this stretch, which features the scenic Murchison Falls and Karuma Falls. The hydrologic regime of the Kyoga Nile is dominated by the outflow of Lake Victoria, although flow is slightly modified by the passage through Lake Kyoga. Nile flows are more or less steady throughout the year with some minor seasonal fluctuations.

Furthermore, it is important to note that the Kyoga Nile is no longer a natural river. The river is now fully regulated with flow controlled by the release policies of the Nalubaale and Kiira hydropower facilities. The primary aim is to optimize power production of the cascade of hydro-power facilities along the Victoria and Kyoga Niles. Because the storage capacity created by these dams is small – and can only regulate daily flows – the hydro-power plants are effectively operated on a run-of-the-river basis. A seasonal – and unregulated – component is added by the tributary inflow, but these flows are small compared to the Nile flow.

Kafu is the largest tributary of the Kyoga Nile (figure 5.24). It drains a large area south of the Nile that reaches the outskirts of Kampala. The river includes the main tributaries Lugoga and Mayanja, but the average yield is low: an estimated 30 mm/year despite a mean annual rainfall of over 1,200 mm (NWRA 2013). The low yield is attributed to the retention of water in the large wetland areas in Kafu Basin. Kafu is a hydrological anomaly, as the river initially drain into the opposite direction. Tectonic events in the Tertiary Period caused an uplift of the western edge of the catchment, even-

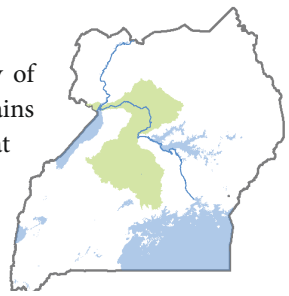


Figure 5.23: River Kafu in the Victoria Nile Basin

Table 5.8: Current and projected water use in the Victoria Nile Basin

Water Demand [mcm]	2012	2030 (projected)
Urban Domestic	1.6	21.5
Rural Domestic	8.3	41.1
Industrial	0.8	0.8
Livestock	23.2	23.2
Irrigation		109.0
Total	33.9	195.6
IRWR	1,440	1,440
Exploitation Index (%)	2.4	13.6

National Water Resources Assessment 2012

tually resulting in a reversal of flow of Kafu River in a north-eastern direction. The reduction of relief led to flooding and sediment aggradation within the wide drainage channels, creating a dendritic pattern of large wetland areas. The wetlands are characterized by a high evaporation, which is the main reason for the low effective yield of Kafu.

Several small rivers drain the norther part of the Victoria Nile Basin, of which Tochi is the largest. They exhibit a normal dendritic pattern but also feature several large permanent and seasonal wetland areas. Nevertheless, the specific runoff and runoff coefficient are quite high – about 100 mm/year about 8% respectively (NWRA 2013).

Figures 5.25, 5.26, and 5.27 present soils, land-cover, and geology of the Victoria Nile catchment respectively.

Hydrological Monitoring

Figure 5.28 presents the hydrometric network in the Victoria Nile Basin. Seven stations were operational in the 1978-2014 timeframe, including three on the main Nile. Several large tributaries on the north bank are not measured but the outflow of the large Kafu sub-basin on the south bank is monitored. The hydrology of Kafu basin is highly complex because of the large wetland areas. Additional monitoring is required to better understand the hydrological processes in this sub-basin.

Tributary flows in the Victoria Nile Basin are highly variable. River Kafu is dominated by the large wetlands in the catchment. The river has a substantial portion of baseflow although flood events are still highly variable.

Baseflow of river Tochi is low and discharge is reduced to a trickle in the lean flow period from February to April. The Flow Duration Curve indicates that incidences of no-flow occur. High flows are unpredictable and highly variable, as evidenced by the stretched line extending from the mean in the box plot in the flood season from July to December.

Groundwater Regime

The whole Basin is made up of Precambrian formations consisting of metamorphic and intrusive rock, apart from the areas near the shores of Lake Victoria and in the valleys along the larger streams where sediments are found (Lake deposits, alluvial sediments, beach terraces). Aquifers in the metamorphic formations are found in fractures, and to a lesser extent in the overburden. The southern part of the Basin is made up of argillites and arenites of the Precambrian Karagwe-Ankolean Formation. The central part of the Basin is made up of undifferentiated gneisses, with west of Mubende town an area of mobilised granite. The northern edge of the Basin, as well as patches of the central part, is made up of argillites and schists of the Buganda-Toro System.

Groundwater overall drains to Lake Victoria, from groundwater levels of 1,800 m amsl in the north-western corner of the Basin to 1,200 m amsl close to Lake Victoria. Groundwater recharge is overall low, generally below 75 mm per year, with the exception of the districts directly north of Lake Victoria, where recharge is in the category 225-250 mm. The groundwater availability is overall poor, especially the central north-south belt from Gomba District, via Ssembabule, Lyantonde, and Kiruhura Districts to Isingiro District bordering Tanzania; another low potential area forms Buikwe District, directly north of Lake Victoria. Only Ntungamo District has a good groundwater potential.

The area has a challenge with groundwater quality, notably because of total iron that is often above maximum allowable levels (2 mg/l), but also sulphate may be above guideline value (250 mg/l) or even maximum allowable values of 500 mg/l.

Water Balances and Trends

Table 5.8 shows that the current water utilization rate is low while the projected one is modest. Water deficits at Basin scale, therefore, are not anticipated in the Victoria Nile Basin. It is noted that table 5.8 present annual average figures. Local and temporary water shortages, therefore, may occur but need to be addressed through specific local measures rather than through Basin-scale interventions.

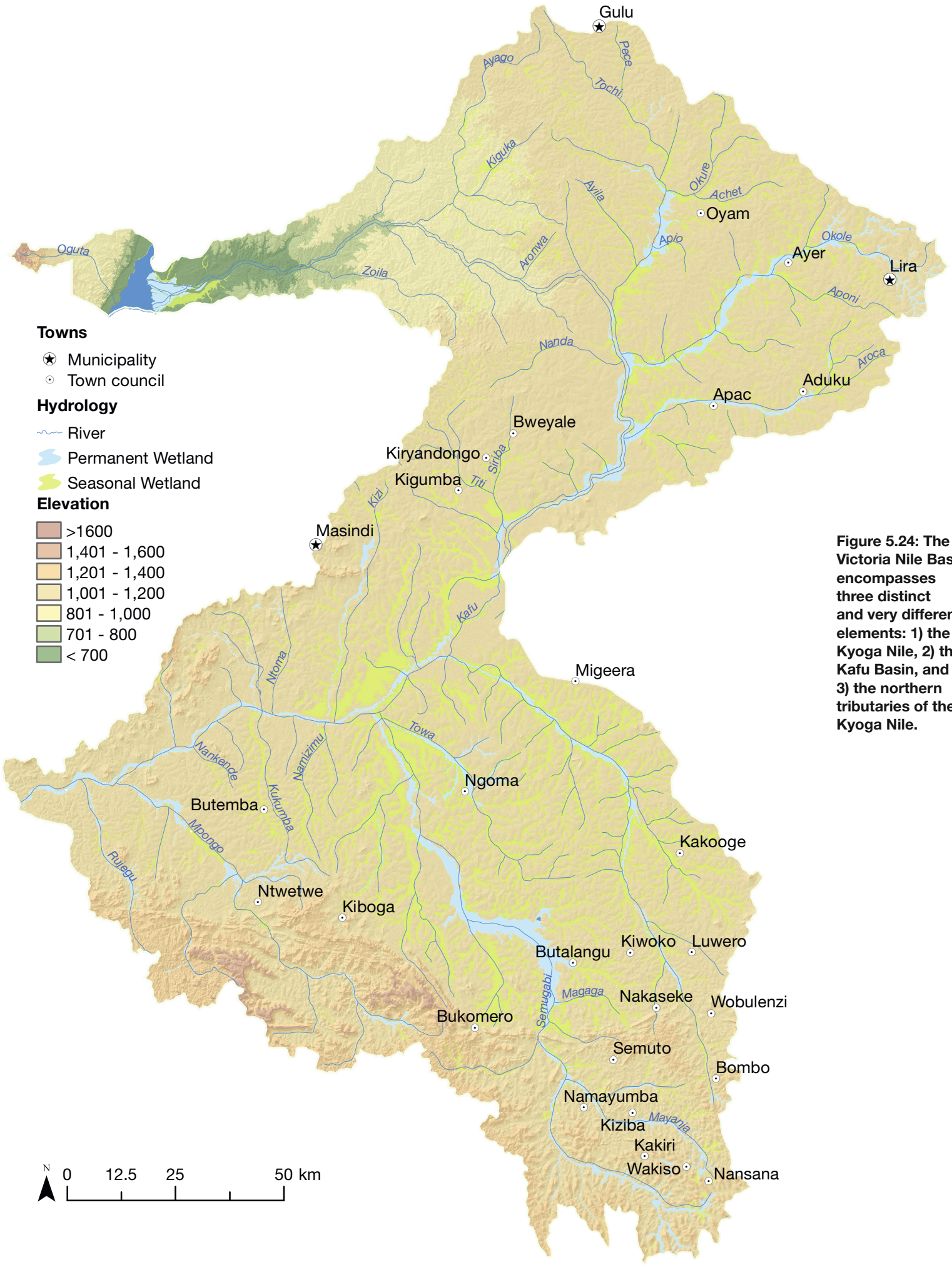


Figure 5.24: The Victoria Nile Basin encompasses three distinct and very different elements: 1) the Kyoga Nile, 2) the Kafu Basin, and 3) the northern tributaries of the Kyoga Nile.

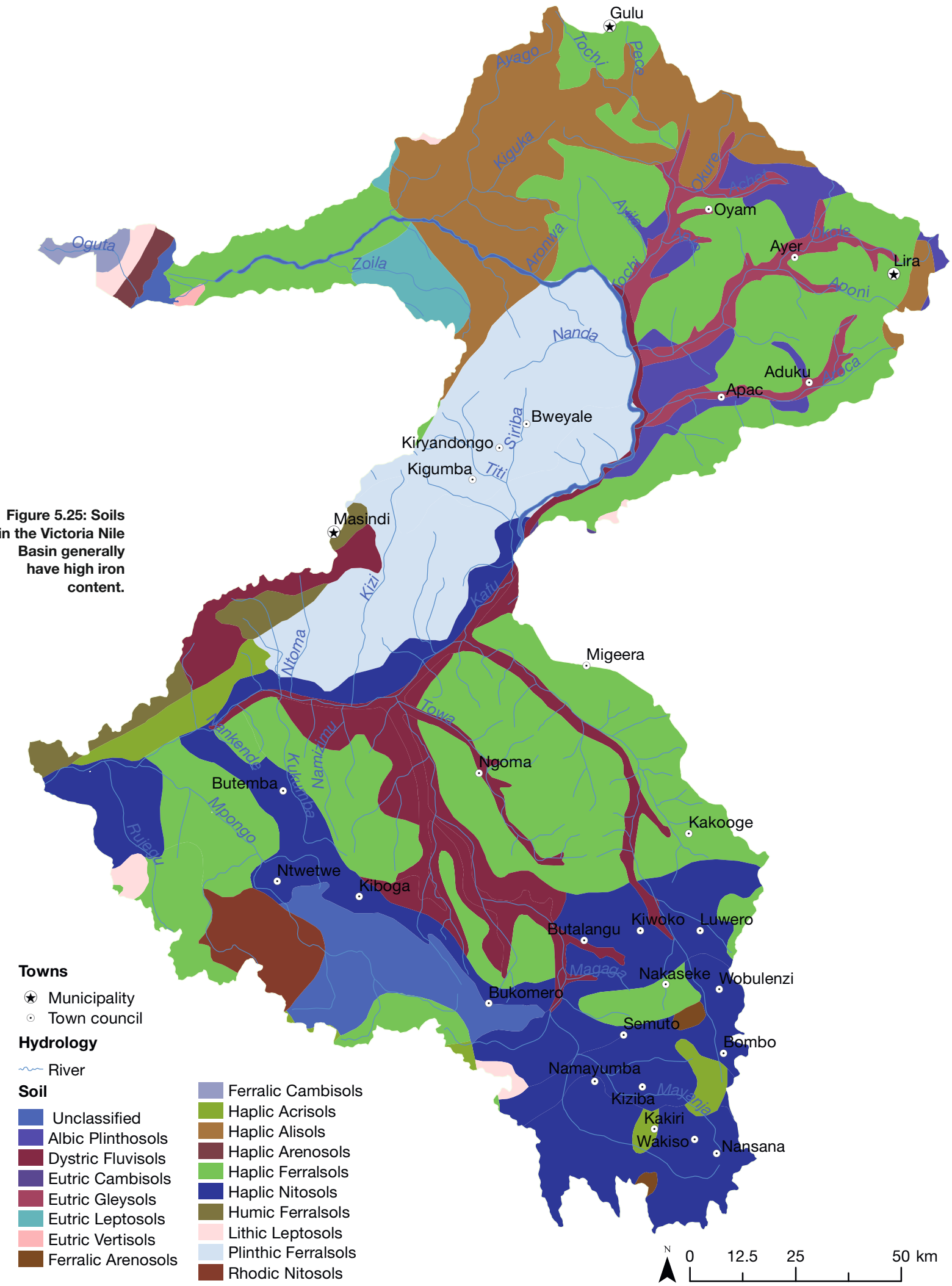


Figure 5.25: Soils in the Victoria Nile Basin generally have high iron content.

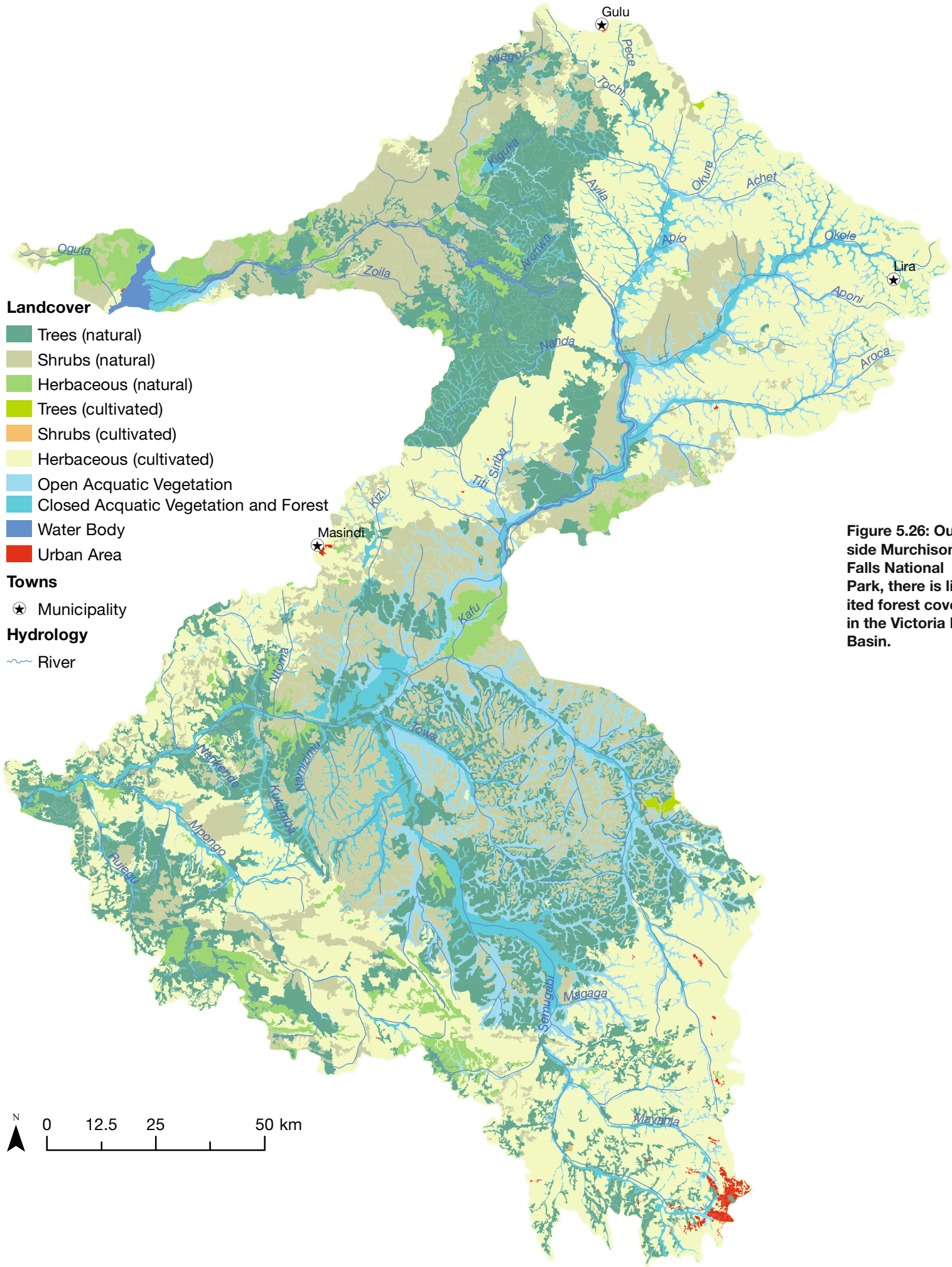
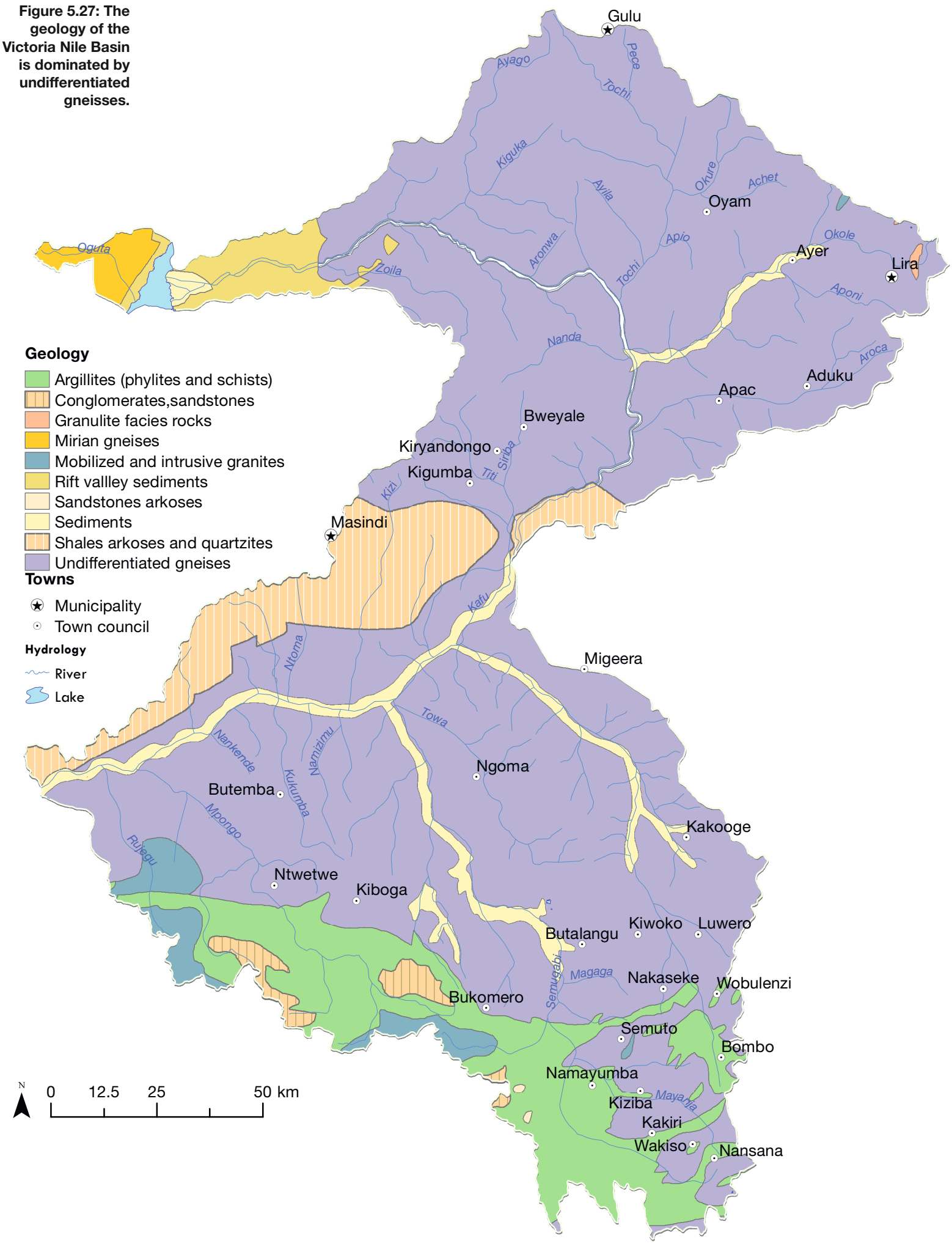


Figure 5.26: Outside Murchison Falls National Park, there is limited forest cover in the Victoria Nile Basin.

Figure 5.27: The geology of the Victoria Nile Basin is dominated by undifferentiated gneisses.



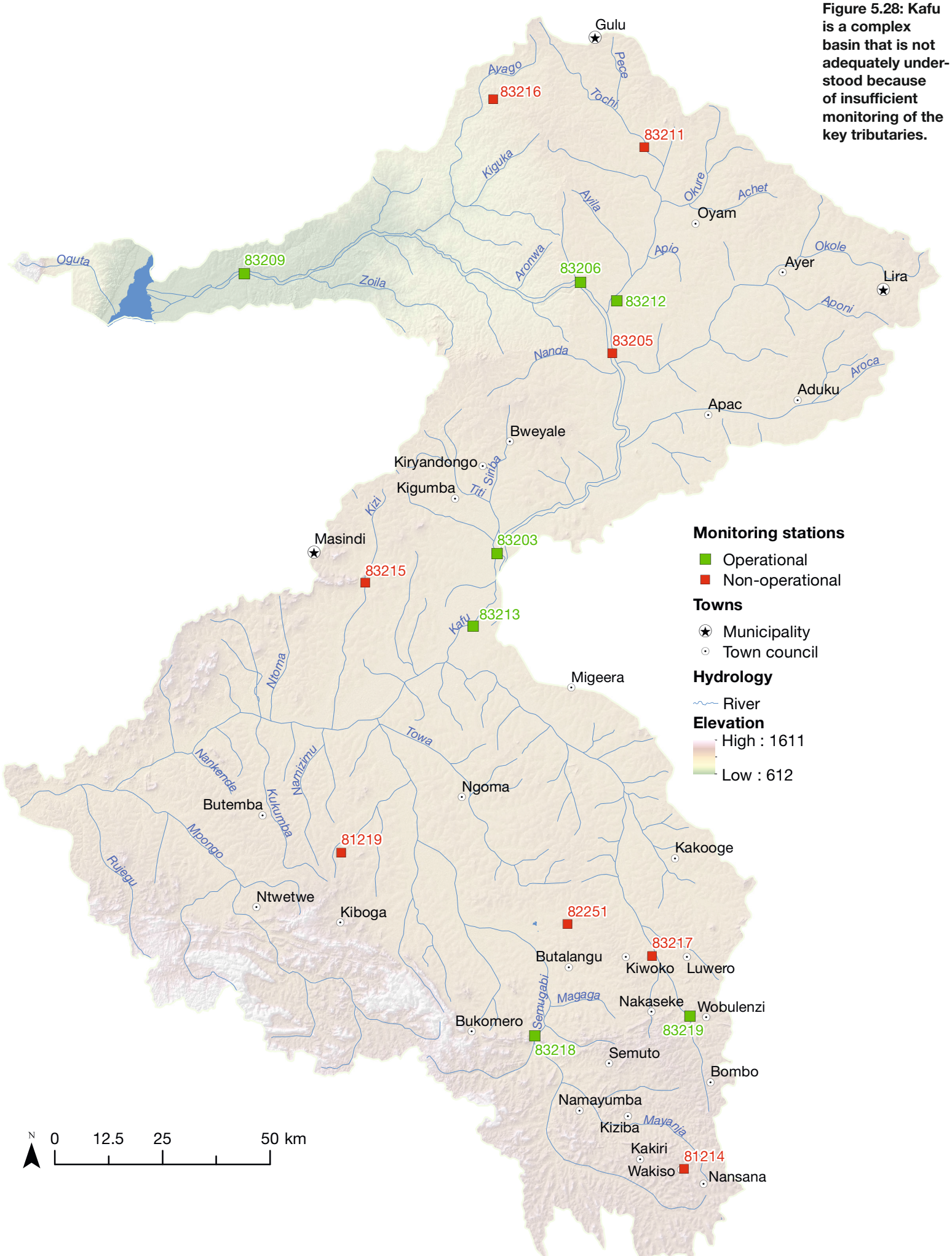


Figure 5.28: Kafu is a complex basin that is not adequately understood because of insufficient monitoring of the key tributaries.

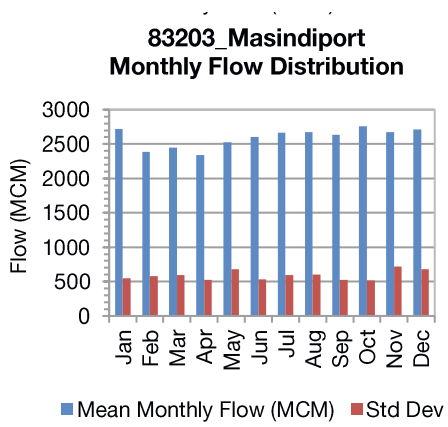
Table 5.9: Monitoring stations in the Victoria Nile Basin

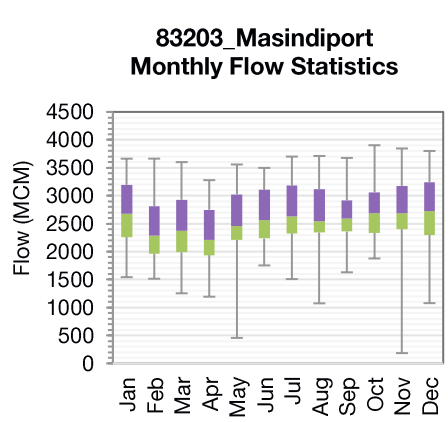
STATION	NAME
81214	L. Victoria at Bukasa Island
81219	R. Katonga at Bugomola
82251	Wamboli at Nabiswera - Gulu Rd
83203	R. Kyoga Nile at Masindi Port
83205	R. Kyoga Nile at Atura
83206	R. Kyoga Nile at Kamdini
83209	R. Kyoga Nile at Paraa
83211	R. Tochi I Gulu - Lira Road

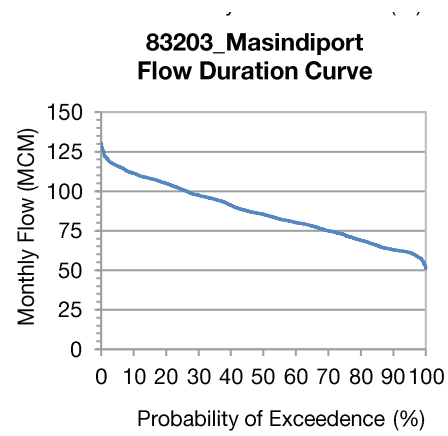
STATION	NAME
83212	R. Tochi II at Gulu - Atura Road
83213	R. Kafu at Kampala - Gulu Road
83215	R. Kizi at Masindi - Kampala Road
83216	R. Ayago at Gulu - Pakwach Road
83217	R. Kagoye at Luwero - Gulu Road
83218	R. Mayanja at Kapeeka - Kakunga Road
83219	R. Kigwe at Semuto - Wobulenzi Road

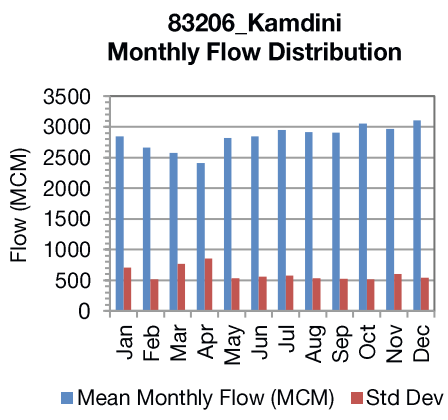
Hydrological Review

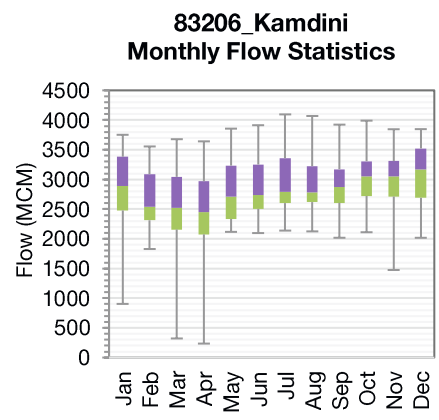
This paragraph presents the seasonal pattern, key statistics, and flow reliability of selected stations within the Victoria Nile Basin.

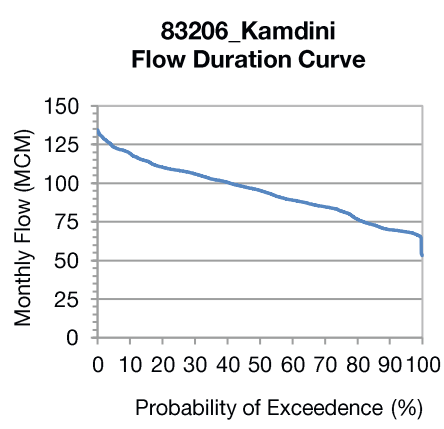


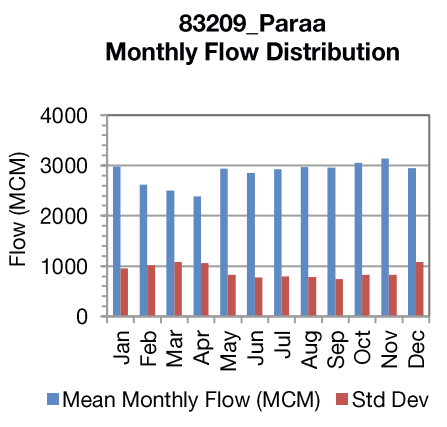


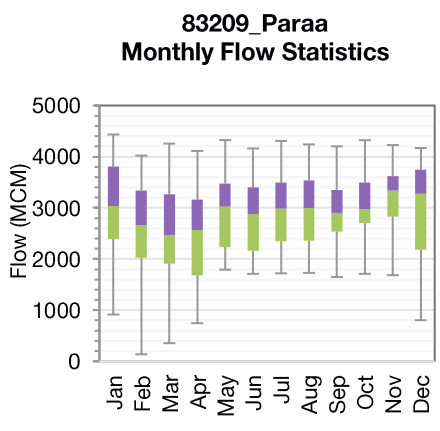


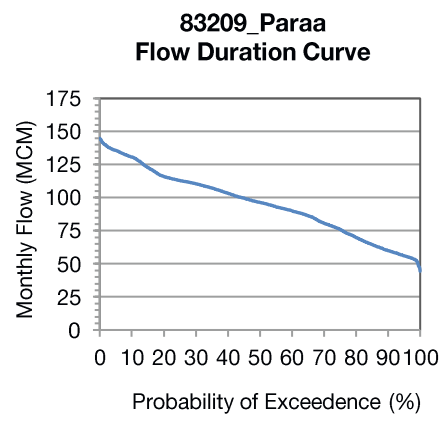




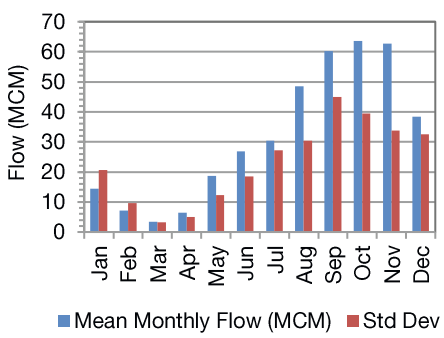




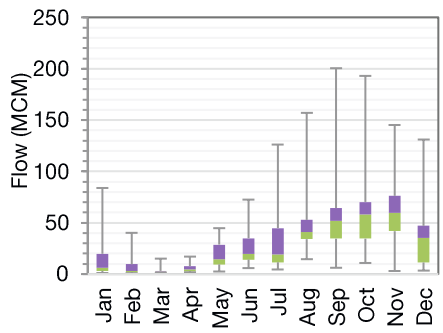




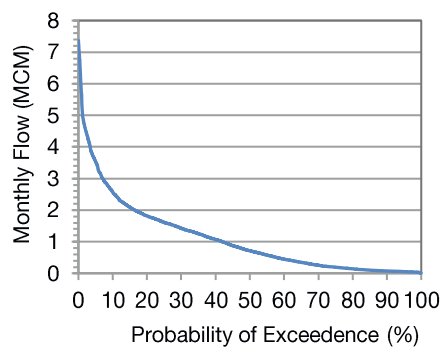
83212_Tochi2
Monthly Flow Distribution



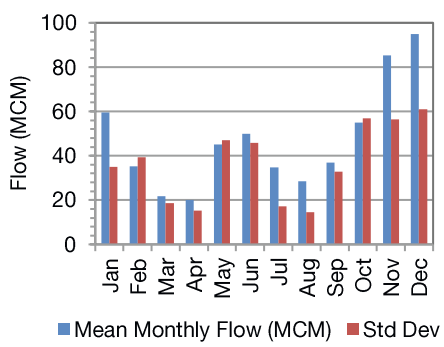
83212_Tochi2
Monthly Flow Statistics



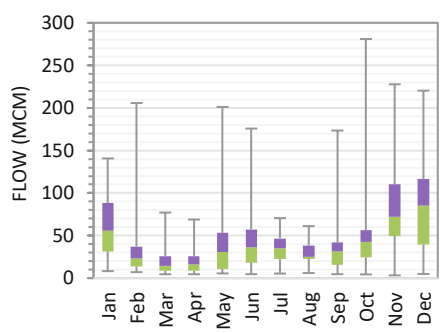
83212_Tochi2
Flow Duration Curve



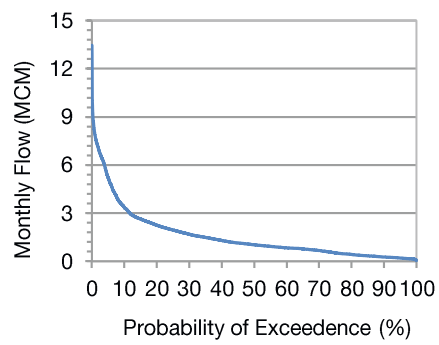
83213_Kafu
Monthly Flow Distribution



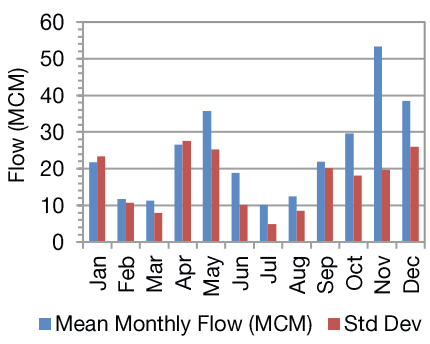
83213_Kafu
Monthly Flow Statistics



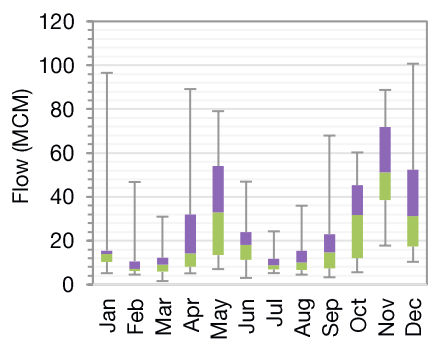
83213_Kafu
Flow Duration Curve



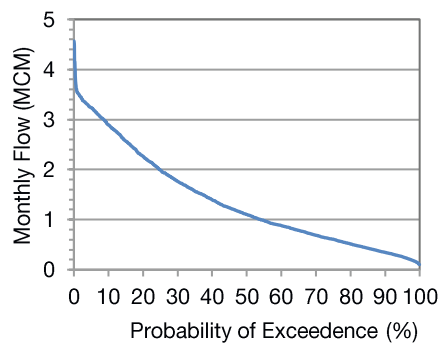
83218_Mayanja
Monthly Flow Distribution



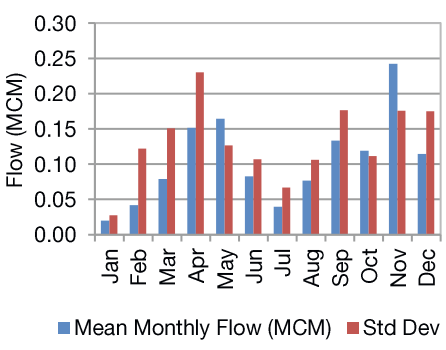
83218_Mayanja
Monthly Flow Statistics



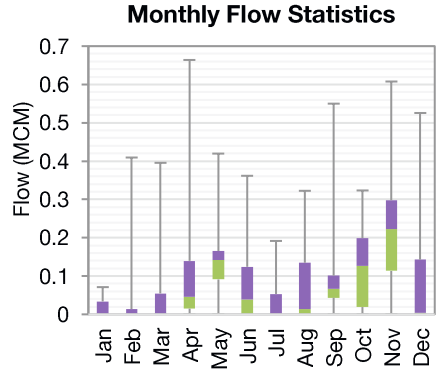
83218_Mayanja
Flow Duration Curve



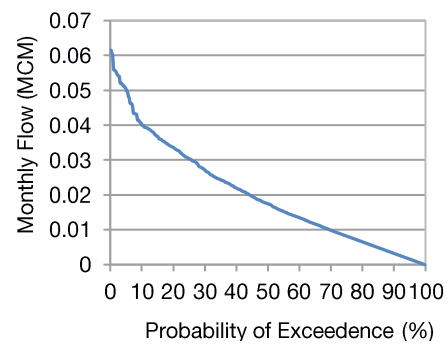
83219_Kigwe
Monthly Flow Distribution



83219_Kigwe
Monthly Flow Statistics



83219_Kigwe
Flow Duration Curve



Lake Albert

Surface Water

The Lake Albert Basin in Uganda is made up of three main elements: 1) Lake Albert, 2) river Semliki, and 3) the tributaries draining the eastern catchments of the lake.

Lake Albert is situated in the western Rift valley and is shared between DR Congo and Uganda. The lake is surrounded by escarpments on the east and by steep mountains on the western side, which rise abruptly to almost 2000 m. With a length of some 150 km and a width of around 35 km, the lake is quite narrow. The climate around the lake is much warmer and dryer than its surroundings. The water balance of Lake Albert is dominated by inflow and outflow of the main Nile. Inflow components include Kyoga Nile (~73%), Semliki inflow (~10%), direct rainfall (~10%), and inflow from the catchments (~7%). Evaporation of Lake Albert is high and results in a net loss to the Nile system.

Semliki is some 140 km long and starts at the outlet of Lake Edward (figure 5.30). It flows to the north in the Albertine Rift before emptying into Lake Albert. Part of the river is in DR Congo. Semliki river drains the entire western side of the Rwenzori mountains, which reach an altitude of over 5,000 m. High rainfall on the slopes cause rapid runoff events. Sediments originating from the steep slopes are mostly deposited in the large Semliki flats at the southern tip of Lake Albert.

The tributaries on the eastern side of Lake Albert are mostly small and characterized by rather narrow drainage channels. They include the Nkuzi, which used to be part of the Kafu river before the latter reversed its drainage direction. Mean annual specific runoff is high in these catchments and generally exceed 150 mm/year. The associated runoff coefficients are between 10% and 15%, which is high in Uganda (NWRA 2013).

Figures 5.31, 5.32, and 5.33 present soils, land-cover, and geology of the Lake Albert catchment respectively.

Hydrological Monitoring

Figure 5.34 presents the hydrometric network in the Lake Albert Basin. There were four operational stations in the 1978-2014 period. Semliki – by far the largest tributary – was not monitored. Only a modest extension of the network is needed to adequately monitor the hydrological processes in this basin.

The Lake Albert tributaries reflect the region's bimodal rainfall regime with peaks in May and November. The rivers are flashy, which is mainly because of the relatively small size of their catchments and steep slopes. Despite the high flow variability, both Waki and Muzizi are perennial rivers that rarely fall dry. Nkuzi, by contrast, occasionally dries up.

Groundwater Regime

For the larger part of the Basin, the groundwater drainage base is formed by Lake Albert; only in the southwestern corner of the Basin, groundwater is draining towards the Semliki River. The groundwater levels drop from 1,400 m amsl in the southeast to 620 m amsl near Lake Albert.

The geology of the areas consists of sedimentary rocks underlying Lake Albert and the rest of the Rift Valley's graben structure. The hardrock formations outside the graben are formed by the Bunyoro Series in the north consisting of shales, schist, phyllites, sandstones and quartzites, and granites and gneissic granitoids in the south.

The groundwater recharge varies between 125 mm in the south and east, to less than 25 mm near Lake Albert.

The groundwater quality is usually good but groundwater in the Semliki River's delta area and some patches spread over the Basin is poor because of high iron concentrations. Boreholes with groundwater characterized with high Total Dissolved Solids are reported in the area between the Rwenzori Mountains and the Semliki River.

Water Balances and Trends

The current and projected water utilization rates for the Lake Albert Basin are presented in table 5.10. The utilization rates are low and the Basin arguably has enough water to meet the anticipated demand in the mid-term future and beyond. Hence, large scale competition over water resources is unlikely although some local and temporary shortages may be experienced;these need to be addressed through local measures and do not involve Basin or sub-Basin scale interventions.

Water Demand [mcm]	2012	2030 (projected)
Urban Domestic	0.8	6.2
Rural Domestic	5.2	24.5
Industrial	0.4	0.4
Livestock	12.5	12.5
Irrigation		
Total	18.9	43.6
IRWR	2,890	2,890
Exploitation Index (%)	0.7	1.5

National Water Resources Assessment 2012

Table 5.10: Current and projected water use in the Lake Albert Basin

Figure 5.29: River Waki in the Lake Albert Basin

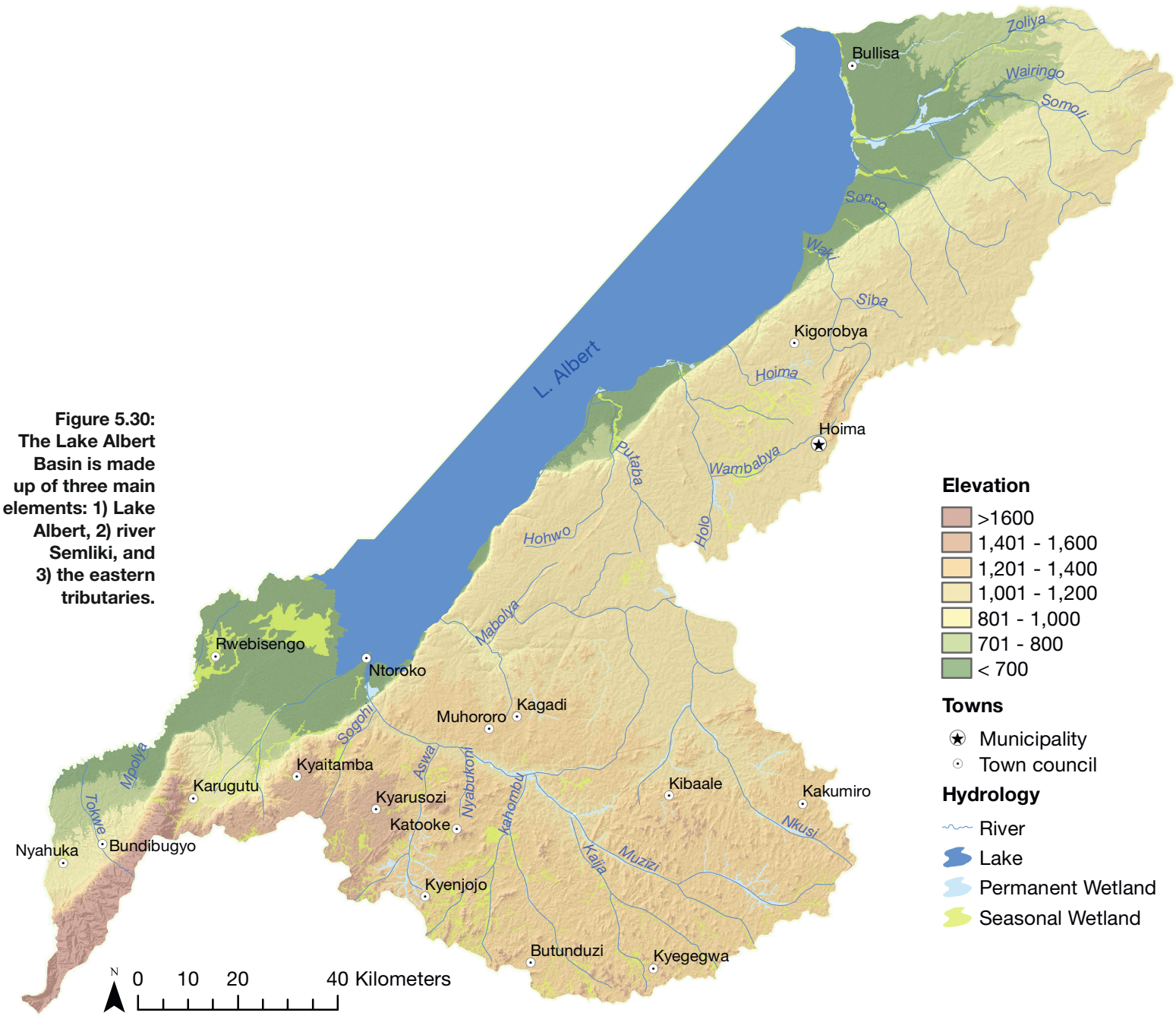


Figure 5.30: The Lake Albert Basin is made up of three main elements: 1) Lake Albert, 2) river Semliki, and 3) the eastern tributaries.

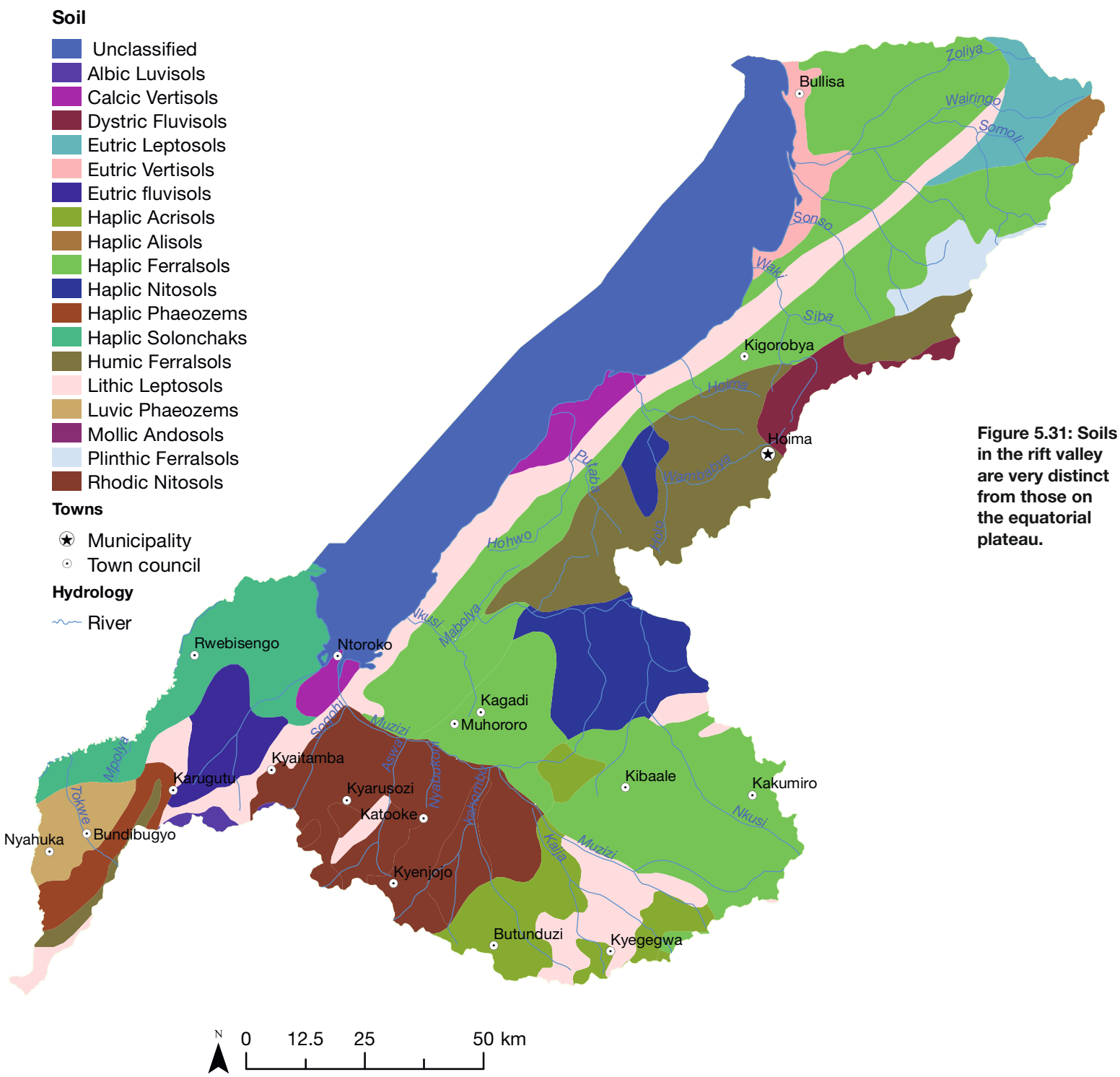


Figure 5.31: Soils in the rift valley are very distinct from those on the equatorial plateau.

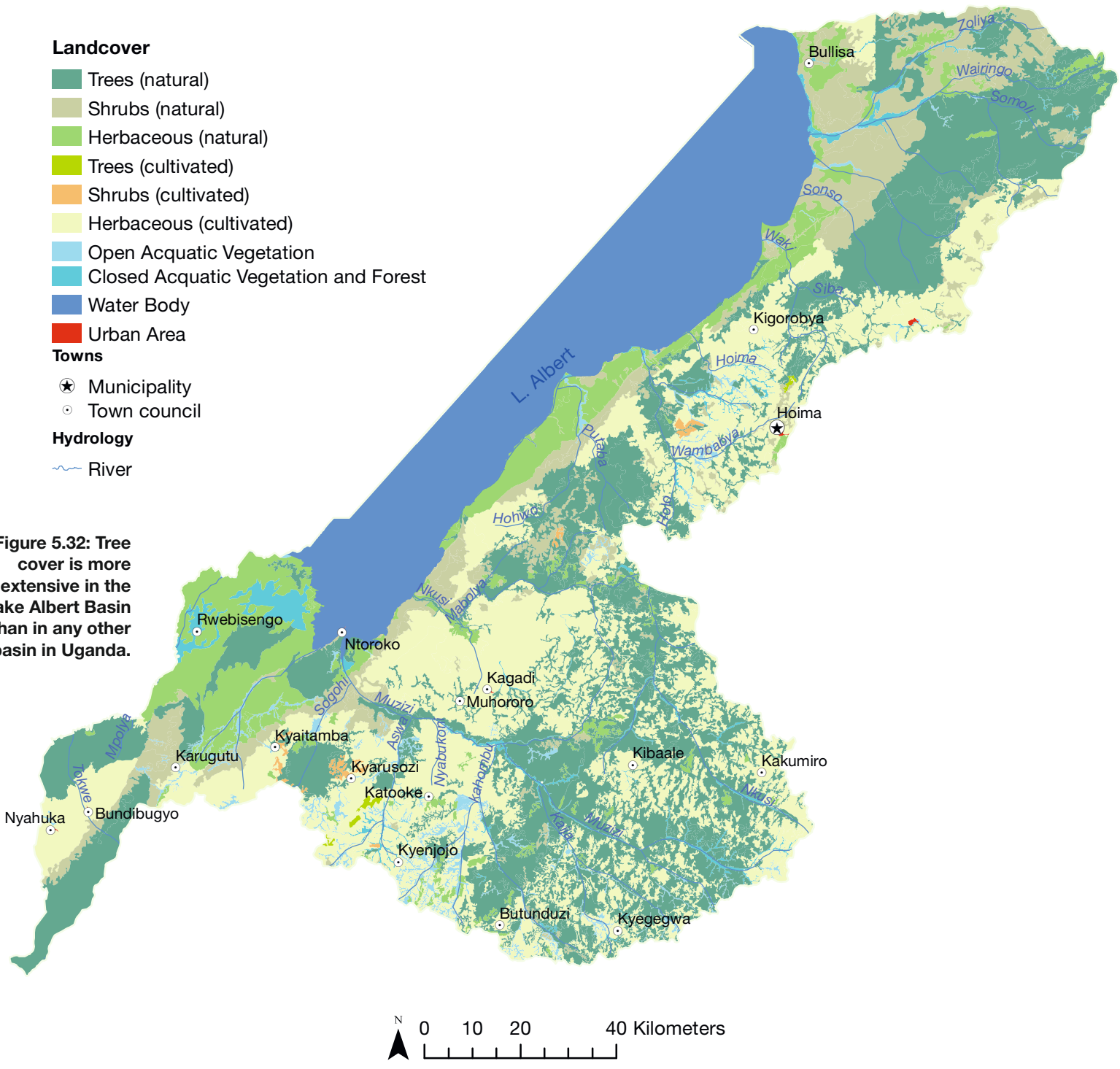


Figure 5.32: Tree cover is more extensive in the Lake Albert Basin than in any other basin in Uganda.

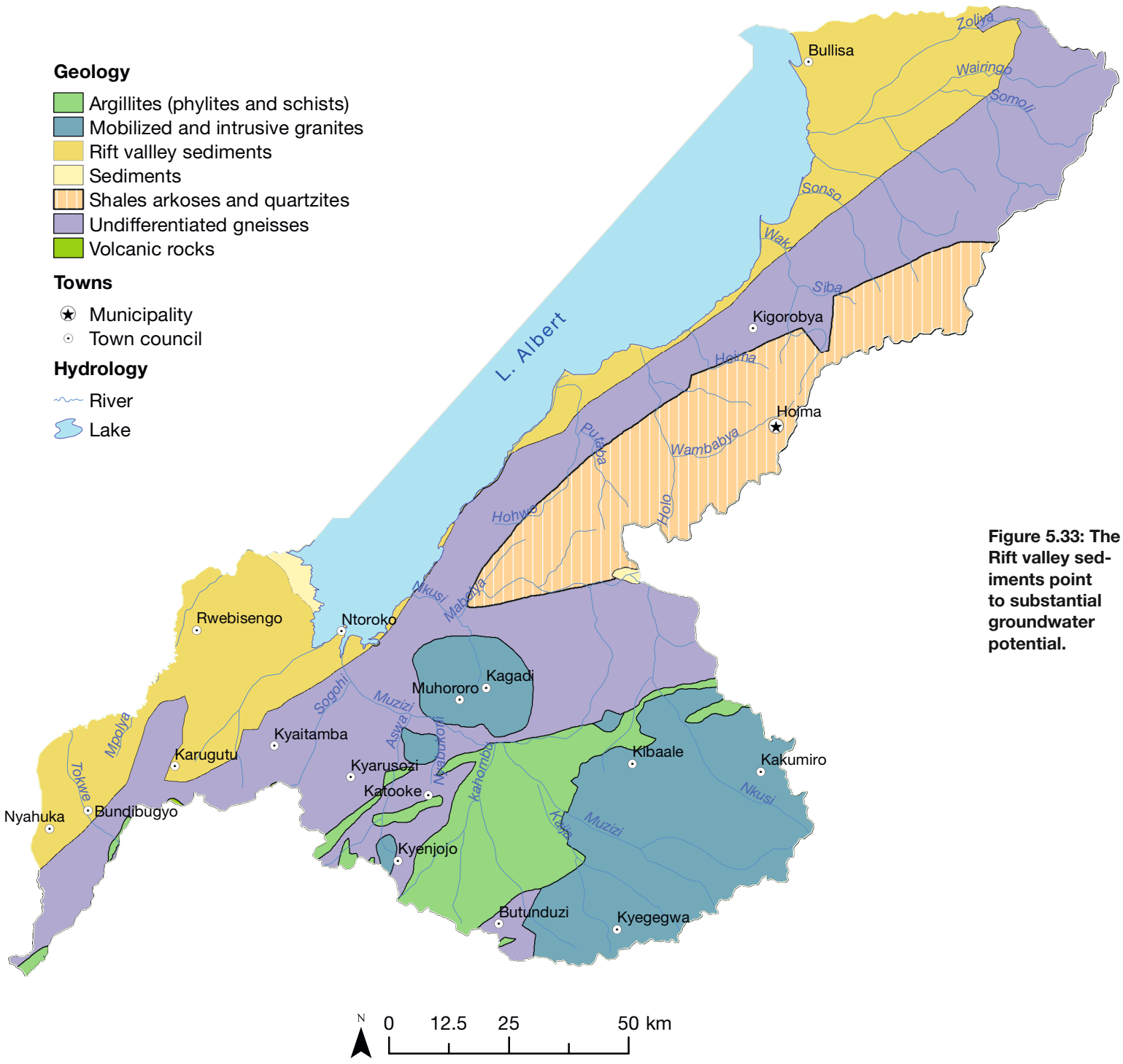


Figure 5.33: The Rift valley sediments point to substantial groundwater potential.

Figure 5.34: Hydrometric network in the Lake Albert Basin. There are several ungauged Lake Albert tributaries, while also Semliki is currently not monitored.

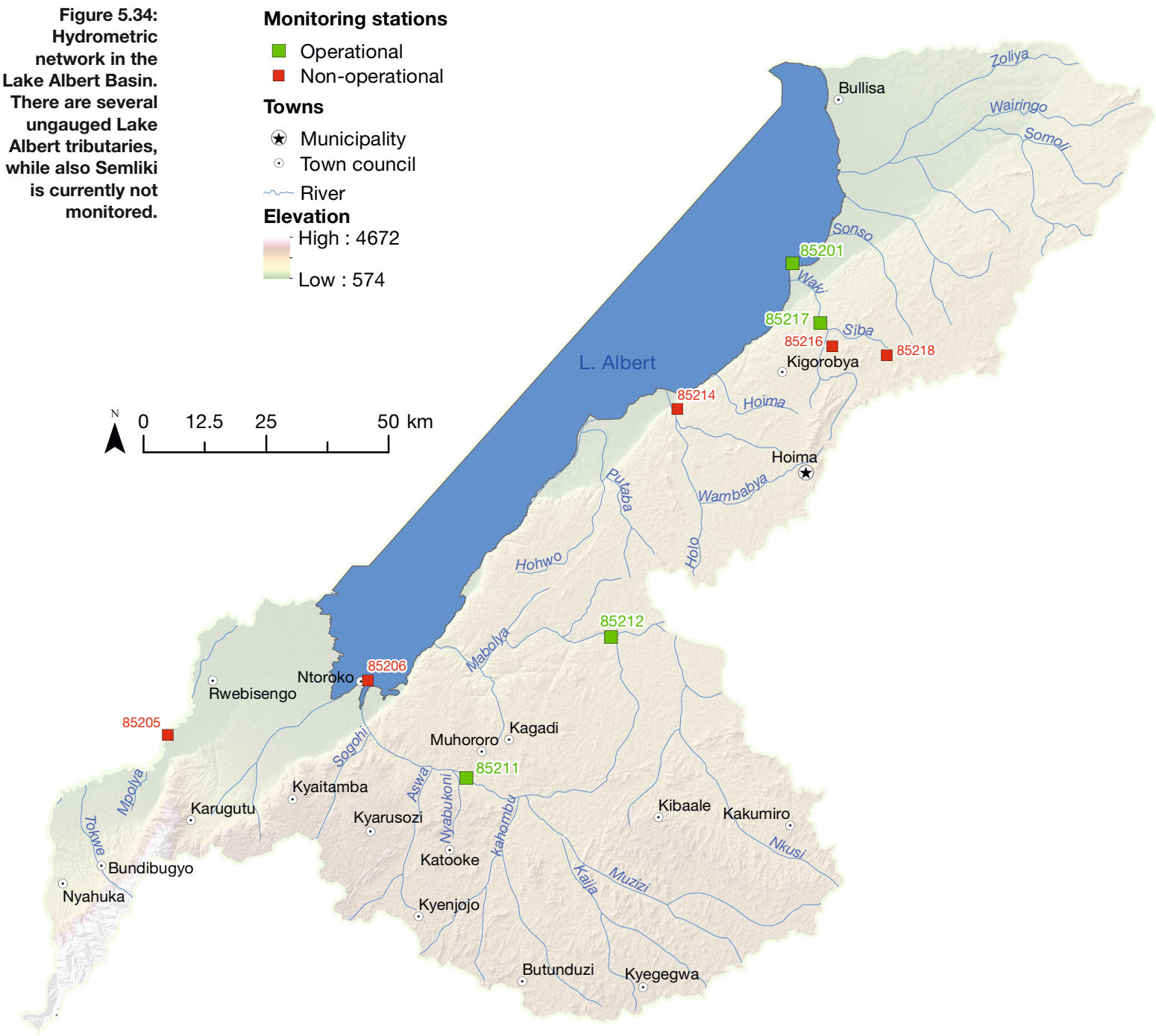


Table 5.11: Monitoring stations in the Lake Albert Basin

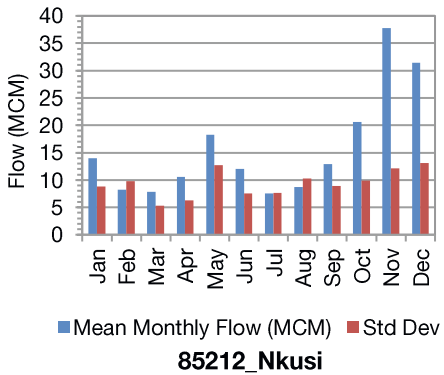
STATION	NAME
85201	L. Albert at Butiaba
85205	R. Semliki at Bweramule
85206	L. Albert at Ntoroko
85211	R. Muzizi at Kyenjojo - Hoima Road
85212	R. Nkussi at Kyenjojo - Hoima Road

STATION	NAME
85214	R. Wambabya at Buseruka
85216	R. Waki I at Siba Forest
85217	R. Waki II at Biiso - Hoima Road
85218	R. Siba at Masindi - Butiaba Road

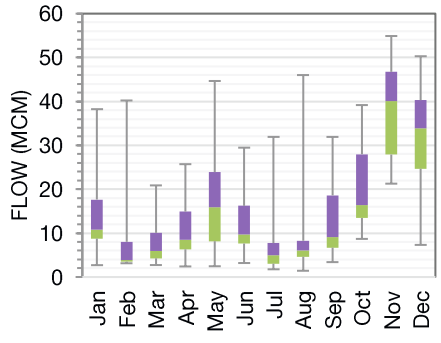
Hydrological Review

This paragraph presents the seasonal pattern, key statistics, and flow reliability of selected stations within the Lake Albert Basin.

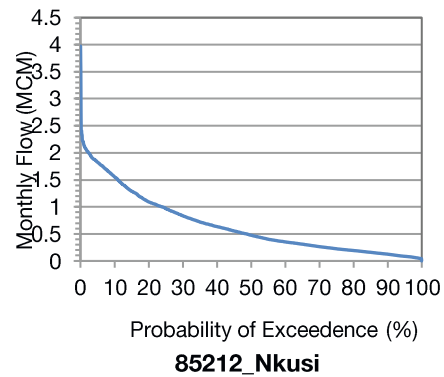
85211_Muzizi
Monthly Flow Distribution



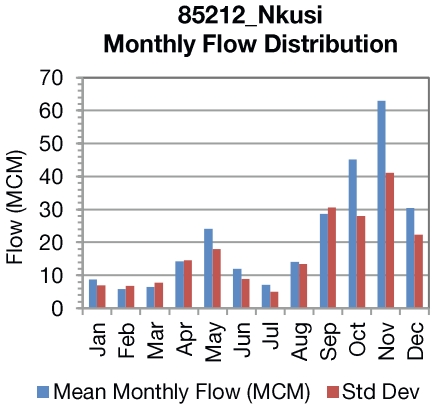
85211_Muzizi
Monthly Flow Statistics



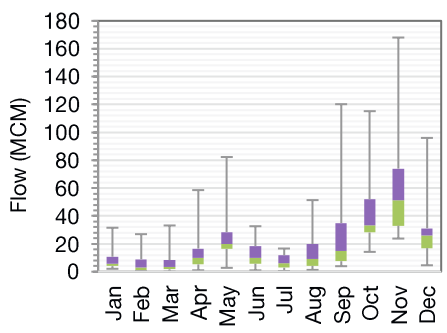
85211_Muzizi
Flow Duration Curve



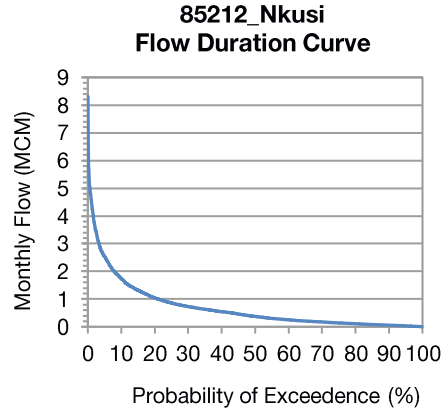
85212_Nkusi
Monthly Flow Distribution



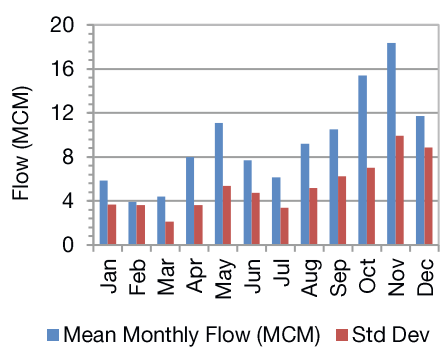
85212_Nkusi
Monthly Flow Statistics



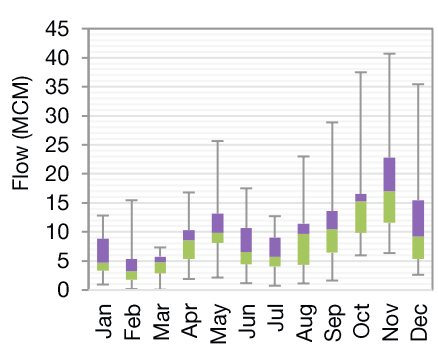
85212_Nkusi
Flow Duration Curve



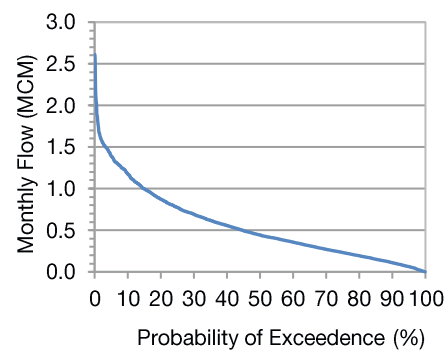
85217_Waki2
Monthly Flow Distribution



85217_Waki2
Monthly Flow Statistics

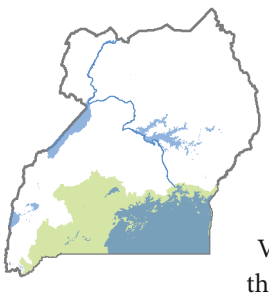


85217_Waki2
Flow Duration Curve



Lake Victoria

Surface Water



The Lake Victoria Basin in Uganda has a peculiar shape (figure 5.36). While very narrow along the northern edge of Lake Victoria, it reaches a width of more than 150 km inland on the western side. Apart from the south-western tip of the Basin, the Lake Victoria catchment in Uganda is very flat. Lake Victoria, obviously, is the dominant hydrological element. The lake is located in a depression on the equatorial plateau between the two arms of the Rift Valley. It overflows to the north into the Victoria Nile at Jinja. The principal components in the water balance of Lake Victoria are over-lake rainfall and lake evaporation. Catchment runoff represents only a minor percentage of the water balance.

Three main rivers drain the Ugandan part of the Lake Victoria Basin: Katonga, Ruizi, and Kagera. The latter, however, has more than 90% of its catchment outside Uganda.

Katonga River drains a large area in central Uganda. The Basin is very flat and covered by a dendritic pattern of extensive seasonal and permanent wetlands in broad valleys. Originally, Katonga drained towards the west. In the Tertiary Period, however, the river reversed its drainage direction because of a tectonic uplift of the western edge of the Basin. Mean annual rainfall over Katonga Basin is quite significant and measures more than 1,000 mm, but only a fraction – about 10 mm/year – reaches Lake Victoria. Most of the water evaporations in the large wetland areas and the runoff coefficient is not more than 1%.

The hydrology of Ruizi river is also affected by large wetland areas. The upper part of the river exhibits a typical mountainous pattern with narrow valleys and considerable relief, but Ruizi then flows into a wide valley with gently undulating terrain and very mild slopes. The lower catchment includes several lakes – e.g. Mburo and Nakivali – connected through extensive wetland systems. When the river finally flows into Lake Victoria, almost all runoff has disappeared. The mean annual specific runoff of Ruizi at its mouth is not more than 11 mm/year, representing a runoff coefficient of only 1%.

Kagera River drains an area of some 60,000 km^2 but only a small portion of the catchment is in Uganda. The river has a high baseflow component. It is noted that Kagera provides the largest component of tributary inflow to Lake Victoria, most of which originates in Burundi, Rwanda, and Tanzania.

Figures 5.37, 5.38, and 5.39 present soils, land-cover, and geology of the Lake Victoria catchment respectively.

Hydrological Monitoring

Figure 5.40 presents the hydrometric network in the Lake Victoria Basin. A total of 8 stations were operational in the 1978-2014 period. The hydrology of the basin is highly complex due to the large wetland areas that interact with river flows. Additional monitoring is required to better understand the hydrological processes in the Lake Victoria basin.

Kagera shows a very regular flow pattern, which is due to its large size and the large wetlands areas in the Kagera catchments that have attenuated the peak flows. Ruizi – which also drains a large catchment area – is more variable. The flow pattern reflects the area's bi-modal rainfall regime. Ruizi is a perennial river with a useful baseflow component and zero-flow events have not been recorded. Nevertheless, the standard deviation of the monthly flow values is high, pointing towards a quick response to a rain event and variable flood flows.

Table 5.12: Current and projected water use in the Lake Victoria Basin

Water Demand [mcm]	2012	2030 (projected)
Urban Domestic	58.6	136.2
Rural Domestic	14.8	77.4
Industrial	28.9	28.9
Livestock	42.3	42.3
Irrigation	10.9	232.0
Total	155.5	516.8
IRWR	1,680	1,680
Exploitation Index (%)	9.3	30.7

National Water Resources Assessment 2012

Groundwater Regime

Virtually the whole Basin is made up of Precambrian metamorphic formations, apart from some discontinuous deposits, predominantly beach sands and gravels, with finer silts and clays along the western border of Lake Victoria. Aq-

Figure 5.35: River Ruizi in the Lake Victoria Basin

uifers in these metamorphic formations are found in fractures, and to a lesser extent in the overburden. Groundwater overall drains to Lake Victoria, from groundwater levels of 1,800 m amsl in the north-western corner of the WMZ to 1,200 m amsl close to Lake Victoria.

Groundwater recharge is overall low, generally below 75 mm per year, with the exception of the districts directly north of Lake Victoria, where recharge is in the category 225-250 mm.

The groundwater availability is overall poor, especially the central north-south belt from Gomba District, via Ssembabule, Lyantonde, and Kiruhura Districts.

The Basin has a challenge with groundwater quality, notably because of total iron that is often above maximum allowable levels (2 mg/l), but also sulphate levels are in placesabove guideline value (250 mg/l) or even maximum allowable values of 500 mg/l.

Water Balances and Trends

Table 5.12 shows that water use increases substantially in the period 2012-2030, and that the projected utilization rate in 2030 is significant and warrants some caution. The following remarks are made:

1. The utilization rate does not consider the External Renewable Water Resources; in the specific case of the Lake Victoria Basin, the ERWR – which include the Nile flows – are considerable and exceed the IRWR by a factor 10 or more;
2. Domestic water supply for large urban areas – including Kampala, Jinja, and Entebbe – is likely sourced from Lake Victoria rather than from local rivers or groundwater; hence the actual water utilization rate in 2030 is probably lower than the figure presented in table 5.12;
3. Although the anticipated utilization rate in 2030 is quite high, there is still sufficient water to satisfy the Basin's water demand; large scale competition over water resources is not anticipated in the Lake Victoria Basin, although local shortages may be experienced.

Figure 5.36: The Lake Victoria catchments are characterized by flat-topped hills with gently sloping sides; the catchment is generally flat, except for the south-western tip.

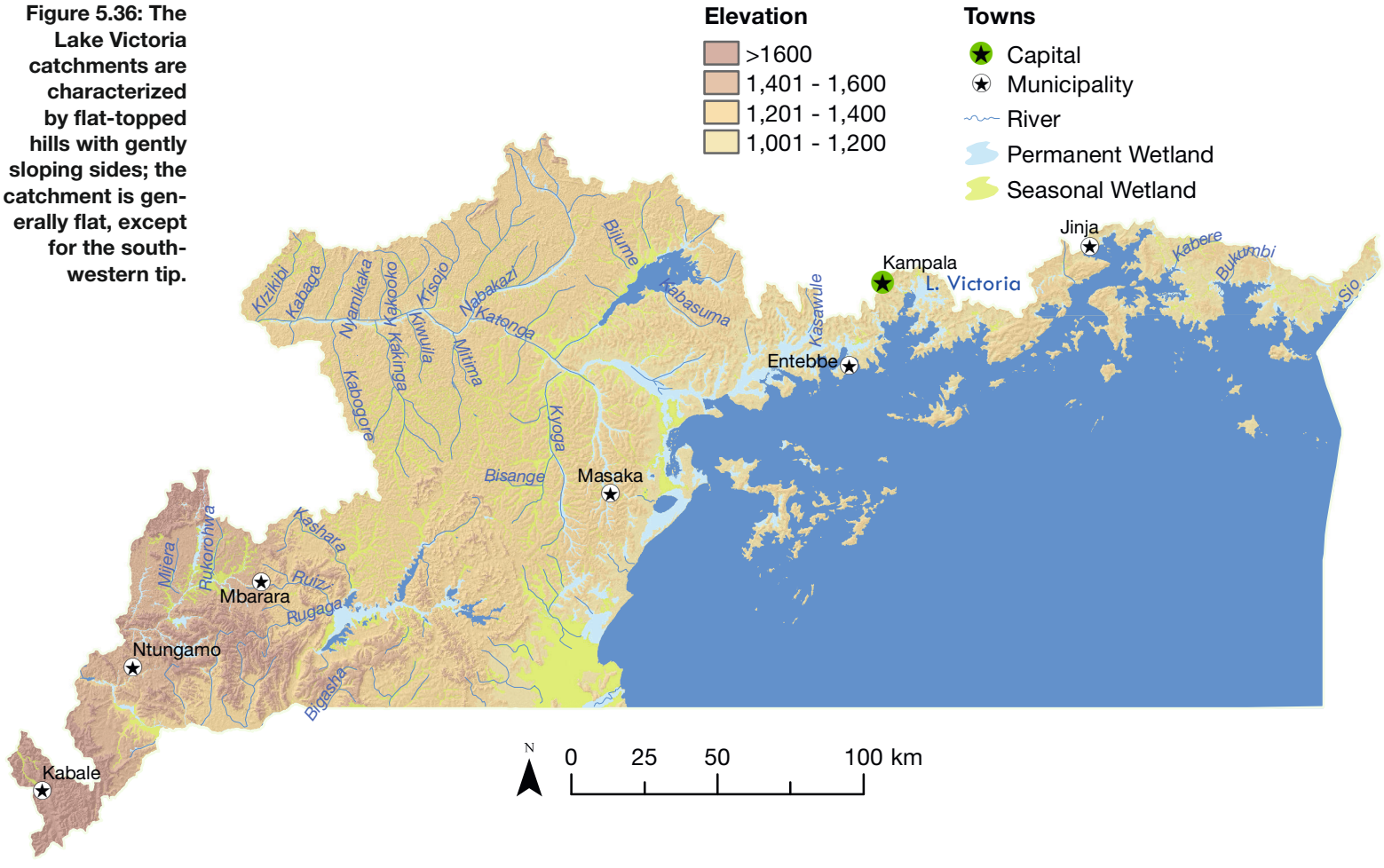
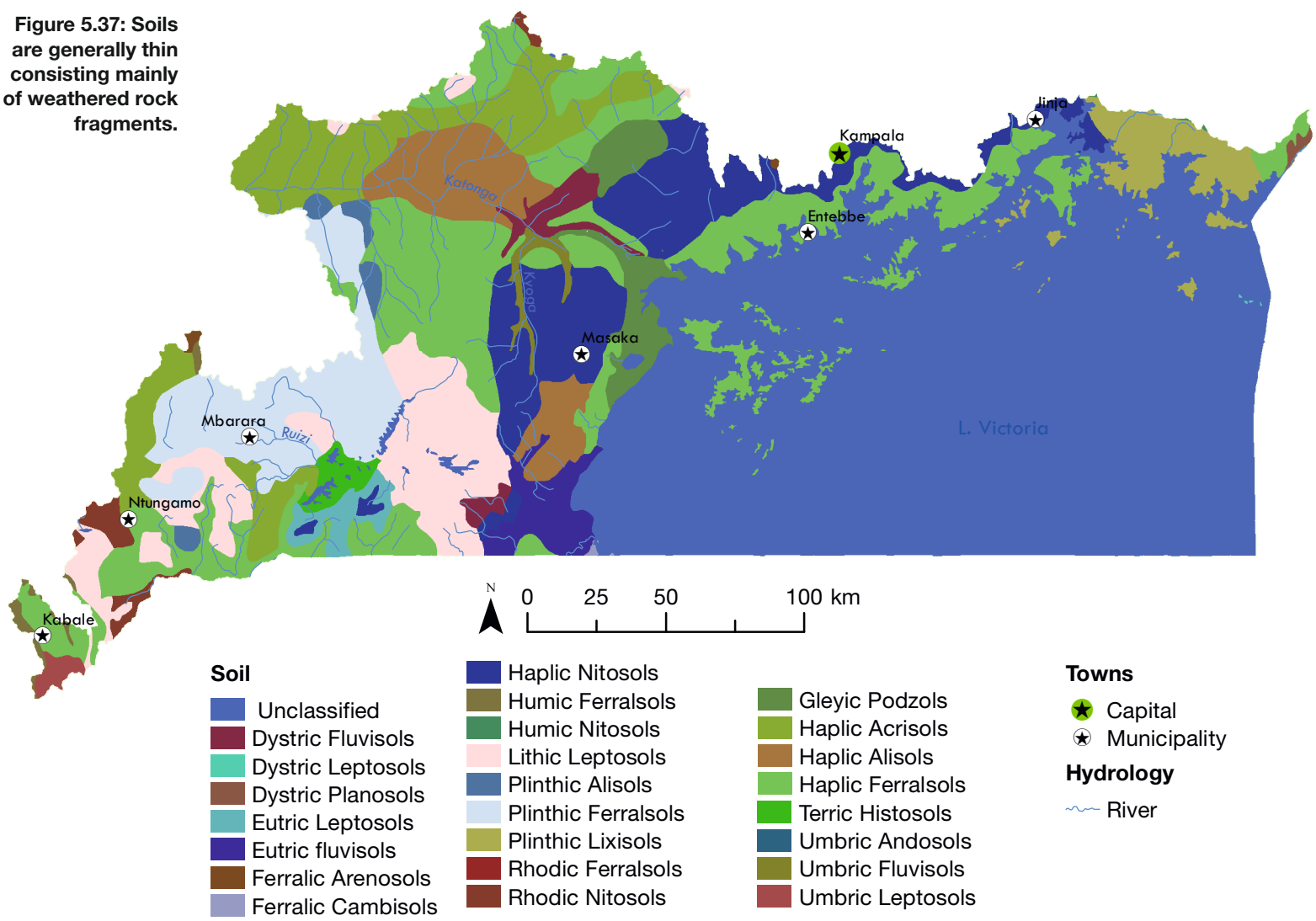


Figure 5.37: Soils are generally thin consisting mainly of weathered rock fragments.



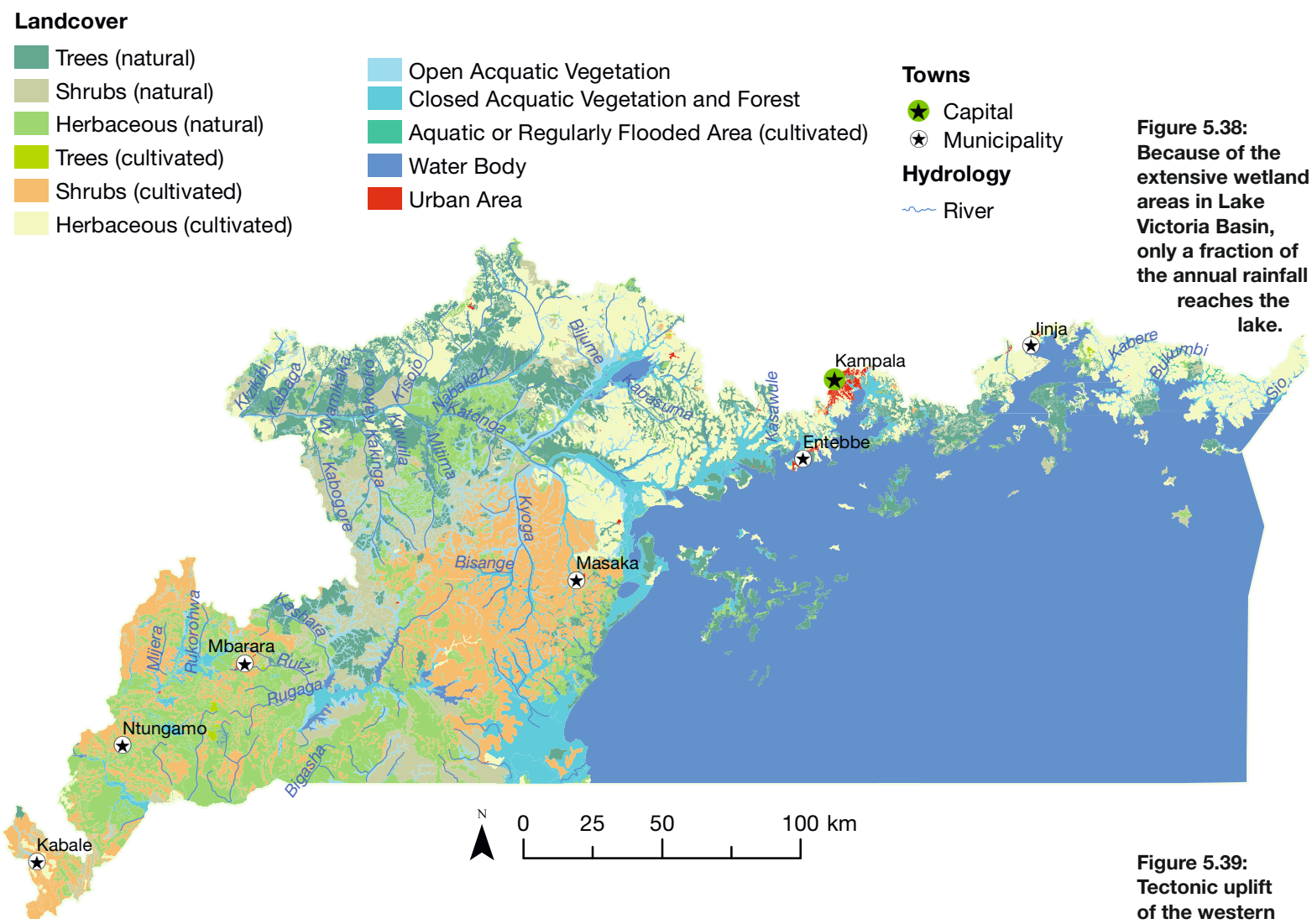


Figure 5.38: Because of the extensive wetland areas in Lake Victoria Basin, only a fraction of the annual rainfall reaches the lake.

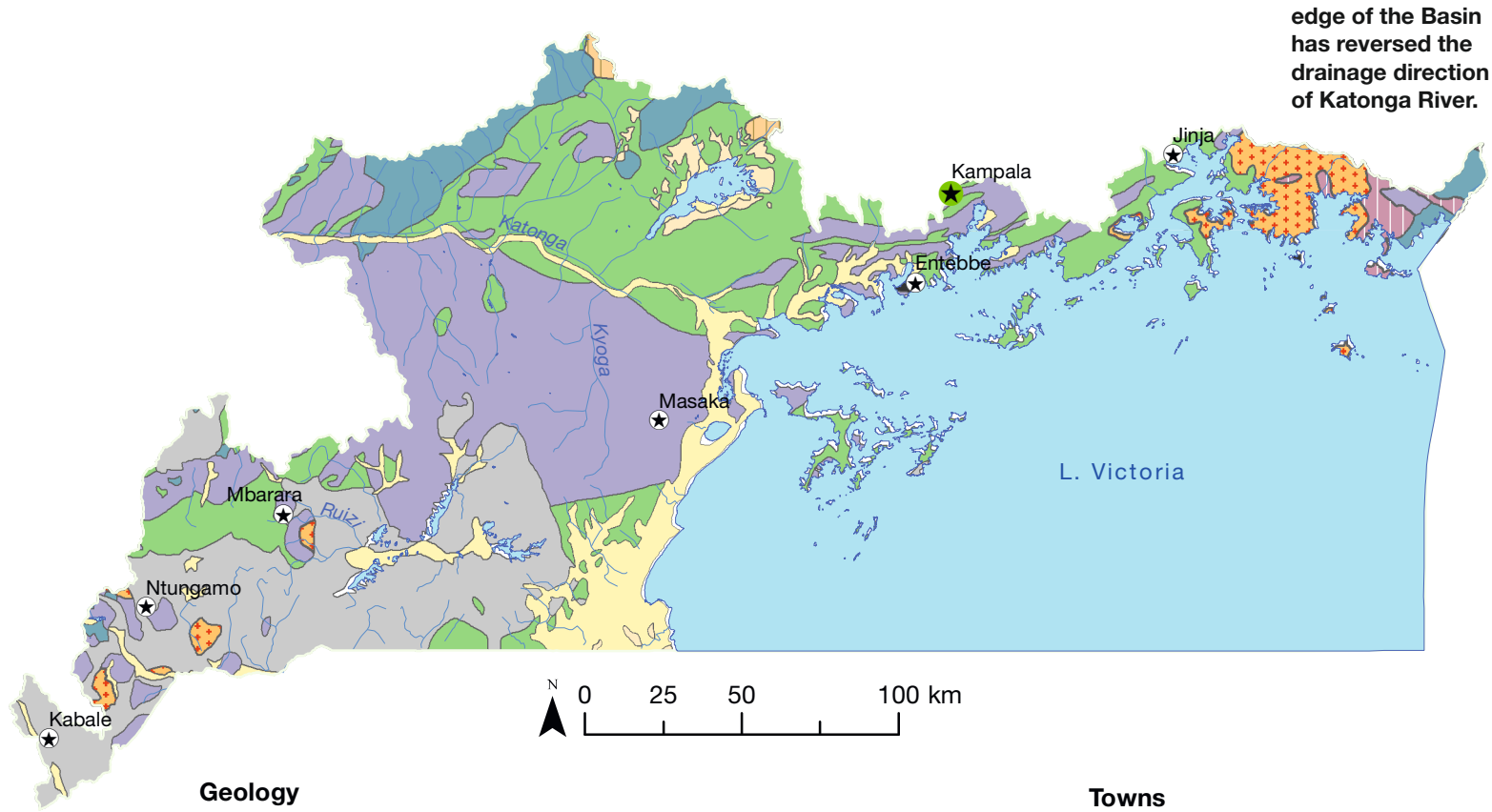


Figure 5.39: Tectonic uplift of the western edge of the Basin has reversed the drainage direction of Katonga River.

Figure 5.40: Hydrometric network in the Lake Victoria Basin. Because of large wetland areas and generally low flow velocities, discharge measurement has proven difficult.

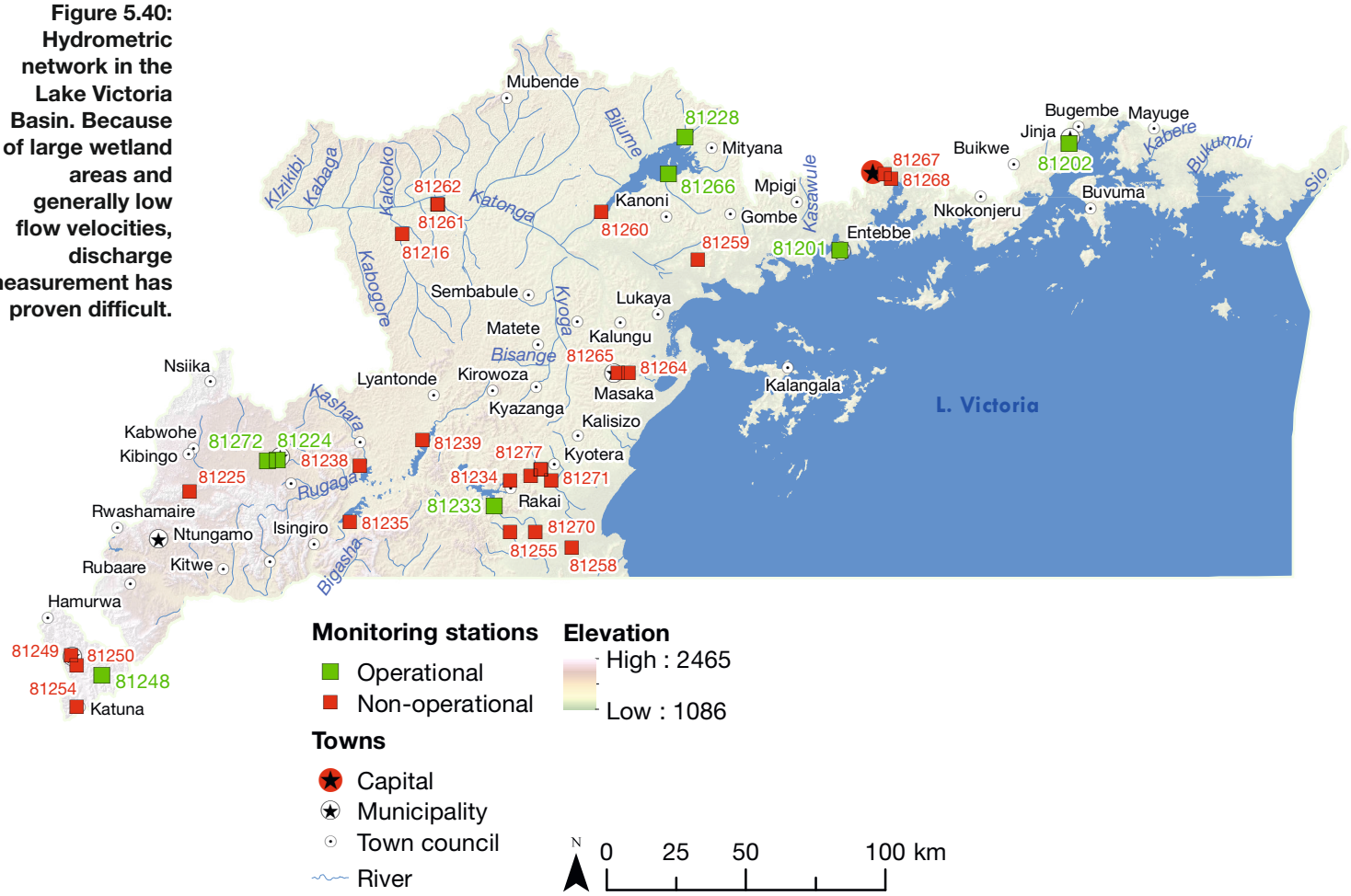


Table 5.13: Monitoring stations in the Lake Victoria Basin

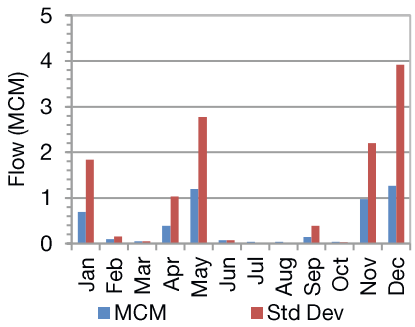
STATION	NAME
81201	L. Victoria at Entebbe Pier
81202	L. Victoria at Jinja Pier (81202)
81216	R. Kakinga Index Catchment
81224	R. Ruizi at Mbarara Water Works (Old)
81225	R. Ruizi Ndeiza at Mbarara - Kaba
81228	R. Mpumujugu at Railway Bridge
81233	R. Kibale at Kalungi (Lower Site)
81234	L. Kijanebalola at Kyetaka
81235	L. Nakivale at Kahirimbi
81238	L. Mburo at Rupoporo
81239	L. Kachera at Rukukuru
81248	R. Nyakizumba at Maziba
81249	R. Kiruruma North at Kabale - Kis
81250	R. Kiruruma South at Kitumba (81250)
81254	R. Kiruruma South at Katuna (81254)
81255	L. Nakivale at Kasojo

STATION	NAME
81258	R. Bukora at Katera
81259	R. Katonga at Kampala - Masaka Road
81260	R. Kibimba at Kinoni - Mubende Road
81261	R. Katonga at Nkonge Railway Brid
81262	R. Katonga at Nkonge Road Bridge
81264	R. Musansala at Katoogo
81265	R. Nabajuzi at Masaka - Bukoba Road
81266	L. Wamala at Lubajja
81267	Nakivubo Channel - 5th Street
81268	Nakivubo Channel - Railway Bridge
81270	R. Bukora at Mutukula - Kyotera Road
81271	R. Kisoma at Mutukula - Kyotera Road
81272	R. Ruizi at New Waterworks
81273	R. Lwanda at Kyotera - Rakai Road
81274	R. Kisoma Upper Stream at Kyotera
81277	R. Kisoma Upper at Kyotera - Rakai

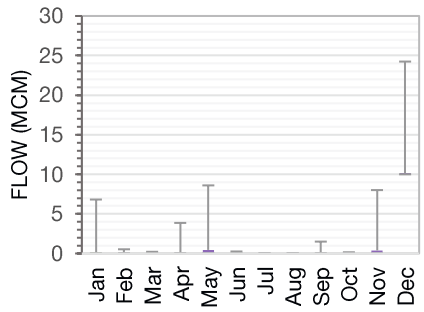
Hydrological Review

This paragraph presents the seasonal pattern, key statistics, and flow reliability of selected stations within the Lake Victoria Basin.

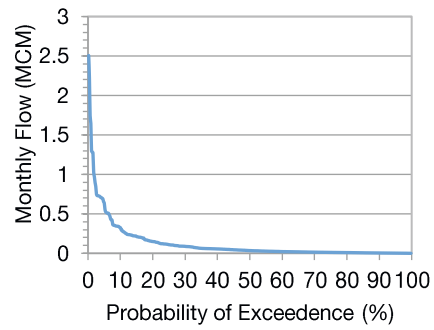
81216_Kakinga
Monthly Flow Distribution



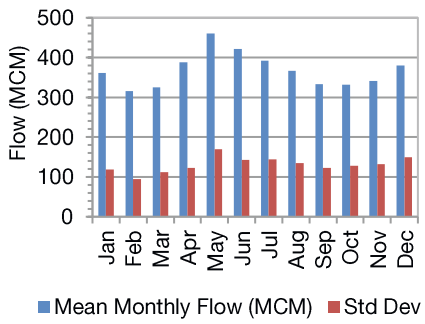
81216_Kakinga
Monthly Flow Statistics



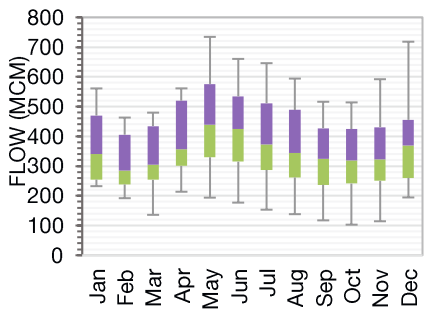
81216_Kakinga
Flow Duration Curve



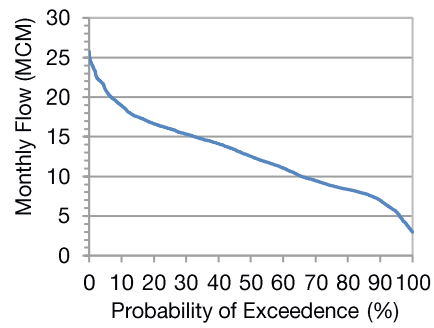
81223_Kagera
Monthly Flow Distribution



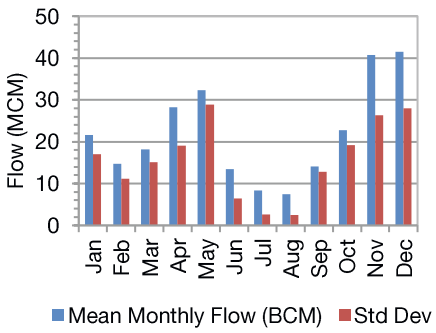
81223_Kagera
Monthly Flow Statistics



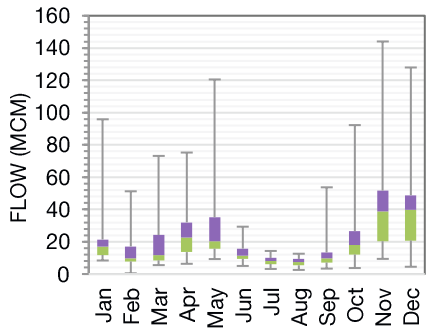
81223_Kagera
Flow Duration Curve



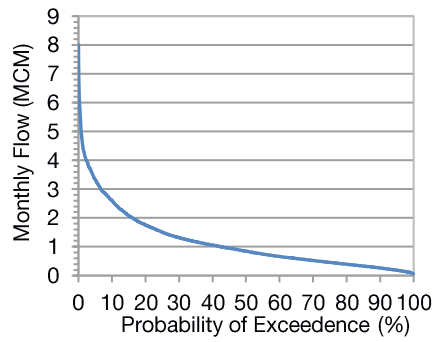
81224_RuiziCurrent
Monthly Flow Distribution



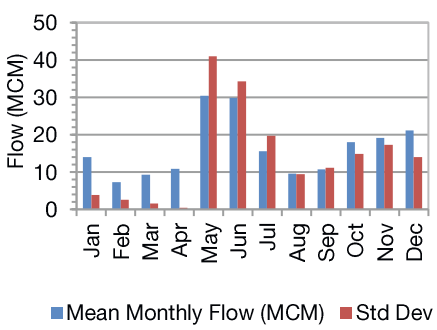
81224_RuiziCurrent
Monthly Flow Statistics



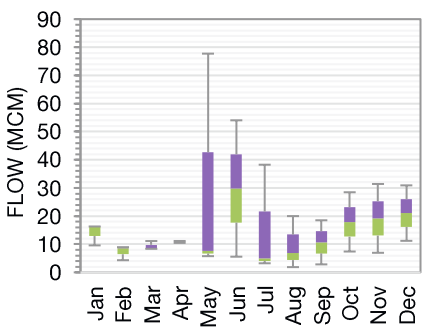
81224_RuiziCurrent
Flow Duration Curve



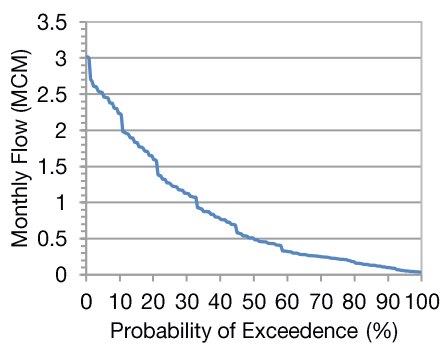
81228_Mpumujugu
Monthly Flow Distribution



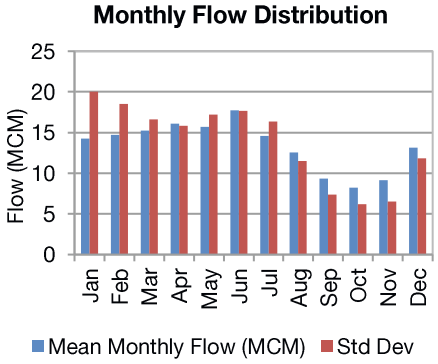
81228_Mpumujugu
Monthly Flow Statistics



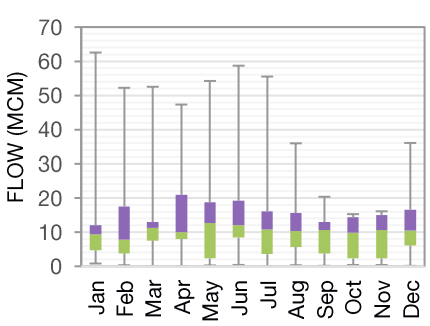
81228_Mpumujugu
Flow Duration Curve



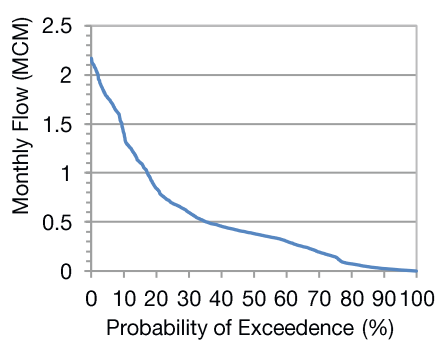
81233_Kibale
Monthly Flow Distribution

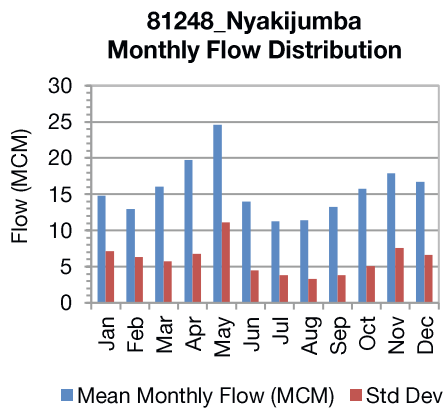


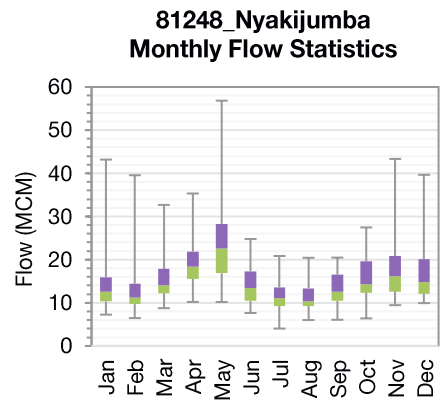
81233_Kibale
Monthly Flow Statistics

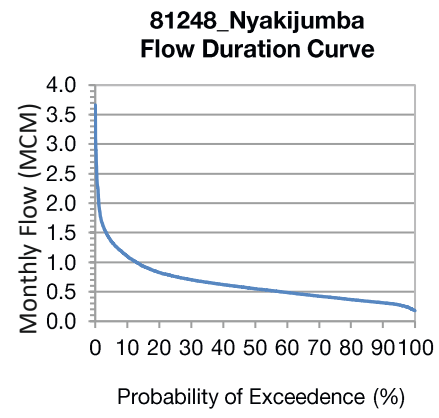


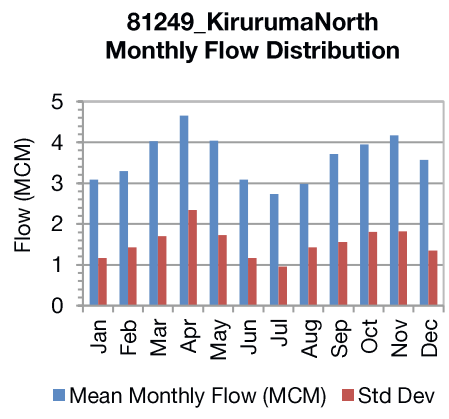
81233_Kibale
Flow Duration Curve

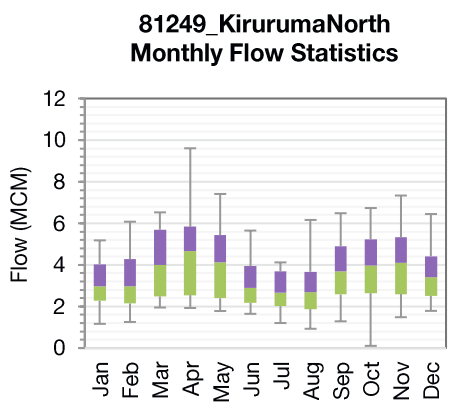


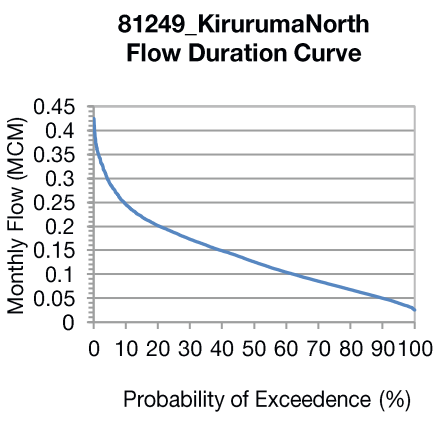

81248_Nyakijumba
Monthly Flow Distribution
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Mean Monthly Flow (MCM)
Std Dev

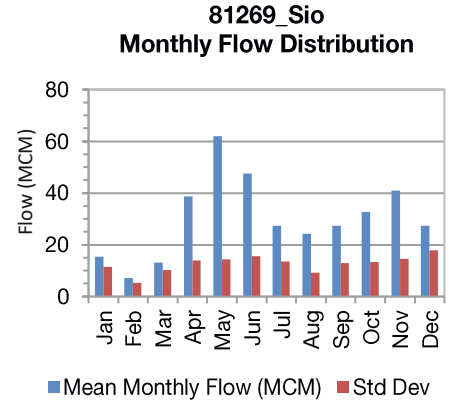

81248_Nyakijumba
Monthly Flow Statistics
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

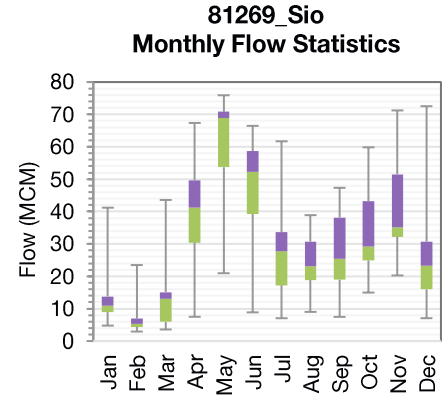

81248_Nyakijumba
Flow Duration Curve
Monthly Flow (MCM)
Probability of Exceedence (%)

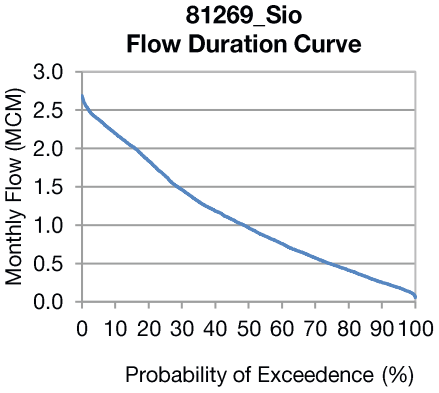

81249_KirurumaNorth
Monthly Flow Distribution
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Mean Monthly Flow (MCM)
Std Dev


81249_KirurumaNorth
Monthly Flow Statistics
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


81249_KirurumaNorth
Flow Duration Curve
Monthly Flow (MCM)
Probability of Exceedence (%)

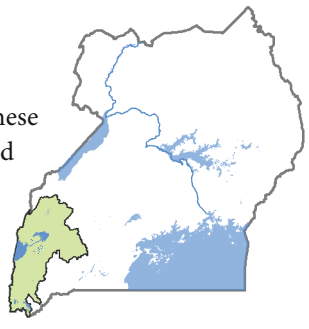

81269_Sio
Monthly Flow Distribution
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Mean Monthly Flow (MCM)
Std Dev


81269_Sio
Monthly Flow Statistics
Flow (MCM)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


81269_Sio
Flow Duration Curve
Monthly Flow (MCM)
Probability of Exceedence (%)

Lake Edward

Surface Water



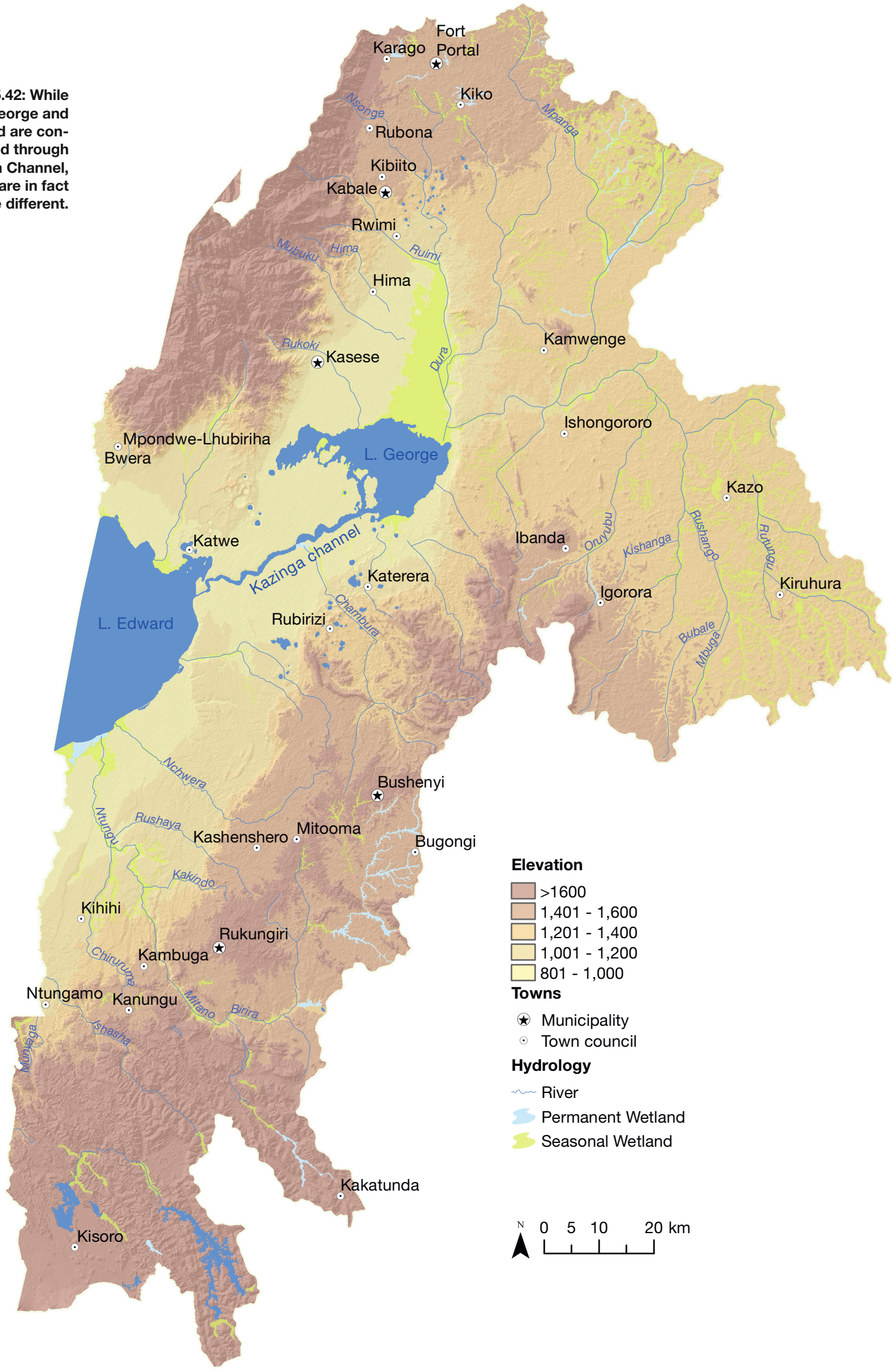
Lakes George and Edward are the two most conspicuous hydrologic elements of the Lake Edward Basin (figure 5.42). The lakes are connected through the Kazinga Channel, but are in fact quite different. The surface area of Lake Edward measures some 2,200 km^2, while the lake is over 100 m deep in parts. Lake Edward is considered the smallest of the African Great Lakes. By contrast, Lake George – with a surface area of about 300 km^2 – is shallow with an average depth of 3 m. Lake George drains a large part of the eastern Rwenzori Mountains and serves effectively as a 'sediment trap' for the sediment generated on the steep mountain slopes, because of the sudden change in gradient when the mountain streams reach the flat plains. For instance, an extensive wetland system has formed at the northern tip of the lake, where river Mubuku drains into Lake George and deposits its sediment.

Several rivers drain into Lake Edward, including Nyamugasani, Ishasha, Rutshuru, Ntungwe, and Rwindi. Because of the gradual uplift of the area due to tectonic movements, these rivers typically have an incised and narrow drainage channel with considerable longitudinal gradient. Mean annual specific runoff of these catchments in high and exceeds 200 mm/year. Runoff coefficients generally exceed 15% and reach more than 30% for smaller catchments draining directly into the lake.

Figures 5.43, 5.44, and 5.45 present soils, land-cover, and geology of the Lake Edward catchment respectively.

Figure 5.41: River Mpanga in the Lake Edward Basin

Figure 5.42: While Lakes George and Edward are connected through Kazinga Channel, they are in fact quite different.



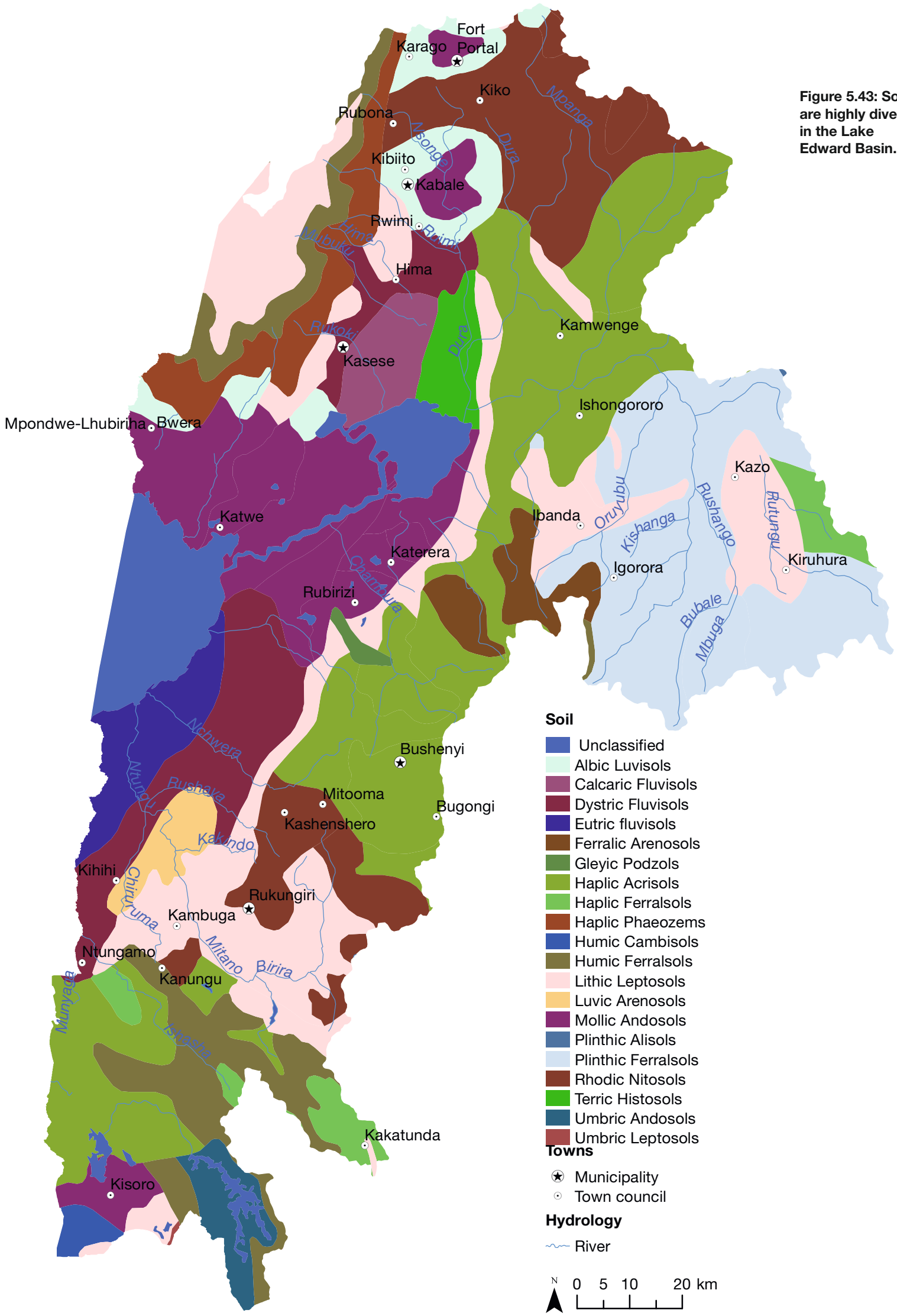
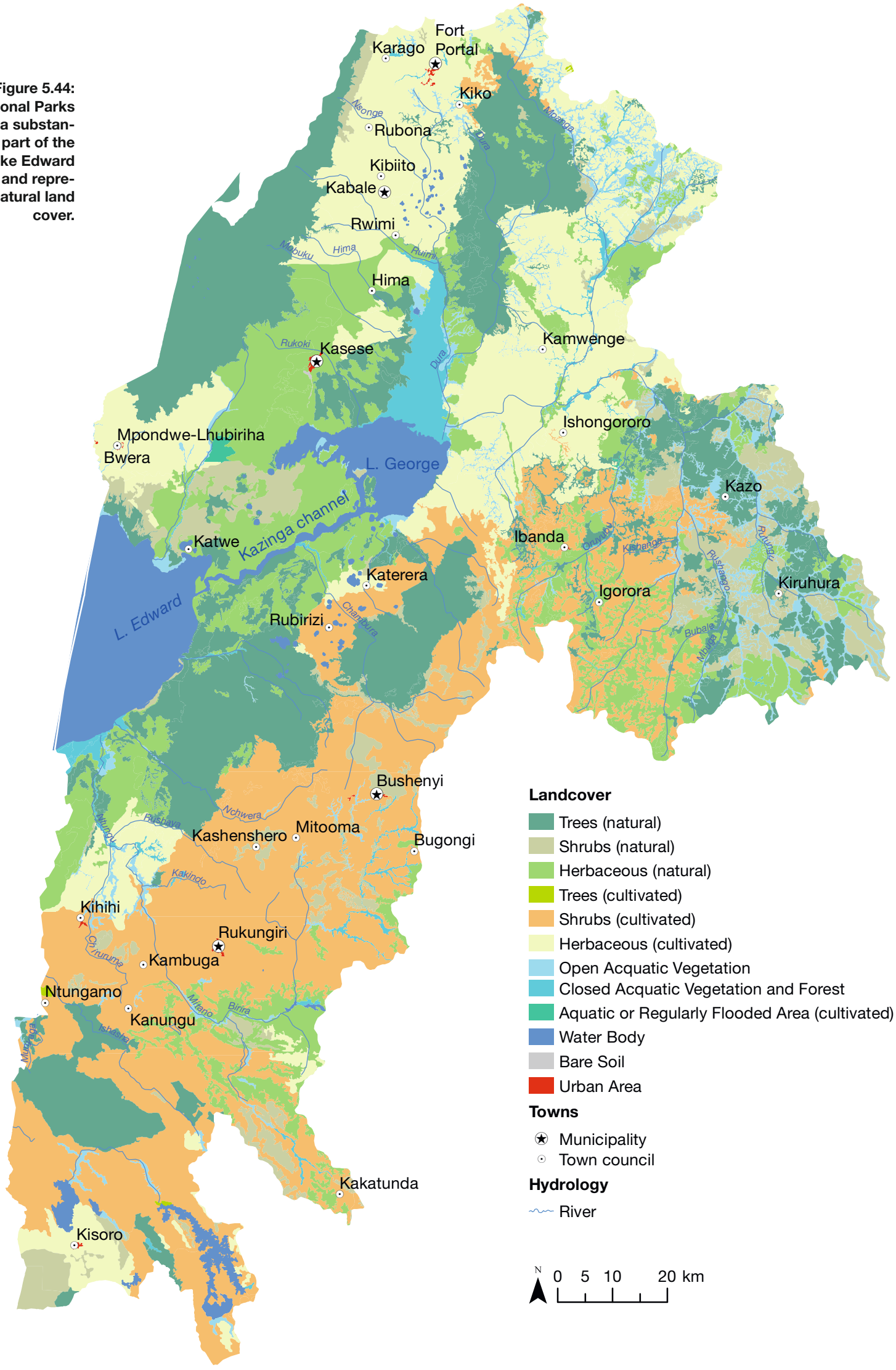


Figure 5.43: Soils are highly diverse in the Lake Edward Basin.

Figure 5.44: National Parks cover a substantial part of the Lake Edward Basin and represent natural land cover.



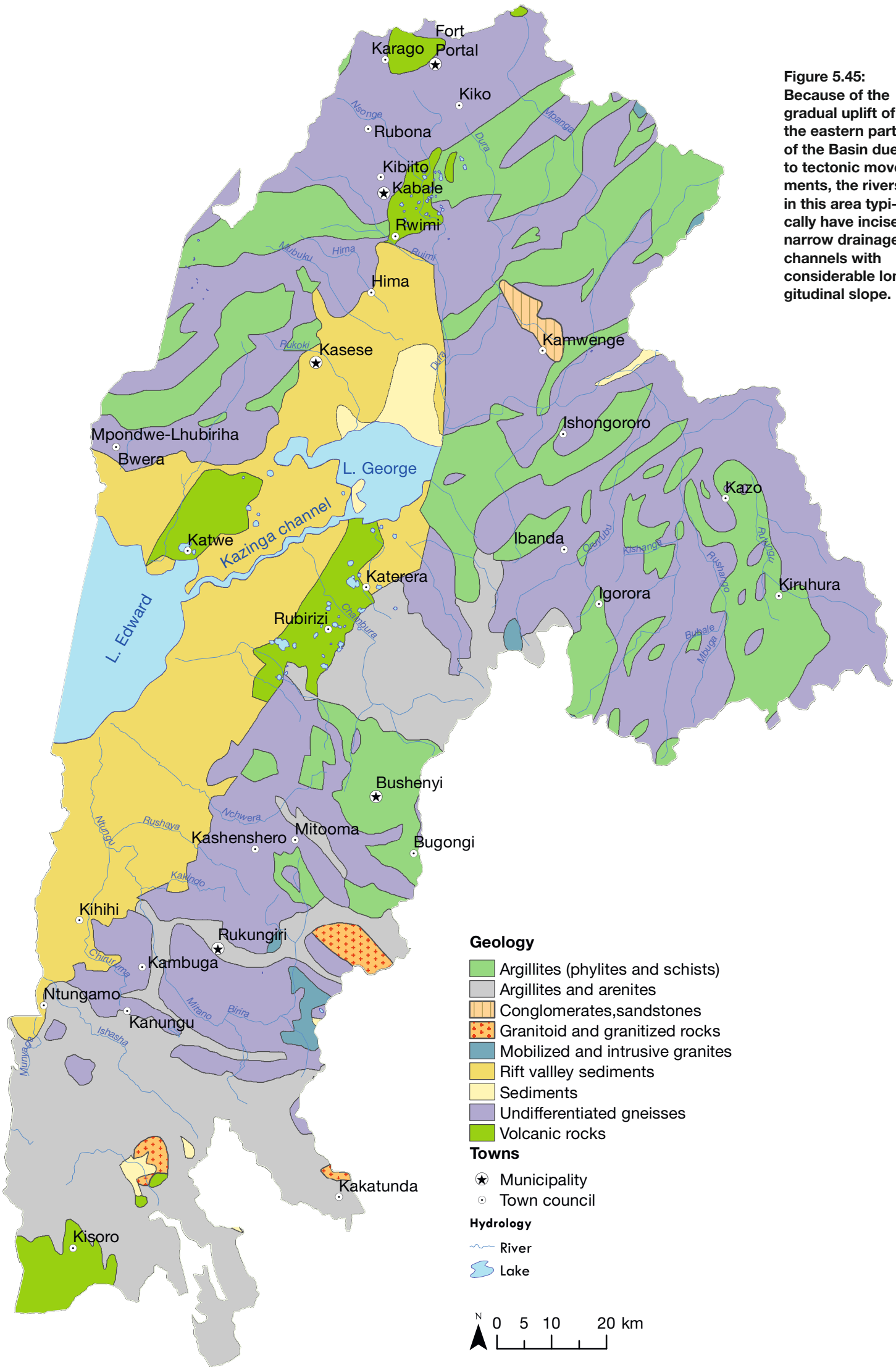
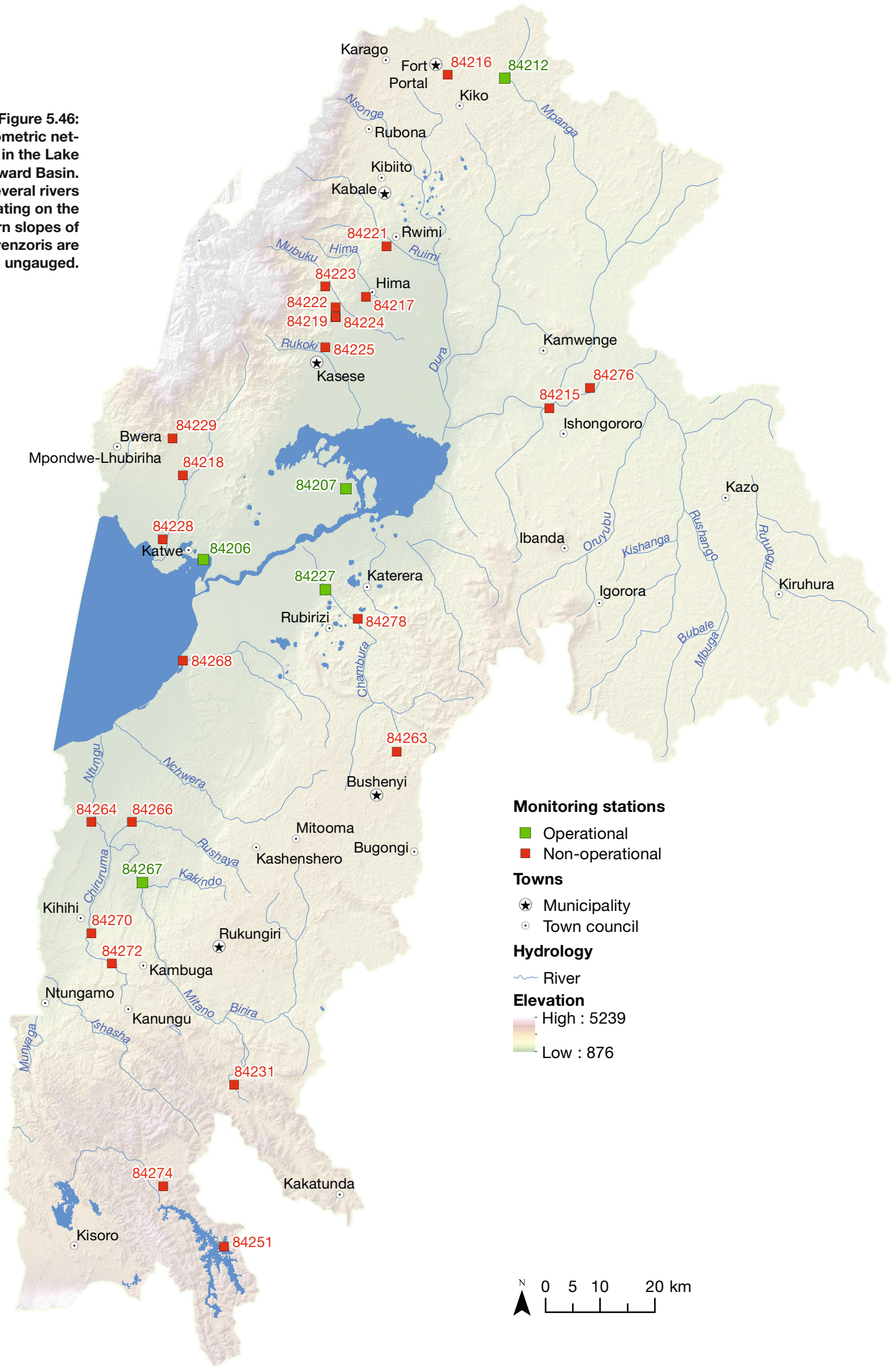


Figure 5.45: Because of the gradual uplift of the eastern part of the Basin due to tectonic movements, the rivers in this area typically have incised narrow drainage channels with considerable longitudinal slope.

Figure 5.46: Hydrometric network in the Lake Edward Basin. Several rivers originating on the eastern slopes of the Rwenzoris are ungauged.



Hydrological Monitoring

Figure 5.46 presents the hydrometric network in the Lake Edward Basin. A total of 5 flow measurement stations were operational in the 1978-2014 period. It is evident that this is not sufficient to understand the hydrological processes in this basin. It is noted that several large tributaries are not monitored right now.

River Mpanga is a highly variable river in which the standard deviation almost equals the mean values. The flashy regime is reflected in the steep curve of the Flow Duration Curve.

By contrast, Chambura is a more stable river that is less affected by extreme events, as reflected by the flatter Flow Duration Curve and the more squeezed box plot.

Water Demand [mcm]	2012	2030 (projected)
Urban Domestic	1.8	17.7
Rural Domestic	12.5	46.6
Industrial	0.9	0.9
Livestock	18.1	18.1
Irrigation	2.2	68.0
Total	35.5	151.3
IRWR	4,470	4,470
Exploitation Index (%)	0.8	3.4

National Water Resources Assessment 2012

Table 5.14: Current and projected water use in the Lake Edward Basin

Groundwater Regime

The groundwater in the Basin flows towards Lake George and Lake Edward, which form the regional drainage base. It is also expected that groundwater flows towards the regional rivers like the Mubuku and Nyamugasani Rivers. Groundwater levels are between 1,600 m amsl in the south to approximately 900 m amsl near Lake Edward.

The Basin is underlain by the recent sediments of the Albert Rift and also by volcanic rocks (lapilli tuffs and alkaline lavas), gneisses and schists, phyllites and sandstones, quartzites and conglomerates.

The recharge is highly variable but generally low with highest values of around 150 mm between Lake George and Lake Edward, and the lowest values of less than 25 mm south of Lake Edward.

The water quality in the western part of the Basin is usually good but groundwater in the eastern part of the Basin often has high iron concentrations.

Water Balances and Trends

Table 5.14 shows that water shortages are not anticipated in the Lake Edward Basin. A large part of the Basin is covered by national parks where land and water use practices are focused on conservation rather than development. Potential irrigation development – inevitably the largest water consumer – is small.

STATION	NAME
84206	L. Edward at Katwe
84207	L. George at Kasenyi
84212	R. Mpanga at Kampala - Fort Portal Road
84215	R. Mpanga at Fort Portal - Ibanda
84216	R. Mpanga at Highway Bridge
84217	R. Hima at Kasese - Fort Portal Road
84218	R. Kanyampara at Equator Road
84219	R. Sebwe at Kasese - Fort Portal
84221	R. Rwimi at Fort Portal - Kasese
84222	R. Mubuku at Fort Portal - Kasese
84223	R. Sebwe at Bugoye
84224	R. Rukoki at Fort Portal - Kasese
84225	R. Kamulikwenzi at Fort Portal -
84227	R. Chambura at Kichwamba

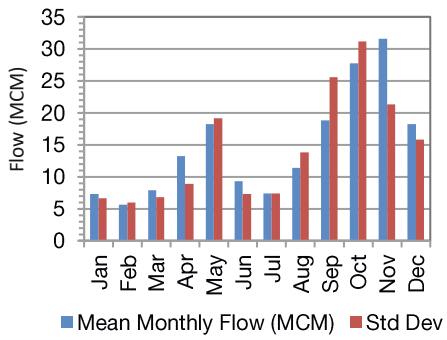
STATION	NAME
84228	R. Nyamugasani at Katwe - Zaire Road
84229	R. Kanyampara at Omukunya
84231	R. Rushoma at Kisizi
84251	L. Bunyonyi at Bwama Island
84263	R. Tenga at 5M Fish Farm Road
84264	R. Ntungwe at Katunguru - Zaire Road
84266	R. Rushaya at Kabale - Rwensama Road
84267	R. Mitano at Kanungu - Rwensama Road
84268	R. Nyamweru at Katunguru - Zaire
84270	R. Chiruruma at Katete - Kihihi Road
84272	R. Ibalya at Kanungu - Katete Road
84274	R. Eisesero at Lake Bunyonyi Outlet
84276	R. Rushangwe at Buteraniro
84278	R. Chambura at Nyakasharu - Kater

Table 5.15: Monitoring stations in the Lake Edward Basin

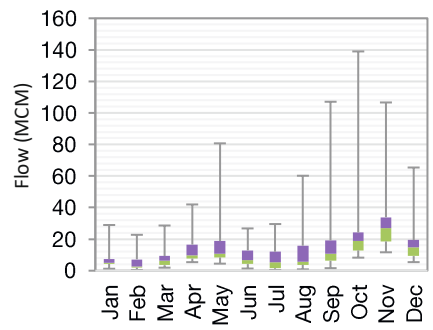
Hydrological Review

This paragraph presents the seasonal pattern, key statistics, and flow reliability of selected stations within the Lake Edward Basin.

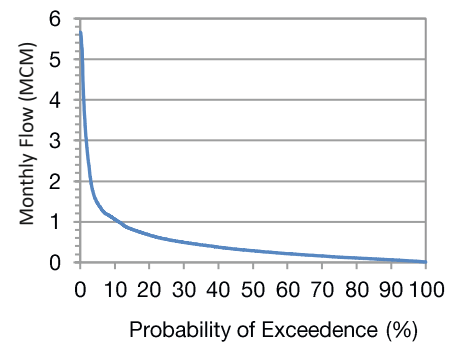
84212_Mpanga
Monthly Flow Distribution



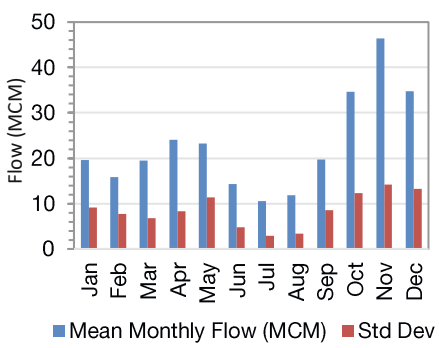
84212_Mpanga
Monthly Flow Statistics



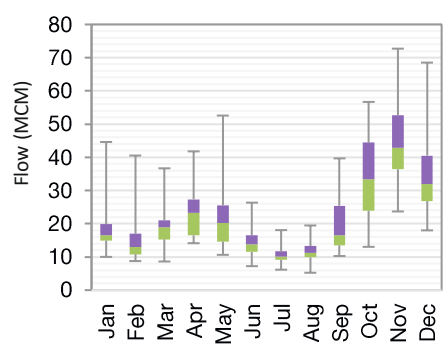
84212_Mpanga
Flow Duration Curve



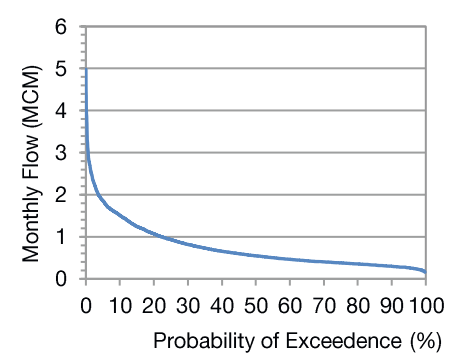
84227_Chambura
Monthly Flow Distribution



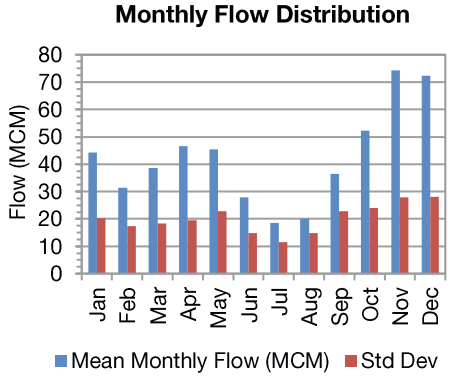
84227_Chambura
Monthly Flow Statistics



84227_Chambura
Flow Duration Curve



84267_Mitano
Monthly Flow Distribution



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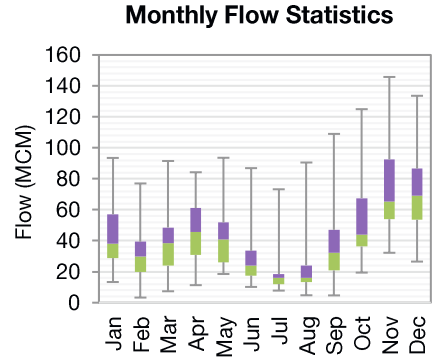
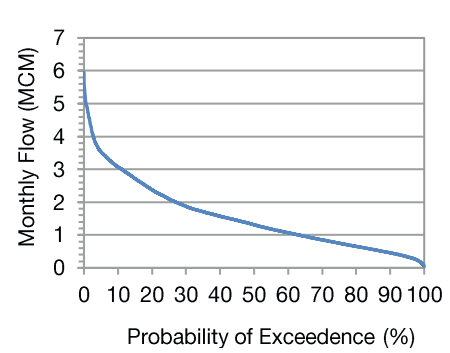
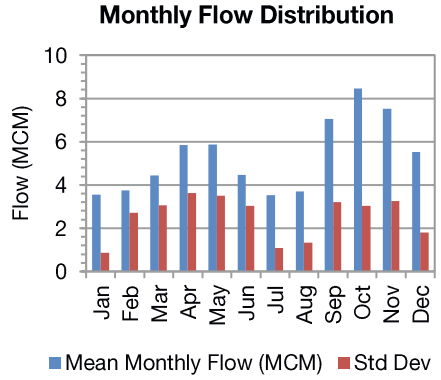
Monthly Flow Statistics



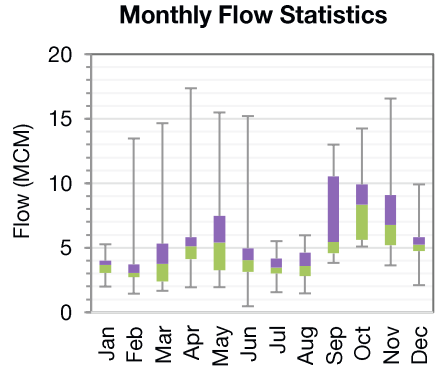
84267_Mitano
Flow Duration Curve



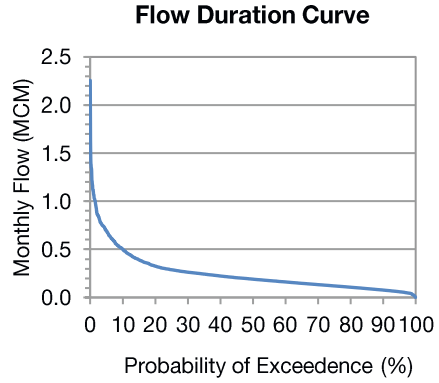
84270_Kiruruma
Monthly Flow Distribution



84270_Kiruruma
Monthly Flow Statistics



84270_Kiruruma
Flow Duration Curve



6 - Conclusion

The performance of key economic sectors in Uganda depends on timely access to adequate quantities of water of suitable quality. It is evident that pressure on finite water resources is increasing because of socio-economic development and population growth, while the impact of climate change is making the availability of water resources more unpredictable. Climate change could also lead to more and longer drought spells, thus further increasing demand for precious water resources. Water managers are tasked to ensure that the productive sectors are supplied with adequate quantities of water while preventing water shortages and conflicting water use at local, regional, and even international level. At the same time, they need to minimize adverse impacts of water resources on the livelihood and security of Uganda's people – such as floods and water-borne diseases. Other tasks are related to maintaining sufficient flows to preserve the environment.

To perform their duties, water managers need to know where Uganda's water resources are – in what volume and quality. They need this information for the present situation, but also for the short and mid-term future. It requires a diverse set of hydrological tools that are based on accurate and timely data about all components of the hydrological cycle.

DWRD has been collecting water data for over a century now. It has resulted in a large database that has proved invaluable for analyzing and describing the diverse hydrologic and climatic regime in the country. The monitoring network covers all major river systems in Uganda. This is a real accomplishment given the vast distances, the inaccessibility of the terrain, and the limited operational resources. Nevertheless, historic data alone are not sufficient for understanding the current and future hydrological processes. Large parts of the river basin are constantly changing: forests are being transferred into agricultural lands, wetlands converted to irrigated areas, while large areas are being paved or covered with houses because of urbanization. For those parts of the river basin, the response to a rain-event has changed and historic rainfall-runoff relations no longer describe the hydrology of the river. It implies that hydrologic monitoring and the collection of water data is – and will be – an ongoing activity.

There are several trends that affect the acquisition of water data. Among the most profound is probably related to the changing expectations of data clients. Data consumers and data end-users will increasingly expect to have access to real-time data of high quality. These data feed into operational models to optimize power production, forecast floods, or finetune water supply to irrigation systems. The public may also expect access to real-time water data through mobile phone Apps. A modern water agency needs to anticipate these developments. The positive aspect of this trend is that real-time use of water data – for many different purposes – will probably increase the value of data, and therefore open-up new revenue streams that can be used to maintain and expand the monitoring network.

Other anticipated trends are related to mass adoption of cheap electronic sensors and real-time communication technology, which will result in large volumes of complex data. Drones will increasingly provide useful data with adequate resolution at river basin and sub-catchment scales. Data management systems, river basin models, and related water information tools should be able to handle these new types of data.

Thus, it is evident that the environmental data field is subject to rapid changes. DWRM will need to prepare for these changes to provide the high quality hydrological data and services that its clients have become accustomed to.

In fact, the Directorate is doing this right now. It has recently established the state-of-the art Aquarius Data Management System that will enable real-time data access. DWRM is also setting up a sophisticated Water Information System, which brings together a fast array of climatic information and other water data. Further, DWRM is currently developing a suite of tools for optimizing power production of the cascade of hydropower facilities along the Victoria and Kyoga Nile, as well as elsewhere in the country. These advanced systems and tools will make it easier for DWRM to accomplish its various tasks.

This publication has presented a comprehensive hydrological review for the 1978-2014 timeframe. It has also reviewed the need for water and environmental data in Uganda, and presented the accomplishments by DWRM in the last decades in the field of water monitoring. Lastly, this document has peeked into the future to assess how water monitoring in the coming decades may look like. It is evident that accurate and timely water data remain essential for fact-based management, development, and protection of the country's water resources for the benefit of the people of Uganda.

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Appendix A

Groundwater hydrographs

This assessment includes 14 groundwater station, of which the monitoring periods are summarised in table A1.1. A location map for these stations can be found in Chapter 4, figure 4.3. The hydrograph for each station is briefly analysed for influences and long-term trends.
The variability of the data between the stations makes it clear that no conclusions can be drawn as to groundwater trends on a national level. As noted in Chapter 2, groundwater potential is highly variable in Uganda, and large differences can occur within the same hydrogeological unit.

No.	Station	Start	End	Major gaps
1	Masindi	2007	2016	06/07-04/09
2	Rukungiri	1999	2016	05/09-02/10
3	Rwebisengo	2009	2016	
4	Soroti	1998	2015	
5	Pallisa	1998	2015	07/11-02/13
6	Serere	1998	2015	01/12-10/12
7	Laropi	2009	2015	05/11-01/12
8	Maracha	2010	2015	
9	Apac	1998	2015	
10	Rakai	1998	2014	
11	Entebbe	1998	2016	
12	Nkozi	1998	2016	08/07-08/08
13	Hoima	1998	2014	08-09, 10/10-10/11, 13
14	Isingiro	2007	2015	10-11

Table A1.1 Overview of groundwater data availability per station

Masindi

Lying on the border between Lake Albert and Victoria Nile Basins, Masindi station has groundwater data availability for only a relatively short period, with the first measurements originating in early 2007. The groundwater level is deep and thus stable without visible influence of seasonal patterns. The groundwater level shows a slight upward trend.

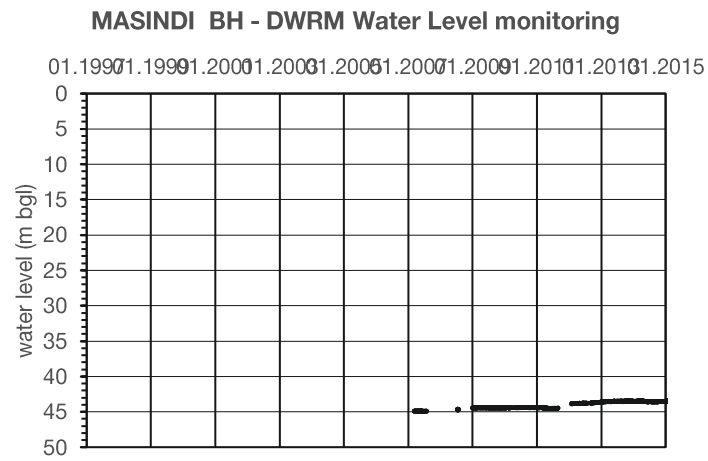

Figure A1.1 Groundwater hydrograph for Masindi station

Rukungiri

Rukungiri station lies in the southern region of the Lake Edward Basin. The monitoring data shows a stable trend around 10 metre depth until 2003, after which a period of very high variability follows. From early 2012 the trend stabilises again at 10 metres. In the last months of 2014 a regime change to 17 metre depth can be observed.

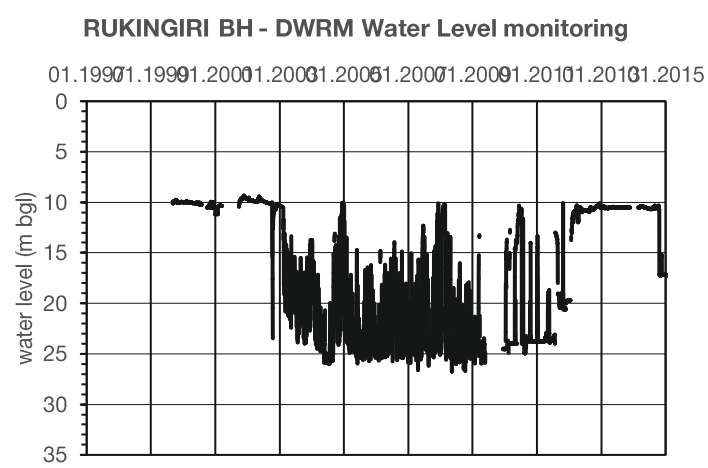

Figure A1.2 Groundwater hydrograph for Rukungiri station

Rwebisengo

Rwebisengo station, lying in the Lake Albert Basin, has a relatively short period of monitoring data coverage. The groundwater levels are shallow and show some variability with a slight upward trend over the period of coverage.

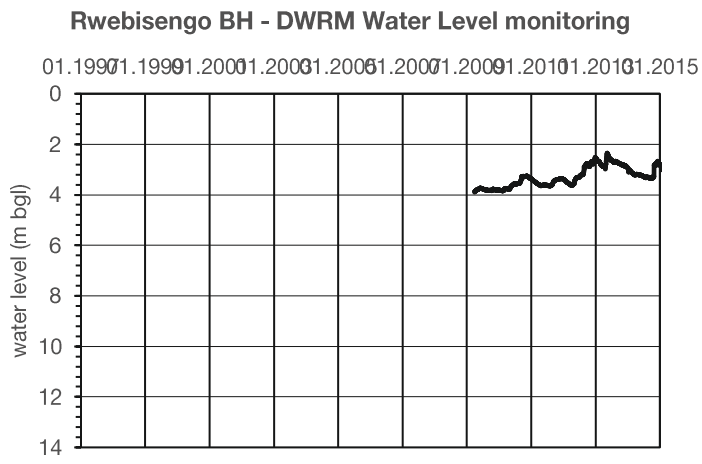

Figure A1.3 Groundwater hydrograph for Rwebisengo station

Pallisa

Located in the Lake Kyoga Basin, Pallisa station is under the influence of seasonal variability. There were two major periods of recharge, in May 2002 and May 2003, after which groundwater levels declined, but after the short data gap in 2011-2012 levels seem to have stabilised.

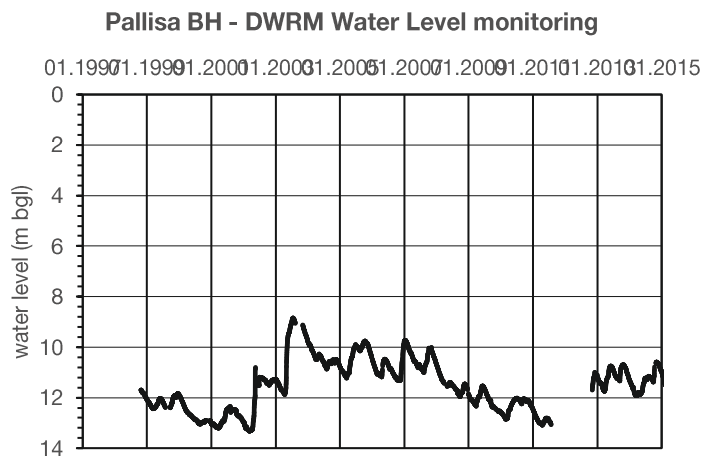

Figure A1.5 Groundwater hydrograph for Pallisa station

Soroti

Soroti station is located in the Lake Kyoga Basin. The groundwater hydrograph shows a strong influence of seasonality, with groundwater levels fluctuating up to 2.5 metres. During the measurement period there is no overall trend towards increasing or decreasing groundwater levels visible.

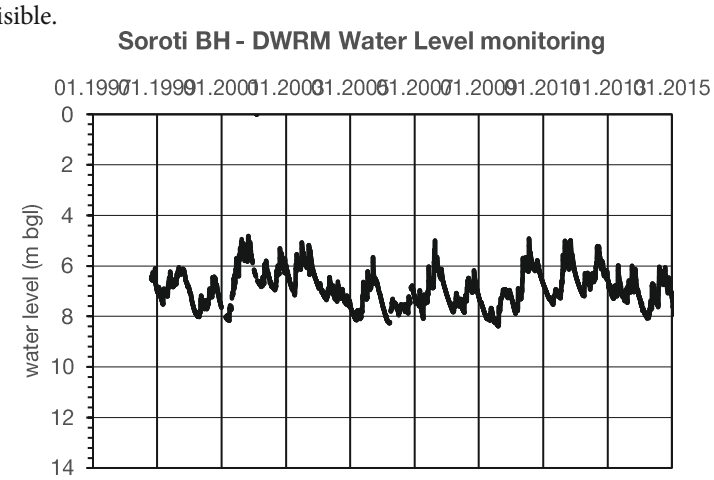

Figure A1.4 Groundwater hydrograph for Soroti station

Serere

Serere station is located in the Lake Kyoga Basin and shows a high seasonal variability, with groundwater levels fluctuating up to 2 metres. Over the relatively short period of data availability no clear up- or downward trend can be discerned.

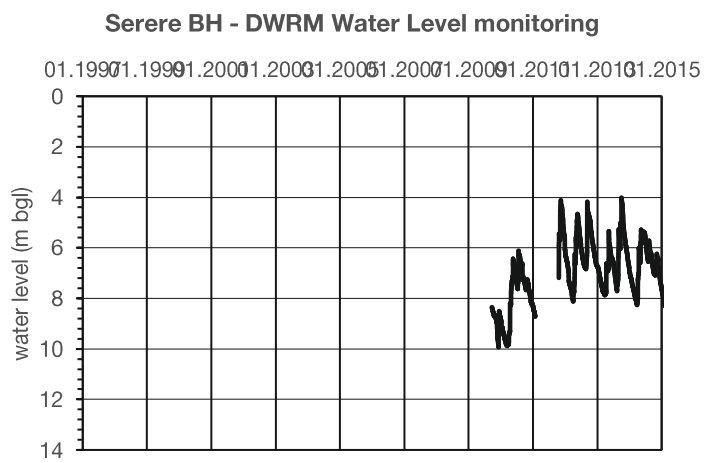

Figure A1.6 Groundwater hydrograph for Serere station

Laropi

Laropi station lies in the Albert Nile Basin. Based on the available data no up- or downward trend can be discerned, and no observations can be made about seasonal influences.

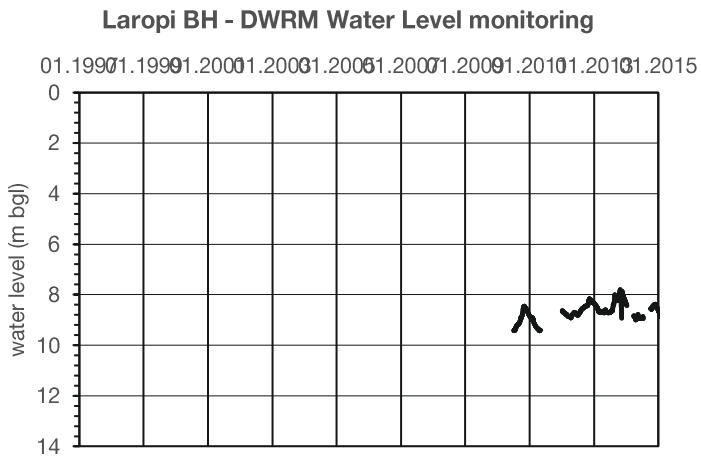

Figure A1.7 Groundwater hydrograph for Laropi station

Apac

Apac station lies in the Victoria Nile Basin and has a good level of coverage with no major data gaps. The hydrograph shows a slight influence of seasonality on the groundwater levels. The overall trend indicates stable groundwater levels over the monitoring period.

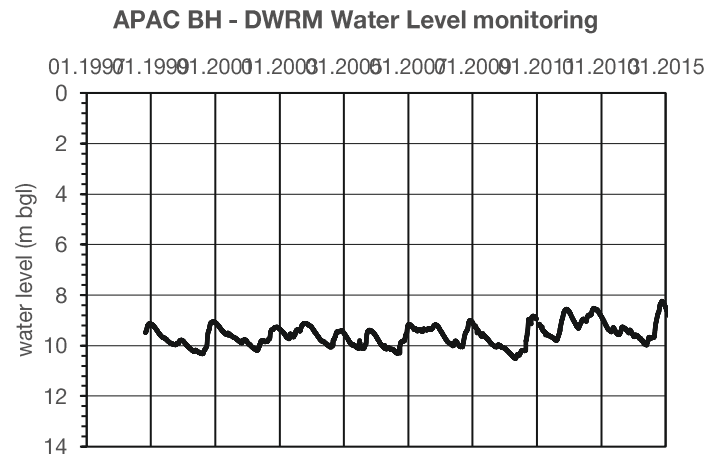

Figure A1.9 Groundwater hydrograph for Apac station

Maracha

Maracha station, located in the Albert Nile Basin, shows a clear seasonal influence with high levels in December-January and low levels in August. Overall the groundwater levels show a clear upward trend.

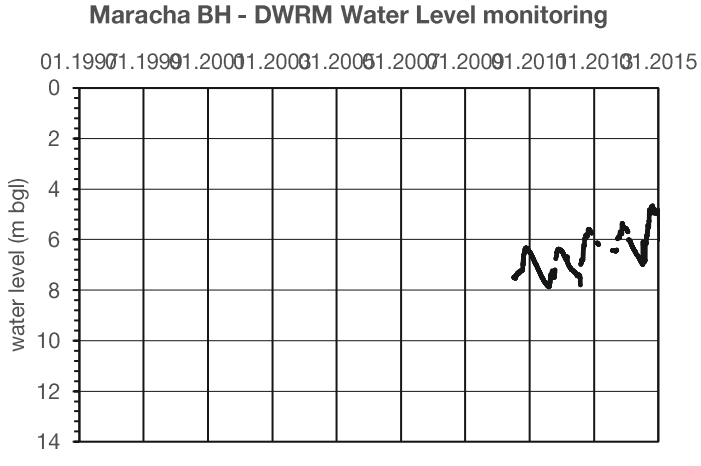

Figure A1.8 Groundwater hydrograph for Maracha station

Rakai

Rakai station is situated in the Lake Victoria Basin. The groundwater levels are relatively deep which is also apparent in the absence of seasonal variability. In the first half of the monitoring period up to 2007 there are some periods of recharge and abstraction, but since 2007 the groundwater levels have been quite stable.

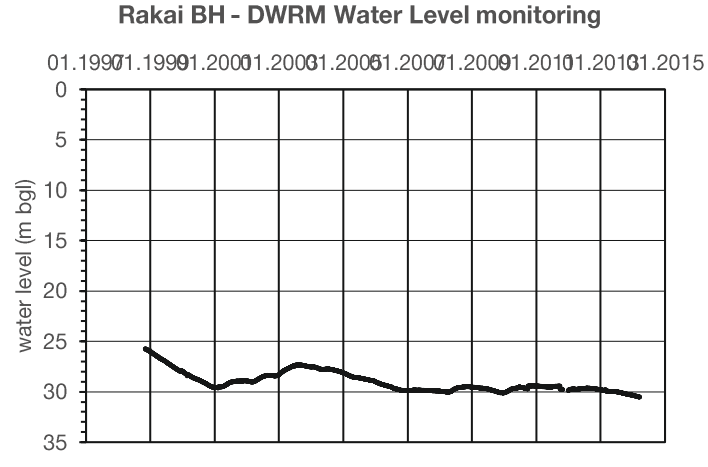

Figure A1.10 Groundwater hydrograph for Rakai station

Entebbe

Located in the Lake Victoria Basin and near the shores of Lake Victoria, Entebbe station has relatively shallow groundwater levels. The hydrograph shows strong seasonal variability with groundwater levels fluctuating up to 3 metres. Apart from a slightly average lower level from 2004-2006, there is no clear overall up- or downward trend.

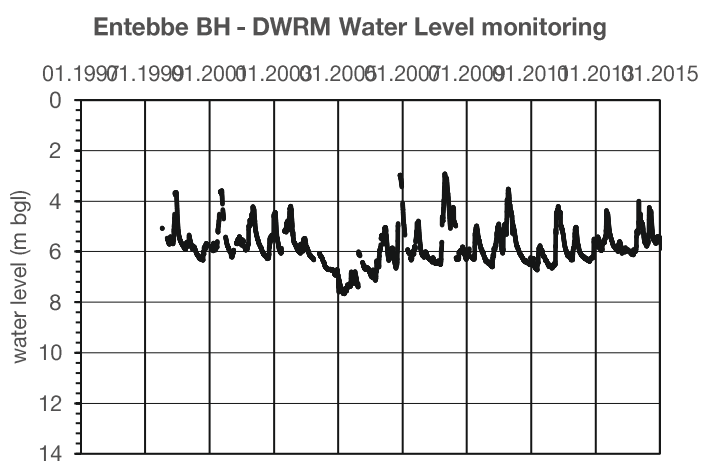

Figure A1.11 Groundwater hydrograph for Entebbe station

Hoima

Hoima station lies in the Lake Albert Basin. The groundwater levels are not shallow but still show a large variability which indicates more than purely seasonal influences. In the first period of measurement the groundwater level trend is stable, however since 2007 an upward trend can be observed.

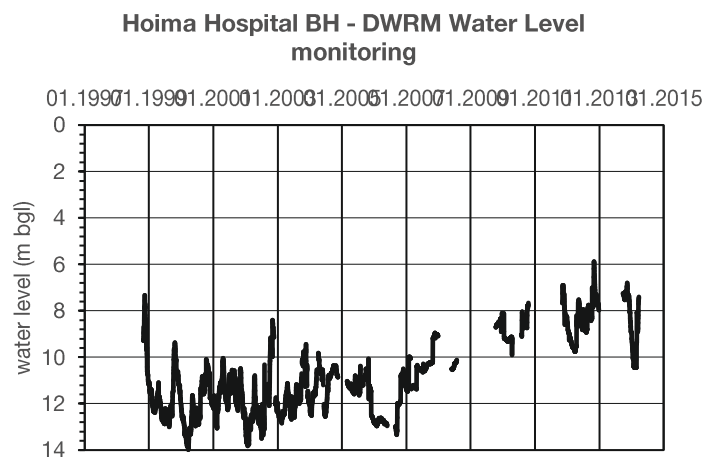

Figure A1.13 Groundwater hydrograph for Hoima station

Nkozi

Nkozi station, located in the Lake Victoria Basin, has shallow groundwater levels with an average of 3 metres below ground level. The shallowness makes it sensitive to external influences which is reflected in the variability of the hydrograph. Overall the groundwater levels appear stable with no clear trend.

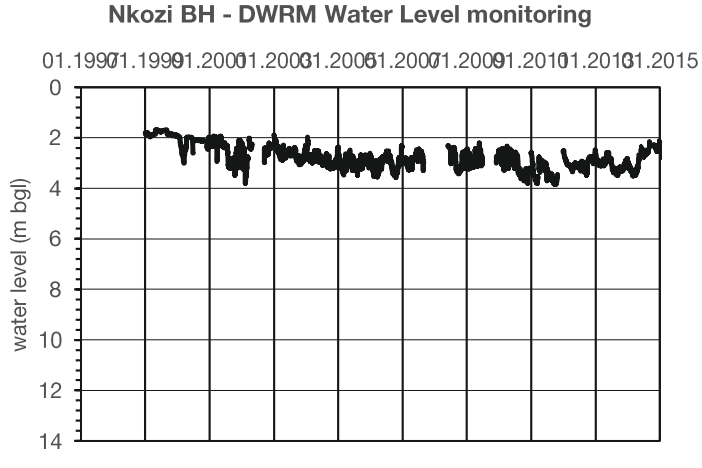

Figure A1.12 Groundwater hydrograph for Nkozi station

Isingiro

Isingiro station is located in the Lake Victoria Basin and has deep groundwater levels. The hydrograph shows a period of stability until 2011. From 2012 onward there is a clear upward trend until September 2012, after which groundwater levels decrease again, however still well above pre-2011 levels.

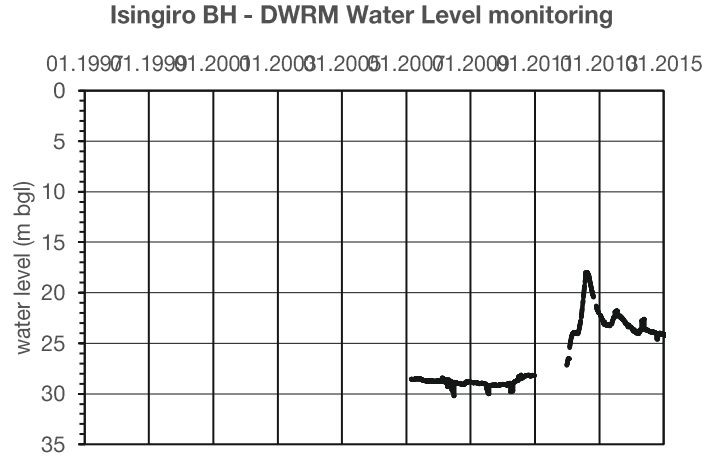

Figure A1.14 Groundwater hydrograph for Isingiro station

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Figure/photo courtesy **Figure 2.1, 2.2, 2.3, 2.10:** MWE (2013). National Water Resources Assessment. Ministry of Water and Environment, Kampala; **Figure 3.1:** Adapted from Stewart, B. (2015). Measuring what we manage – the importance of hydrological data to water resources management. Hydrological Sciences and Water Security: Past, Present and Future. Proceedings of the 11th Kovacs Colloquium, Paris, France, June 2014. IAHS Publ. 366; **Figure 3.2, 3.3:** WMO (2015). Valuing weather and climate: Economic assessment of meteorological and hydrological services. Joint WMO, World Bank Group, and Climate Services Partnership book, No 1153; **Figure 4.3, 4.4, 4.5, 4.7, 4.8, 5.17, 5.23, 5.35:** Bart Hilhorst; **Figure 4.10, 4.12, 4.13:** MWE (2016). Detailed assessment of requirement for a Water resources Information System – WIS Design and Operationalisation Report. Ministry of Water and Environment, Kampala; **Figure 5.1, 5.29, 5.41:** Benjamin Ssekamuli.