Water Balance and Allocation Modelling in Rwanda

FINAL REPORT

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Executive Summary

In an effort to introduce integrated land and water management within hydrological units (catchments), the Government of Rwanda, through Water for Growth Rwanda, has commenced the development of catchment plans. Water for Growth Rwanda, a platform to promote improved, integrated management of Rwanda's water resources (IWRM), is supported by the Embassy of the Kingdom of the Netherlands. Over the course of 2015-2019 this platform receives technical assistance from an international IWRM support unit within the Rwanda Natural Resources Authority (RNRA).

One component of Water for Growth Rwanda is focused entirely on the introduction of catchment planning and management in four so-called "demonstration catchments" (Upper Nyabarongo, Sebeya, Nyabugogo, and Muvumba). To support the development of these catchment plans quantitative information is required. These plans should go beyond analyzing the current situation (by monitoring) and need to look at projections (e.g. climate change, macro-economic development, population growth) and at alternatives (interventions). To support this goal an extensive modeling exercise has been undertaken, using the WEAP tool, to evaluate future water resources, demand, supply and shortage.

Main conclusions and recommendations from the analysis as described in this report based on the extensive modeling analysis are:

Water scarcity: Vision 2020 states "the country is endowed with reserves that could provide enough water for both human consumption and agricultural purposes". However, a simple definition of water scarcity does not exist as this is very much time and location specific, as demonstrated by water scarcity issues occurring already in the country. In the near-future this is expected to increase even further as climate change is expected to intensify water resource with higher precipitation during wet periods and lower precipitation during the dry periods. Population growth and macro-economic development are expected to increase water demand substantially.

Location and time specific: Water shortage is a very time and location specific phenomena. Vast quantity of water in the country flows from west to east, while at the same time Lake Kivu might become a virtually unlimited source of water if proper treatment measures at affordable prices are available. All actions considered should consider upstream-downstream linkages at every level of detail.

Actions: The analyses show clearly that if no changes in current water management practices are taken future water shortages will have a severe negative impact on people, economic activities and environment. The results show that actions, referred to as Alternatives, should be taken local specific and results presented in this report give a first indication where which Alternative is preferred. It is very clear that a limited sectoral approach is not effective and that integrated actions should be taken.

Economics: Water consumption is an economic act and provides services and benefits that should be quantified to support decision making process. A typical example is that nonmanageable water consumption (e.g. evaporation from forests and grasslands) provide services that should be valued.

Capacity development: The modeling tools described in this report require maintenance and updating at regular intervals. Better and more accurate data and information will become available that makes the models and therefore decision support more accurate. Also, new models might be needed at higher level of detail to support implementation decisions. Most importantly, additional alternatives will emerge that should be evaluated before these will become policy. Extensive capacity development of staff is therefore needed.

The authors would like to acknowledge the fruitful collaboration with the entire W4GR program team including all staff from Rwanda Natural Resources Authority (RNRA) and the IWRM Support Unit (ISU). Special thanks to Mr. Kabalisa, Tetero and Mugunga for their support and sharing their knowledge to bring the assignment to a higher level. Other staff and interns of RNRA were also very instrumental in supporting the work. Special thanks to ISU staff in supporting our assignment. Especially Mr. Smidt, Nieuwenhuis to provide guidance, and other staff including Benon, Beatrice, Fred, Max, Richard, and Giress. Finally, the financial and also overall guidance of the Netherlands Embassy and especially Mr. Jan Vlaar were highly appreciated.

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1 Introduction

The Republic of Rwanda and the Kingdom of the Netherlands are engaged in an Integrated Water Resources Management (IWRM) planning program. The overall aim of the program is to "effectively manage water resources to contribute to sustainable socio-economic development and equitably improved livelihoods". Important components of the program are:

- Research and capacity building on IWRM
- Implementation of IWRM principles for shared learning in four Demonstration Catchments
- The development of sustainable integrated water management plans
- Creation of an IWRM Investment Fund, also open to other financial contributors

In order to support the overall aims of this program a Terms of Reference was developed entitled "Catchment Study: Water balance and allocation modelling (four demonstration catchments and national level)". The objectives of this TOR are:

"*To support the IWRMD and ISU in the assessment of different catchment plan management alternatives and autonomous development scenarios; to provide a tool for allocation of water to different large users; to train IWRMD in the development, enhancement, and use of WEAP model for water balance and allocation issues.*"

This study falls within the framework of the Netherlands Government funded IWRM project that aims to build capacity at national, catchment and local level with regard to catchment management and IWRM. Specifically, the IWRM department has expressed their wish to enhance their skills in the development and adaptation of IWRM scenarios and – as a result – the ability to independently use IWRM scenario tools in the future. This is the red line on which the project is accomplished. Our approach is client-centered, and the tools used are carefully selected based on the ease of use, flexibility towards the availability of data and having a strong focus on future scenario development.

Many Integrated Water Resources Management (IWRM) planning projects fail as a clear future focus is lacking. Such a future focus should be based on scenario analysis in two ways: projections and interventions. Projections (sometimes referred to as pathways) are future scenarios that can be hardly influenced by local water planners and decision makers. Typical examples are climate change, population growth, and economic development. This in contrast to interventions (sometimes referred to as adaptations, or implementation scenarios), where water decisions makers play an important role. Examples are constructing reservoirs, irrigation planning, groundwater permits, watershed conservation, amongst many others.

By combining local data sets and data obtained from remote sensing in hydrological models, information on crop transpiration, groundwater flows, recharge and runoff can be obtained. This results in a more complete knowledge base on water resources availability. Where remote sensing can provide information on historical and current water availability situations, hydrological models can provide future scenarios (both short term and long term) of water resources availability in a basin. These future scenarios form an important contribution to the complex decision making process that policy makers face with regard to water allocation to competing sectors and multi-year strategic water resources planning (Figure 1).

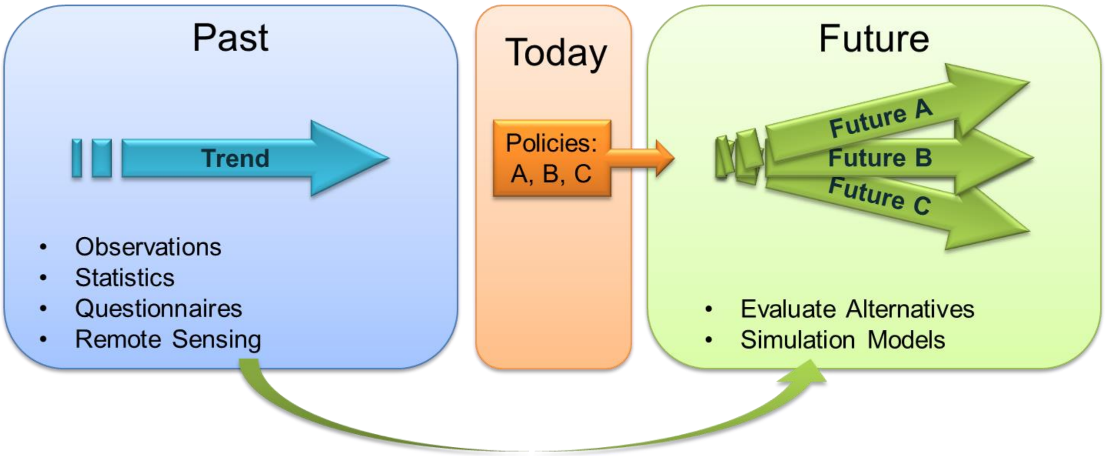


Figure 1: The future focus needed: Integrated Water Resources Management planning and its linkage to data.

This report is the result of a four months consultancy where an appropriate water balance and scenario tool (WEAP) and the most relevant data from remote sensing were combined. Results analyze the role of Integrated Water Resources Management on the impact of projections and to the potential of interventions combined in different development alternatives. This approach was applied to four pilot catchments and on a scoping level at the national level.

2 Remote Sensing of Evapotranspiration and Biomass Water Productivity

2.1 Relevance

Remote Sensing uses satellite technology to scan the earth surface and provide data on crop water and climate parameters. The advantage of using satellite based information is that it provides spatial information per pixel for a large area at once, up to entire river basins and countries. Additionally, satellites revisit regularly, which allows for an operational service with data being updated in (near) real time. For Rwanda we mainly use the MODIS satellite which passes over daily and provides data at a resolution of 250m. For Rwanda, Evapotranspiration (ET), Biomass production (BP) and the associated Biomass Water Productivity are of interest.

Besides rainfall, evapotranspiration is the biggest component of the hydrological balance in Rwanda. Evapotranspiration over large areas can be obtained by Remote Sensing. Evapotranspiration (ET) is the sum of the volume of water that is evaporated from the soil and water surfaces (E) and the volume of water that is transpired by vegetation (T). Where non-consumed water can be recaptured for downstream use, or replenishes the groundwater, evapotranspiration cannot. It represents the actual volume of water that is consumed by both natural vegetation as agricultural crops by means of vaporization and is expressed in mm. A substantial part of the available water resources in a river basin is consumed via evapotranspiration (ET).

eLEAF's ET-Look model is one of the internationally leading algorithms for estimating actual evapotranspiration (ETact). Based on satellite imagery it calculates a range of evapotranspiration data products, biomass production, and other data components on a pixel-by-pixel basis. The algorithm uses the energy balance to determine the available energy per pixel and determines how much of that energy is used for soil and air temperature changes (see Appendix Remote Sensing). The residual energy is available for the evapotranspiration process which results in biomass production. Based on the amount of residual energy, the algorithm calculates the actual ET presented in mm as well as the Biomass Production in kg/ha/timestep.

2.2 The ETLook Model

Reference evapotranspiration is the water use of a well-watered reference crop, usually grasslands. Crop coefficients can be used to translate the reference evapotranspiration to potential ET. The drawback of generic correction factors – referred to as crop coefficients Kc – is that they are measured elsewhere under different circumstances. Values of crop coefficients are available for various crops and countries but crop stress due to soil moisture constraints and atmospheric factors is thereby excluded. As with all surface energy balance models, the SEBAL (Bastiaanssen et al. 1998; Bastiaanssen et al. 2005) and ETLook (Pelgrum et al. 2011; Bastiaanssen et al. 2012) models eliminate the need to use generalized crop coefficients. SEBAL has been widely validated internationally (among others (Bastiaanssen et al. 1998; Morse et al. 2000; Conrad et al. 2007; Allen et al. 2011).

SEBAL was intended for use in catchment and crop growth monitoring studies and not for extensive areas. Due to this constraint, the need for another type of energy balance model was recognized and the ETLook model was developed (Pelgrum et al. 2011; Bastiaanssen et al.

2012). ETLook was released in 2009 and used extensively in the Nile Basin, China, India, Pakistan, Australia, Syria, Morocco, Iran, Ukraine, Poland, Canada and the Netherlands. Results of a validation of the model in the Indus Basin were presented during a conference of the International Association of Hydrological Sciences (IAHS) (Pelgrum et al. 2011). ETLook and SEBAL use the land surface energy balance, including net radiation (Ksoi), soil heat flux (G), sensible heat flux (H) and latent heat flux (E and T). Several previous studies demonstrated that SEBAL and ETLook provide similar results.

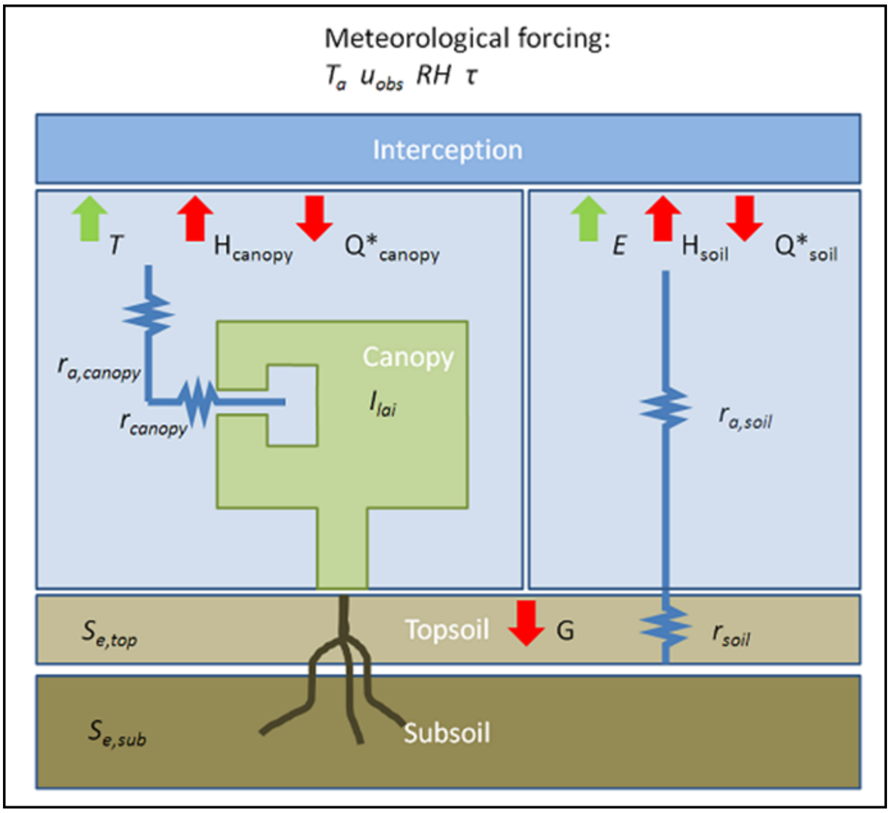
ETLook is a two-layer energy balance model that computes evaporation from soil and water surface (E) and transpiration (T) from canopies using transport resistances in conjunction with the Penman-Monteith equation. The latent heat flux (of the energy balance is directly related to the actual ET on the water balance: 28 W/m2 = 1 mm/d. Different physically defined aerodynamic and evaporation resistances for bare soil and canopies are incorporated into ETLook. The bio-physical datasets used for the Penman-Monteith equation are surface albedo; surface emissivity; surface roughness; surface leaf area index; and surface canopy resistance. The meteorological datasets cover input map data of air temperature, relative humidity, wind and transmissivity. The bio-physical parameters are retrieved from satellite measurements, while the meteorological data (except for transmissivity which is gained from MSG) are retrieved from meteorological stations.

A basic outline of ETLook is depicted in Figure 1. The soil resistance rsoil¬ ¬is a function of the soil moisture content in the topsoil. The values of the resistances can be updated regularly, using measurements from satellite earth observations. The canopy resistance rcanopy is a function of the leaf area index (LAI; [m2/m2]) and four dimensionless stress functions. These stress factors express the influence of radiation, temperature, vapour pressure (meteorological conditions) and soil moisture content in the subsoil. The aerodynamic canopy (ra,canopy) and soil resistance (ra,soil) are a function of wind speed and surface roughness. An iteration procedure is performed to correct for unstable conditions. The Monin-Obukhov Similarity Theory (Monin & Obukhov 1954) is used to parameterize the effects of shear stress and buoyancy. The Penman-Monteith equation is solved separately for vegetation and soil in order to split evapotranspiration in transpiration (T) and evaporation (E):

$$T = \frac{\Delta(Q^*_{canopy}) + \rho c_p \frac{\Delta_e}{r_{a,canopy}}}{\Delta + \gamma(1 + \frac{r_{canopy}}{r_{a,canopy}})} \quad E = \frac{\Delta(Q^*_{soil} - G) + \rho c_p \frac{\Delta_e}{r_{a,soil}}}{\Delta + \gamma(1 + \frac{r_{soil}}{r_{a,soil}})}$$

where	Δ	is slope of saturation vapour pressure curve [mbar / K];
	Δ_e	is the vapour pressure deficit [mbar];
	P	is air density [kg m^{-3}];
	C_p	is specific heat capacity of dry air [J/kg/K];
	γ	is a psychrometric constant [mbar/K];
	G	is soil heat flux [W/m^2];
	Q^*_{canopy}	is the radiation for canopy [W/m^2];
	Q^*_{soil}	is the radiation for soil [W/m^2];
	r_{canopy}	is canopy resistance [s/m];
	r_{soil}	is soil resistance [s/m];
	$r_{a,canopy}$	is aerodynamic canopy resistance [s/m]; and
	$r_{a,soil}$	represents aerodynamic soil resistance [s/m].

Both actual and potential transpiration fluxes are computed. The difference expresses vegetation water stress (Tpot – Tact) induced by limited availability of soil moisture in the root zone (Pelgrum et al. 2011).



2.3 Biomass Water Productivity

The looming water crisis has prompted programs by international organizations, governments, NGOs, industries, and food suppliers to focus on optimizing output per unit of water used. In the agricultural sector this has become known as 'more crop per drop' but the issue is also pressing in the management of e.g. natural parks and reserves.

eLEAF has developed a methodology to quantify the volume of water that is used for the production of a specific amount of biomass – known as Biomass Water Productivity (BWP). BWP is defined as the ratio between Biomass Production (in kg/ha) and ET (in mm) resulting in BWP in (kg/m^3) and is increasingly used as an indicator for sustainable water management.

BWP can be used to compare production systems, value them and to set goals for improvement. We understand that under a separate study, land cover maps of Rwanda will be developed. When these land cover maps become available, it is possible to combine it with ET, BP and BWP to create insight in the water use of the different land cover classes as well as the BWP of these different classes. This will assist IWRMD in making management decision per land cover class.

Biomass Water Productivity was calculated for the years of 2009, 2012 and 2015. The output is directly based on biomass and evapotranspiration. Results have been aggregated to indicate monthly rates of these factors. The scale of BWP depicts low productivity at 0, as for instance applicable to large water bodies. High values indicate high productivity. Values differ from one land cover class to another as well as between different territories and elevation.

Different scopes of observation were chosen to compare BWP between years. Annual overviews serve to understand national trends and highlight regional differences. Figure 2 displays the most recent trends of water productivity.

The most remarkable changes are very high BWP in the west and northwest of the country in 2015. This can be explained with the influence of El Niño in the end of 2015 and the very dry month of March in the same year resulting in lower evapotranspiration in the months March and November. As biomass is stable in those areas despite droughts the amount of kg/m3 is higher. This can be better seen when directly comparing with ET and biomass (Figure 3 and Figure 4). The annual figures of those variables show that annual ET for the western areas are very low with an overall of close to 300 mm despite relatively high accumulated biomass of 40,000 kg/ha. The eastern areas show the contrary. Whereas annual ET rates are stable with values of close to 900 mm, accumulated biomass drops drastically to 20,000-25,000 kg/ha. Furthermore, the effects of reduced biomass can be observed in effectively lower BWP for 2015. The general trend of biomass, however, is showing an increase especially from the year 2009 to 2012.

As annual BWP is calculated from monthly figures, additional value can be created through statistical analysis. Interesting parameters can be maximum, minimum and mean range. The minimum values of 2015 show a clear division between west and east Rwanda (**Figure 5**). It can be interesting to check how these findings coincide with current land cover to understand their source.

Mean range indicates the difference between maximum and minimum per month. It can be seen that within the last six years this parameter is changing for a substantial amount of surface (**Figure 6**). In 2009 ranges were seen to relatively low with 2-4. Those decreased towards 2012 and then increased again to a relatively high level in 2015 with ranges of 4-6 for most regions. Reasons hereof can be regional weather phenomena causing more extreme minimum and maximum values or a change in farming systems, as e.g. the shift from perennial or mixed cropping to annual crop systems within a whole region. The most extreme range values are seen in the west where, as explained before, especially the influence of relatively low annual ET impacts the results.

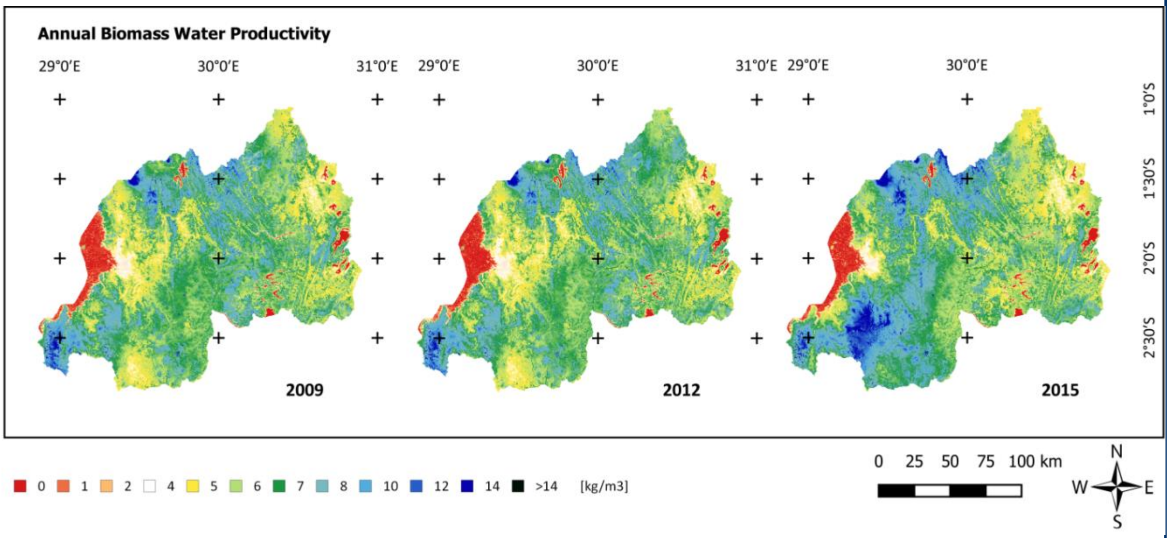


Figure 2 Annual Biomass Water Productivity 2009 - 2015

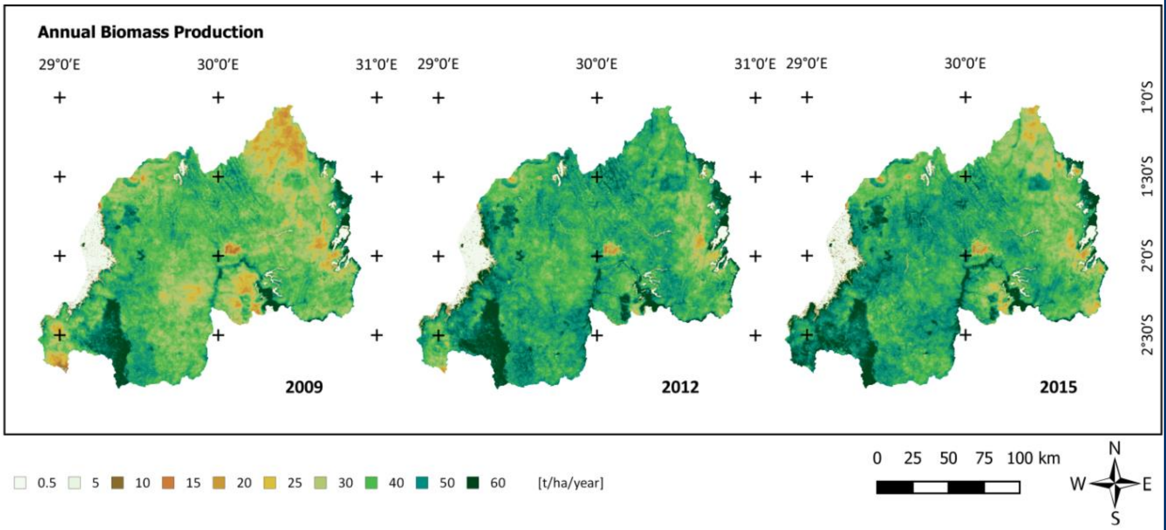


Figure 3 Annual Biomass Production 2009 - 2015

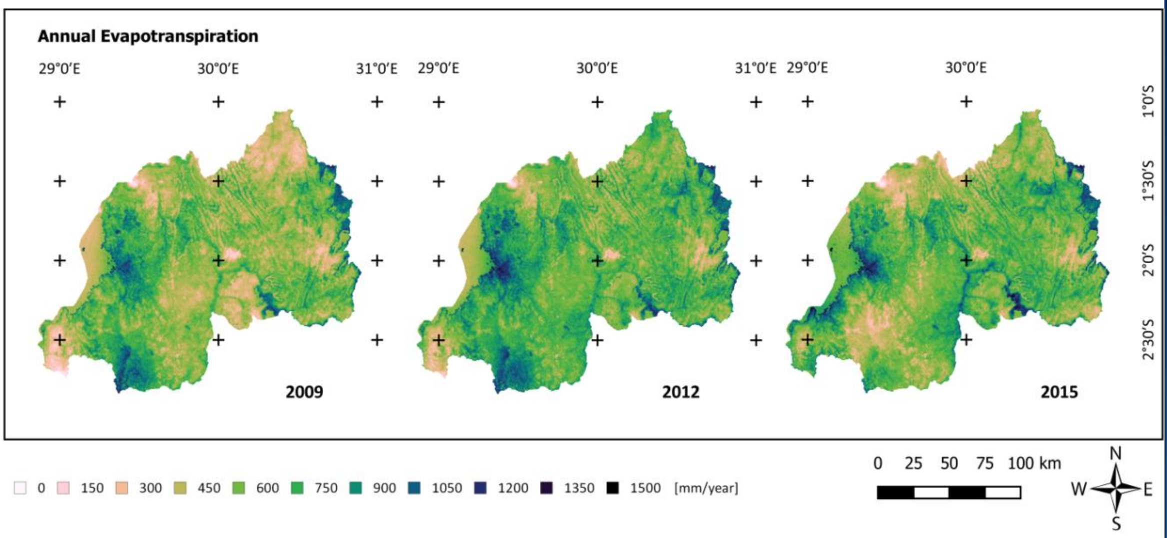


Figure 4 Annual Evapotranspiration 2009 - 2015

As mentioned above it is very interesting to link our measurements with Land Cover Classes. Figure 5 shows a land cover classification of Land Cover produced by FutureWater. It can be seen that western areas close to Lake Kivu are dominated by forests and bushlands. The western regions are mainly covered by croplands and shrubland. Annual croplands are dominating types, whereas only a very small percentage of the country is used for perennial crops. Those are locally aggregated. If only croplands are taken into account, an interpretation of the data can be even more effective. We can observe that measurements are less extreme as they do not take into account self-buffering systems such as evergreen forest or extreme high points such as Mount Karisimbi. Yet, still the results are very heterogeneous (Figure 7). Although the years 2009 and 2012 seem to be very similar, on close look differences can be observed. Especially the eastern regions showed higher water productivities than in the year before. Southern regions are stable throughout all three years with slight increases from 80 to 90 kg/m³.

Lastly, it should be pointed out that next to annual comparisons also monthly comparison can add value to understanding water usage within different regions and describing trends in farming systems and seasonality changes. Especially in areas where monocultures are dominating the landscape water productivity might be significantly different throughout the whole year. Comparing monthly BWP values of different years can help understanding trajectories of cropland change or the influence of extreme weather. In Figure 8 we depicted the months of January, which shows low changes within the years 2015 and 2009; and the months of March and December which show high rates of BWP-decrease and increase, respectively.

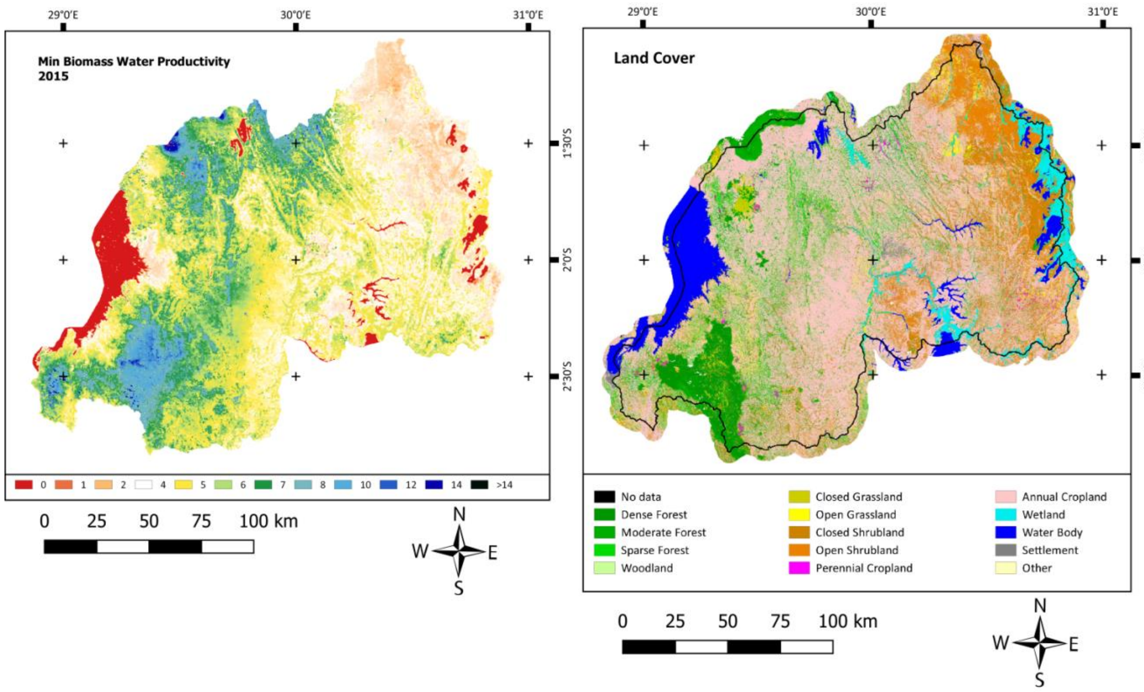


Figure 5 Minimum Monthly Biomass Water Productivity and Land Cover Classification of Rwanda

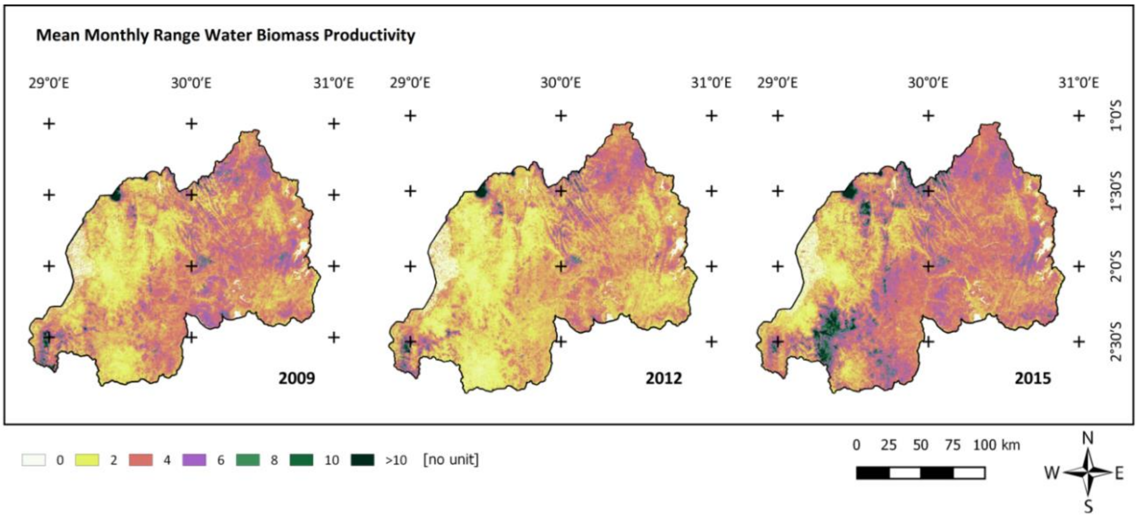


Figure 6 Mean Monthly Range WBP

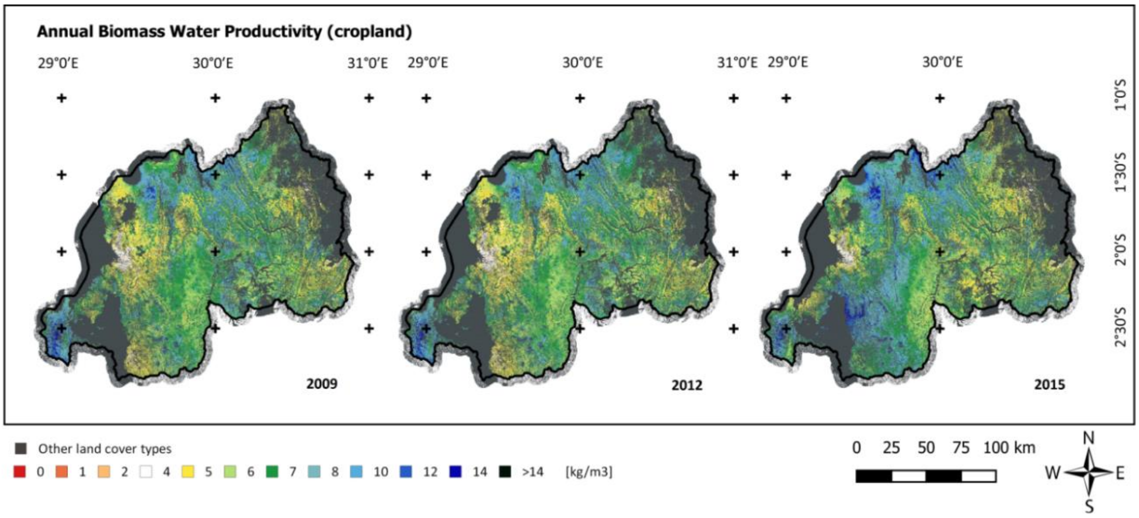


Figure 7 Annual BWP of cropland and mosaic landscapes

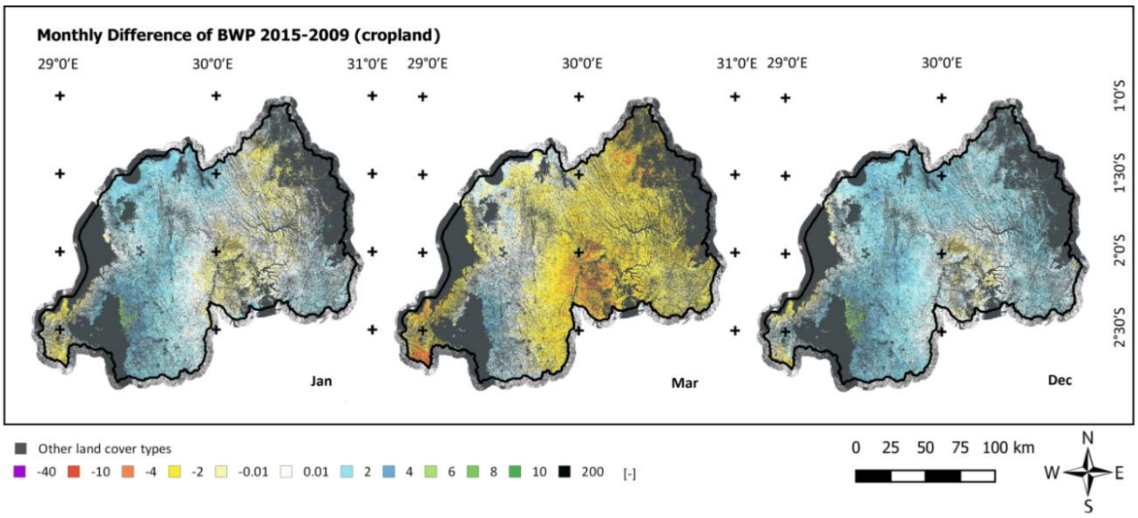


Figure 8 Monthly Difference of BWP 2015-2009 of cropland and mosaic landscapes

3 Methodology of developing WEAP-C and WEAP-R

3.1 Background WEAP

Various IWRM tools exist and appropriate selection of the most relevant is essential for the success of a project (Figure 9). For the proposed analysis at the four demonstration catchments and the nation-wide analysis the WEAP framework can be considered as the most suitable.

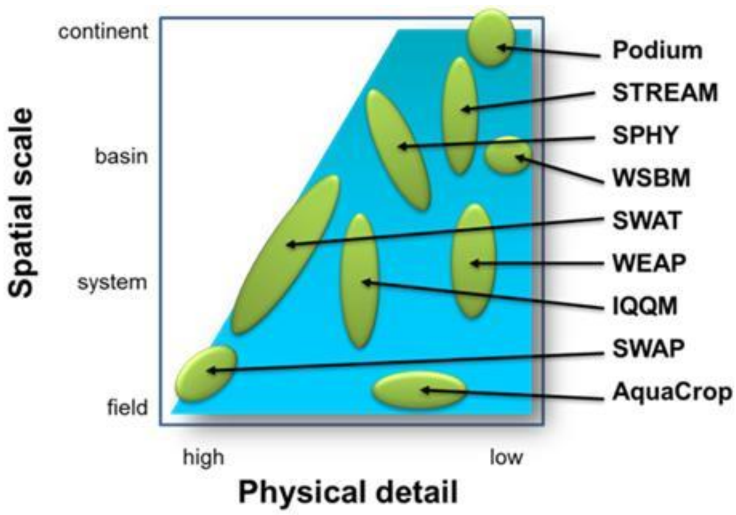


Figure 9: Relation between spatial scale and physical detail in water allocation tools. The green ellipses show the key strength of some well-known models. (Source: Droogers and Bouma, 2014)

Conventional supply-oriented simulation models are not always adequate for exploring the full range of management options. Over the last decade, an integrated approach to water development has emerged which places water supply projects in the context of demand-side management, and water quality and ecosystem preservation and protection. WEAP incorporates these values into a practical tool for water resources planning and policy analysis.

There are various reasons for choosing the WEAP framework as the most relevant. Most important is that WEAP is completely focused towards scenario analysis in a user-friendly approach. Second, WEAP is very scalable and a first-order setup of a particular region can be easily expanded when more data/resources are available. Third, WEAP is commonly used world-wide for IWRM analyses. Finally, WEAP is freely available for organizations in developing countries.

A detailed discussion on WEAP can be found in the WEAP manual which can be freely downloaded from the WEAP website (http://www.weap21.org/). In summary WEAP have the following features:

- Integrated Approach: Unique approach for conducting integrated water resources planning assessments.
- Stakeholder Process: Transparent structure facilitates engagement of diverse stakeholders in an open process.

- Water Balance: A database maintains water demand and supply information to drive mass balance model on a link-node architecture.
- Simulation Based: Calculates water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and in-stream water quality under varying hydrologic and policy scenarios.
- Policy Scenarios: Evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.
- User-friendly Interface: Graphical drag-and-drop GIS-based interface with flexible model output as maps, charts and tables.
- Model Integration: Dynamic links to other models and software, such as QUAL2K, MODFLOW, MODPATH, PEST, Excel and GAMS. Links to all other models can be developed quite easily since WEAP can read and write plain text files similar as SWAT, SPHY, SWAP, Mike11, HEC-HMS, HEC-RAS and Geo-SFM.

3.1.1 WEAP Input Data

Availability and access to good quality of data is essential for IWRM analysis using WEAP. Required input data can be divided into the following main categories:

- Model building
    - Static data[1]
        - Digital Elevation Model
        - Soils
        - Land use, land cover
        - Population
        - Reservoir operational rules
    - Dynamic data
        - Climate (rainfall, temperature, reference evapotranspiration)
        - Evapotranspiration by crops and natural vegetation
        - Water demands by all sectors
        - Reservoir releases
- Model validation/calibration
    - Stream flow

Each of the above categories can be refined depending on availability and accessibility of data. The WEAP framework is flexible in level of details of data availability. A typical example is that water demands can be included as a total amount of water, but can be also estimated by WEAP using for example the population, their daily required intake and daily and/or monthly variation. Similarly, climate data can be entered at annual, monthly, 10-days or daily level. The more refined the input dataset is, the higher the accuracy of the WEAP model scenarios will be.

This feature is very useful in areas with low data availability or where more and better quality data will become gradually available as is the case in Rwanda. The WEAP set-up gives the user the flexibility to add more detailed data when it becomes available, without having to start from scratch with every updated data set.

[1] Nota that static data can still vary over longer time frames, but are fairly constant over days/weeks

Some input data will need to be locally sourced or are available in the public domain (Figure 10). Additionally, relevant input data to for IWRM planning using the WEAP model will be collected using remote sensing

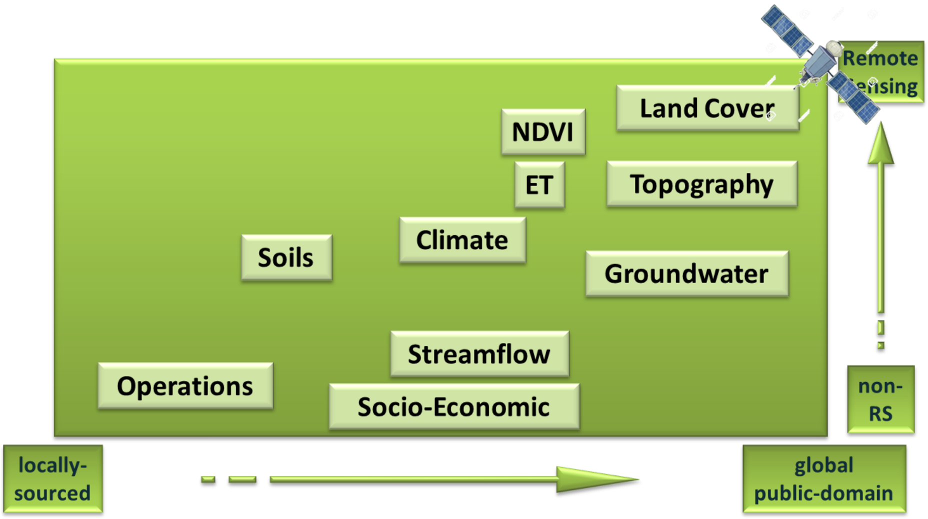


Figure 10: Development in data availability to support water allocation tools over the last 20 years.

3.2 Development WEAP-C for Four Catchment

Four demonstration catchments have been selected by the project to focus on. For each of these catchments a WEAP model will be built to improve the understanding of past water allocations and water balances, and to have a tool to undertake scenario analysis. The four demonstration catchments are:

- Muvumba (**MUV**)
- Nyabugogo (**NYA**)
- Sebeya (**SEB**)
- Upper Nyabarongo (**UNY**)

Besides these models for the four demonstration catchments a nation-wide WEAP model (**WEAP-R**) covering the nine level-two catchments will be developed. This model will be used to analyze past water allocation and water dynamics for the entire country, and as a tool to explore future changes.

The models built use the so-called hydrological response unit (HRU) approach: water resources present in an HRU are considered to be available to all users in the HRU considered. In practice this implies that accessibility of water is not restricted by the distribution system (small streams, piped networks, canals etc.). In reality restrictions will occur and are normally accountant for. In the current models a standard approach is used where accessibility to water is a function of the monthly precipitation. The equation used for this approach is:

$$\text{Accessibility (\%)} = \text{SecAcc} + \text{Precipitation} * (100-\text{SecAcc})/\text{PcpThres}$$

with:

SecAcc = secured access under dry conditions (%)
Precipitation = monthly precipitation (mm/month)

PcpThres = precipitation threshold value below access to water is restricted (mm/month)

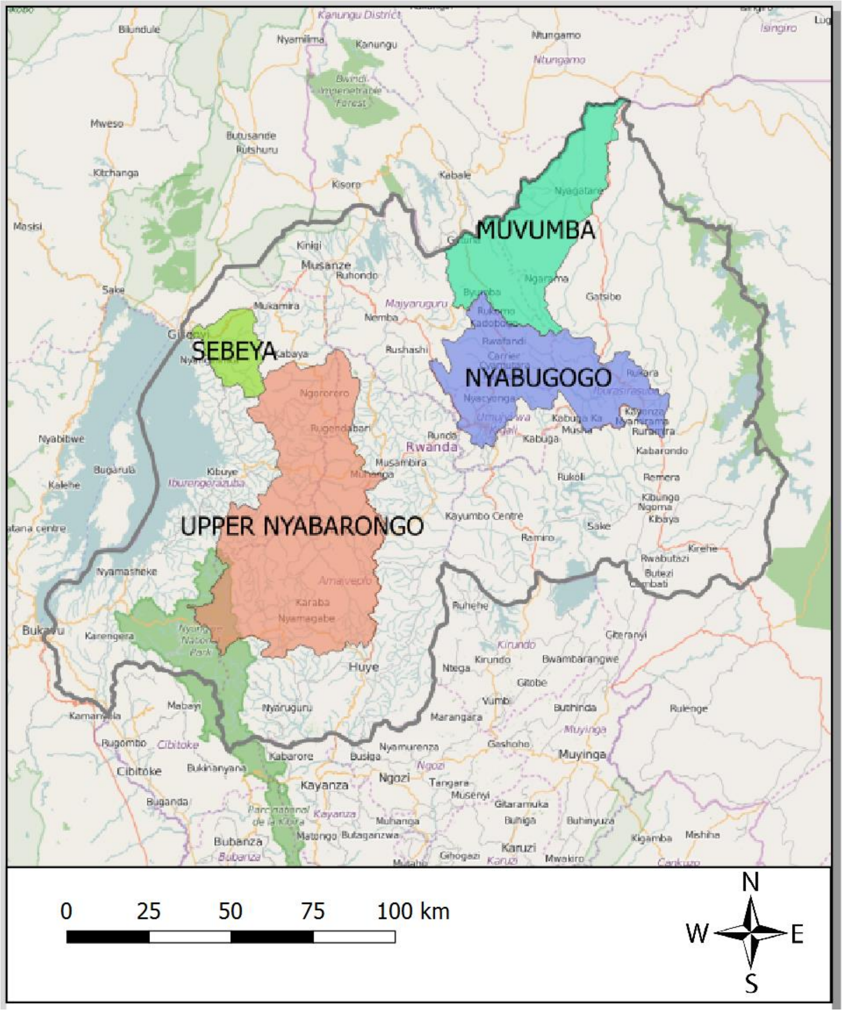


Figure 11. The four demonstration catchments of the Water for Growth Rwanda program.

Important to note is that water availability is not the same as water accessibility. In cases where water availability is below water demand, shortage will always occur, even if accessibility is 100%.

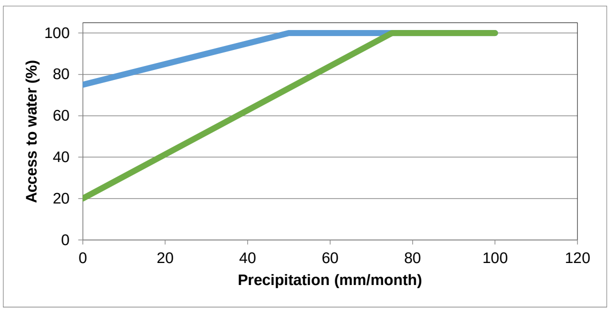


Figure 12. Accessibility to water as a function of monthly presentation. Blue line is example of secured access of 75% and threshold of 50 mm/month. Green line shows secured access of 20% and threshold of 75 mm/month.

Some typical examples of how the WEAP Schematic input was created can be seen in the following Figures:

- River Nodes (Figure 13)
- Catchments Nodes (Figure 14)
- Groundwater Nodes (Figure 15)
- Demand Nodes (Figure 16)

Detailed description of model setup, data and scenarios is provided hereafter.

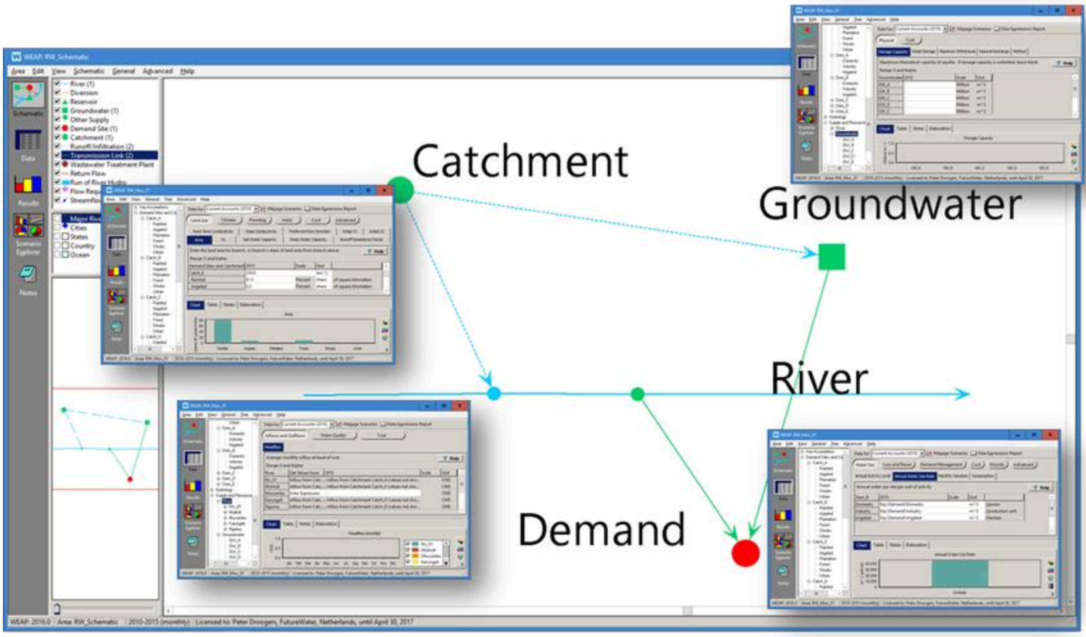


Figure 13. Schematization of one Sub-Catchment. Each demonstration catchment has been divided in five to six of these Sub-Catchments.

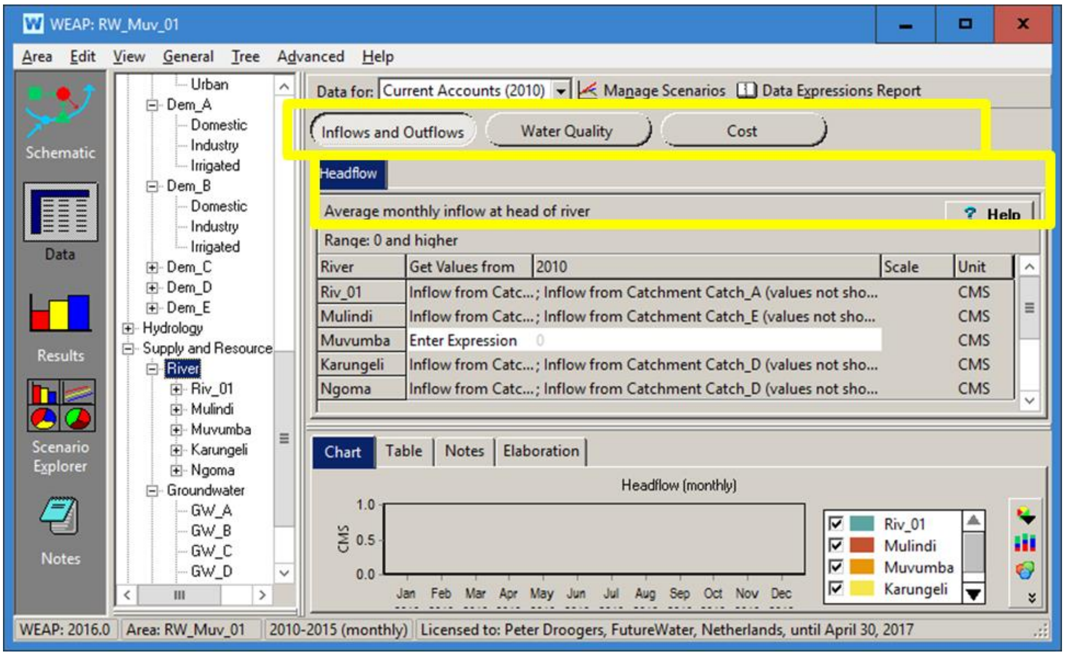


Figure 14. Most relevant input fields for the River Nodes in a Sub-Catchment.

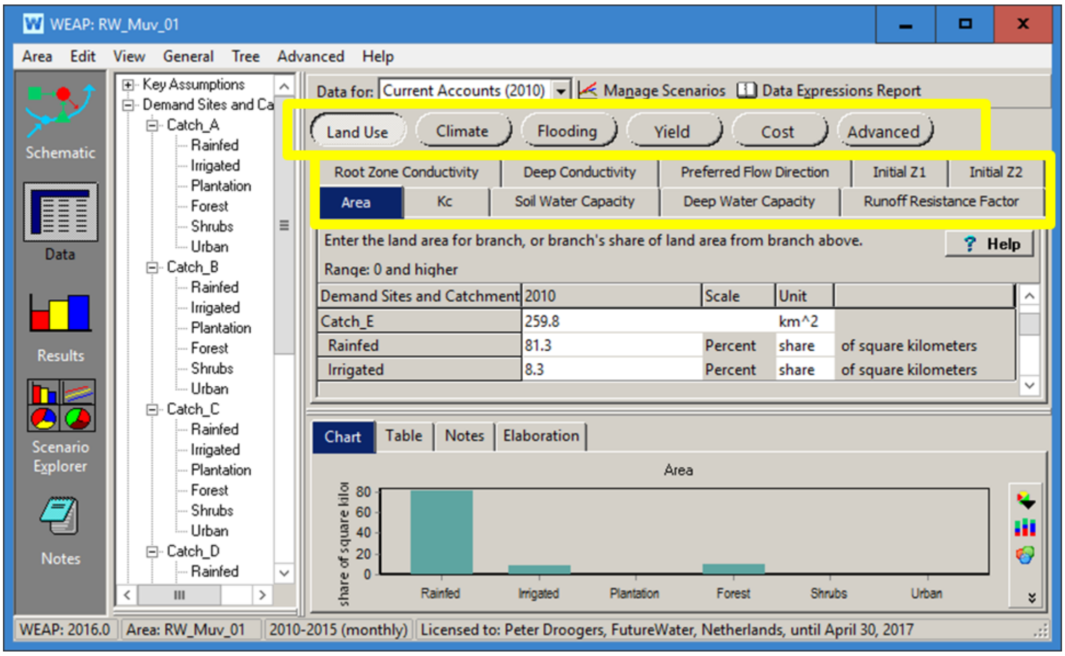


Figure 15. Most relevant input fields for the Catchment Nodes in a Sub-Catchment.

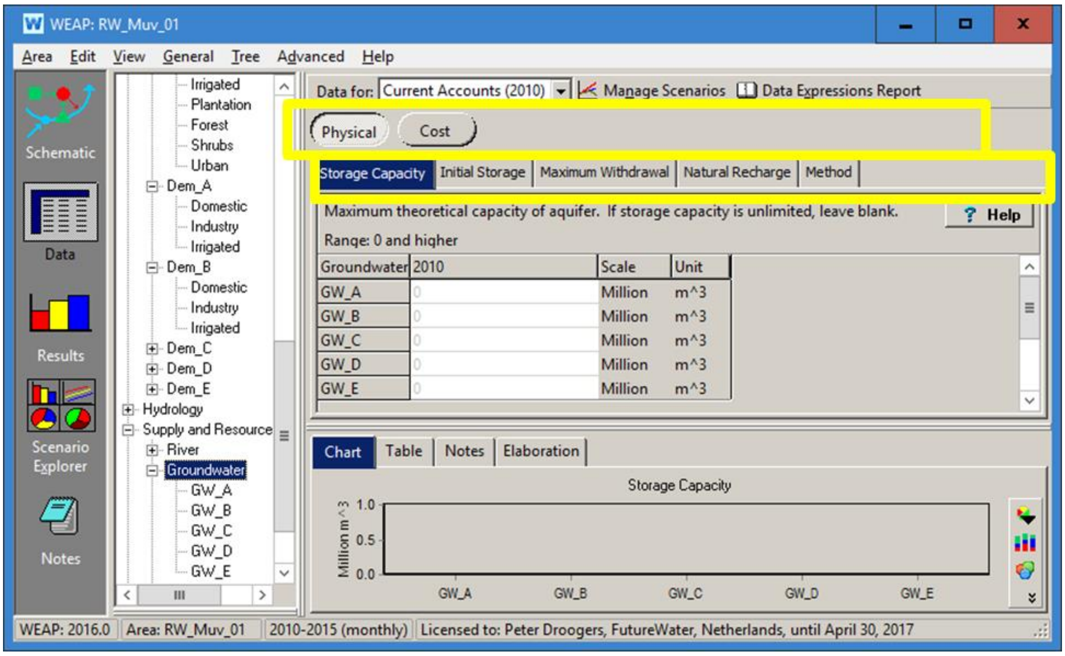


Figure 16. Most relevant input fields for the Groundwater Nodes in a Sub-Catchment.

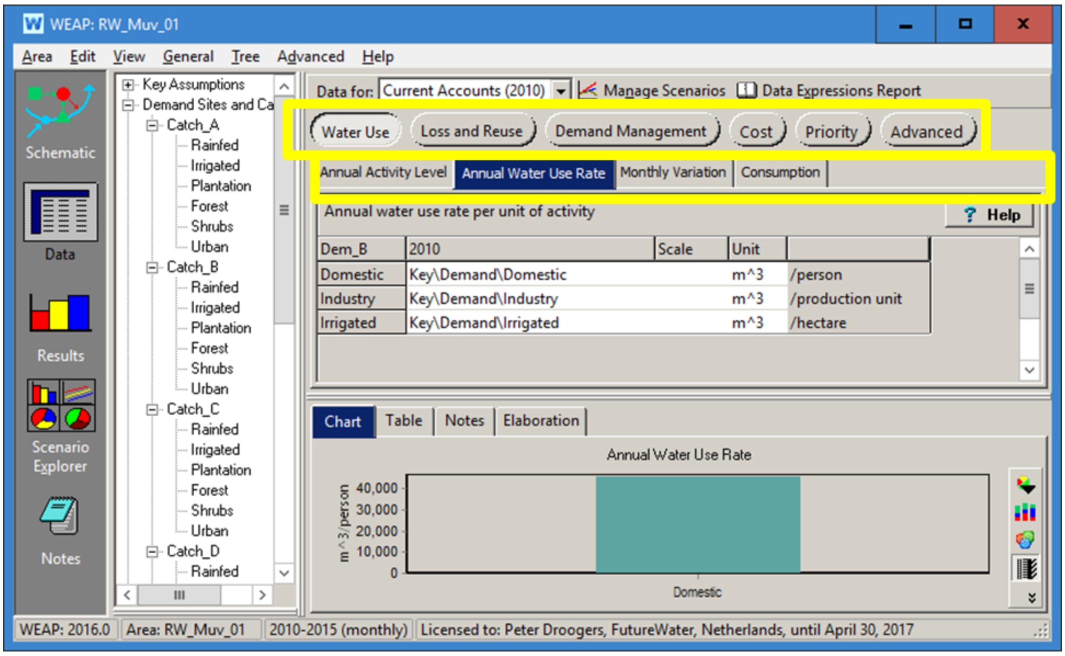


Figure 17. Most relevant input fields for the Demand Nodes in a Sub-Catchment.

4 Projections and Interventions

4.1 Future focus in water resources planning

Every water resources assessment should have a clear future focus. Such a future focus should be based on scenario analysis in two ways: projections and alternative. Projections (sometimes referred to as pathways or storylines) are future scenarios that can be hardly influenced by water planners and decision makers. Typical examples are climate change, population growth, and macro-economic development. This in contrast to alternatives (sometimes referred to as interventions, adaptations, or implementation scenarios), where water decisions makers play an important role. Examples are constructing reservoirs, training farmers, irrigation planning, groundwater permits, erosion control, watershed conservation, amongst many others.

For the Rwanda catchment planning project this distinction between projections and alternatives is also followed. Note that sometimes the word "scenario" is used as well. Here we call every evaluation of the future (whether this is a projection or an alternative) a scenario. In summary the following projections and alternatives have been analyzed:

- Baseline: Current status
- Projections (for all of these a low, medium and high):
  - Climate Change (temperature, precipitation and potential evaporation)
  - Population growth
  - Macro-economic development
  - Combined
- Alternatives
  - PASB: Planning by Administrative and Sectoral Boundaries (previously called: sectoral interventions)
  - PCB: Planning by Catchment Boundaries (previously called: integrated planning
  - Sub-variants of PASB (7 options)
  - PASB+: Planning by Catchment Boundaries Enhanced (enhanced catchment rehabilitation)
  - PASB-: Planning by Catchment Boundaries Water Saving (reduced irrigation development)
  -

Note that these scenarios (= generic name of a "projection" or "alternative") were evaluated for three time horizons:

- 2023: To reflect results of the first implementation period 2018-2023
- 2030: Target year for the Sustainable Development Goals
- 2050: Distant planning horizon

Combining all these projections, alternatives and time horizons leads to a total of 67 scenarios to be analyzed. The development of projections is presented in the following sections.

The combination of the current situation combined with the projections and the alternatives for the three future time horizons results in a total of 67 scenarios (1 baseline, 36 projections, and 30 alternatives). A consistent naming convention is used to keep track of this quite large number of scenarios:

- First two numbers: sequence
- Second two numbers: time horizon (e.g. 23 = 2023)
- First letters: type of scenario
- Last letters: specifics of scenario

Table 1. Narrative of Projections and Alternatives.

		00_Base	Baseline Current climate, population, economic, landcover
= = = FUTURE = = =	Projections	nn_yy_CC_low	Climate change low impact Lower range temperature and higher range precipitation projections (Rwanda 2nd National Communication)
		nn_yy_CC_med	Climate change medium impact Medium range temperature and medium range precipitation projections (Rwanda 2nd National Communication)
		nn_yy_CC_high	Climate change high impact Higher range temperature and lower range precipitation projections (Rwanda 2nd National Communication)
		nn_yy_Pop_low	Population growth low Lower population growth projection (NISR)
		nn_yy_Pop_med	Population growth medium Medium population growth projection (NISR)
		nn_yy_Pop_high	Population growth high High population growth projection (NISR)
		nn_yy_Eco_low	Macro-economic development low Lower macro-economic development projection (Vision 2050)
		nn_yy_Eco_med	Macro-economic development medium Medium macro-economic development projection (Vision 2050)
		nn_yy_Eco_high	Macro-economic development high High macro-economic development projection (Vision 2050)
		nn_yy_Fut_min	Future minimum water stress Low climate change, low population growth, low economic growth
		nn_yy_Fut_med	Future medium water stress Medium climate change, medium population growth, medium economic growth
		nn_yy_Fut_high	Future high water stress High climate change, high population growth, high economic growth
	Alternatives	nn_yy_Alter_sect	Sectoral approach (ASBBA) Limited implementation and less coordinated alternatives are implmented. No specific catchment rehabilitation.
		nn_yy_Alter_int	Intgrated catchment approach (CBBA) Combination of the 6 seperate alternatives as described below
		nn_yy_Alter_agr	CBBA: Climate smart agriculture only Improved soil quality, improved Irrigation productivity, drought tolerant crops. Double compared to CBBA
		nn_yy_Alter_store	CBBA: Additional water storage capacity only. Double compared to CBBA.
		nn_yy_Alter_irr	CBBA: Irrigation master plan only Based on irrigation master plan.
		nn_yy_Alter_ind	CBBA: Industrial Reuse and reduction in water use for all industry. Double compared to CBBA.
		nn_yy_Alter_cities	CBBA: Urban water management only Reuse and reduction in urban water use.Double compared to CBBA.
		nn_yy_Alter_wp	CBBA: Imrpoved water productivity only Agriculutre, industry, livestock, domestic water producitvty improvements.Double compared to CBBA.
		nn_yy_Alter_inov	Innovative integrated catchment approach (CBBA) With a very strong focus on catchment rehabilitation implementation and additional storage capacity. Full irrigation.
		nn_yy_Alter_full	Full Innovative intgrated catchement approach (CBBA) Same as the normal Integrated approach, but now with limited irrigation to reduce water shortage.

4.2 Projections

4.2.1 Climate Change projection

Climate change might alter supply and demand of water. The Rwanda Second National Communication to the UNFCCC concluded that there is still a large uncertainty in the projections. Based on the best available data and information the following three projections for temperature, two projections for rainfall, and one projection for potential evaporation were derived for 2050. Baseline years used varied between 1971 and 2010.

- For mean temperature three projections show that an increase by 1.3ºC (two projections) and 1.9ºC are forecasted.
- For precipitation two projections were described as potential possible. One projection forecast that annual average rainfall will increase by 59 mm/y, the other forecasts a decrease by 59 mm/y. However both scenarios are consistent in projecting an in increase in the wet season and a substantial decrease during the dry season.
- Annual potential evapotranspiration is expected to increase by 11% by 2050.

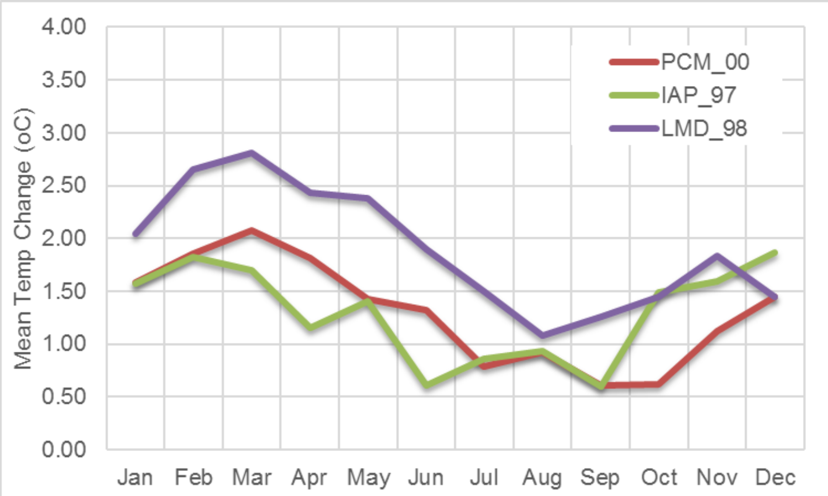


Figure 18. Projected increase in mean monthly temperature according to three GCMs. Source: Rwanda Second National Communication to the UNFCC.

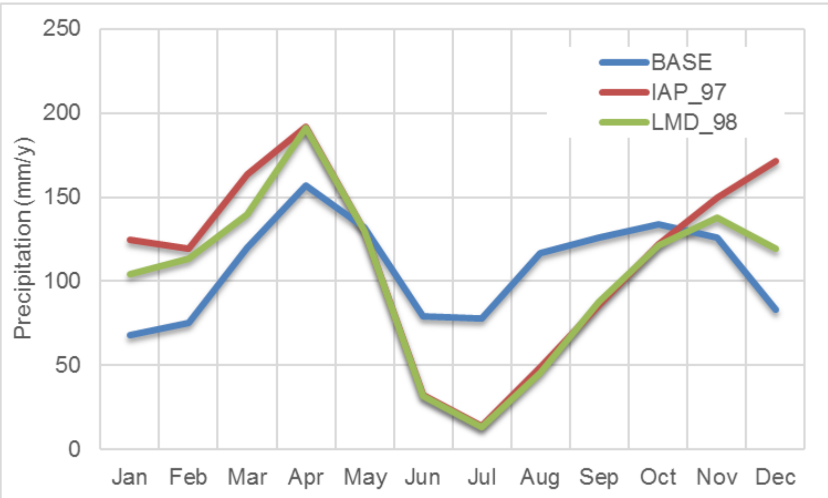


Figure 19. Projected changes in monthly precipitation according to two GCMs. Source: Rwanda Second National Communication to the UNFCC.

4.2.2 Population growth projections

Changes in population as well as percentage of people living in rural areas will have an impact on water demands. Data of these forecasts were obtained from Fourth Population and Housing Census, Rwanda, which was published in 2014 by Ministry of Finance and Economic Planning, National Institute of Statistics of Rwanda. Forecasts were provided up to the year 2032. Data for the year 2050 was obtained by extrapolating the records of 2023 and 2050. This extrapolation was checked by considering UNDP numbers which show a medium forecast of 21.2 million and a range between 19.1 and 23.5 million.

Table 2. Population growth according to National Institute of Statistics of Rwanda.

	High	Medium	Low	Urban (%)
2023	13,688,000	13,547,000	13,135,000	24.0
2030	16,151,000	15,711,000	14,897,000	28.6
2050	23,393,000	21,923,000	19,960,000	42.2

4.2.3 Macro-economic projections

Projections on economic growth are taken from the Vision 2050 as presented by the Ministery of Finance and Economic Planning, December 2016. All numbers are considered as present value US dollars.

Table 3. Economic development according to Vision 2050 (Ministery of Finance and Economic Planning, December 2016).

Growth Scenario required	Year 2035 target income	Year 2050 target income
Current average growth of 6.5%	Low middle income of $1,487	Low middle income of $2,938
8% growth on average	Low middle income of $1,893	Upper middle income of $4,617
High Growth above 10% on average	Upper middle income above $4,035	High Income above $12,476

There is some inconsistency in those numbers as the growth scenarios given in percentages do not match the numbers given in US Dollars. For example, current GDP per capita is US$ 697 (2015). With an average growth rate of 8% this will lead to a GDP per capita in 2050 of US$ 10,305 (697*1.08^35), while the table provides a number of US$ 4,167. It was therefore decided not using the percentages but the actual numbers given in US$.

4.3 Alternatives

The Projections as explained above can hardly be influenced by decision makers in the water sector. This in contrast to Alternatives (sometimes referred to as interventions, adaptations, or implementation scenarios) where water decision makers and planners can and should play an important role. The number of Alternatives is virtually unlimited and in the current study some broad-scale Alternatives has been analyzed. Obviously, the WEAP models developed can be adjusted relatively easily to analyze other Alternatives. The following Alternatives have been analyzed and results are presented and discussed for each demonstration Catchment.

- **PASB**: Planning by Administrative and Sectoral Boundaries
    - Continuation of planning and implementation as usual – no integrated water resources management or catchment planning and coordinated implementation. All sector ministries, agencies, and districts, as well as private sector and NGOs implement existing plans in relative isolation. Measures planned run into circa 2020 at maximum. Limited implementation and less coordinated alternatives are implemented. No specific catchment rehabilitation.
    - In WEAP implemented by: (i) no specific catchment rehabilitation will take place (slopes, infiltration capacity, soil water capacity unchanged), (ii) some minor water savings in irrigation (93% of baseline), (iii) some minor implementation of drought resistance crops (Kc 93% of baseline), (iv) minor savings in industry and domestic water demand (95% of baseline), (v) minor overall improvement of water productivity (5%), (vi) implementation of irrigation master plan by 50% in 2023, 100% in 2030 and even 50% more in 2050.

- **PCB**: Planning by Catchment Boundaries
    - The catchment plans are developed in a participative and vertically and horizontally integrated manner, resulting in a coherent program of measures for each sub-catchment. Implementation is coordinated between implementing agencies, with support of the Catchment Coordination Office and overseen by RNRA and Catchment Task Forces. Potential maps are used to assess economic development potential.
    - In WEAP implemented by: (i) catchment rehabilitation will take place (more pronounced terraces, infiltration capacity and soil water capacity higher), (ii) water savings in irrigation (85% of baseline), (iii) implementation of drought resistance crops (Kc 85% of baseline), (iv) savings in industry and domestic water demand (85% of baseline), (v) overall improvement of water productivity (10%), (vi) additional water storage, (vii) implementation of irrigation master plan by 50% in 2023, 100% in 2030 and even 50% more in 2050.

- **PCB+**: PCB with strong catchment rehabilitation component
    - Same as the normal PCB but here specific emphasis on catchment rehabilitation.
    - In WEAP implemented by using same parameters as PCB, but with more pronounced terraces, infiltration capacity and soil water capacity higher.

- **PCB-**: PCB with reduced irrigation development
    - Same as the normal PCB but here with limited implementation of the irrigation sector.
    - In WEAP implemented by using same parameters as PCB, but with irrigation development of only 50% of the irrigation master plan.

In order to better understand the relative impact of the PCB Alternatives, additional analyzes have been undertake where only one component is considered and at a more pronounced implementation level:

- PCB_agr: PCB explored by focus on Climate Smart Agriculture only. Only the climate smart agriculture component of PCB is considered to be implemented and in a more intensive way.

- PCB_store: PCB explored by focus on additional water storage only, and in a more intensive way.
- PCB_irr: PCB explored by focus on water savings in irrigation only.
- PCB_ind: PCB explored by focus on water savings in the industrial sector only.
- PCB_cities: PCB explored by focus on water savings in the domestic sector only.
- PCB_wp: PCB explored by focus on increasing water productivity only.

4.4 Criteria

In order to evaluate the impact of these Projections and Interventions a set of criteria has been used. The following criteria were used for this:

- Water Demand
  - Total demand for domestic, industry, livestock and irrigation (MCM/y)
- Water Shortage
  - Water shortage based on water demand for the specific scenario (MCM/y)
- Water Short Months
  - Number of months over 10 years where water shortage occurs (nr)
- Evaporation Demand
  - Demand of entire landscape, including rainfed, excluding irrigation (MCM/y)
- Evaporation Shortage
  - Shortage (MCM/y)
- Average Flow
  - Average mean flow over 10 years leaving the basin (MCM/y)
- Peak Flows
  - Highest flow over 10 years (MCM/y)
- Low Flows
  - Lowest flow over 10 years (MCM/y)
- Fast Runoff
  - The fast (surface) runoff (MCM/y)
- Slow Runoff
  - The slow (base) flow (MCM/y)
- Groundwater Recharge
  - Groundwater recharge (MCM/y)

Obviously these criteria should be considered as the starting point for evaluating the projections and alternatives. The WEAP model offers a virtually unlimited amount of outputs that can be used to analyze current and future water balances and allocations.

5 Muvumba Catchment: Water Balance and Allocation Modeling

5.1 Background

Located in the Kagera sub basin, the Muvumba catchment is part of the most upstream parts of the Nile Basin, with its ultimate outflow into the Mediterranean Sea. The Muvumba Catchment finds its source in Rwanda on the Mulindi River that is located in the mountainous and high rainfall central northern part of the country at an altitude of 2030 m. The Mulindi River flows North over a length of 22.5 km to Uganda onto a flat wetland zone near Kabale from where a complex flow pattern originates that ultimately joins the Muvumba River before it eventually flows back into Rwanda. The length of the Muvumba river in Rwanda is about 56 km. Just south of Nyagatare the Ngoma River with a number of tributaries contribute their flow to the Muvumba River which flows in a north easterly direction to follow the border between Rwanda and Uganda before finally joining the Akagera River where the borders of Uganda, Rwanda and Tanzania meet.

A more detailed description of Muvumba can be found in the see Catchment Plan Report.

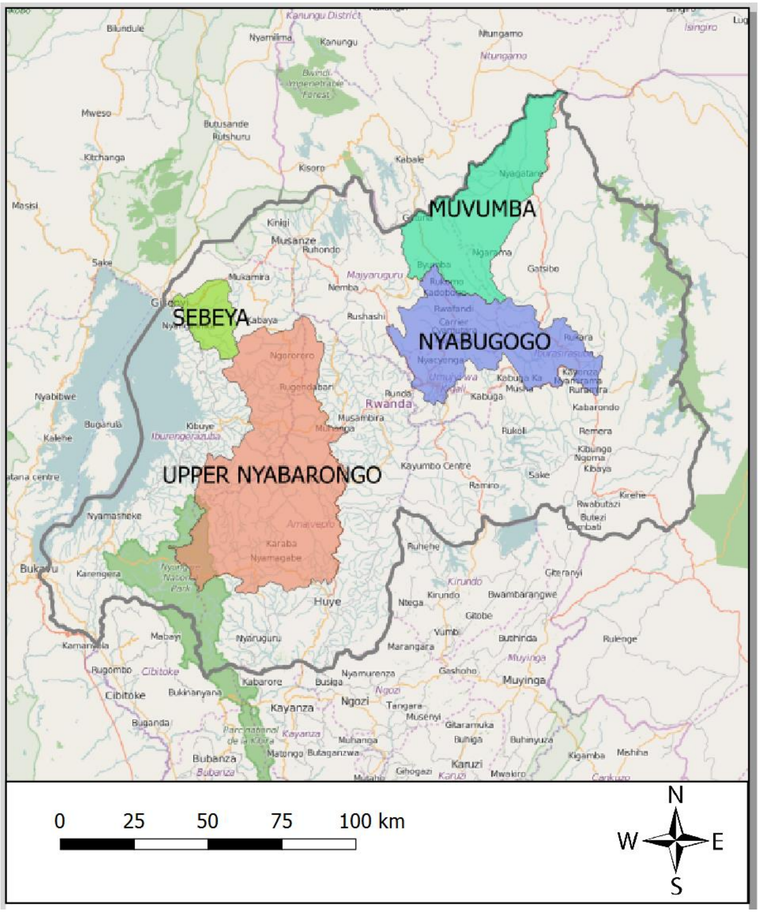


Figure 20. The four demonstration catchments of the Water for Growth Rwanda program.

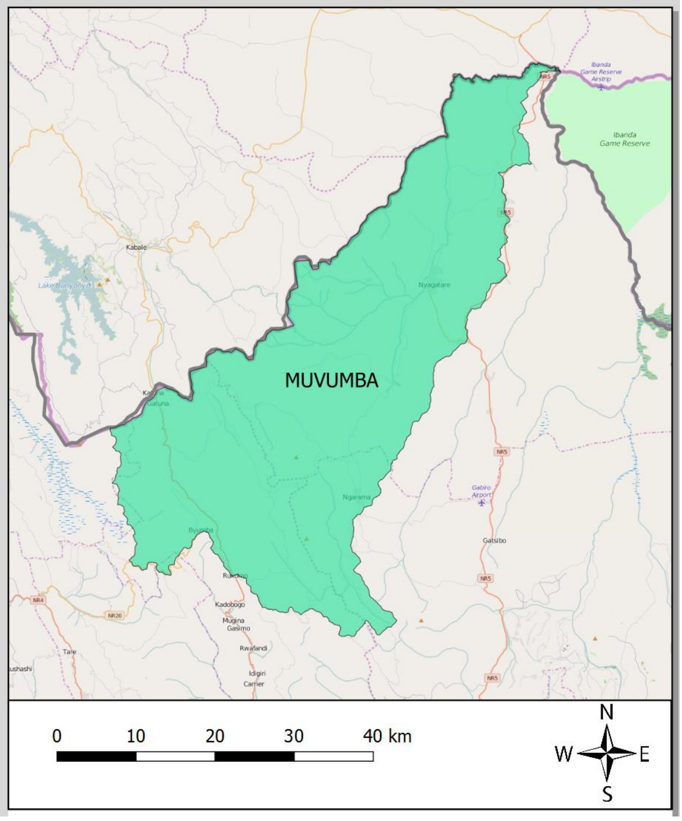


Figure 21. The Muvumba Catchment in northern Rwanda.

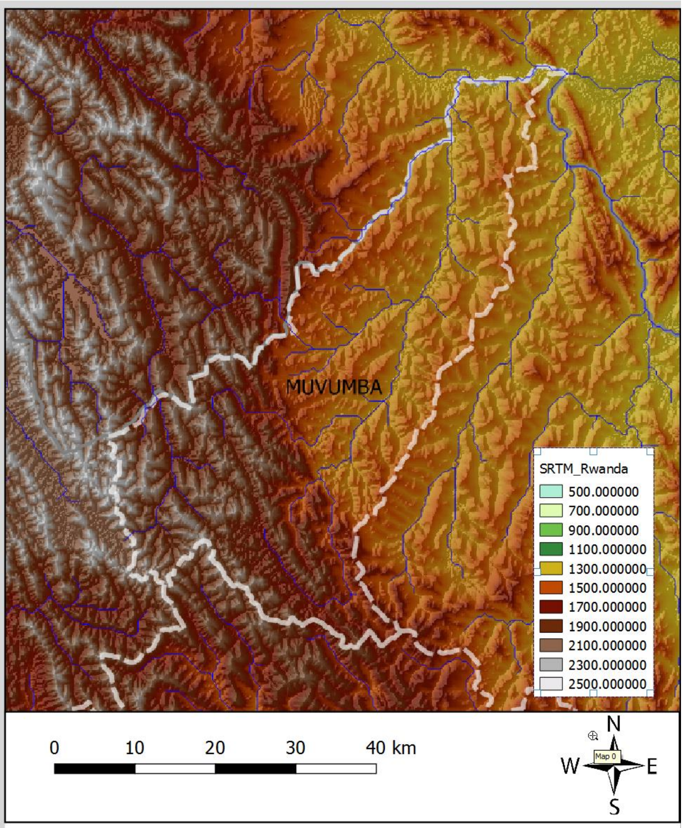


Figure 22. Elevation of the Muvumba Catchment (in MASL).

5.2 Model development

5.2.1 Schematization

5.2.1.1 Catchments

The Muvumba catchment has been divided into sub-catchment to be used in WEAP. The number of sub-catchments should be large enough to characterize the main features in the catchment, but small enough to have output at a level suited to the project requirements. In general a number of around five is sufficient. Each sub-catchment is divided into 14 land use classes, making a total of 52 units within the catchment.

Rwanda distinguishes four levels of Catchment planning. For the Muvumba catchment the following number of sub-catchment at each level are:

- Level 1: 1 sub-catchment
- Level 2: 2 sub-catchments
- Level 3: 52 sub-catchments
- Level 4: 399 sub-catchments

It can be concluded that working at Level 2 does not provide the level of detail required for the schematization of WEAP. However, also the Level 3 sub-catchment will not work as for this the level of detail (52 sub-catchment) is too much for the specific project needs. It was therefore decided to create an in-between level by using the SRTM DEM as input and vary the number of so-called "Minimum size of exterior watershed basin". For the Muvumba catchment a minimum size of 50,000 pixels resulted in 5 sub-catchments and was used as schematization for WEAP. This schematization was used for initial calibration, validation and scenario analysis.

During an expert-knowledge driven approach, it was decided to change sub-catchment boundaries to ensure a better linkage with existing and future planning procedures. This process resulted in a delineation existing out of five sub-catchments that can be seen in Figure 22.

5.2.1.2 River network

The river network of Muvumbu catchment is quite complex (for details see Catchment Plan Report). In WEAP this river network is incorporated by defining so-called River Nodes. A total of five River Nodes have been included in the model:

- Muvumba: the stream that enters from Uganda and flow north and eventually flows into the Kagera at the Rwanda-Uganda-Tanzania border.
- Mulindi: the upper tributary in Catchment E that flows through Uganda and feeds into the Muvumba
- Ngoma: stream in Catchment D that flows into the Karungeli
- Karungeli: stream in Catchment D that flows into the Muvumba just west of Nyagatare
- Riv_01: a small stream located in the northern Catchment A
- Maziba: stream located in the Ugandan part of the Muvumba

5.2.1.3 Groundwater Node

For each sub-catchment a so-called Groundwater Node is defined. For each Groundwater Node recharge is calculated by WEAP and abstractions are based on the demand of users and the actual storage.

5.2.1.4 Demand Nodes

For each sub-catchment four so-called Demand Nodes are defined. Each demand node has a specific water user: domestic, industry (including mining), livestock, and irrigated agriculture. For domestic a sub-division between urban and domestic has been made. These water users can take water from surface water and from ground water. Since the Muvumba Catchment is a transnational basin (Uganda and Rwanda) also the main water user in the Uganda part of the catchment, Kabele town, is included. The 2014 national population census conduced in August, put the population of Kabale at 49,667. The Maziba stream in Uganda that enters the Mulindi just west of Kabele has been included as well. Since the Uganda part of the Muvumba was not explicitly modelled, it was considered that the Mulindi sub-catchment can be used as proxy for the runoff. Given the difference in size of these catchments a factor of two was added to the generated flow from Mulindi sub-catchment to represent the Uganda part.

For each sub-catchment four so-called Demand Nodes are defined. Each demand node has a specific water user: domestic, industry (with four sub-sectors), livestock, and irrigated agriculture. For domestic a sub-division between urban and domestic has been made. These water users can take water from surface water and from ground water.

Water demand per sector is taken from various sources such as Catchment Plans, National Water Resources Master Plan, Irrigation Master Plan and various data sources collected during the project. More importantly, expert knowledge was used to get the best estimates of water demand by various sectors. It is important to realize that if better data are available, these can be easily incorporated in the existing WEAP model (using the Key Assumptions approach).

In November 2016, a Water Users' Survey was carried out to get an overview of the water usage in each of the four studied catchments. The observed water users in this survey are: coffee washing stations, hydropower plants, water treatment plants, mineral extraction sites, dams, irrigation schemes, fishing farms, industries and land parcels above 100 ha. Incorporating the data from this survey in WEAP support a well-founded and transparent view on the water allocating dynamics in each (sub-)catchment.

For domestic use, the water intake is expected to vary somewhere in the range of 40-80 L/cap/day. However, according to the Water Use Survey daily water intake per capita ranges between less than 2 L/cap/day for Muvumba up to 851 L/cap/day for Upper Nyabarongo. Possible explanations for these large differences in domestic water use between catchments could be the survey's inability to quantify small water using intakes for personal use and to focus mainly on large water users. Also, it might be possible that the large water intake for domestic use in the Upper Nyabarongo could to some extent be transported to other areas balancing the mutual differences between the catchments. As the Water Users' Survey appears to contain large uncertainties for domestic water consumption, it was selected not to use data from the Water Users' Survey for domestic use at this moment. Obviously if improved data might become available these can be easily incorporated in WEAP.

Instead, for domestic water demand the numbers from the Catchment Plan are used indicating that rural water demand is 40 l/cap/d and for urban 60 l/cap/d. Based on expert knowledge this number was considered outdated. Therefore in the WEAP model rural water demand was set at 80 l/cap/d and for urban 100 l/cap/d.

Some inter-catchment transfer happens in Muvumba. Gicumbi town is supplied by Nyamabuye and Nyamabye water treatment plants. Nyagatare town is supplied by Cyondo water treatment plant. These transfers have been included in the WEAP model.

Industrial water demand including mining is according to the National Water Resources Master Plan (p. 125) 3 l/cap/d. This number is outdated and data from the recently completed Water Users' Survey have been used. Exact distinction between various industrial uses was not completely clear from the data set. However, distinction between mining and other industrial use could be derived. The current version of the Water Users' Survey did not include sufficient records for the Muvumba basin. It was therefore decided to use results from the other demonstration catchments. Since it is known that industrial activities are quite low in Muvumba compared to the other demonstration catchments, water use was set at halve of the lowest values of one of the other catchments. The following data based on the Water Users' Survey were derived and used in the WEAP model for Muvumba:

- Mining: 36 l/cap/d
- Coffee washing: 17 l/cap/d
- Tea factories: 9 l/cap/d
- Other: 9 l/cap/d

Data on water demand for irrigation varies substantial between different sources. It was therefore decided to follow the overall figures as mentioned in NWRMP similar to the approach in the Catchment Plans. The average irrigation water demand depends on the type of irrigated land. Marshland irrigated areas requires between 200 and 250 mm irrigation per year, while hill side irrigated areas require 600 to 800 mm irrigation per year. These numbers were obtained from the National Water Resources Master Plan (p. 107 and 108). Obviously, if better estimates will become available, these can be used in an updated version of the model. Total irrigated areas where derived from the land use map. However, distinction between whether these areas are marshland or hill-side irrigated is not known. Therefore this distinction was done by taking the slopes in each sub-catchment. It was considered that if slopes are steeper than 10 degrees, hill-side irrigation is applied. Since average slopes for each sub-catchment were used, a linear interpolation was used (marshland% = 150 -10*slope). Field visits might be necessary to obtain a more accurate estimate for this. Obviously, if more detailed data will become available, this can be easily implemented in the existing WEAP model.

Water consumption by livestock is considered as well in the WEAP model, given the importance in many parts of Rwanda. The National Water Resources Master Plan (p. 105) states however that "… the record of animals per administrative unit is notoriously inaccurate". Number of animals was therefore derived from the rural population. It was assumed that for each 5 people one animal (excluding chickens) is present. Water consumption was taken as 25 l/head/day. Obviously, if more accurate date will become available, these can be included in the model. Field visits might be required to get more accurate data.

Environmental flow requirements are defined according to the National Water Resources Master Plan (p. 143) as fraction of the total demand compared to "water surplus" in a particular month. A fraction of 1/3 was used. This so called "water surplus" is the "non-demanded" water. To translate this kind of cryptic wording one could say that the environmental flow requirement is not met as the total demand is more than 2/3 of the available water resources in a particular month. As example: if total water resources in a month are 100 MCM, environmental flow requirements are not met if demand in that month exceeds 66 MCM. Interesting in this definition is that the flow in a river is not considered as a criterion.

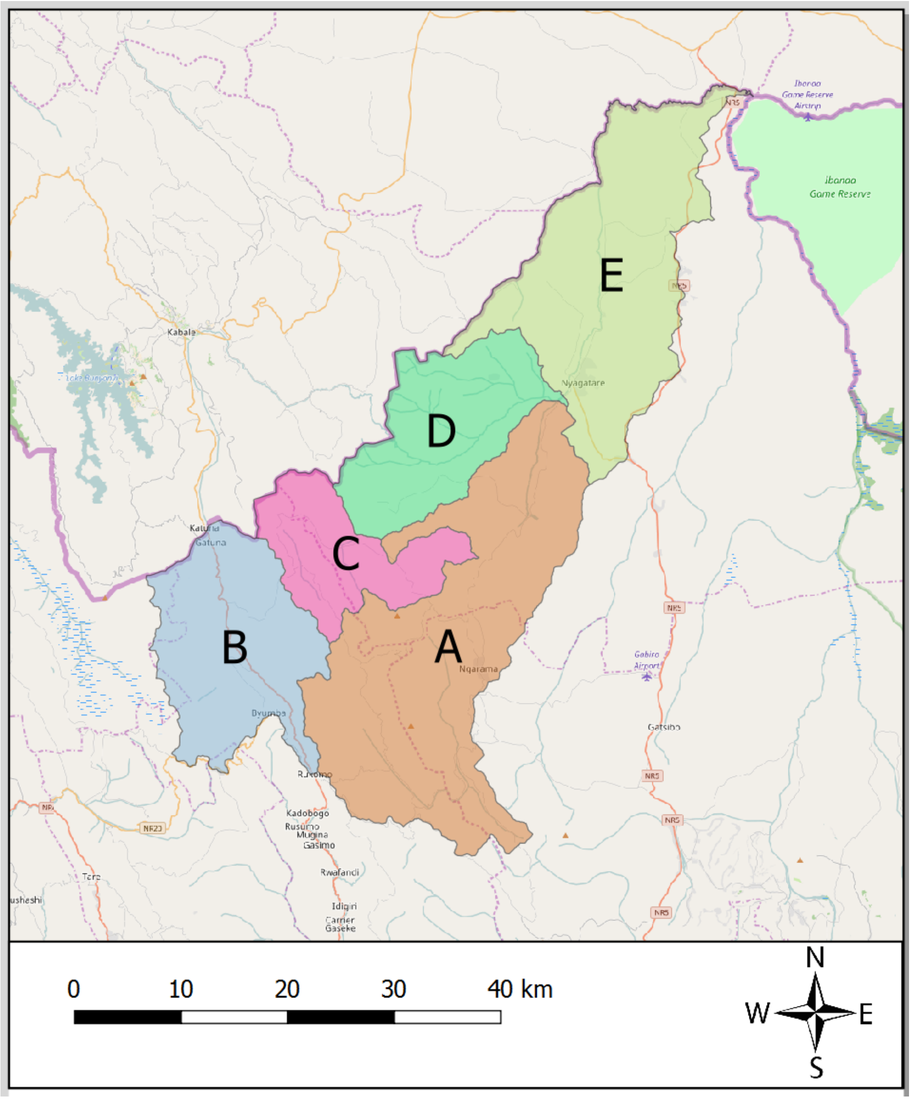


Figure 23. The five sub-catchments in Muvumba as used in the WEAP model.

5.2.2 Land cover

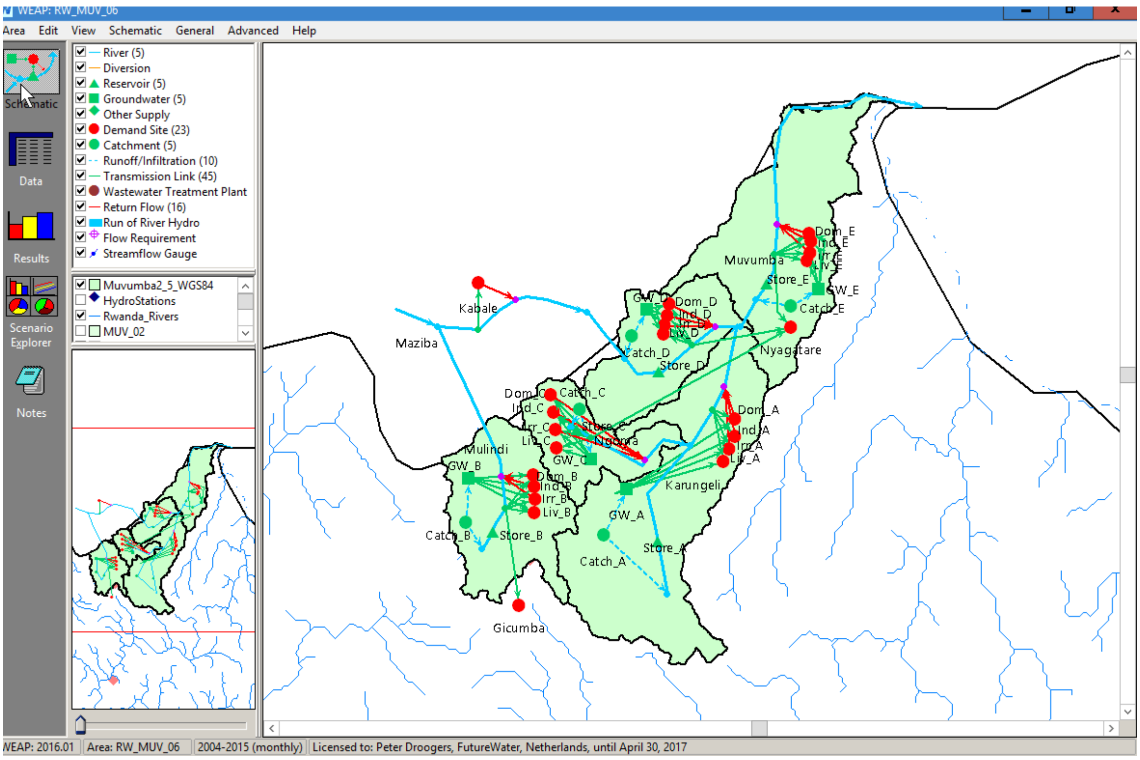
Land class data is used in WEAP to simulate the hydrological relations between the soil, the atmosphere and runoff. For the WEAP models a list of 14 land cover classes is used:

- Agroforestry with progressive terraces
- Agroforestry with radical terraces
- Agroforestry without terraces
- Forest
- Grassland
- Irrigated marshland
- Irrigated hillslope

- Progressive terraces without agroforestry
- Radical terraces without agroforestry
- Rainfed agriculture
- River buffer zones
- Shrubs
- Urban
- Wetlands

A land cover map of Rwanda in 2015 is provided by the RNRA and used to calculate the land cover areas per sub-catchment. As information on terraces and irrigation is lacking from this map, these are added separately. A Google Earth analysis has been performed to quantify the currently terraced areas. Terraces are distinguished in four categories; radical terraces and progressive terraces both either with or without agroforestry. Terraces and agroforestry are forms of soil, water and crop management and therefore will also influence the WEAP soil and water retention characteristics accordingly. Furthermore, the soil and water retention characteristics also varies for each of the remaining land use classes and is stored in the WEAP models respectively.

In WEAP, these characteristics are defined by the root-zone conductivity, soil water capacity, preferred flow direction and the runoff-resistance factor. The runoff-resistance factor controls the amount of water that enters the upper soil layer, the soil water capacity determines the amount of water that can be stored in the upper soil layer and the root-zone conductivity and the preferred flow direction influence the water percolation from the upper soil layer to the deeper soil layer. For example, increasing the terraced area in a sub-catchment will increase the water retention capacity by enhancing the runoff-resistance, the soil water capacity, preferred flow direction and the root zone conductivity.



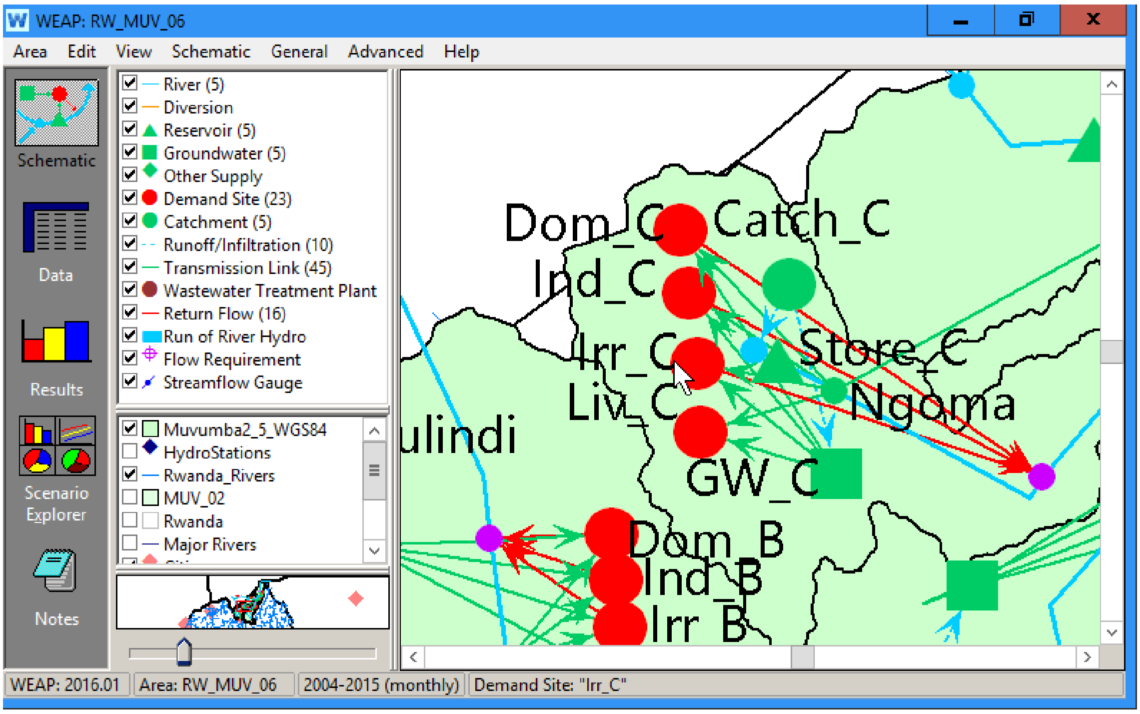


Figure 24. Schematization of Muvumba in the WEAP model. Top: complete model. Bottom: detail for Sub-Catchment C.

5.2.3 Meteorological data

5.2.3.1 Rainfall

Meteorological data and especially rainfall data is essential to develop catchment planning. Quite some data are observed and available for Rwanda. However, recent data is difficult to obtain, spatial coverage is somewhat fragmented, and quality control should be performed. Global initiatives of various research group around the world have resulted in consistent data sets of precipitation, based on using remote sensing, observations and advanced data assimilation techniques. One of the most commonly used and accepted as high quality is the so-called Chirps data set.

CHRIPS is the Climate Hazards Group InfraRed Precipitation with Station data and is a 30+ year quasi-global rainfall dataset. Spanning 50°S-50°N (and all longitudes), starting in 1981 to near-present, CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

Estimating rainfall variations in space and time is an important aspect of drought early warning and environmental monitoring. An evolving dryer-than-normal season must be placed in historical context so that the severity of rainfall deficits may be quickly evaluated. However, estimates derived from satellite data provide areal averages that suffer from biases due to complex terrain which often underestimate the intensity of extreme precipitations events. Conversely, precipitation grids produced from station data suffer in more rural regions where there are less rain gauge stations. CHIRPS was created in collaboration with scientists at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center to deliver reliable, up to date, and more complete datasets for a number of early warning objectives (such as trend analysis and seasonal drought monitoring).

Early research focused on combining models of terrain-induced precipitation enhancement with interpolated station data. More recently, new resources of satellite observations such as gridded satellite-based precipitation estimates from NASA and NOAA have been leveraged to build high resolution (0.05°) gridded precipitation climatologies. When applied to satellite-based precipitation fields, these improved climatologies can remove systematic bias, a key technique in the production of the 1981 to near-present CHIRPS dataset. The creation of CHIRPS has supported drought monitoring efforts by the USAID Famine Early Warning Systems Network (FEWS NET).

The CHIRPS data can be downloaded free of charge from http://chg.geog.ucsb.edu/data/chirps/. Data are delivered for the entire continent at a daily based. Using QGIS and python scripting these data were aggregated to monthly values for each sub-catchment.

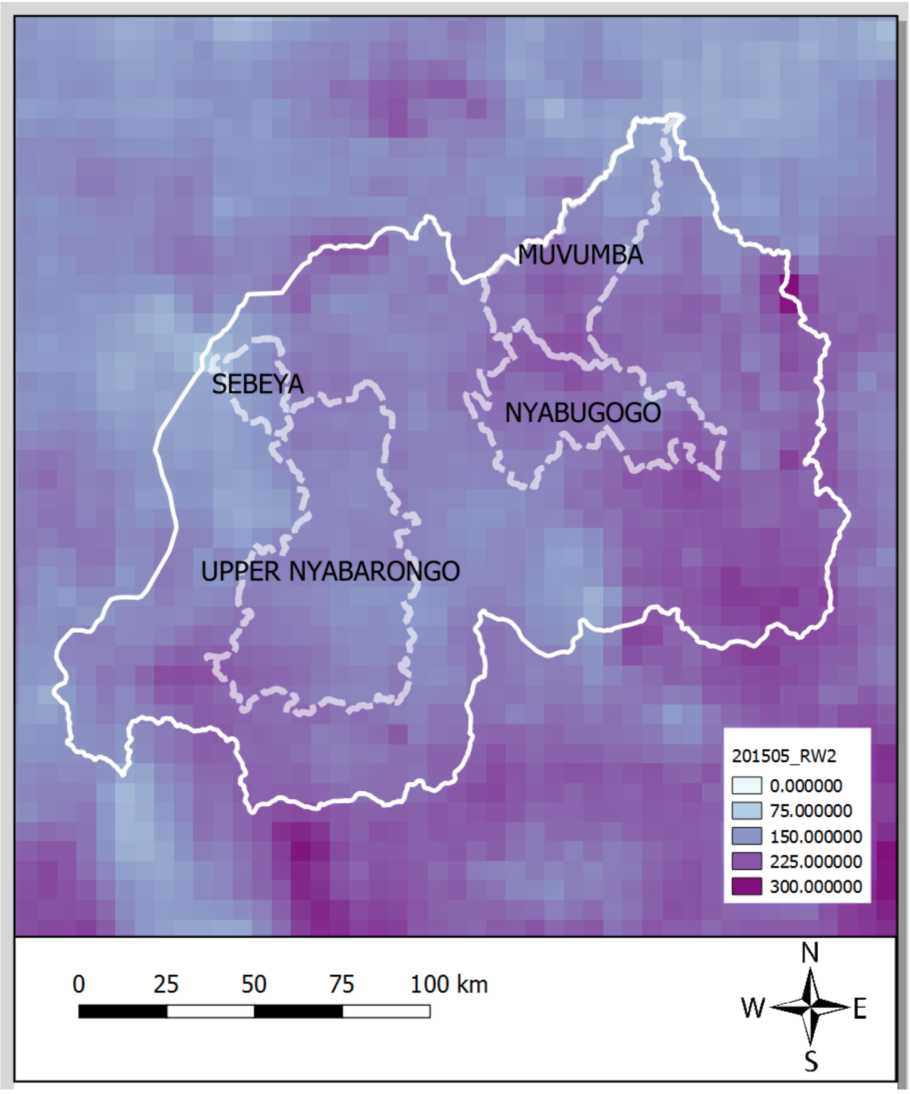


Figure 25. Example of rainfall data derived from the CHIRSP product. Data in mm for Apr-2015.

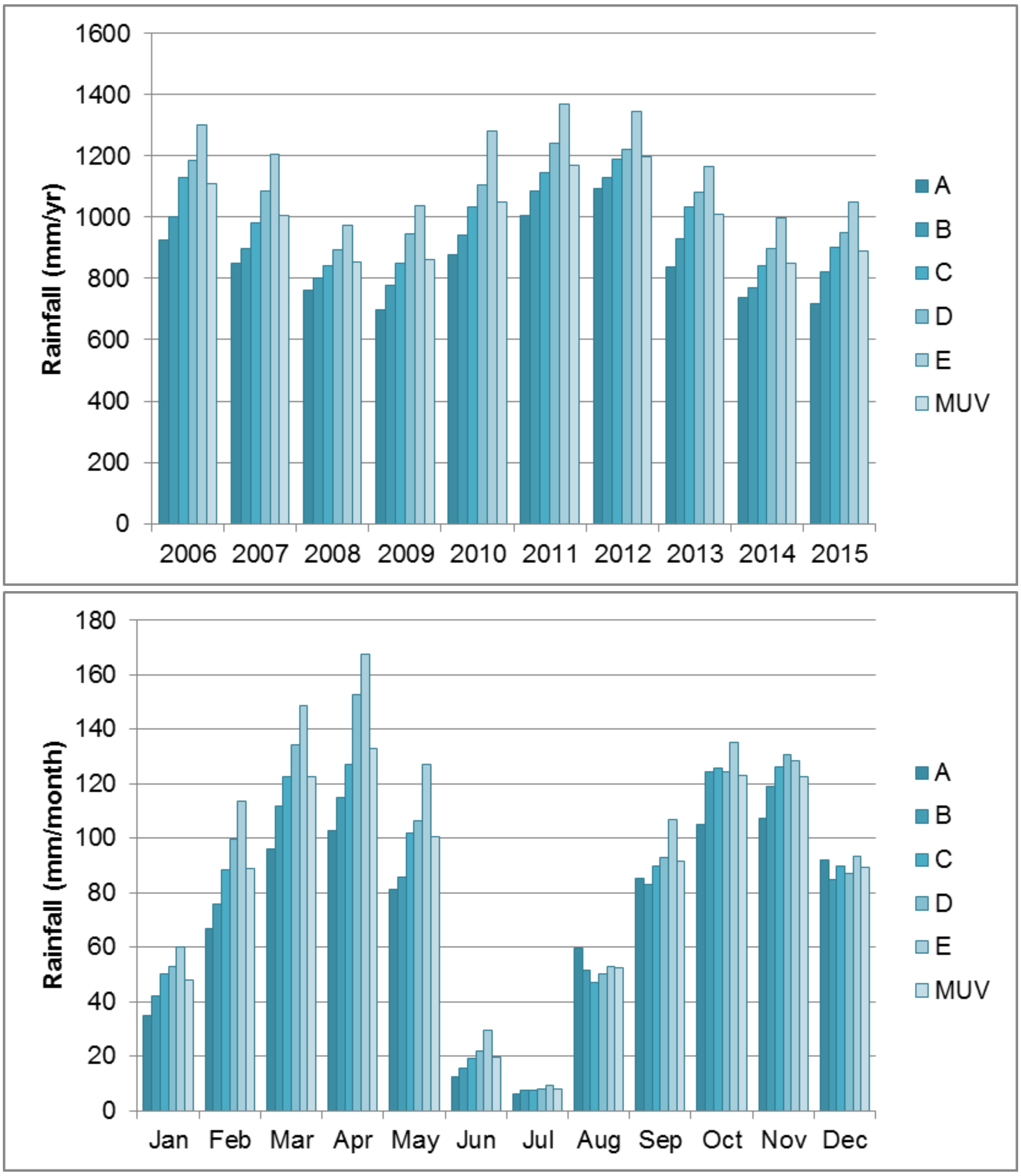


Figure 26. Rainfall data for Muvumba catchment and the five sub-catchments as derived from the CHRIPS dataset. Top: total annual rainfall. Bottom: average monthly rainfall over 2006-2015. A-E are the sub-catchments; MUV is average entire Muvumba Catchment.

5.2.3.2 Other climate variables

The Rwandan climate is quite constant during the year except for the rainfall (as discussed in the previous section). For the WEAP model additional climate data are needed to estimate the potential evapotranspiration. For temperature the average monthly values of Kigali (elevation 1567 MASL) have been used and scaled to the average elevation using a lapse-rate. Lapse rates are in general between 0.6 and 1.0^{o}C depending on the stability of the air and the extent of high elevation plateaus. If air is not completely saturated and no extended plateaus exist a lapse rate of 1^{o}C per 100 meter applies. So taken Kigali elevation as reference the following equation applies: Tcorr (^{0}C) = 15.67 – 0.01*Elevation(m). For relative humidity also the average monthly data for Kigali have been used. Finally, cloudiness fraction has been derived from the monthly average rainfall records, where it was assumed that if rainfall exceeds 100 mm per month cloud fraction is 50%, and with lower rainfall linear scaled to 100%.

Obviously, if additional and more accurate climate data are becoming available, these can be easily included in the existing model.

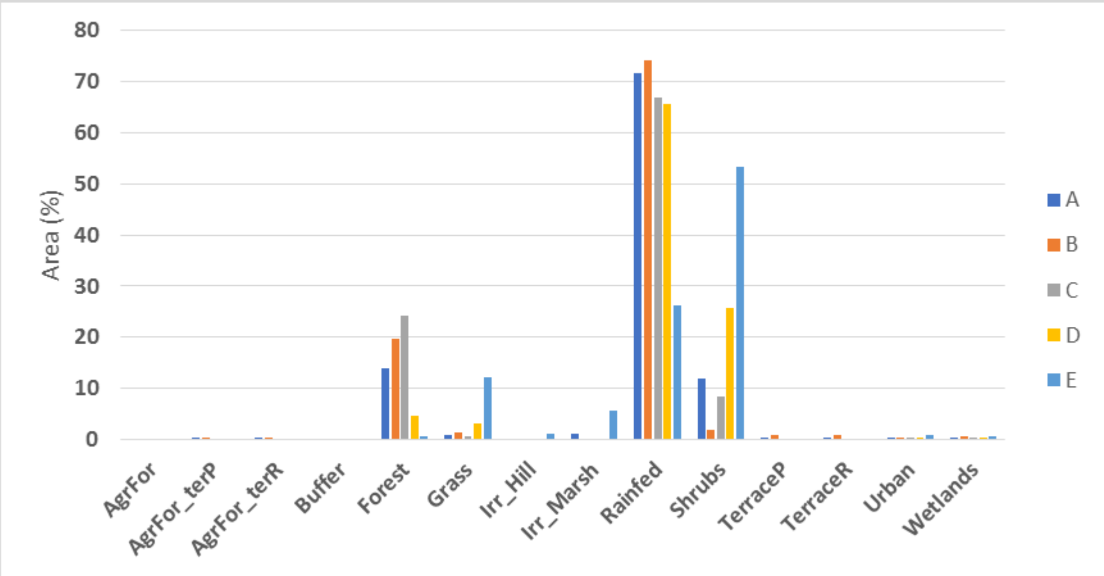


Figure 27. Land cover distribution in the Muvumba sub-catchments.

5.3 Model Performance

The WEAP model has been widely applied in many regions across the globe. WEAP has proven to be a reliable tool for water balance and water allocation analysis. Obviously, quality of a model for s specific area depends completely on the accuracy of the available data. For this specific study it is important to realize the difference between “absolute” accuracy and “relative” accuracy. “Absolute” accuracy relates to how well the model represents reality; “relative” accuracy relates to the accuracy of comparing different scenarios. It has been proven that even if “absolute” accuracy is low, “relative” accuracy can be still high.

Nevertheless, it remains important to assess the performance of the model, even if data is scarce. This has been done using:

- Flow station data
- References such as NWRMP
- ET results from satellite information

For the Muvumba data of four streamflow gauges are available (in brackets average flow):

- Kagitumba (14.2 $m^3 s^{-1}$)
- Ngarama (4.4 $m^3 s^{-1}$)
- Ngoma (2.2 $m^3 s^{-1}$)
- Nyagahanga (0.7 $m^3 s^{-1}$)

Location of these four stations and the associated WEAP River Sections is:

- Kagitumba → Muvumba 18
- Ngarama → Karungeli 8
- Ngoma → Ngoma 2
- Nyagahanga → Karungeli 2

Note that data of these stations are very fragmented and the derived stage-discharge relationships are for some of the stations based on limited data points. For each gauging station the graphs for flows, annual averages and monthly averages have been plotted. From these graphs it is clear that data is erratic in terms of available records as well as sudden unexplainable jumps. Therefore it was decided to focus on the Kagitumba station for evaluating the model performance.

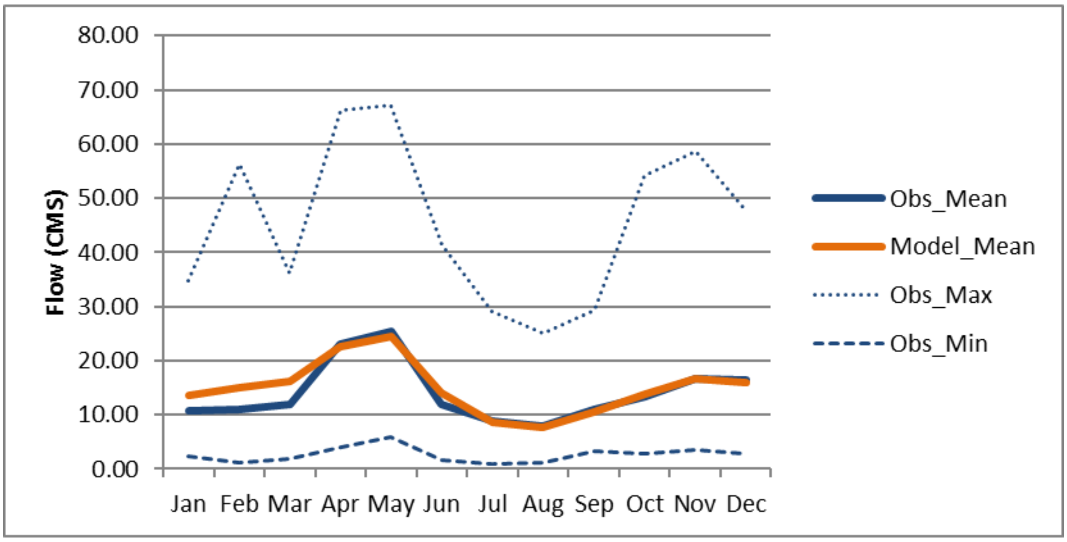


Figure 28. Observed and simulated mean, min and max flow for station Kagitumba.

Table 4. Comparing water balance terms from NWRMP and WEAP model for Muvumba.

	NWRMP	Model		
		AVG	Min	Max
Kagitumba flow (m3/s)	14.4	15.7	11.3	20.4
Precipitation (MCM/y)	1,560	1,615	1,368	1,901
Actual evaporation (MCM/y)	1,367	1,121	1,034	1,229
Surface runoff (MCM/y)	193	368	274	475
Groundwater recharge (MCM/y)	111	124	154	98
Domestic use (MCM/y)	0.9	4.5	4.5	4.5
Irrigation use (MCM/y)	9.7	22.6	20.3	24.9
Industrial use (MCM/y)	N/A	0.3	0.3	0.3
Livestock use (MCM/y)	N/A	23.3	23.3	23.3

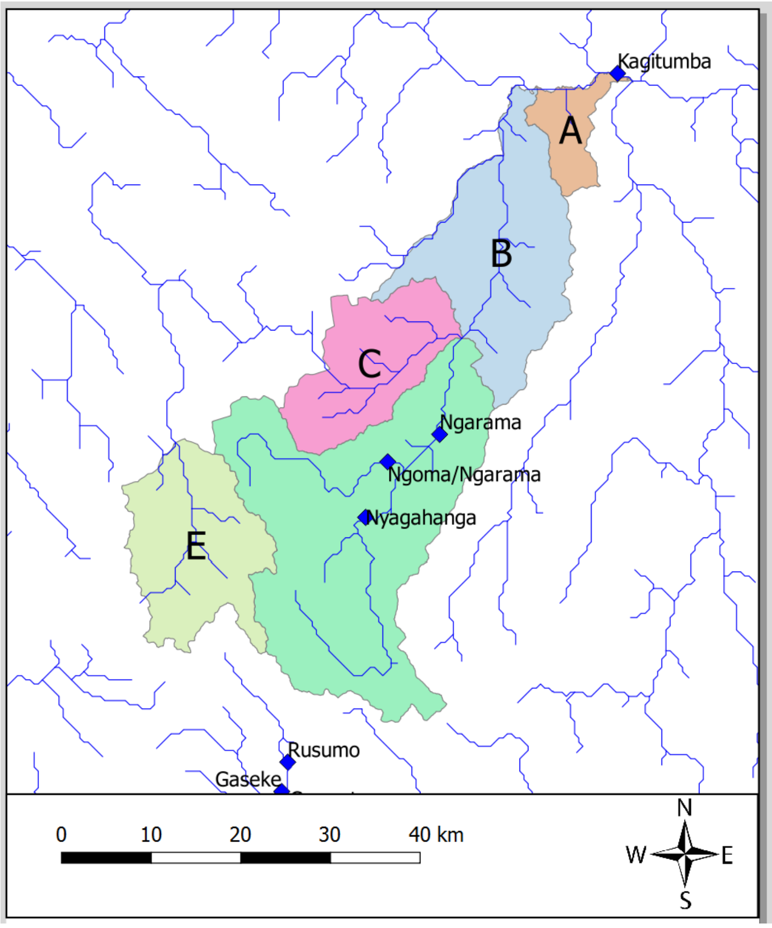


Figure 29. Flow gauging stations in the Muvumba Catchment.

5.4 Current situation

The WEAP model was used to set the Baseline that is used to compare with future Projections and Alternatives. This Baseline can be considered as the current situation and was analyzed by using data and information from a ten years period (2006-2015).

From the following Tables it is clear that most of the available water (= rainfall and inflow from Uganda) is evaporated by vegetation. Outflow from the catchment and groundwater recharge are other important components in the catchment. Interesting is that the so-called manageable water (sometimes referred to as Blue Water) is about 30% of total water resources. Only a small fraction is actually withdrawn for domestic, industry, irrigation and livestock.

These summary tables are essential to understand total water issues in the catchment. However, the WEAP models developed provide a wealth of more detailed information. The two screenshots hereafter on water demand and supply are shown as example of what can be obtained from the model.

Table 5. Summarized water balance for the entire basin for the baseline as 10 years average for the Muvumba catchment.

IN	*(MCM/y)*	**OUT**	*(MCM/y)*
Precipitation	1,543	Evapotranspiration	995
Return flows	13	Withdrawals	30
Storage change	1	Outflow	526
Inflow	198	Groundwater recharge	203
Total	*1,755*	*Total*	*1,755*

Table 6. Summarized water balance for the manageable water components (Blue Water) as 10 years average for the Muvumba catchment.

IN	*(MCM/y)*	**OUT**	*(MCM/y)*
Runoff	39	Domestic	2
Baseflow	303	Industry	9
Groundwater	3	Irrigation	18
Return flows	13	Livestock	1
Inflow	198	Outflow	526
Total	*556*	*Total*	*556*

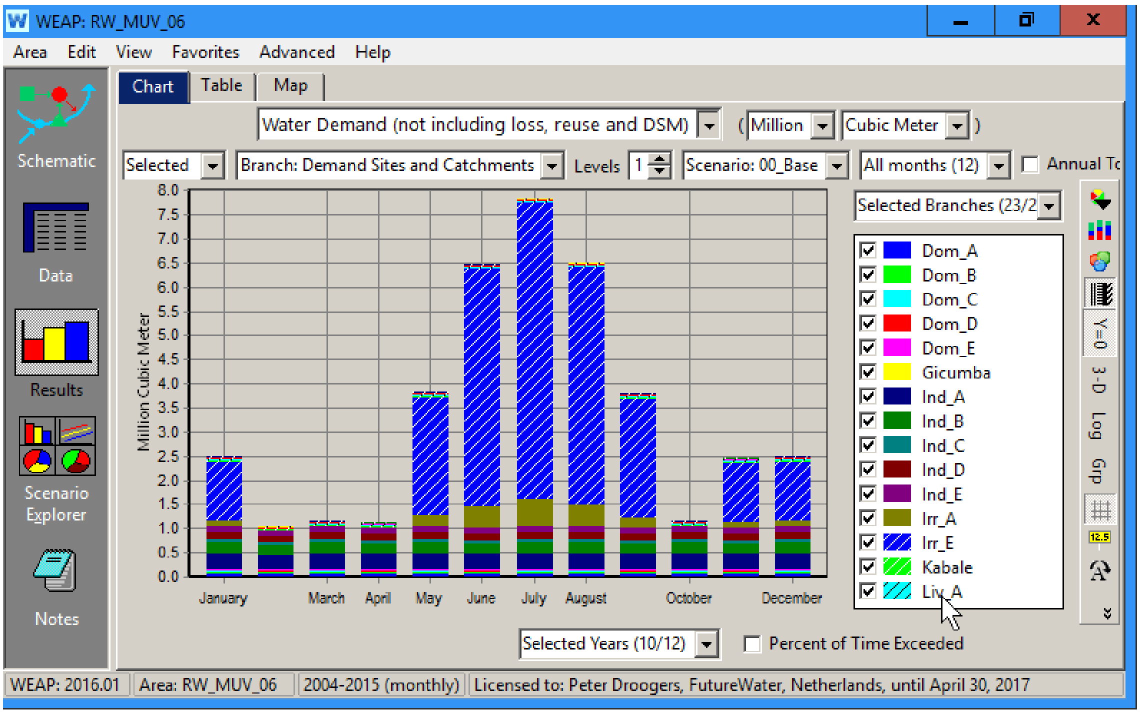


Figure 30. Example of WEAP results for the baseline: monthly average water demand.

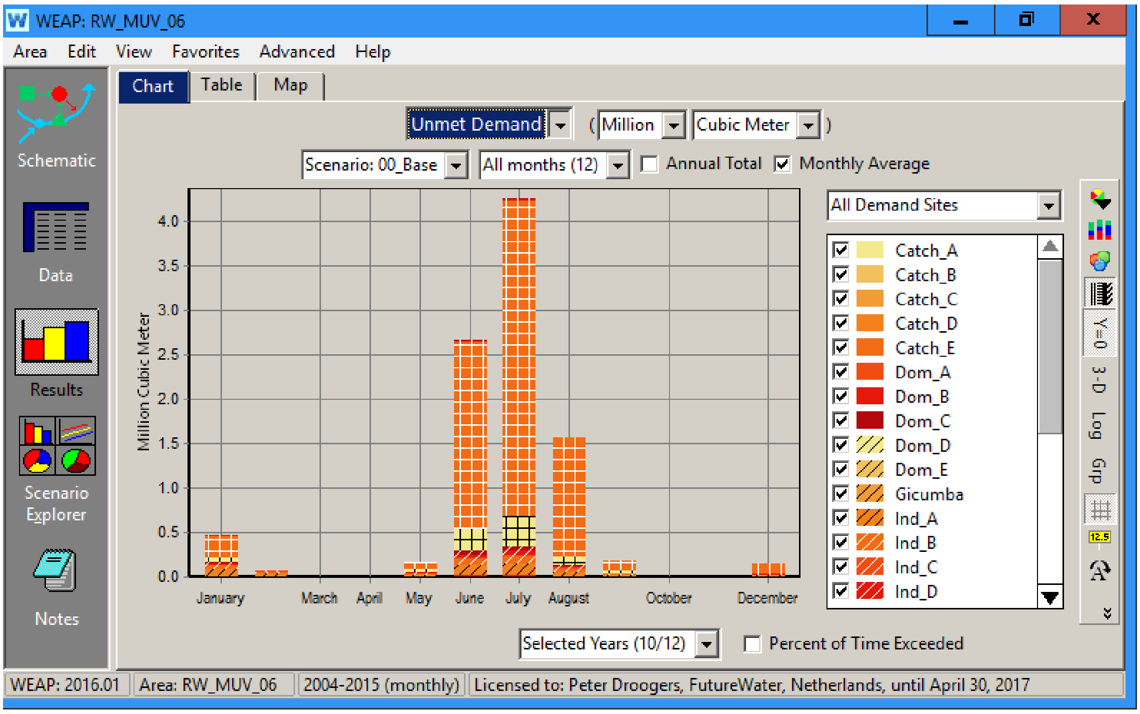


Figure 31. Example of WEAP results for the baseline: monthly average water shortages.

5.5 Future: Projections and Alternatives

5.5.1 Projections

Projections (sometimes referred to as pathways or storylines) are future scenarios that can be hardly influenced by water planners and decision makers. Four different types of Projections were analyzed: climate change, population growth, and macro-economic development. For each of these three Projections a total of three time-horizons were considered (2023, 2030, 2050) as well as a low, medium and high impact projection. Moreover, as these Projections will not happen in isolation also nine combined groups were evaluated (three time horizons x three impacts)

Most important conclusions that can be drawn from these Projections as shown in the as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models.

Most relevant conclusions regarding these projections:

- Water demand is expected to increase substantially in the future: from currently 40 MCM/y to 464 MCM/y in 2050. Since the future has quite some uncertainty in climate, economic growth and population a low and a high-impact projection have been run as well. Result show that water demand by 2030 will be 6 to 8 times higher.
- Water shortage (unmet demand) is expected to increase substantially. Without proper actions taken it is expected that 35% of the demand by 2030 cannot be delivered.
- Streamflow flowing out of the catchment is projected to decrease substantially in the future to average flows of 70% compared to today. Especially low flows during dry months are expected to decrease by around 70%.

Further details and exact numbers can be obtained from the figures below and the appendix. Obviously, the WEAP model itself provide an unlimited number of results and options to plot figures for further analysis.

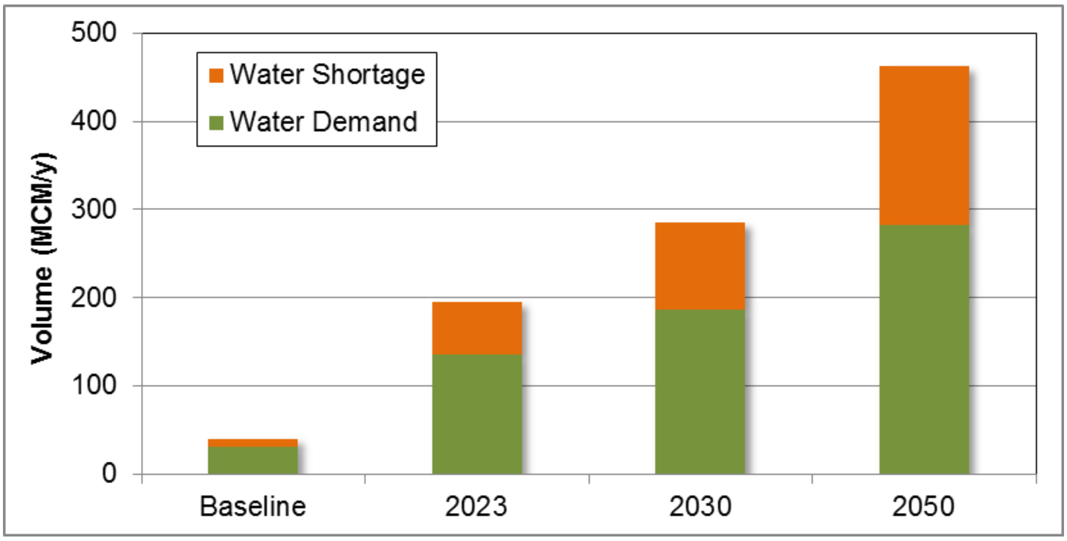


Figure 32. Water demand and shortage for the Muvumba. Results are presented for the medium future projections.

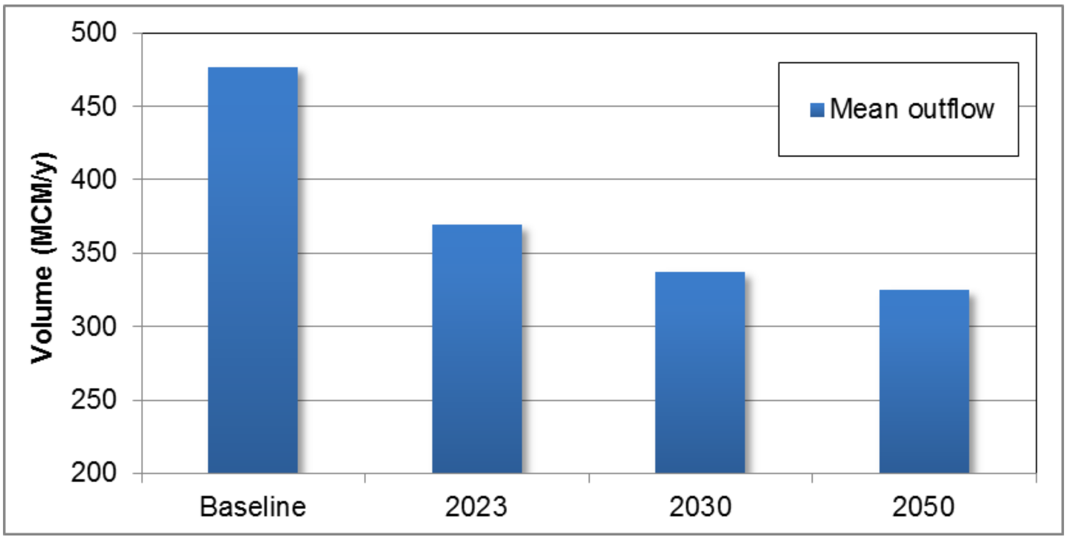


Figure 33. Mean outflow of the Muvumba. Results are presented for the medium future projections.

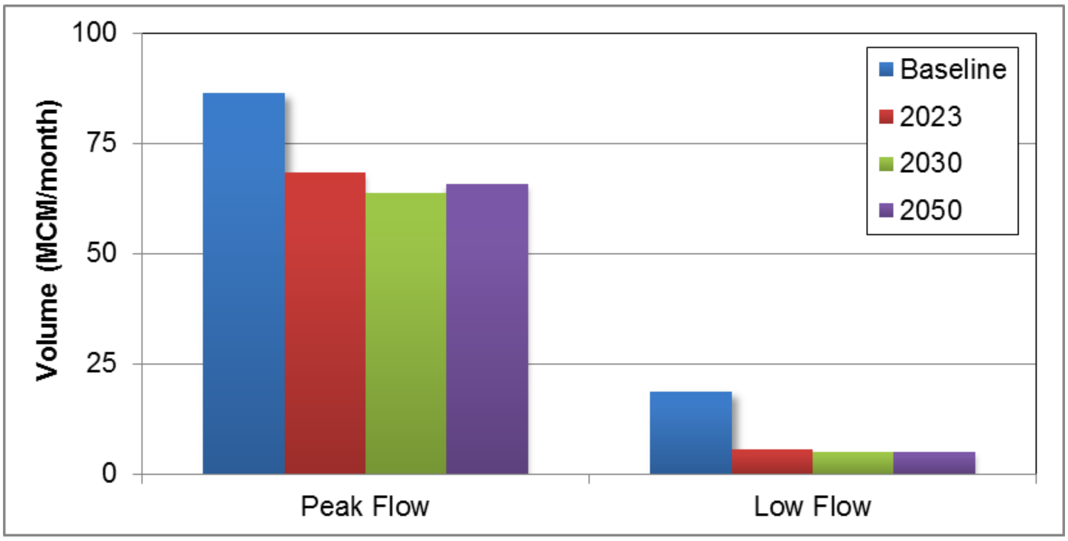


Figure 34. Peak and low flows of the Muvumba. Results are presented for the medium future projections.

5.5.2 Alternatives

In contrast to the Projections as described above are the so-called Alternatives. Alternatives (sometimes referred to as interventions, adaptations, or implementation scenarios) are decisions initiated by policymakers and implemented by water managers that will optimize water resources management. Examples are constructing reservoirs, training farmers, irrigation planning, groundwater permits, erosion control, watershed conservation, amongst many others.

The Alternatives (interventions) are evaluated for 10 different options for each three time horizons. Note that the Table below where percentages and colors are presented is based on the comparing with the Future Medium Projection (and not with the Baseline). This was done as this Future Medium is the selected scenario for climate change, economic growth and population changes. So even for example as for the 2050 Alternative many water demands are green (lower than 100%) this demand compared with Baseline is still much higher.

Most important conclusions that can be drawn from these Alternatives as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models. Main conclusions regarding the results of these Alternatives:

- Most alternatives have a positive impact on the water demand, water shortage, streamflow and catchment hydrology.
- The alternative of Planning by Administrative and Sectoral Boundaries (PASB) is less effective compared to other alternatives, especially in the context of alleviation of water shortages and low flows.
- The alternative Planning by Catchment Boundaries (PCB), and its subs PCB+ and PCB- are the preferred alternatives. PCB- looks the most effective one, but is should be kept in mind that for this irrigation development is quite reduced, having impact on food security.
- PCB+ and PCB- are able to reduce projected water shortages by 50% to 60%.

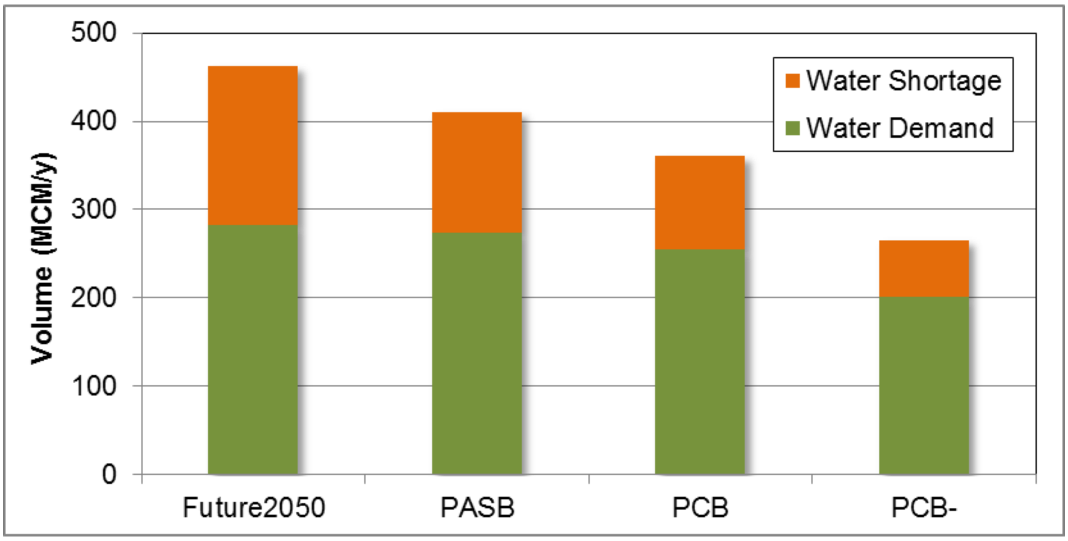


Figure 35. Water demand and shortage for the Muvumba. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

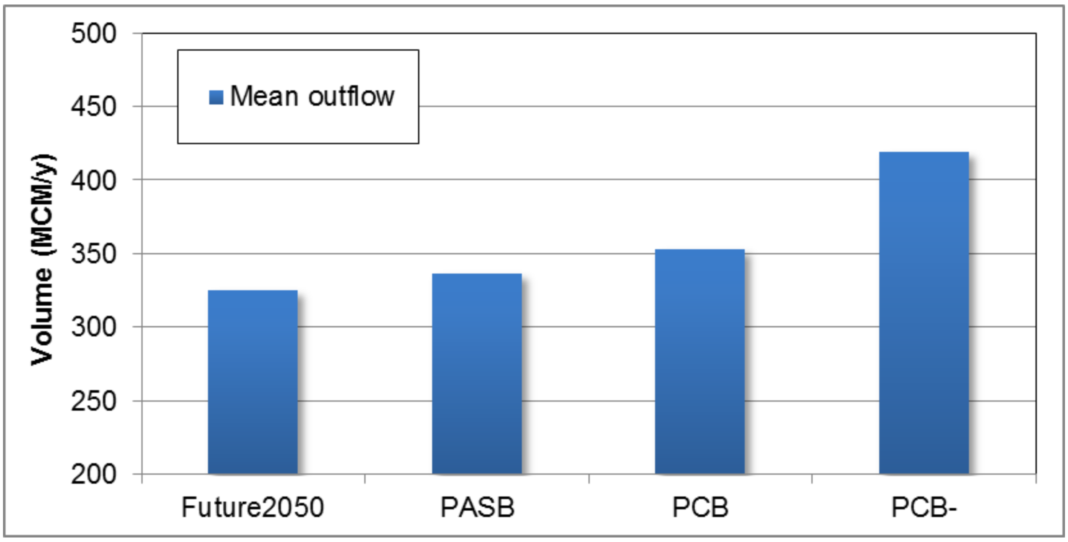


Figure 36. Mean outflow of the Muvumba. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

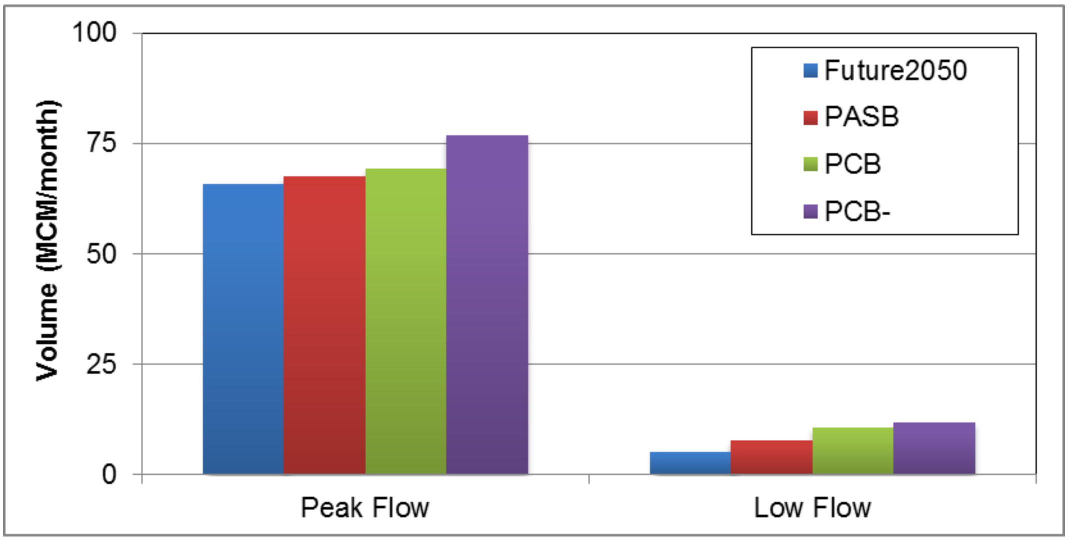


Figure 37. Peak and low flows of the Muvumba. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

6 Nyabugogo Catchment: Water Balance and Allocation Modeling

6.1 Background

The Nyabugogo catchment is part of the Nile basin and a tributary of the lower Nyabarongo River. It is rather centrally located with a wedge extending into the eastern and dryer part of Rwanda. The total surface area of the Nyabugogo catchment is 1662 km² which represents about 6 % of the total surface area of Rwanda (26,338 km² including water bodies). Lake Muhazi, which winds over a length of about 80 km from East to West, is a central feature of the catchment. The Nyabugogo River itself has a length of 46 km from the outflow of Lake Muhazi to its confluence with the Lower Nyabarongo River in the vicinity of Kigali.

A more detailed description of Nyabugogo can be found in the see Catchment Plan Report.

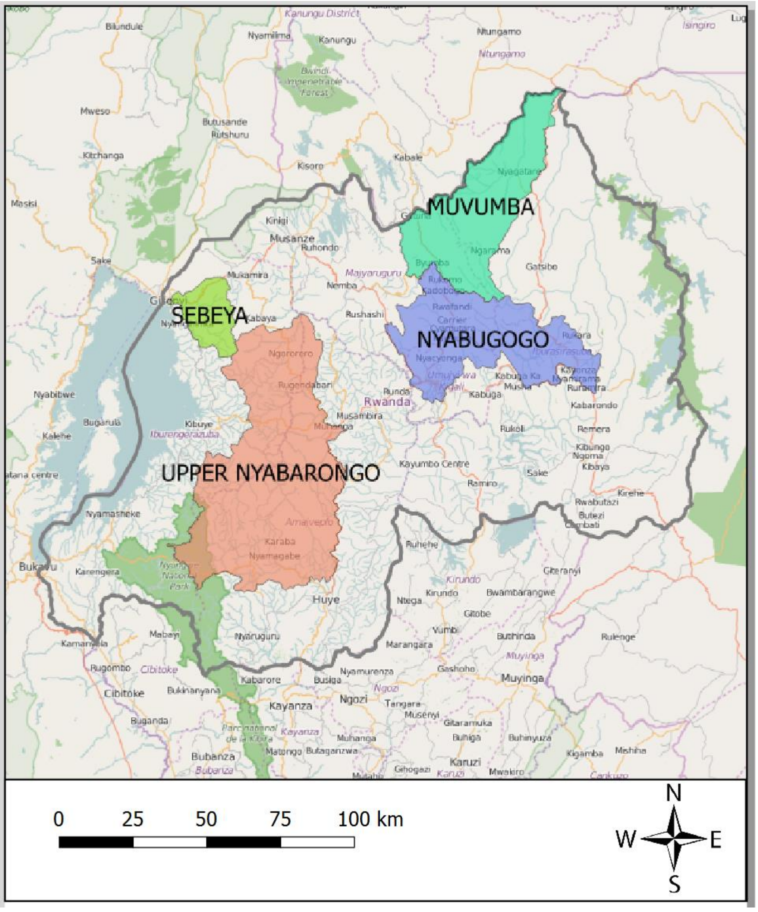


Figure 38. The four demonstration catchments of the Water for Growth Rwanda program.

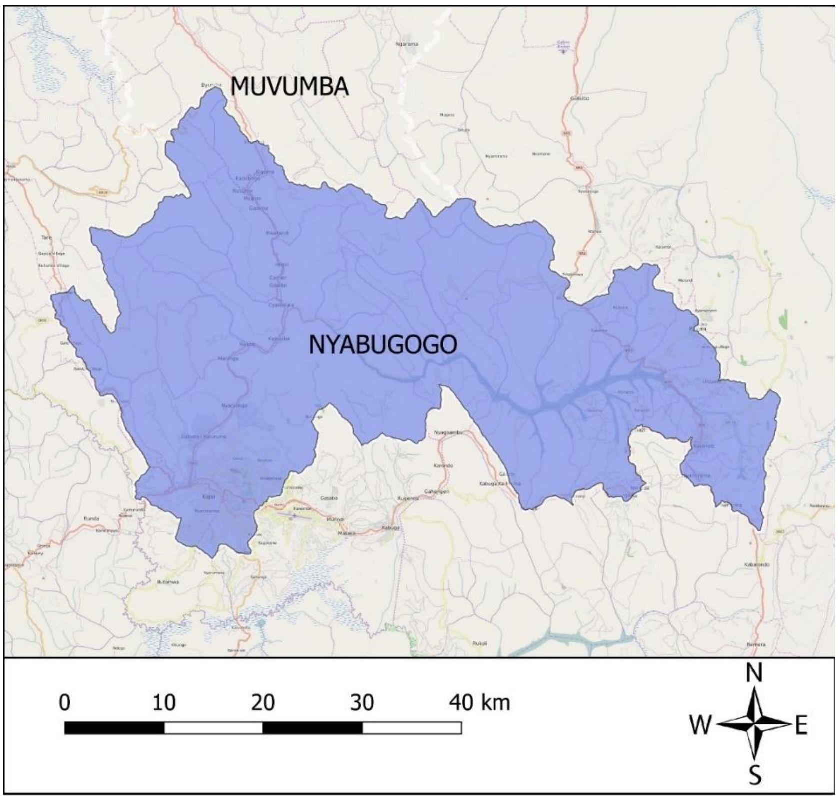


Figure 39. The Nyabugogo Catchment in northern Rwanda.

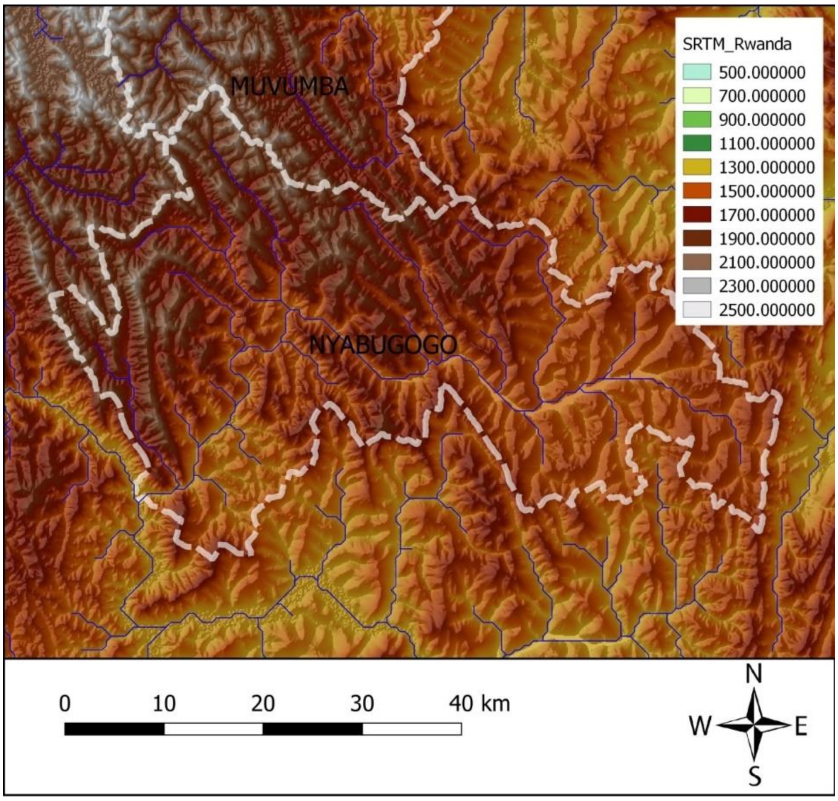


Figure 40. Elevation of the Nyabugogo Catchment (in MASL).

6.2 Model development

6.2.1 Schematization

6.2.1.1 Catchments

The catchment has been divided into sub-catchment to be used in WEAP. The number of sub-catchments should be large enough to characterize the main features in the catchment, but small enough to have output at a level suited to the project requirements. In general a number of around five is sufficient. Each sub-catchment is divided into six land use classes, making a total of 30 units within the catchment.

Rwanda distinguishes four levels of Catchment planning. For the Nyabugogo catchment the following number of sub-catchment at each level exists:

- Level 1: bigger than 1 sub-catchment
- Level 2: exactly 1 sub-catchments
- Level 3: 66 sub-catchments
- Level 4: 524 sub-catchments

It can be concluded that based on this analysis working at Level 2 does not provide the level of detail required for the schematization of WEAP. However, also the Level 3 sub-catchment will not work as for this the level of detail (66 sub-catchment) is too many for the project needs. It was therefore to create an in-between level by using the SRTM as input a vary the number of so-called “Minimum size of exterior watershed basin”. For the Nyabugogo catchment a minimum size of 15,000 pixels resulted in five sub-catchments and was used.

During an expert knowledge driven approach, it was decided to change sub-catchment boundaries to ensure a better linkage with existing and future planning procedures. This process resulted in a delineation existing out of six sub-catchments.

6.2.1.2 Groundwater Node

For each sub-catchment a so-called Groundwater Node is defined. For each Groundwater Node recharge is calculated by WEAP and abstractions are based on the demand of users and the actual storage.

6.2.1.3 Demand Nodes

For each sub-catchment four so-called Demand Nodes are defined. Each demand node has a specific water user: domestic, industry (four sub-sectors), livestock, and irrigated agriculture. For domestic a sub-division between urban and domestic has been made. These water users can take water from surface water and from ground water.

Water demand per sector is taken from various sources such as Catchment Plans, National Water Resources Master Plan, Irrigation Master Plan and various data sources collected during the project. More importantly, expert knowledge was used to get the best estimates of water demand by various sectors. It is important to realize that if better data are available, these can be easily incorporated in the existing WEAP model (using the Key Assumptions approach).

In November 2016, a Water Users’ Survey was carried out to get an overview of the water usage in each of the four studied catchments. The observed water users in this survey are:

coffee washing stations, hydropower plants, water treatment plants, mineral extraction sites, dams, irrigation schemes, fishing farms, industries and land parcels above 100 ha. Incorporating the data from this survey in WEAP could support a well-founded and transparent view on the water allocating dynamics in each (sub-)catchment.

For domestic use, the water intake is expected to vary somewhere in the range of 40-80 L/cap/day. However, according to the Water Use Survey daily water intake per capita ranges between less than 2 L/cap/day for Muvumba up to 851 L/cap/day for Upper Nyabarongo. Possible explanations for the large difference in domestic water use between catchments could be the survey's inability to quantify small water using intakes for personal use and to focus mainly on large water users. Also, it might be possible that the large water intake for domestic use in the Upper Nyabarongo could to some extent be transported to other areas balancing the mutual differences between the catchments. As the Water Users' Survey appears to contain large uncertainties for domestic water consumption, it was selected not to use data from the Water Users' Survey for domestic use.

Instead, for domestic water demand the numbers from the Catchment Plan are used indicating that rural water demand is 40 l/cap/d and for urban 60 l/cap/d. Based on expert knowledge this number was considered outdated. Therefore in the WEAP model rural water demand was set at 80 l/cap/d and for urban 100 l/cap/d.

Inter-catchment transfer of water in the Nyabugogo catchment takes place. This has been incorporated in the model. The following main supplies and abstractions have been included:The node of water demand Kigali is supplied by:

- Yanze River (in Nyabugogo catchment from Yanze sub catchment) to Kigali
- Karenge WTP (Akagera upper) (surface water of Mugesera lake) to Kigali
- Nzove WTP groundwater to Kigali
- Nyabarongo WTP (Nyabarongo River) to Kigali
- Outside transfer from Nyabugogo catchment to Rwamagana, Gatsibo and Kayonza towns get water from Muhazi Lake

For industrial water the Industrial water demand including mining is according to the National Water Resources Master Plan (p. 125) 3 l/cap/d. This number is outdated and data from the recently completed Water Users' Survey have been used. Exact distinction between various industrial uses was not completely clear from the data set. However, distinction between mining and other industrial use could be derived. The following data were derived and used in the WEAP models:

- Mining: 73 l/cap/d
- Coffee washing: 40 l/cap/d based on (50% van 80 l/cap/d)
- Tea factories: 20 l/cap/d based on (25% van 80 l/cap/d)
- Other: 20 l/cap/d based on (25% van 80 l/cap/d)

Data on water demand for irrigation varies substantial between different sources. It was therefore decided to follow the overall figures as mentioned in NWRMP as also done in the Catchment Plans. The average irrigation water demand depends on the type of irrigated land. Marshland irrigated areas requires between 200 and 250 mm irrigation per year, while hill side irrigated areas require 600 to 800 mm irrigation per year. Total irrigated areas where derived from the land use map. However, distinction between whether these areas are marshland or hill-side irrigated is not known. Therefore, this distinction was done by taking the slopes in each sub-catchment. It was considered that if slopes are steeper than 10 degrees, hill-side irrigation is applied. Since average slopes for each sub-catchment were used, a linear interpolation was used (marshland% = 150 -10*slope). Field visits might be necessary to obtain a more accurate estimate for this. Obviously, if more detailed data will become available, this can be easily implemented in the existing WEAP model.

Water consumption by livestock is considered as well, given the importance in many parts of Rwanda. The National Water Resources Master Plan (p. 105) states however that "… the record of animals per administrative unit is notoriously inaccurate". Number of animals was therefore derived from the rural population. It was assumed that for each 5 people one animal (excluding chickens) is present. Water consumption was taken as 125 l/head/day. Obviously, if more accurate date are becoming available, these can be included in the model. Field visits might be required to get more accurate data.

Environmental flow requirements are defined according to the National Water Resources Master Plan (p. 143) as fraction of the total demand compared to "water surplus" in a particular month. A fraction of 1/3 was used. This so called "water surplus" is the "non-demanded" water. To translate this kind of cryptic wording one could say that the environmental flow requirement is not met as the total demand is more than 2/3 of the available water resources in a particular month. As example: if total water resources in a month are 100 MCM, environmental flow requirements are not met if demand in that month exceeds 66 MCM. Interesting in this definition is that the flow in a river is not considered as a criterion.

6.2.2 Land cover

Land class data is used in WEAP to imitate the hydrological relations between the soil, the atmosphere and runoff. For the WEAP models a list of 14 land cover classes is used:

- Agroforestry with progressive terraces
- Agroforestry with radical terraces
- Agroforestry without terraces
- Forest
- Grassland
- Irrigated marshland
- Irrigated hillslope
- Progressive terraces without agroforestry
- Radical terraces without agroforestry
- Rainfed agriculture
- River buffer zones
- Shrubs
- Urban
- Wetlands

A land cover map of Rwanda in 2015 is provided by the RNRA and used to calculate the land cover areas per sub-catchment. As information on terraces and irrigation is lacking from this map, these are added separately. A Google Earth exercise has been performed to quantify the currently terraced areas. Terraces are distinguished in four categories; radical terraces and progressive terraces both either with or without agroforestry. Terraces and agroforestry are forms of soil, water and crop management and therefore will also influence the WEAP soil and water retention characteristics accordingly. Furthermore, the soil and water retention characteristics also varies for each of the remaining land use classes and is stored in the WEAP models respectively.

In WEAP, these characteristics are defined by the root-zone conductivity, soil water capacity, preferred flow direction and the runoff-resistance factor. The runoff-resistance factor controls the amount of water that enters the upper soil layer, the soil water capacity determines the amount of water that can be stored in the upper soil layer and the root-zone conductivity and the preferred flow direction influence the water percolation from the upper soil layer to the deeper soil layer. For example, increasing the terraced area in a sub-catchment will increase the water retention capacity by enhancing the runoff-resistance, the soil water capacity, preferred flow direction and the root zone conductivity.

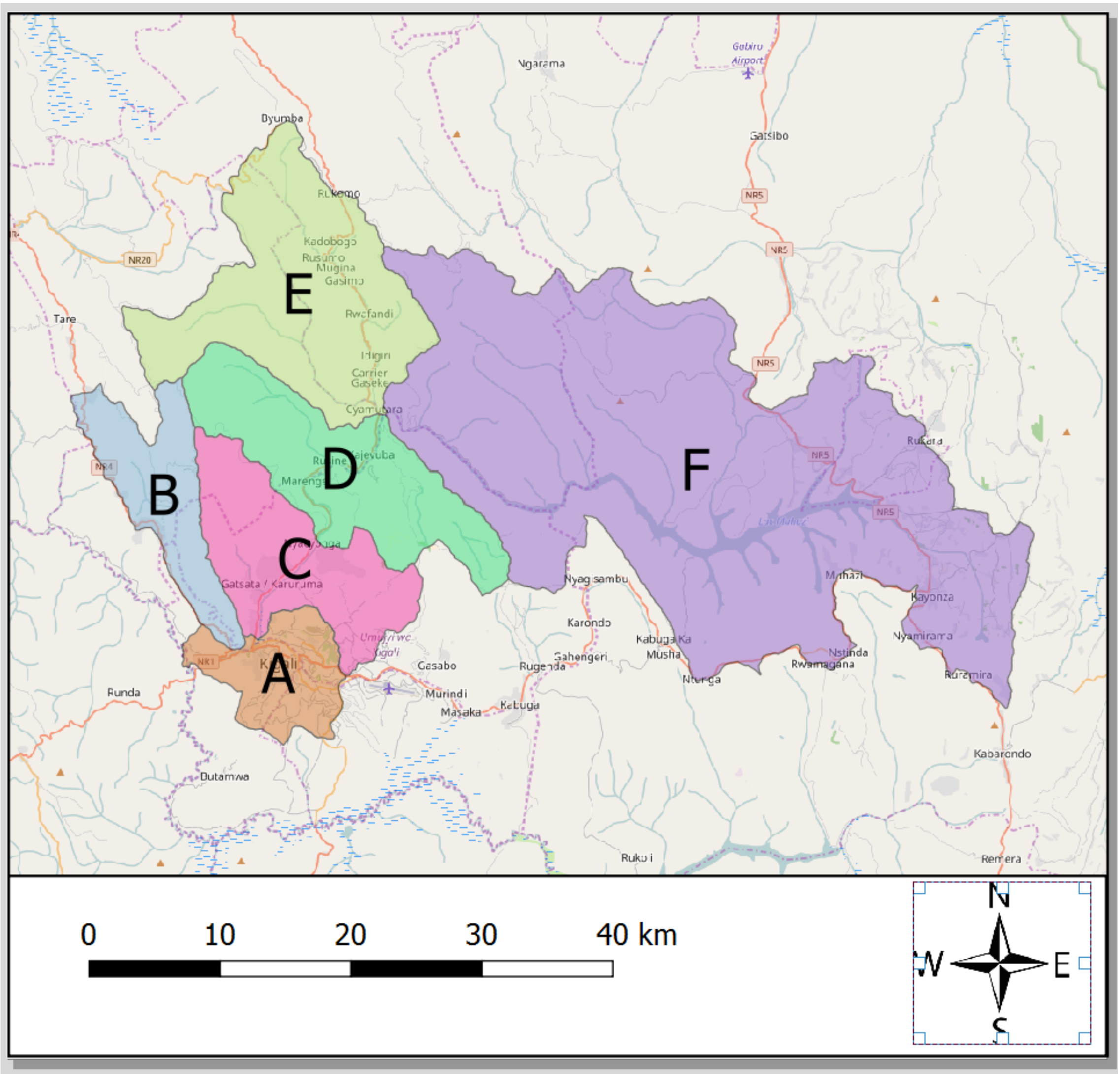


Figure 41. The six sub-catchments in Nyabugogo as used in the WEAP model.

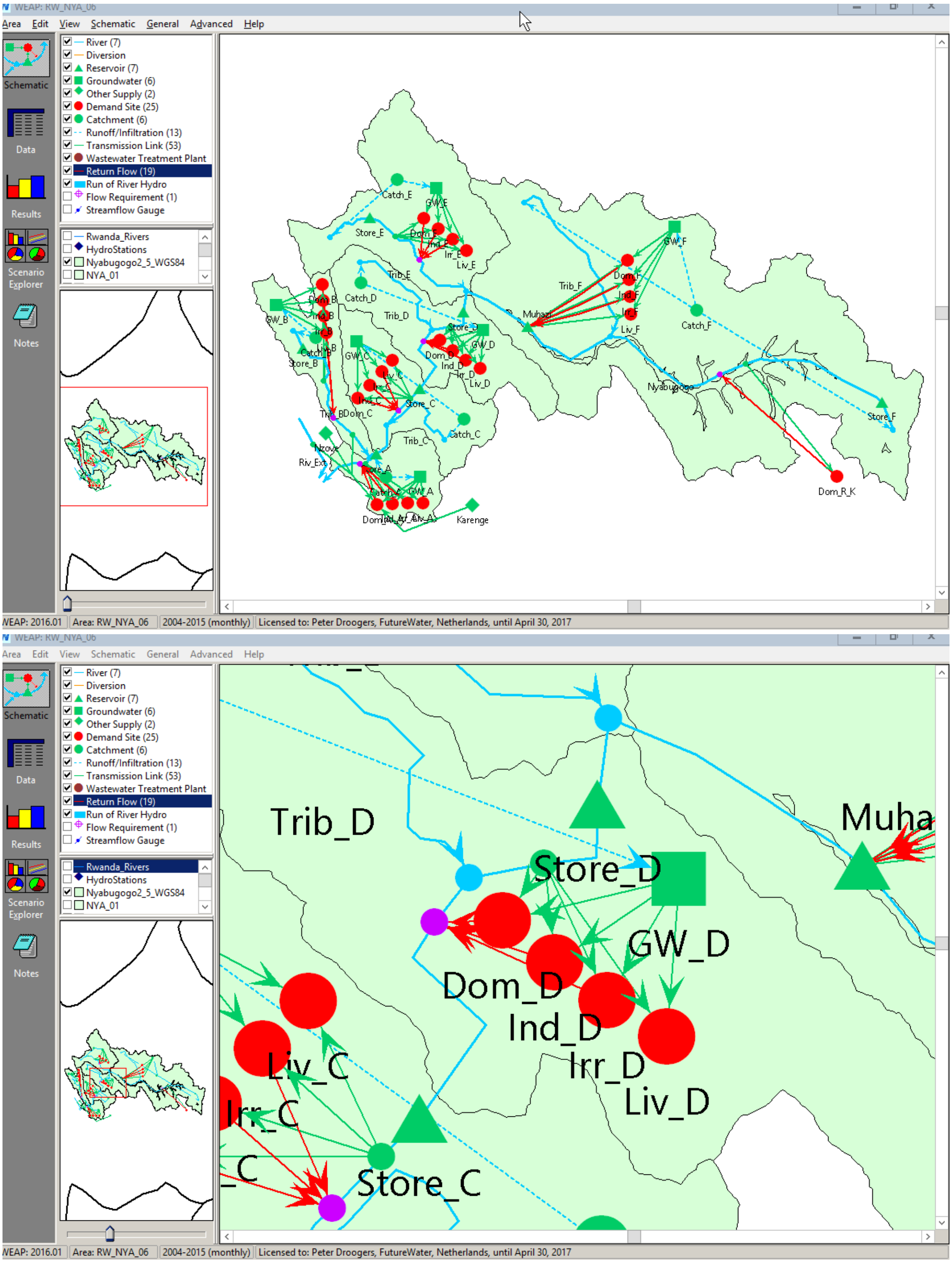


Figure 42. Schematization of Nyabugogo Catchment in the WEAP model. Top: complete model. Bottom: detail for Sub-Catchment D.

6.2.3 Meteorological data

6.2.3.1 Rainfall

Meteorological data and especially rainfall data is essential to develop catchment planning. Quite some data are observed and available for Rwanda. However, recent data is difficult to obtain, spatial coverage is somewhat fragmented, and quality control has to be performed. Global initiatives of various research group around the world have resulted in consistent data sets of precipitation, based on using remote sensing, observations and advanced data assimilation techniques. One of the most commonly used and accepted as high quality is the so-called Chirps data set.

CHRIPS is the Climate Hazards Group InfraRed Precipitation with Station data and is a 30+ year quasi-global rainfall dataset. Spanning 50°S-50°N (and all longitudes), starting in 1981 to near-present, CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

Estimating rainfall variations in space and time is an important aspect of drought early warning and environmental monitoring. An evolving dryer-than-normal season must be placed in historical context so that the severity of rainfall deficits may be quickly evaluated. However, estimates derived from satellite data provide areal averages that suffer from biases due to complex terrain which often underestimate the intensity of extreme precipitations events. Conversely, precipitation grids produced from station data suffer in more rural regions where there are less rain gauge stations. CHIRPS was created in collaboration with scientists at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center in order to deliver reliable, up to date, and more complete datasets for a number of early warning objectives (such as trend analysis and seasonal drought monitoring).

Early research focused on combining models of terrain-induced precipitation enhancement with interpolated station data. More recently, new resources of satellite observations such as gridded satellite-based precipitation estimates from NASA and NOAA have been leveraged to build high resolution (0.05°) gridded precipitation climatologies. When applied to satellite-based precipitation fields, these improved climatologies can remove systematic bias, a key technique in the production of the 1981 to near-present CHIRPS dataset. The creation of CHIRPS has supported drought monitoring efforts by the USAID Famine Early Warning Systems Network (FEWS NET).

The CHIRPS data can be downloaded free of charge from http://chg.geog.ucsb.edu/data/chirps/. Data are delivered for the entire continent at a daily based. Using QGIS and python scripting these data were aggregated to monthly values for each sub-catchment.

6.2.3.2 Other climate variables

The Rwandan climate is quite constant during the year with the exception of the rainfall (as discussed in the previous section). For the WEAP model additional climate data are needed to estimate the potential evapotranspiration. For temperature the average monthly values of Kigali (elevation 1567 MASL) have been used and scaled to the average elevation using a lapse-rate. Lapse rates are in general between 0.6 and 1.0^{o}C depending on the stability of the air and the extent of high elevation plateaus. If air is not completely saturated and no extended plateaus exist a lapse rate of 1^{o}C per 100 meter applies. So taken Kigali elevation as reference the following equation applies: Tcorr (^{0}C) = 15.67 – 0.01*Elevation(m). For relative humidity also the average monthly data for Kigali have been used. Finally, cloudiness fraction has been derived from the monthly average rainfall records, where it was assumed that if rainfall exceeds 100 mm per month cloud fraction is 50%, and with lower rainfall linear scaled to 100%.

Obviously, if additional and more accurate climate data are becoming available, these can be easily included in the existing model.

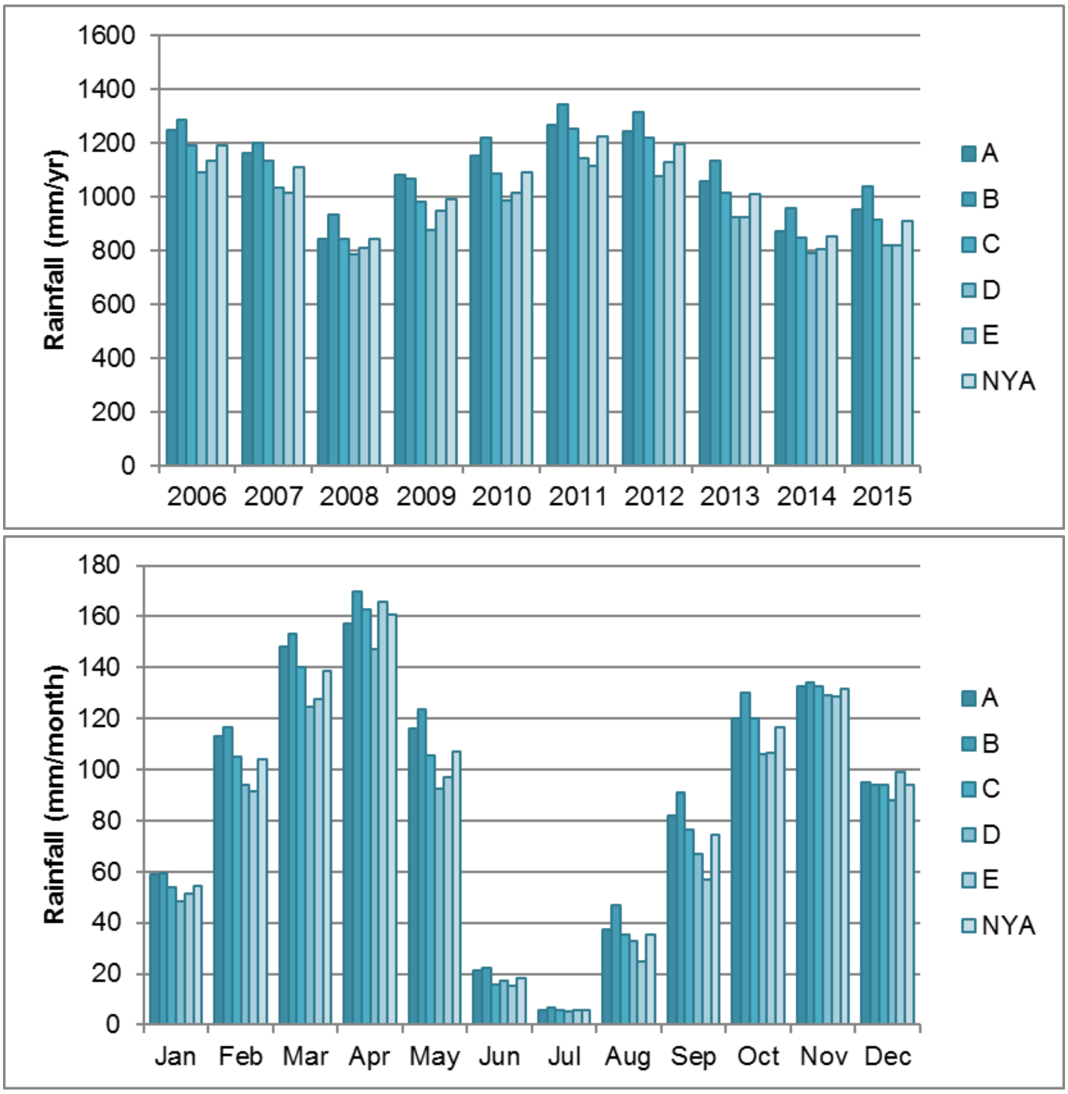


Figure 43. Rainfall data for Nyabugogo catchment and the five sub-catchments as derived from the CHRIPS dataset. Top: total annual rainfall. Bottom: average monthly rainfall over 2006-2015. A-E are the sub-catchments; MUV is average entire Nyabugogo Catchment.

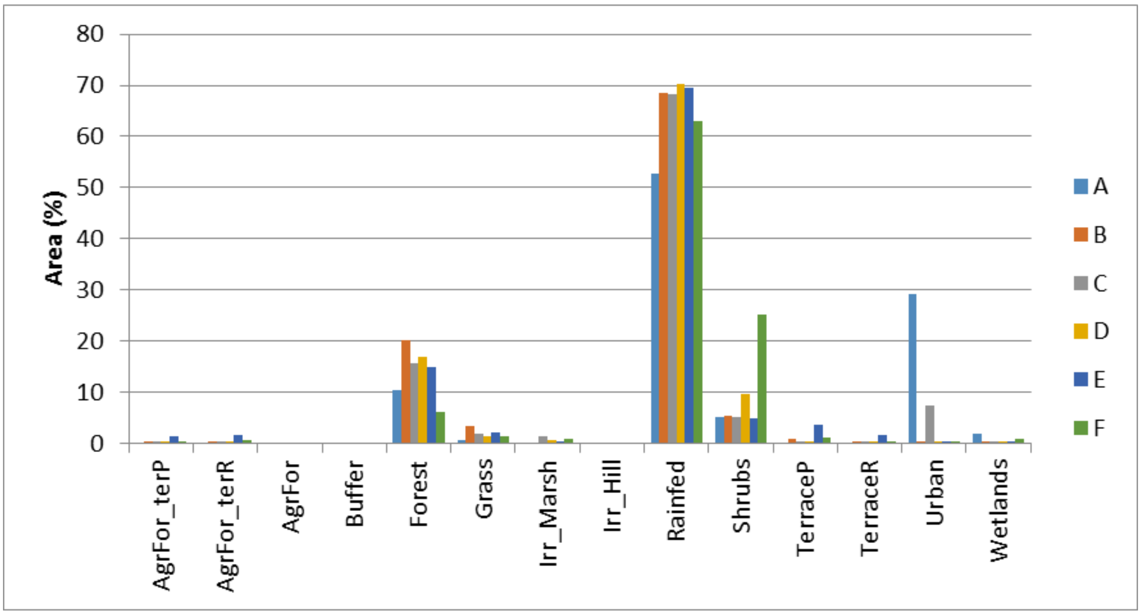


Figure 44. Land cover distribution in the Nyabugogo sub-catchments.

6.3 Model Performance

The WEAP model has been widely applied in many regions across the globe. WEAP has proven to be a reliable tool for water balance and water allocation analysis. Obviously, quality of a model for s specific area depends completely on the accuracy of the available data. For this specific study it is important to realize the difference between “absolute” accuracy and “relative” accuracy. “Absolute” accuracy relates to how well the model represents reality; “relative” accuracy relates to the accuracy of comparing different scenarios. It has been proven that even if “absolute” accuracy is low, “relative” accuracy can be still high.

Nevertheless, it remains important to assess the performance of the model, even if data is scarce. This has been done using:

- Flow station data
- References such as NWRMP. Since for Nyabugo no results are presented in the NWRMP a cross validation is not possible.
- ET results from satellite information

For the Nyabugogo data of the following streamflow gauges are available (in brackets average flow):

- Rusumo_Mwange (0.35 $m^3 s^{-1}$)
- Gaseke → no discharge measurements available to creating rating curve
- Cyamutara (1.70 $m^3 s^{-1}$)
- Rwesero_lac_muhazi → no discharge measurements available to creating rating curve
- Kimisagara (3.28 $m^3 s^{-1}$)
- Nemba (5.36 $m^3 s^{-1}$)

Note that data of these stations are very fragmented and the derived stage-discharge relationships are for some of the stations based on limited data points. For each gauging station the graphs for flows, annual averages and monthly averages have been plotted. From these graphs, it is clear that data is erratic in terms of available records as well as sudden unexplainable jumps. Therefore, it was decided to focus on the Nemba station for evaluating the model performance.

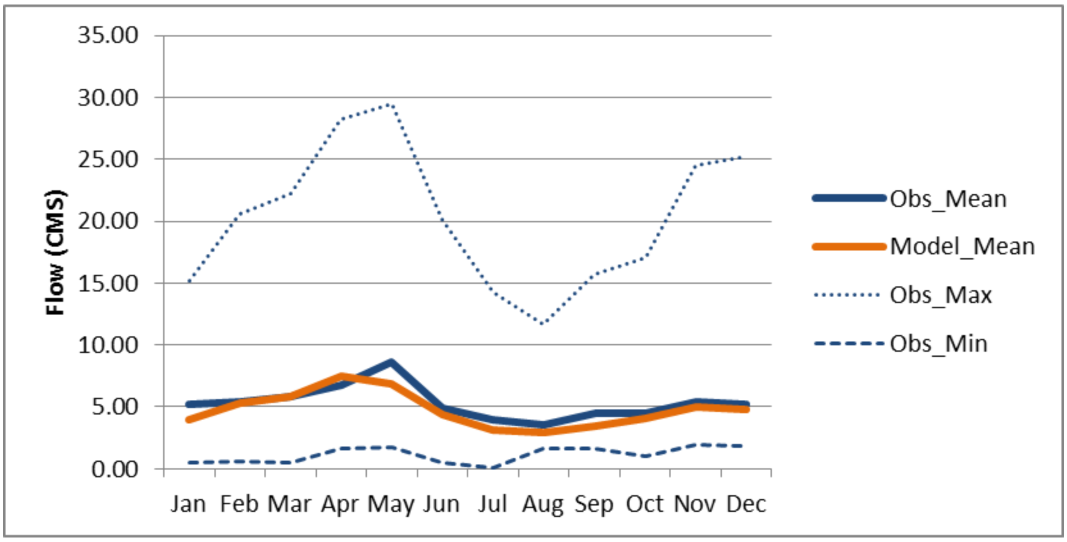


Figure 45. Observed and simulated mean, min and max flow for station Nemba.

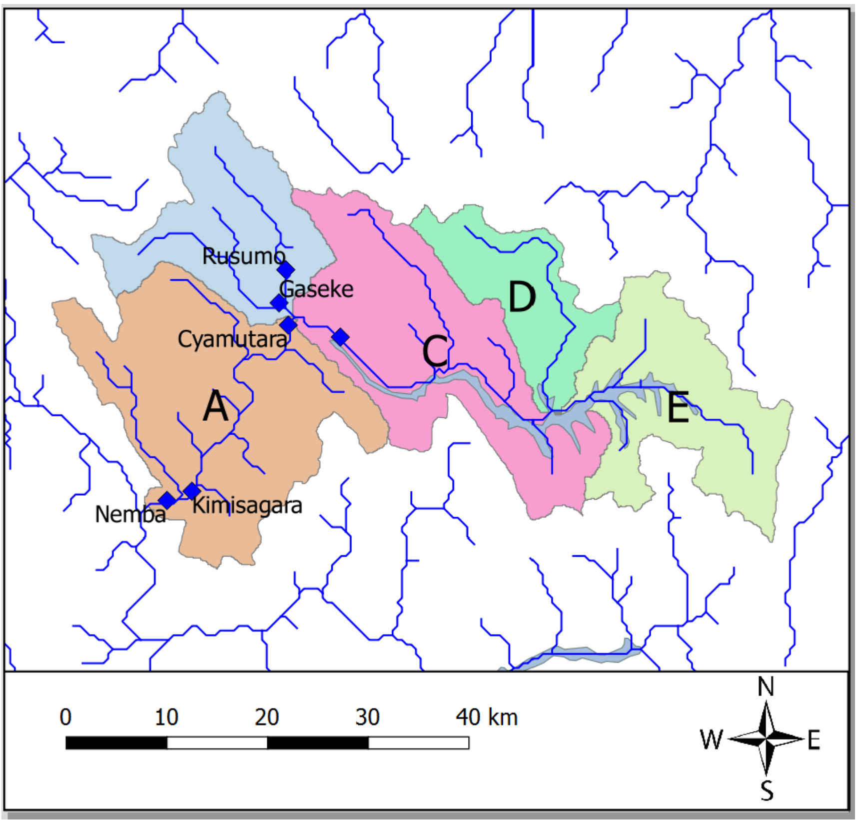


Figure 46. Flow gauging stations in the Nyabugogo Catchment.

6.4 Current situation

The WEAP model was used to set the Baseline that is used to compare with future Projections and Alternatives. This Baseline can be considered as the current situation and was analyzed by using data and information from a ten years period (2006-2015).

From the following Tables it is clear that most of the available water (= rainfall) is evaporated by vegetation. Outflow from the catchment and groundwater recharge are other important components in the catchment. Interesting is that the so-called manageable water (sometimes referred to as Blue Water) is about 30% of total water resources. Only a small fraction is currently withdrawn for domestic, industry, irrigation and livestock.

These summary tables are essential to understand total water issues in the catchment. However, the WEAP models developed provide a wealth of more detailed information. The two screenshots hereafter on water demand and supply are shown as example of what can be obtained from the model.

Table 7. Summarized water balance for the entire basin for the baseline as 10 years average for the Nyabugogo catchment.

IN	*(MCM/y)*	**OUT**	*(MCM/y)*
Precipitation	1,713	Evapotranspiration	1,329
Return flows	27	Withdrawals	42
Storage change	15	Outflow	167
		Groundwater recharge	216
Total	*1,755*	*Total*	*1,755*

Table 8. Summarized water balance for the manageable water components (Blue Water) as 10 years average for the Nyabugogo catchment.

IN	*(MCM/y)*	**OUT**	*(MCM/y)*
Runoff	45	Domestic	4
Baseflow	160	Industry	32
Groundwater	3	Irrigation	4
Return flows	27	Livestock	1
		Open water evaporation	26
		Outflow	167
Total	*235*	*Total*	*235*

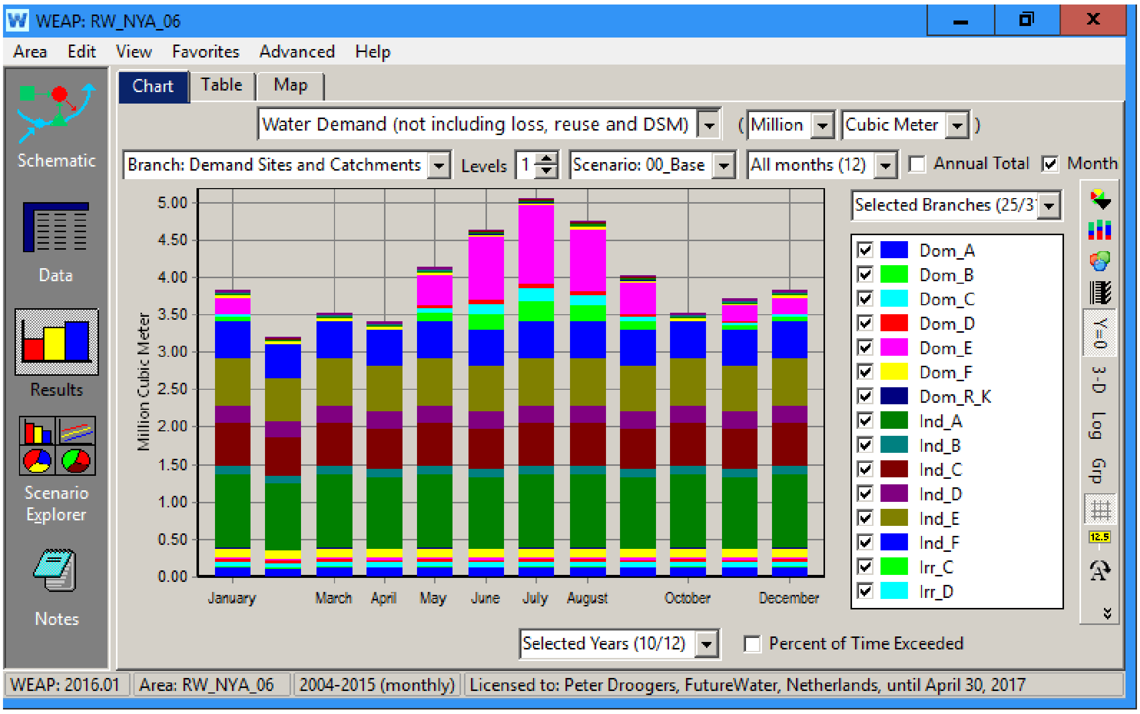


Figure 47. Example of WEAP results for the baseline: monthly average water demand.

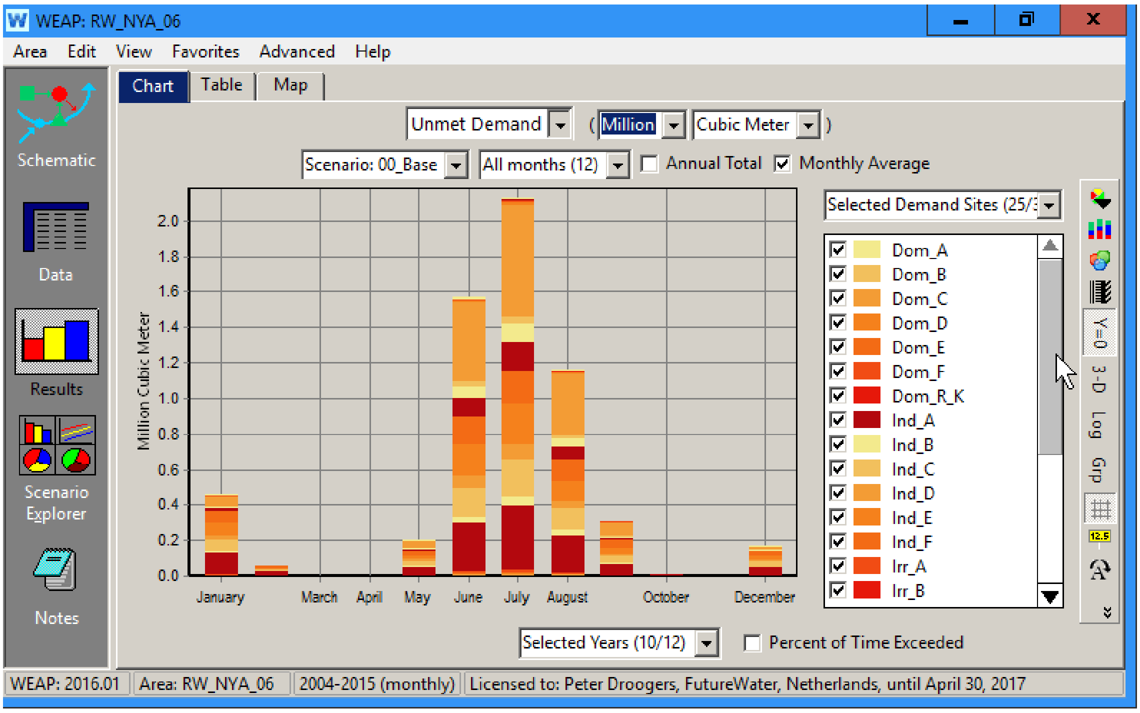


Figure 48. Example of WEAP results for the baseline: monthly average water shortages.

6.5 Future: Projections and Alternatives

6.5.1 Projections

Projections (sometimes referred to as pathways or storylines) are future scenarios that can be hardly influenced by water planners and decision makers. Four different types of Projections were analyzed: climate change, population growth, and macro-economic development. For each of these three Projections a total of three time-horizons were considered (2023, 2030, 2050) as well as a low, medium and high impact projection. Moreover, as these Projections will not happen in isolation also nine combined groups were evaluated (three time horizons x three impacts)

Most important conclusions that can be drawn from these Projections as shown in the as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models.

Most relevant conclusions regarding these projections:

- Water demand is expected to increase substantially in the future: from currently 48 MCM/y to 828 MCM/y in 2050. Since the future has quite some uncertainty in climate, economic growth and population a low and a high-impact projection have been run as well. Results show that water demand by 2030 will be 8 to 12 times higher.
- Water shortage (unmet demand) is expected to increase substantially. Without proper actions taken it is expected that about 30% of the demand by 2030 cannot be delivered.
- Streamflow flowing out of the catchment is projected to decrease substantially in the future to average flows of 50% compared to today. Especially low flows during dry months are expected to decrease by around 60%.

Further details and exact numbers can be obtained from the figures below and the appendix. Obviously, the WEAP model itself provide an unlimited number of results and options to plot figures for further analysis.

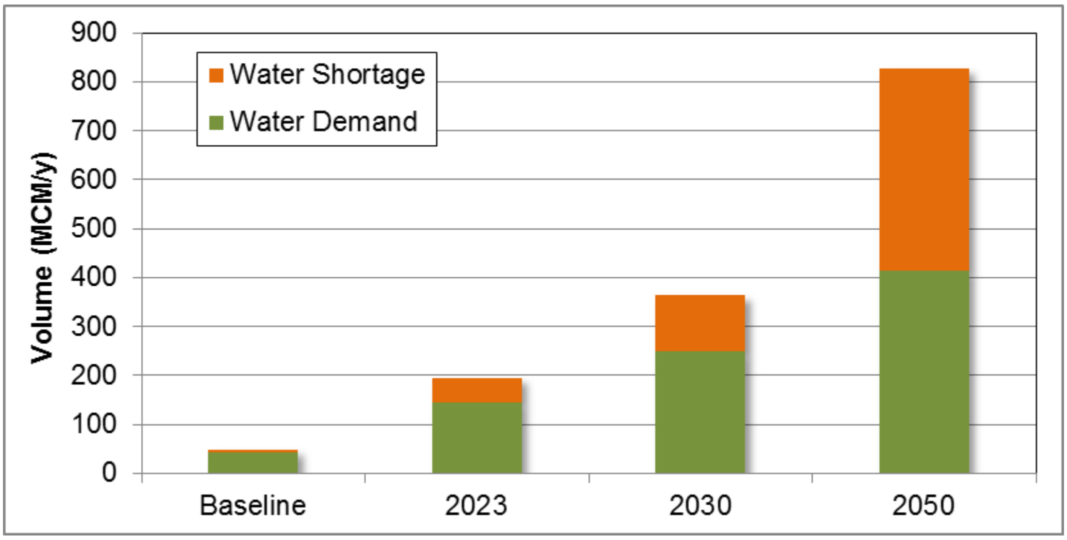


Figure 49. Water demand and shortage for the Nyabugogo. Results are presented for the medium future projections.

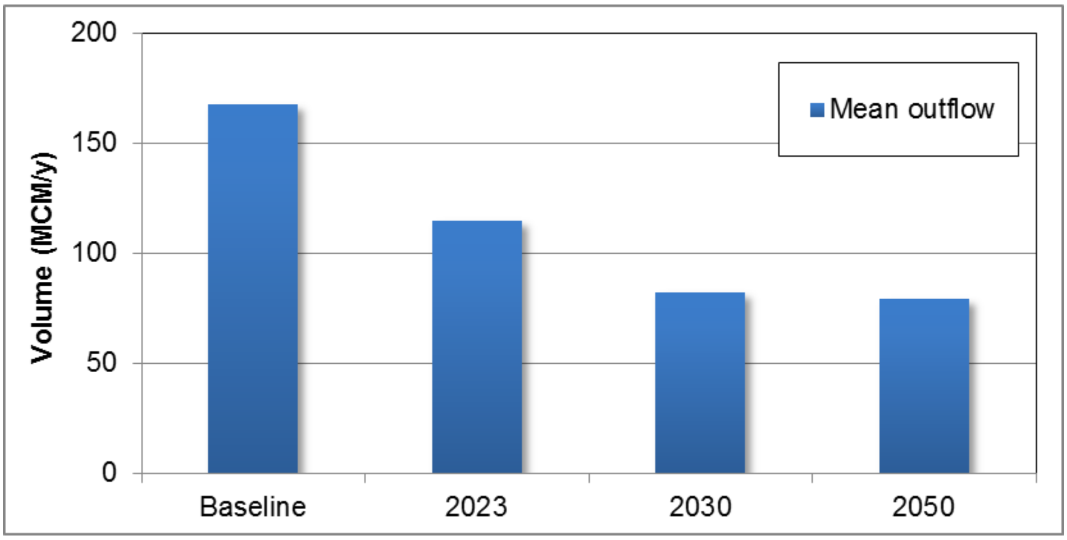


Figure 50. Mean outflow of the Nyabugogo. Results are presented for the medium future projections.

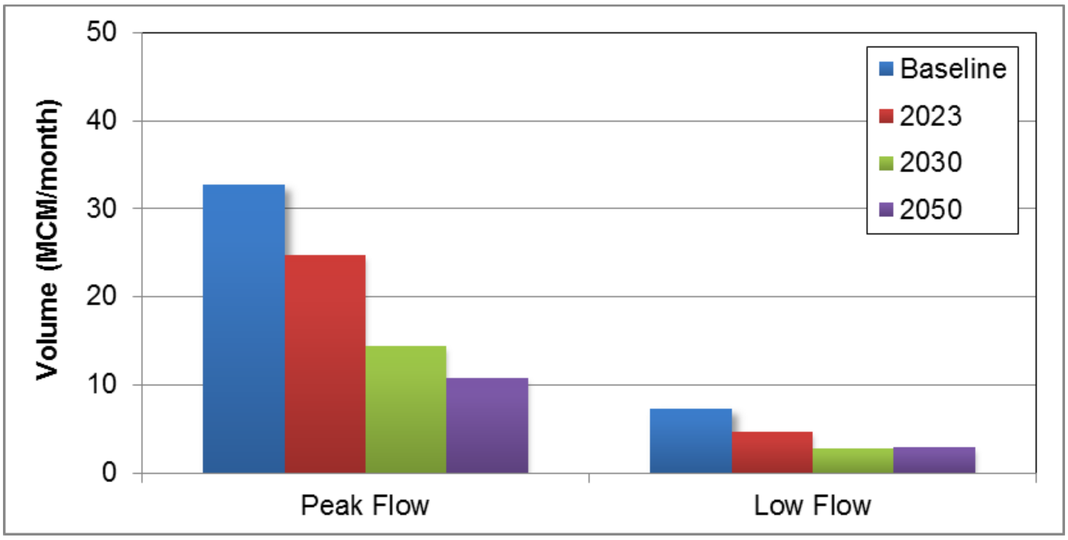


Figure 51. Peak and low flows of the Nyabugogo. Results are presented for the medium future projections.

6.5.2 Alternatives

In contrast to the Projections as described above are the so-called Alternatives. Alternatives (sometimes referred to as interventions, adaptations, or implementation scenarios) are decisions initiated by policymakers and implemented by water managers that will optimize water resources management. Examples are constructing reservoirs, training farmers, irrigation planning, groundwater permits, erosion control, watershed conservation, amongst many others.

The Alternatives (interventions) are evaluated for 10 different options for each three time horizons. Note that the Table below where percentages and colors are presented is based on the comparing with the Future Medium Projection (and not with the Baseline). This was done as this Future Medium is the selected scenario for climate change, economic growth and population changes. So even for example as for the 2050 Alternative many water demands are green (lower than 100%) this demand compared with Baseline is still much higher.

Most important conclusions that can be drawn from these Alternatives as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models. Main conclusions regarding the results of these Alternatives:

- Most alternatives have a positive impact on the water demand, water shortage, streamflow and catchment hydrology.
- The alternative of Planning by Administrative and Sectoral Boundaries (PASB) is less effective compared to other alternatives, especially in the context of alleviation of water shortages and low flows.
- The alternative Planning by Catchment Boundaries (PCB), and its subs PCB+ and PCB- are the preferred alternatives. PCB- looks the most effective one, but is should be kept in mind that for this irrigation development is quite reduced, having impact on food security.
- PCB+ and PCB- are able to reduce projected water shortages by 60% to 70%.

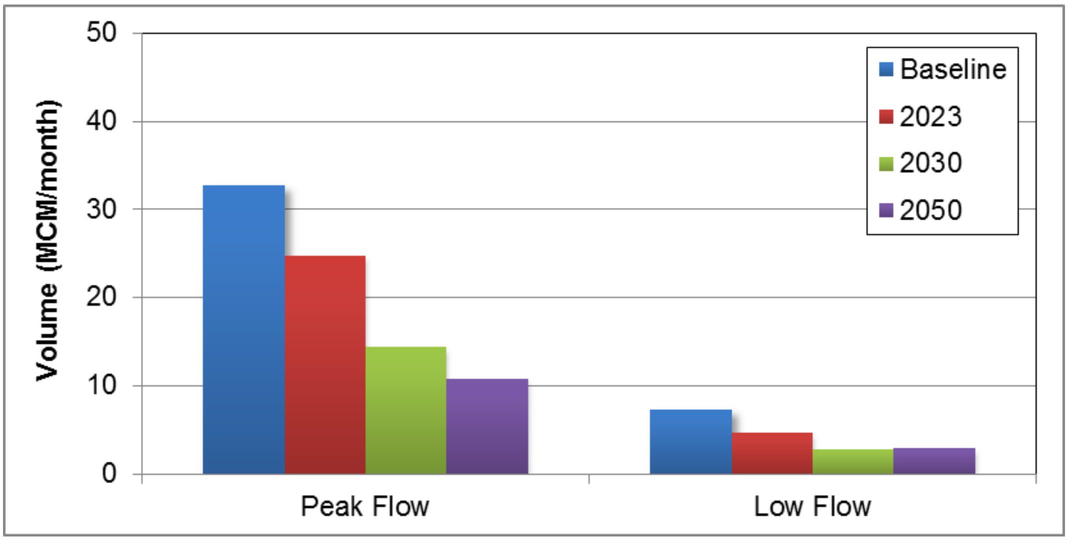


Figure 52. Water demand and shortage for the Nyabugogo. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

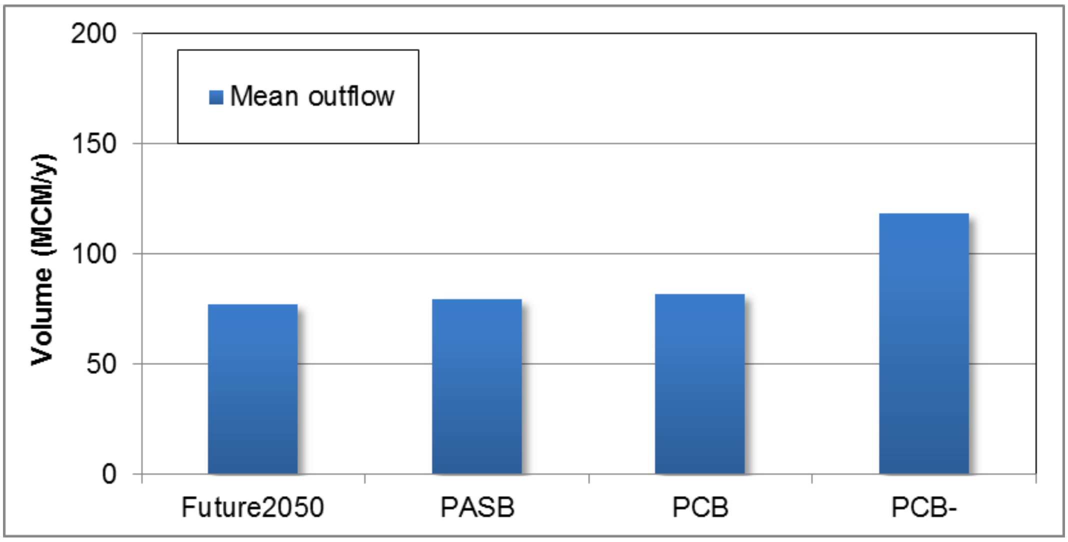


Figure 53. Mean outflow of the Nyabugogo. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

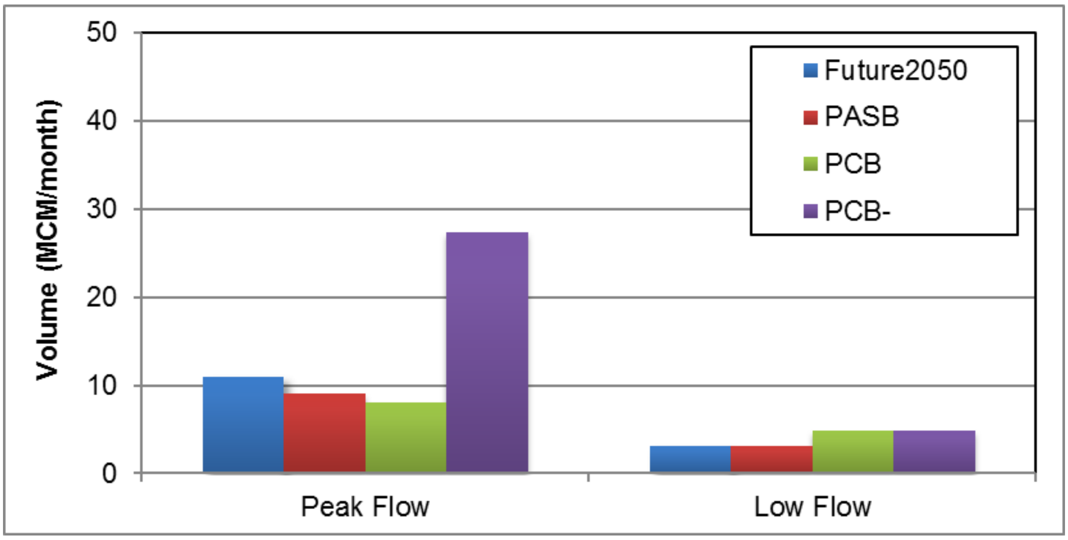


Figure 54. Peak and low flows of the Nyabugogo. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

7 Sebeya Catchment: Water Balance and Allocation Modeling

7.1 Background

The Sebeya catchment is part of the Congo-Kivu (level 1) catchment in the upper part of the Congo basin. It is one of the larger of many small (level 2) catchments that drain the western slopes of the Nile Congo watershed in the western part of Rwanda. The total surface area of the Sebeya catchment is 336 km², which represents 1.4% of the total surface area of Rwanda. The length of the Sebeya River is 48 km and it runs in a north-westerly direction on the Nile Congo basin watershed into Lake Kivu. Almost 80% of this land, particularly in the east of the catchment, is of high altitude (above 2000 masl), peaking at 2950 masl. The outflow of the Sebeya river is into Lake Kivu.

A more detailed description of Sebeya can be found in the see Catchment Plan Report.

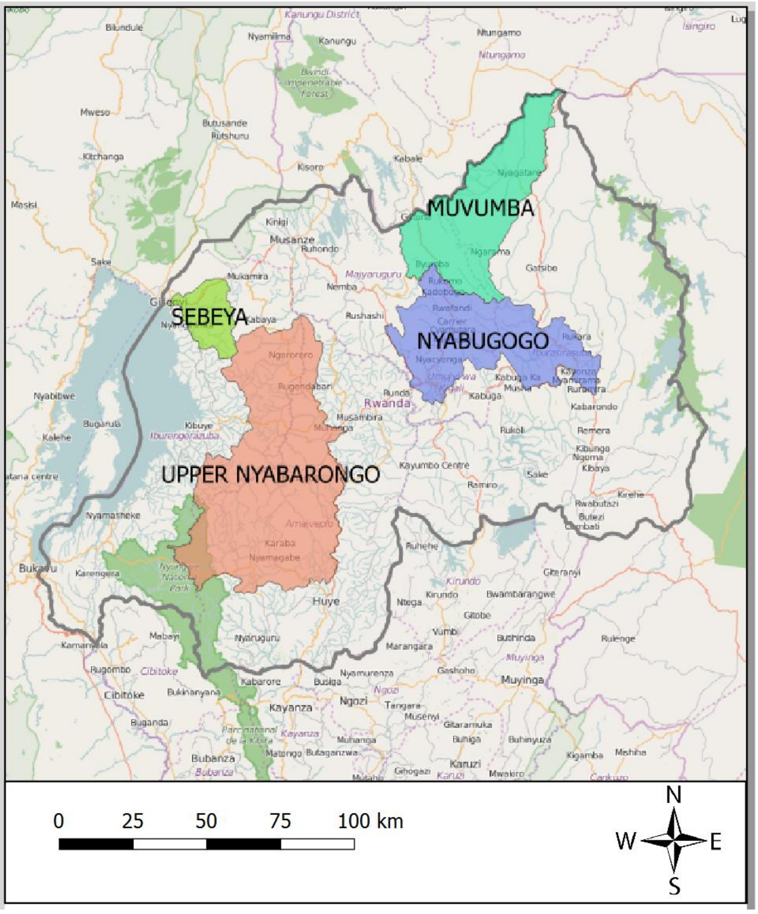


Figure 55. The four demonstration catchments of the Water for Growth Rwanda program.

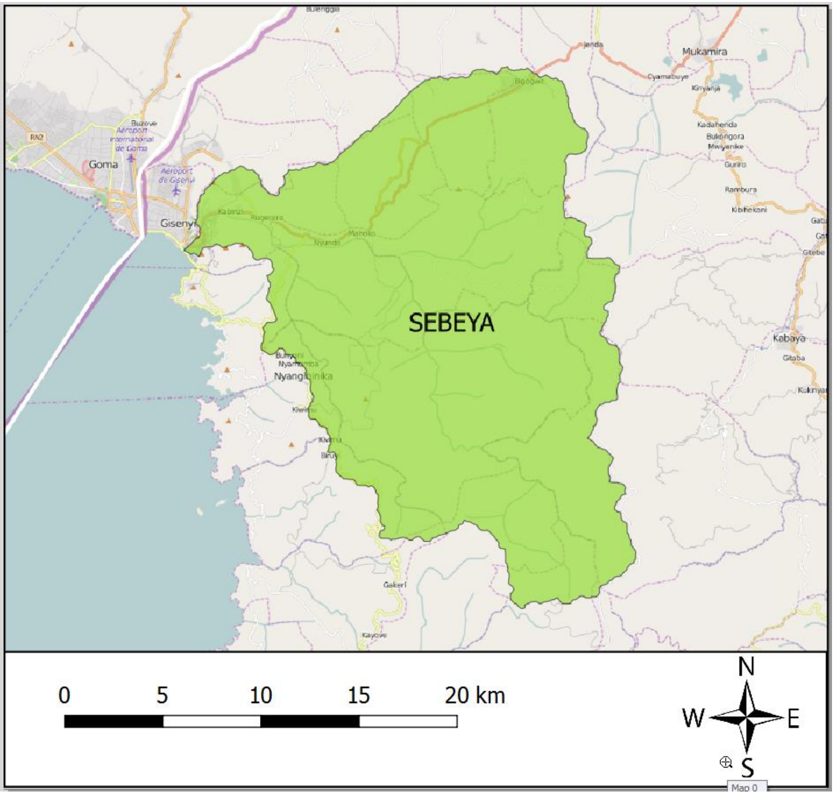


Figure 56. The Sebeya Catchment close to Lake Kivu.

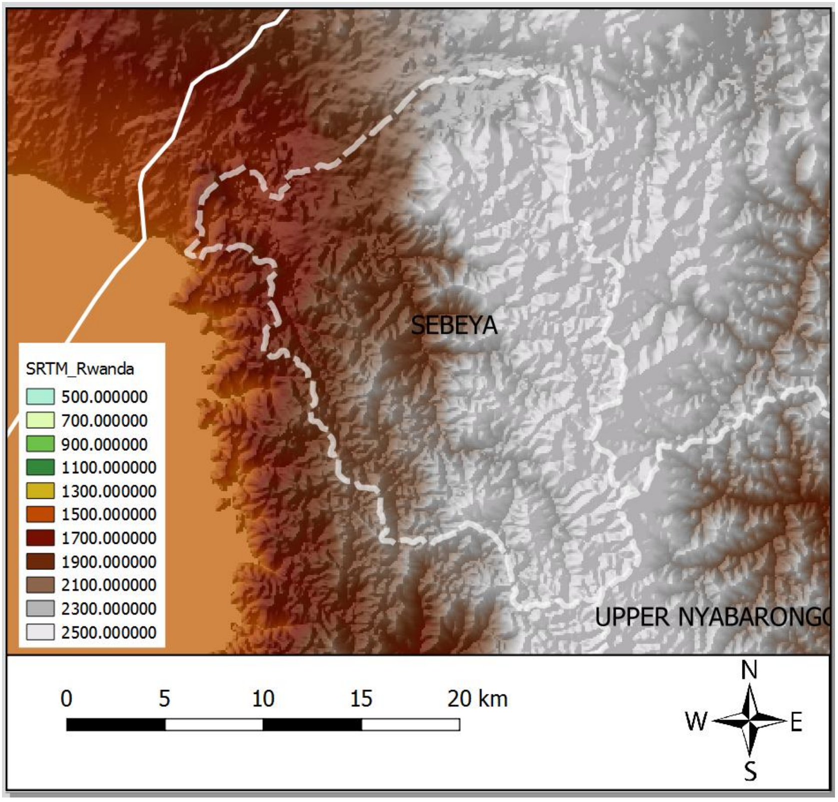


Figure 57. Elevation of the Sebeya Catchment (in MASL).

7.2 Model development

7.2.1 Schematization

7.2.1.1 Catchments

The catchment has been divided into sub-catchment to be used in WEAP. The number of sub-catchments should be large enough to characterize the main features in the catchment, but small enough to have output at a level suited to the project requirements. In general a number of around five is sufficient, as within such a WEAP Catchment Node different land use classes and water users can be defined.

Rwanda distinguishes four levels of Catchment planning. For the Sebeya catchment the following number of sub-catchment at each level exists:

- Level 1: bigger than 1 sub-catchment
- Level 2: bigger than 1 sub-catchments
- Level 3: 10 sub-catchments
- Level 4: 99 sub-catchments

It can be concluded that based on this analysis working at Level 2 does not provide the level of detail required for the schematization of WEAP. However, also the Level 3 sub-catchment will not work as for this the level of detail (10 sub-catchment) is too much for the project needs. It was therefore decided to use this Level 3 sub-catchments and based on especially the landcover (Gishwati Forest National Park) aggregate these to 5 sub-catchments. The Catchment has two rivers: Sebeya and Pfunda.

During an expert knowledge driven approach it was decided to change sub-catchment boundaries to ensure a better linkage with existing and future planning procedures. This process resulted in a delineation existing out of five sub-catchments that can be seen in Figure 57.

7.2.1.2 Groundwater Node

For each sub-catchment a so-called Groundwater Node is defined. For each Groundwater Node recharge is calculated by WEAP and abstractions are based on the demand of users and the actual storage.

7.2.1.3 Demand Nodes

For each sub-catchment four so-called Demand Nodes are defined. Each demand node has a specific water user: domestic, industry (four sub-sectors), livestock, and irrigated agriculture. For domestic a sub-division between urban and domestic has been made. These water users can take water from surface water and from ground water.

Water demand per sector is taken from various sources such as Catchment Plans, National Water Resources Master Plan, Irrigation Master Plan and various data sources collected during the project. More importantly, expert knowledge was used to get the best estimates of water demand by various sectors. It is important to realize that if better data are available, these can be easily incorporated in the existing WEAP model (using the Key Assumptions approach).

In November 2016, a Water Users' Survey was carried out to get an overview of the water usage in each of the four studied catchments. The observed water users in this survey are: coffee washing stations, hydropower plants, water treatment plants, mineral extraction sites, dams, irrigation schemes, fishing farms, industries and land parcels above 100 ha. Incorporating the data from this survey in WEAP could support a well-founded and transparent view on the water allocating dynamics in each (sub-)catchment.

For domestic use, the water intake is expected to vary somewhere in the range of 40-80 L/cap/day. However, according to the Water Use Survey daily water intake per capita ranges between less than 2 L/cap/day for Muvumba up to 851 L/cap/day for Upper Nyabarongo. Possible explanations for the large difference in domestic water use between catchments could be the survey's inability to quantify small water using intakes for personal use and to focus mainly on large water users. Also, it might be possible that the large water intake for domestic use in the Upper Nyabarongo could to some extent be transported to other areas balancing the mutual differences between the catchments. As the Water Users' Survey appears to contain large uncertainties for domestic water consumption, it was selected not to use data from the Water Users' Survey for domestic use.

Instead, for domestic water demand the numbers from the Catchment Plan are used indicating that rural water demand is 40 l/cap/d and for urban 60 l/cap/d. Based on expert knowledge this number was considered outdated. Therefore in the WEAP model rural water demand was set at 80 l/cap/d and for urban 100 l/cap/d.

In Sebeya inter-basin transfer of water occurs. Rubavu town and Bralirwa brewery are supplied by water originating from Sebeya and Pfunda River. These abstractions have been included in the WEAP model as well.

For industrial water the Industrial water demand including mining is according to the National Water Resources Master Plan (p. 125) 3 l/cap/d. This number is outdated and data from the recently completed Water Users' Survey have been used. Exact distinction between various industrial uses was not completely clear from the data set. However distinction between mining and other industrial use could be derived. The following data were derived and used in the WEAP models:

- Mining: 100 l/cap/d
- Coffee washing: 60 l/cap/d based on (50% van 121 l/cap/d)
- Tea factories: 30 l/cap/d based on (25% van 121 l/cap/d)
- Other: 30 l/cap/d based on (25% van 121 l/cap/d)

Data on water demand for irrigation varies substantial between different sources. It was therefore decided to follow the overall figures as mentioned in NWRMP as also done in the Catchment Plans. The average irrigation water demand depends on the type of irrigated land. Marshland irrigated areas requires between 200 and 250 mm irrigation per year, while hill side irrigated areas require 600 to 800 mm irrigation per year. Total irrigated areas where derived from the land use map. However, distinction between whether these areas are marshland or hill-side irrigated is not known. Therefore this distinction was done by taking the slopes in each sub-catchment. It was considered that if slopes are steeper than 10 degrees, hill-side irrigation is applied. Since average slopes for each sub-catchment were used, a linear interpolation was used (marshland% = 150 -10*slope). Field visits might be necessary to obtain a more accurate estimate for this. Obviously, if more detailed data will become available, this can be easily implemented in the existing WEAP model.

Water consumption by livestock is considered as well, given the importance in many parts of Rwanda. The National Water Resources Master Plan (p. 105) states however that "… the record of animals per administrative unit is notoriously inaccurate". Number of animals was therefore derived from the rural population. It was assumed that for each 5 people one animal (excluding chickens) is present. Water consumption was taken as 125 l/head/day. Obviously, if more accurate date are becoming available, these can be included in the model. Field visits might be required to get more accurate data.

Environmental flow requirements are defined according to the National Water Resources Master Plan (p. 143) as fraction of the total demand compared to "water surplus" in a particular month. A fraction of 1/3 was used. This so called "water surplus" is the "non-demanded" water. To translate this kind of cryptic wording one could say that the environmental flow requirement is not met as the total demand is more than 2/3 of the available water resources in a particular month. As example: if total water resources in a month are 100 MCM, environmental flow requirements are not met if demand in that month exceeds 66 MCM. Interesting in this definition is that the flow in a river is not considered as a criterion.

7.2.2 Land cover

Land class data is used in WEAP to imitate the hydrological relations between the soil, the atmosphere and runoff. For the WEAP models a list of 14 land cover classes is used:

- Agroforestry with progressive terraces
- Agroforestry with radical terraces
- Agroforestry without terraces
- Forest
- Grassland
- Irrigated marshland
- Irrigated hillslope
- Progressive terraces without agroforestry
- Radical terraces without agroforestry
- Rainfed agriculture
- River buffer zones
- Shrubs
- Urban
- Wetlands

A land cover map of Rwanda in 2015 is provided by the RNRA and used to calculate the land cover areas per sub-catchment. As information on terraces and irrigation is lacking from this map, these are added separately. A Google Earth exercise has been performed to quantify the currently terraced areas. Terraces are distinguished in four categories; radical terraces and progressive terraces both either with or without agroforestry. Terraces and agroforestry are forms of soil, water and crop management and therefore will also influence the WEAP soil and water retention characteristics accordingly. Furthermore, the soil and water retention characteristics also varies for each of the remaining land use classes and is stored in the WEAP models respectively.

In WEAP, these characteristics are defined by the root-zone conductivity, soil water capacity, preferred flow direction and the runoff-resistance factor. The runoff-resistance factor controls the amount of water that enters the upper soil layer, the soil water capacity determines the amount of water that can be stored in the upper soil layer and the root-zone conductivity and the preferred flow direction influence the water percolation from the upper soil layer to the deeper soil layer. For example, increasing the terraced area in a sub-catchment will increase the water retention capacity by enhancing the runoff-resistance, the soil water capacity, preferred flow direction and the root zone conductivity.

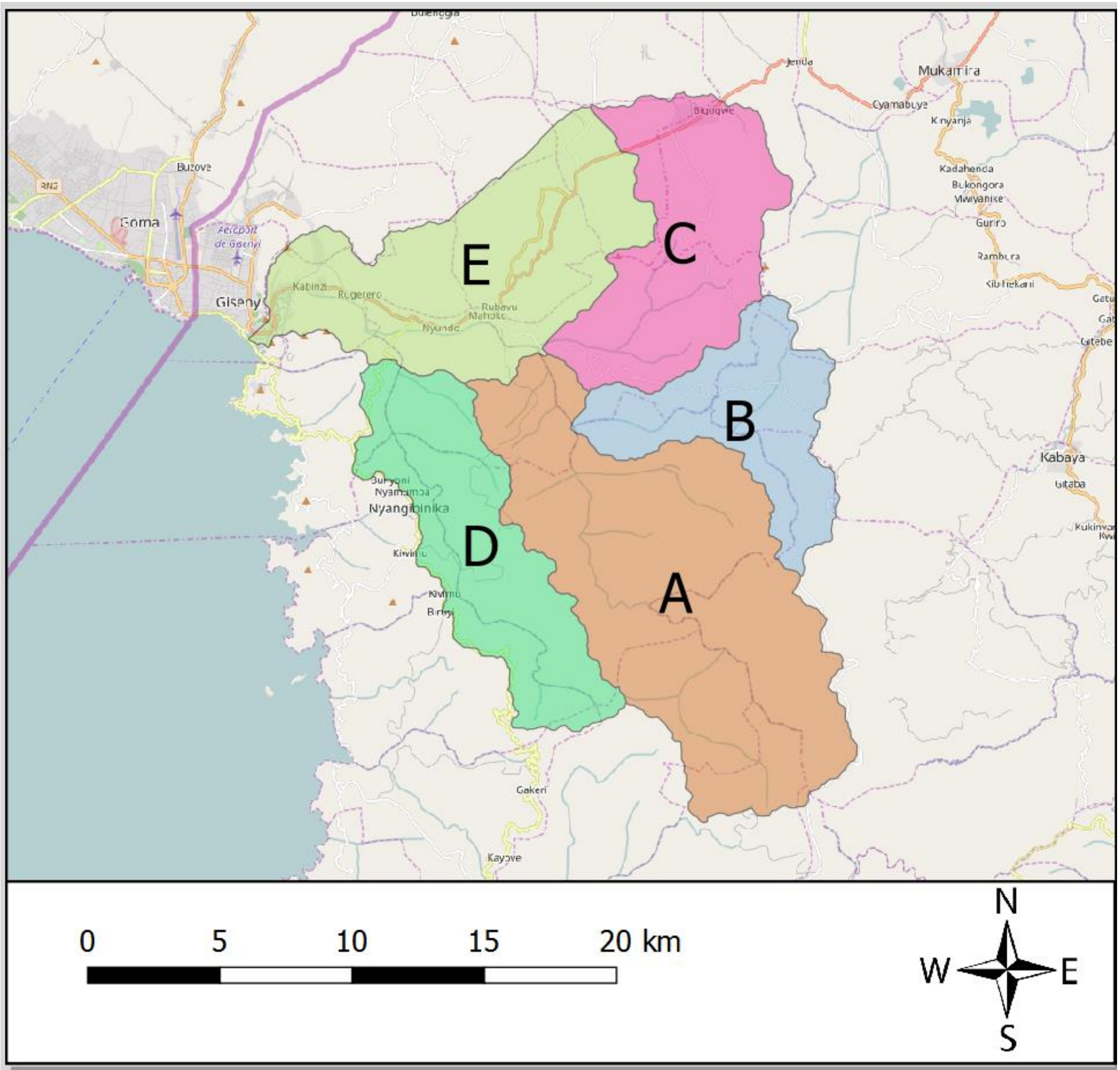


Figure 58. The five sub-catchments in Sebeya as used in the WEAP model.

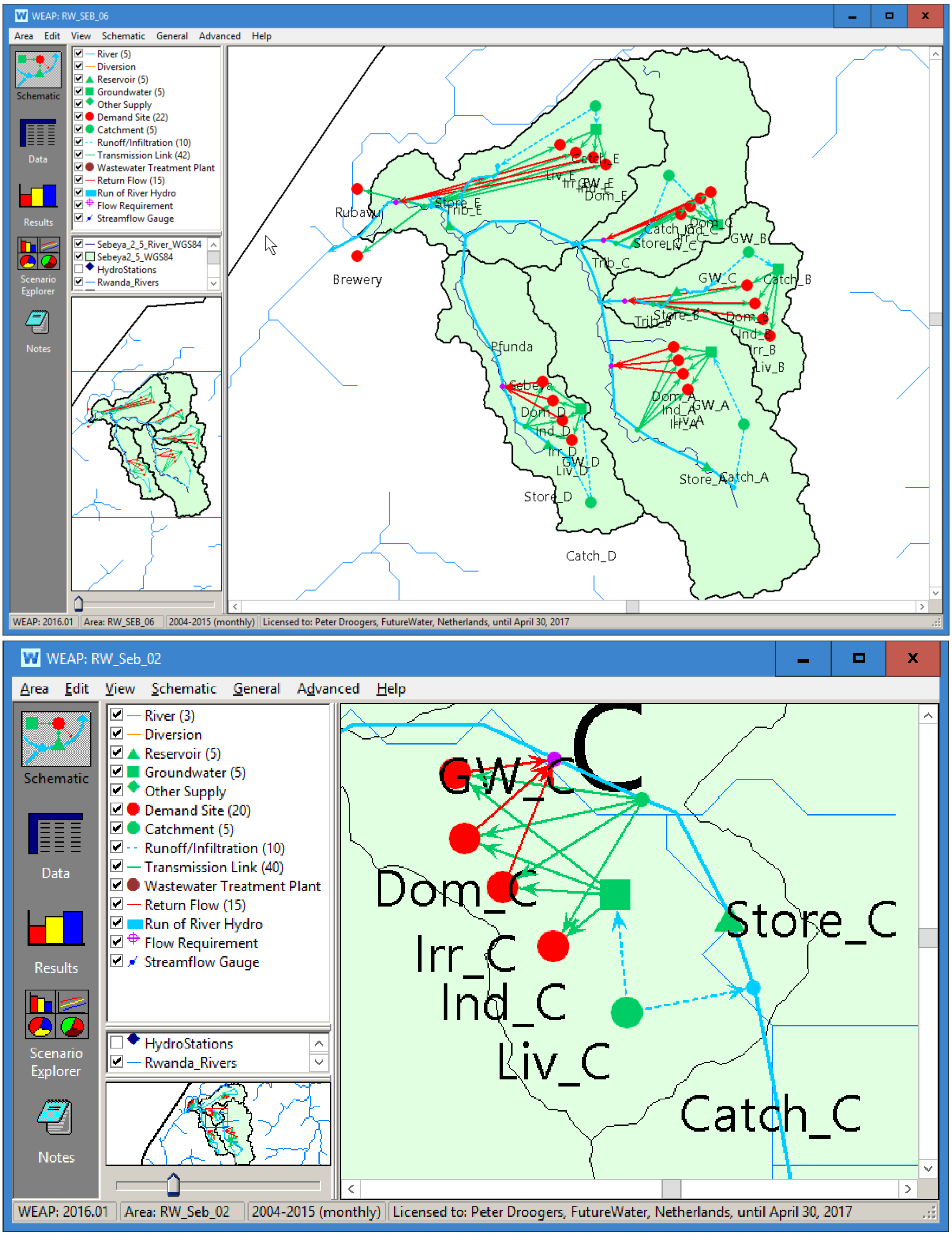


Figure 59. Schematization of Sebeya in the WEAP model. Top: complete model. Bottom: detail for Sub-Catchment C.

7.2.3 Meteorological data

7.2.3.1 Rainfall

Meteorological data and especially rainfall data is essential to develop catchment planning. Quite some data are observed and available for Rwanda. However, recent data is difficult to obtain, spatial coverage is somewhat fragmented, and quality control has to be performed. Global initiatives of various research group around the world have resulted in consistent data sets of precipitation, based on using remote sensing, observations and advanced data assimilation techniques. One of the most commonly used and accepted as high quality is the so-called Chirps data set.

CHRIPS is the Climate Hazards Group InfraRed Precipitation with Station data and is a 30+ year quasi-global rainfall dataset. Spanning 50°S-50°N (and all longitudes), starting in 1981 to near-present, CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

Estimating rainfall variations in space and time is an important aspect of drought early warning and environmental monitoring. An evolving dryer-than-normal season must be placed in historical context so that the severity of rainfall deficits may be quickly evaluated. However, estimates derived from satellite data provide areal averages that suffer from biases due to complex terrain which often underestimate the intensity of extreme precipitations events. Conversely, precipitation grids produced from station data suffer in more rural regions where there are less rain gauge stations. CHIRPS was created in collaboration with scientists at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center in order to deliver reliable, up to date, and more complete datasets for a number of early warning objectives (such as trend analysis and seasonal drought monitoring).

Early research focused on combining models of terrain-induced precipitation enhancement with interpolated station data. More recently, new resources of satellite observations such as gridded satellite-based precipitation estimates from NASA and NOAA have been leveraged to build high resolution (0.05°) gridded precipitation climatologies. When applied to satellite-based precipitation fields, these improved climatologies can remove systematic bias, a key technique in the production of the 1981 to near-present CHIRPS dataset. The creation of CHIRPS has supported drought monitoring efforts by the USAID Famine Early Warning Systems Network (FEWS NET).

The CHIRPS data can be downloaded free of charge from http://chg.geog.ucsb.edu/data/chirps/. Data are delivered for the entire continent at a daily based. Using QGIS and python scripting these data were aggregated to monthly values for each sub-catchment.

7.2.3.2 Other climate variables

The Rwandan climate is quite constant during the year with the exception of the rainfall (as discussed in the previous section). For the WEAP model additional climate data are needed to estimate the potential evapotranspiration. For temperature the average monthly values of Kigali (elevation 1567 MASL) have been used and scaled to the average elevation using a lapse-rate. Lapse rates are in general between 0.6 and 1.0ºC depending on the stability of the air and the extent of high elevation plateaus. If air is not completely saturated and no extended plateaus exist a lapse rate of 1ºC per 100 meter applies. So taken Kigali elevation as reference the following equation applies: Tcorr (^{0}C) = 15.67 – 0.01*Elevation(m). For relative humidity also the average monthly data for Kigali have been used. Finally, cloudiness fraction has been derived from the monthly average rainfall records, where it was assumed that if rainfall exceeds 100 mm per month cloud fraction is 50%, and with lower rainfall linear scaled to 100%.

Obviously, if additional and more accurate climate data are becoming available, these can be easily included in the existing model.

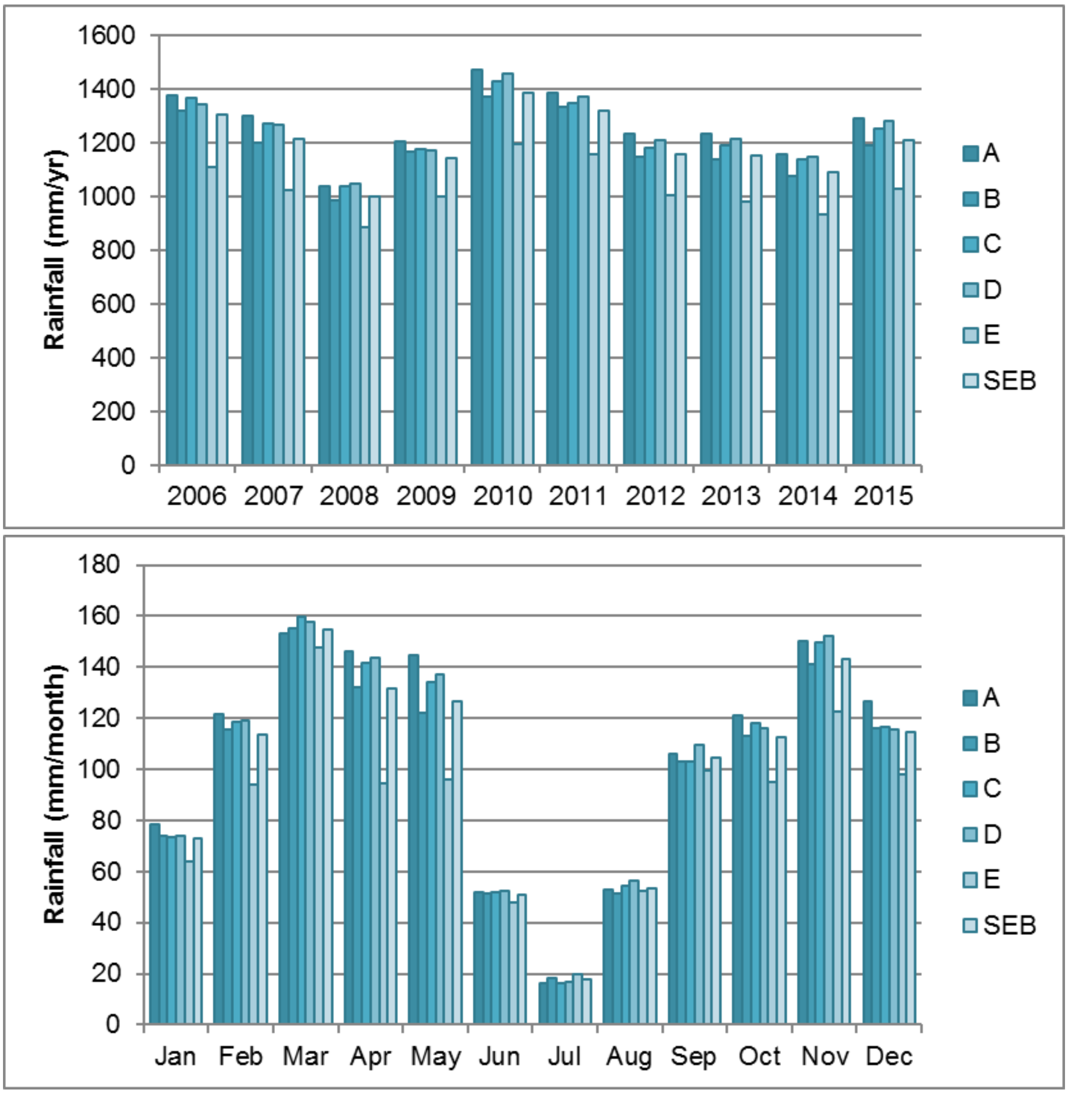


Figure 60. Rainfall data for Sebeya catchment and the five sub-catchments as derived from the CHRIPS dataset. Top: total annual rainfall. Bottom: average monthly rainfall over 2006-2015. A-E are the sub-catchments; SEB is average entire Sebeya Catchment.

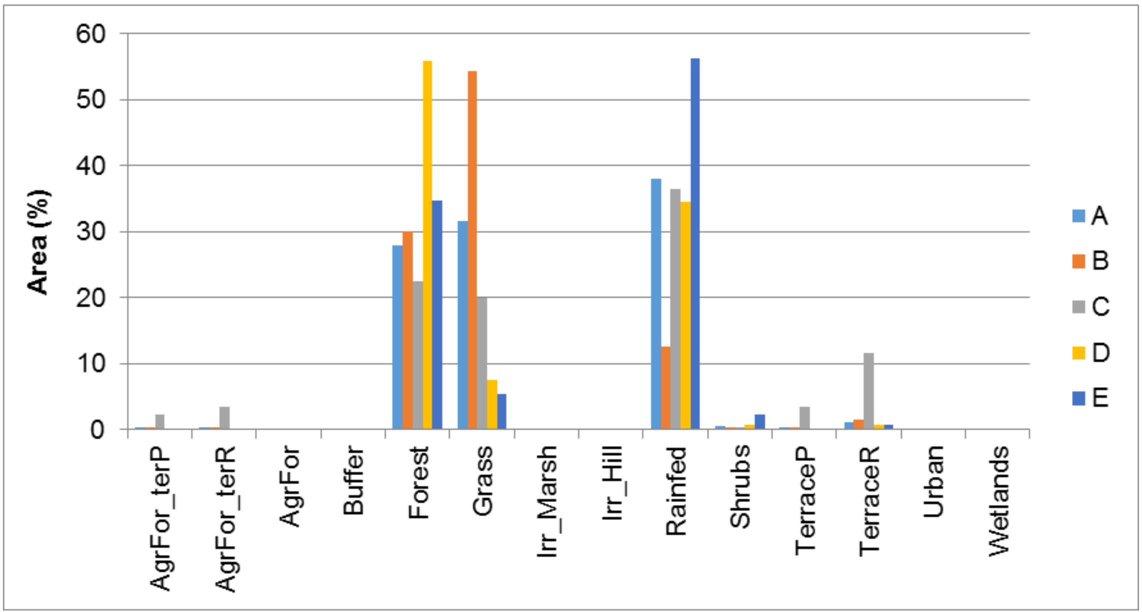


Figure 61. Land cover distribution in the Sebeya sub-catchments.

7.3 Model Performance

The WEAP model has been widely applied in many regions across the globe. WEAP has proven to be a reliable tool for water balance and water allocation analysis. Obviously, quality of a model for s specific area depends completely on the accuracy of the available data. For this specific study it is important to realize the difference between “absolute” accuracy and “relative” accuracy. “Absolute” accuracy relates to how well the model represents reality; “relative” accuracy relates to the accuracy of comparing different scenarios. It has been proven that even if “absolute” accuracy is low, “relative” accuracy can be still high.

Nevertheless, it remains important to assess the performance of the model, even if data is scarce. This has been done using:

- Flow station data
- References such as NWRMP
- ET results from satellite information

For the Sebeya data of two streamflow gauges are available (in brackets average flow):

- Nyundo (3.14 m^3 s^{-1})
- Gisneyi (2.26 m^3 s^{-1})

Note that data of these stations are very fragmented and the derived stage-discharge relationships are for some of the stations based on limited data points. For each gauging station the graphs for flows, annual averages and monthly averages have been plotted. From these graphs it is clear that data is erratic in terms of available records as well as sudden unexplainable jumps. Therefore it was decided to focus on the Nyundo station for evaluating the model performance.

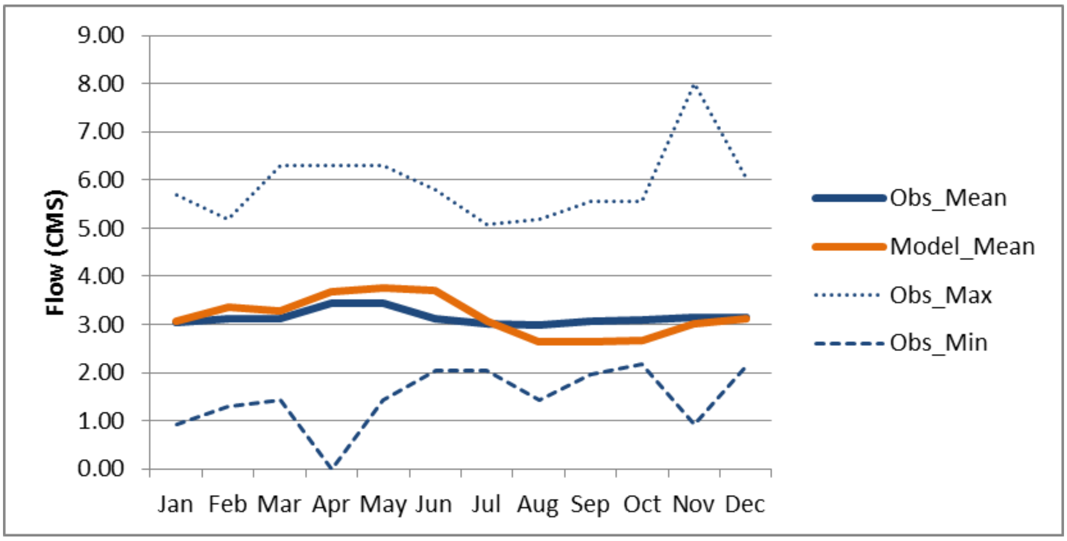


Figure 62. Observed and simulated mean, min and max flow for station Nyundo.

Table 9. Comparing water balance terms from NWRMP and WEAP model for Sebeya.

	NWRMP	Model		
		AVG	Min	Max
Giseny (m3/s)	2.8	3.5	2.8	4.3
Precipitation (MCM/y)	898	471	389	545
Actual evaporation (MCM/y)	N/A	250	238	258
Surface runoff (MCM/y)	N/A	104	89	118
Groundwater recharge (MCM/y)	N/A	114	100	124
Domestic use (MCM/y)	5.9	0.8	0.8	0.8
Irrigation use (MCM/y)	0.4	0.0	0.0	0.0
Industrial use (MCM/y)	N/A	13.0	13.0	13.0
Livestock use (MCM/y)	N/A	0.3	0.3	0.3

NOTE: NWRMP rainfall is unrealistic high. Converting to mm/y gives 2672 mm, while at the same time NWRMP mentioned that precipitation is about 1200 mm/y

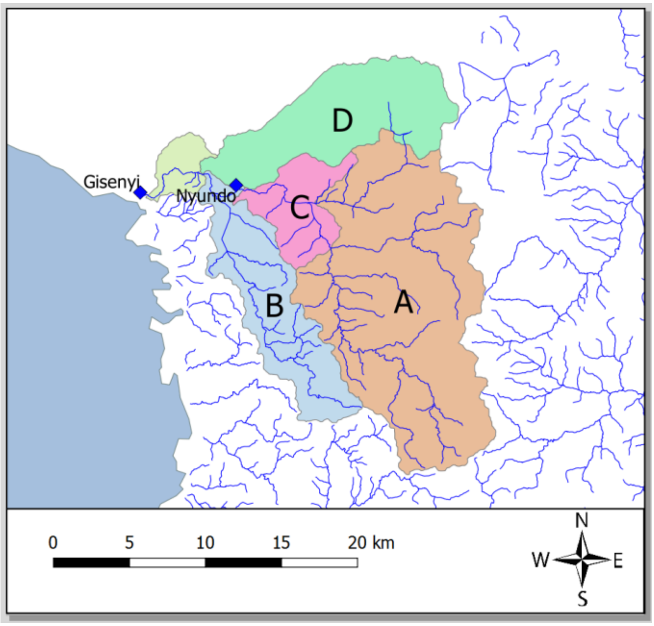


Figure 63. Flow gauging stations in the Sebeya Catchment.

7.4 Baseline

The WEAP model was use to set the Baseline which can be considered as the current situation. This Baseline can be considered as the current situation and was analyzed by using data and information from a ten years period (2006-2015).

The following Tables it is clear that most of the available water (= rainfall) is evaporated by vegetation. Outflow from the catchment and groundwater recharge are other important components in the catchment. Interesting is that the so-called manageable water (sometimes referred to as Blue Water) is about 30% of total water resources. Only a small fraction is actually withdrawn for domestic, industry, and livestock.

These summary tables are essential to understand total water issues in the catchment. However, the WEAP models developed provide a wealth of more detailed information. The two screenshots hereafter on water demand and supply are shown as example of what can be obtained from the model.

Table 10. Summarized water balance for the entire basin for the baseline as 10 years average for the Sebeya catchment.

IN	*(MCM/y)*	**OUT**	*(MCM/y)*
Precipitation	471	Evapotranspiration	250
Return flows	11	Withdrawals	16
Storage change	-3	Outflow	99
		Groundwater recharge	114
Total	*479*	*Total*	*479*

Table 11. Summarized water balance for the manageable water components (Blue Water) as 10 years average for the Sebeya catchment.

IN	*(MCM/y)*	**OUT**	*(MCM/y)*
Runoff	0.72	Domestic	0.76
Baseflow	103.62	Industry	14.42
Groundwater	0.62	Irrigation	0.00
Return flows	10.62	Livestock	0.32
		Outflow	100.09
Total	*115.58*	*Total*	*115.58*

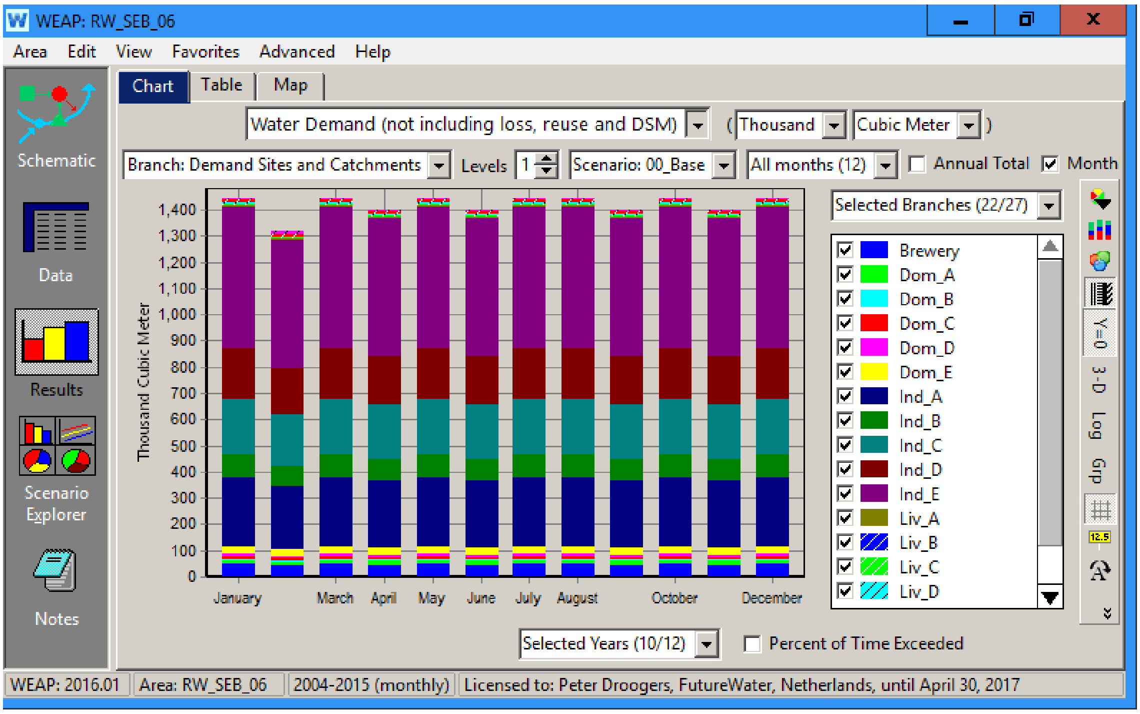


Figure 64. Example of WEAP results for the baseline: monthly average water demand.

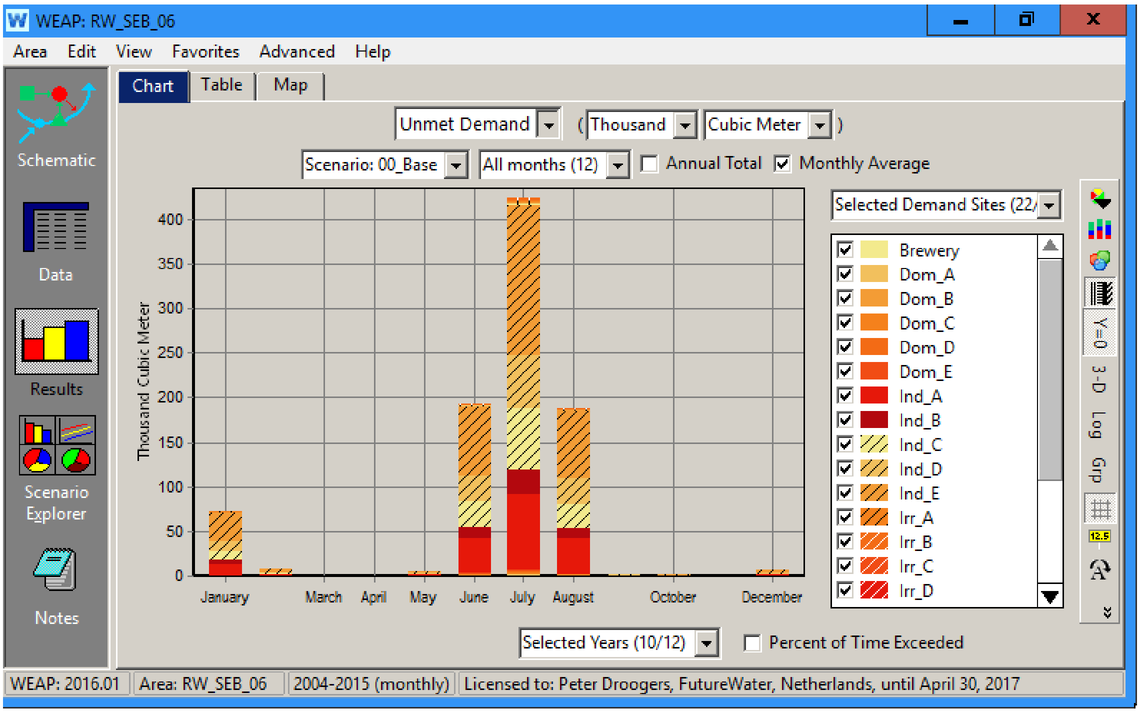


Figure 65. Example of WEAP results for the baseline: monthly average water shortages.

7.5 Future: Projections and Alternatives

7.5.1 Projections

Projections (sometimes referred to as pathways or storylines) are future scenarios that can be hardly influenced by water planners and decision makers. Four different types of Projections were analyzed: climate change, population growth, and macro-economic development. For each of these three Projections a total of three time-horizons were considered (2023, 2030, 2050) as well as a low, medium and high impact projection. Moreover, as these Projections will not happen in isolation also nine combined groups were evaluated (three time horizons x three impacts)

Most important conclusions that can be drawn from these Projections as shown in the as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models.

Most relevant conclusions regarding these projections:

- Water demand is expected to increase substantially in the future: from currently 18 MCM/y to 249 MCM/y in 2050. Since the future has quite some uncertainty in climate, economic growth and population a low and a high-impact projection have been run as well. Results show that water demand by 2030 will be 4 to 10 times higher.
- Water shortage (unmet demand) is expected to increase substantially. Without proper actions taken it is expected that 15% of the demand by 2030 cannot be delivered.
- Streamflow flowing out of the catchment is projected to decrease substantially in the future to average flows of 60 to 75% compared to today. Especially low flows during dry months are expected to decrease by around 40%.

Further details and exact numbers can be obtained from the figures below and the appendix. Obviously, the WEAP model itself provide an unlimited number of results and options to plot figures for further analysis.

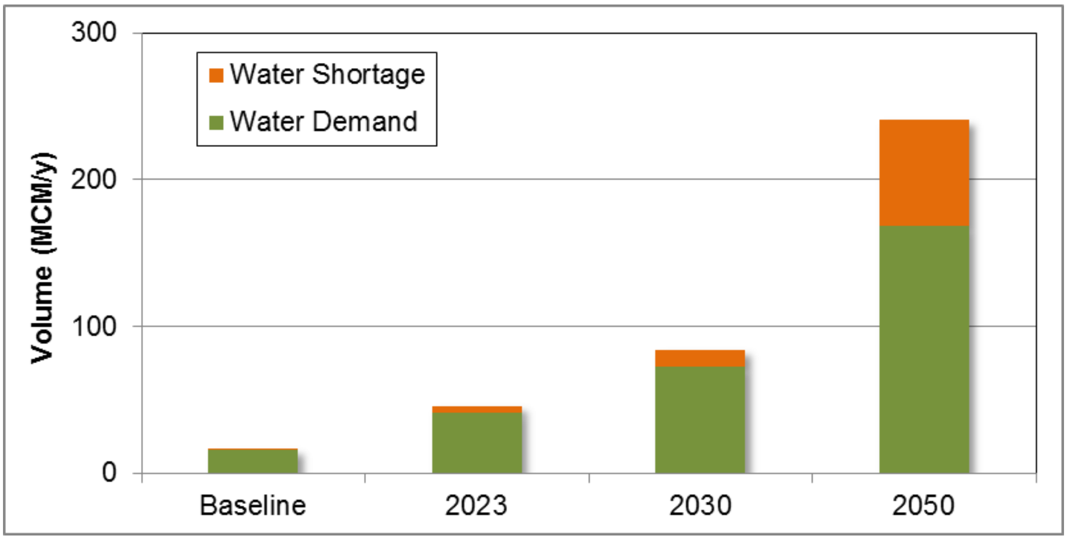


Figure 66. Water demand and shortage for the Sebeya. Results are presented for the medium future projections.

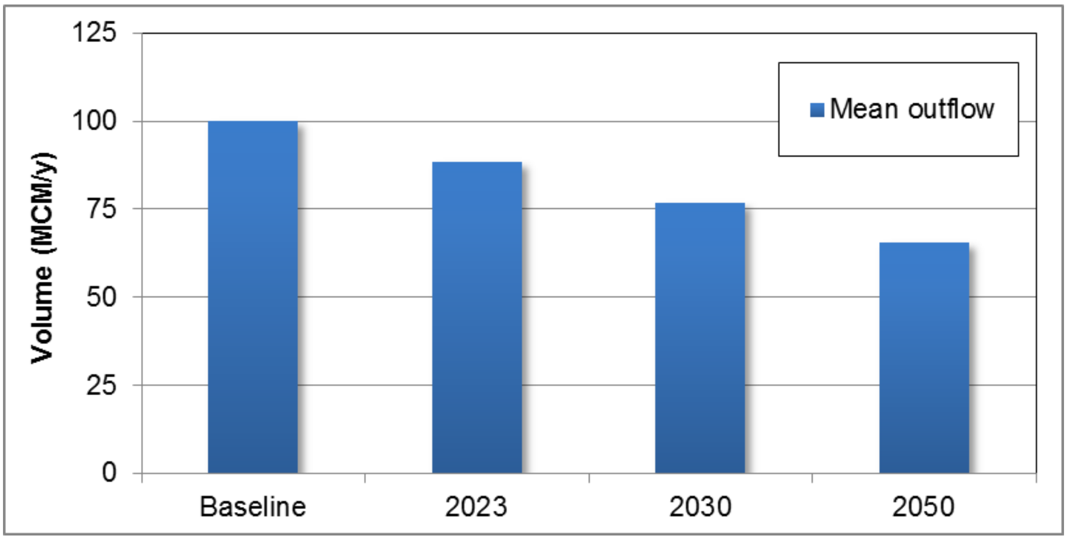


Figure 67. Mean outflow of the Sebeya. Results are presented for the medium future projections.

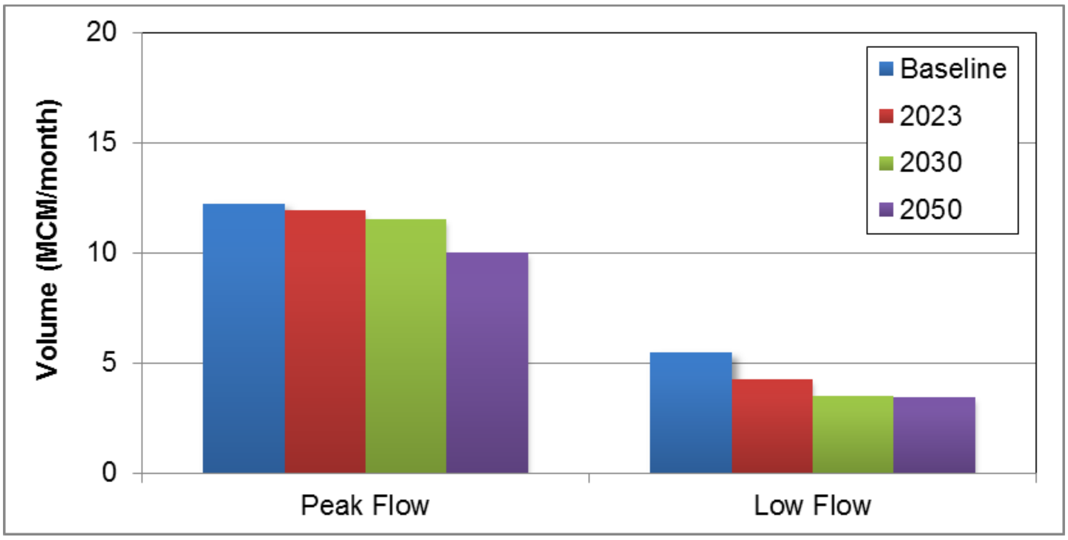


Figure 68. Peak and low flows of the Sebeya. Results are presented for the medium future projections.

7.5.2 Alternatives

In contrast to the Projections as described above are the so-called Alternatives. Alternatives (sometimes referred to as interventions, adaptations, or implementation scenarios) are decisions initiated by policymakers and implemented by water managers that will optimize water resources management. Examples are constructing reservoirs, training farmers, irrigation planning, groundwater permits, erosion control, watershed conservation, amongst many others.

The Alternatives (interventions) are evaluated for 10 different options for each three time horizons. Note that the Table below where percentages and colors are presented is based on the comparing with the Future Medium Projection (and not with the Baseline). This was done as this Future Medium is the selected scenario for climate change, economic growth and population changes. So even for example as for the 2050 Alternative many water demands are green (lower than 100%) this demand compared with Baseline is still much higher.

Most important conclusions that can be drawn from these Alternatives as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models. Main conclusions regarding the results of these Alternatives:

- Most alternatives have a positive impact on the water demand, water shortage, streamflow and catchment hydrology.
- The alternative of Planning by Administrative and Sectoral Boundaries (PASB) is less effective compared to other alternatives, especially in the context of alleviation of water shortages and low flows.
- The alternative Planning by Catchment Boundaries (PCB), and its subs PCB+ and PCB- are the preferred alternatives. PCB- looks the most effective one, but is should be kept in mind that for this irrigation development is quite reduced, having impact on food security.
- PCB+ and PCB- are able to reduce projected water shortages by 60% to 70%.

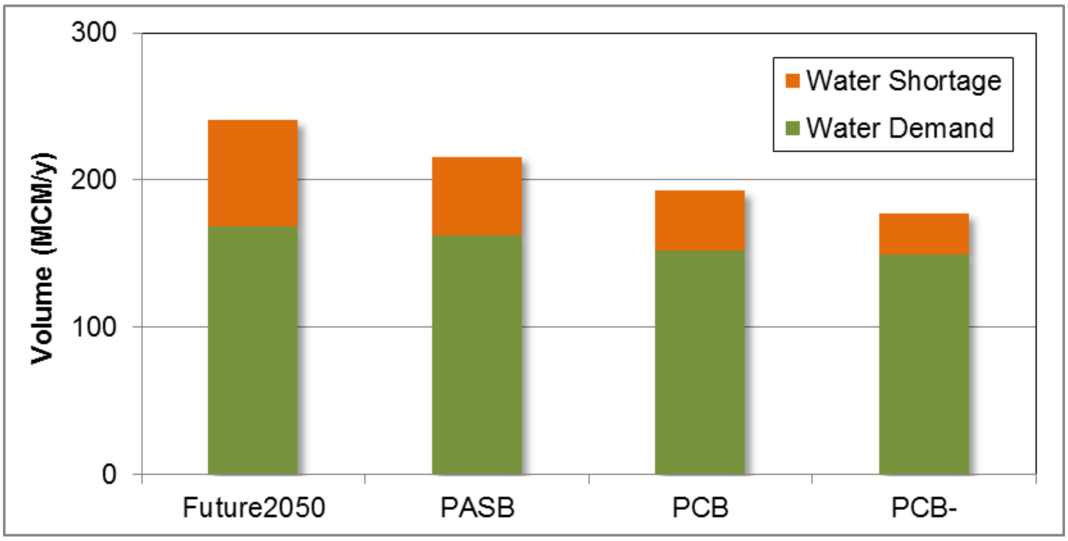


Figure 69. Water demand and shortage for the Sebeya. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

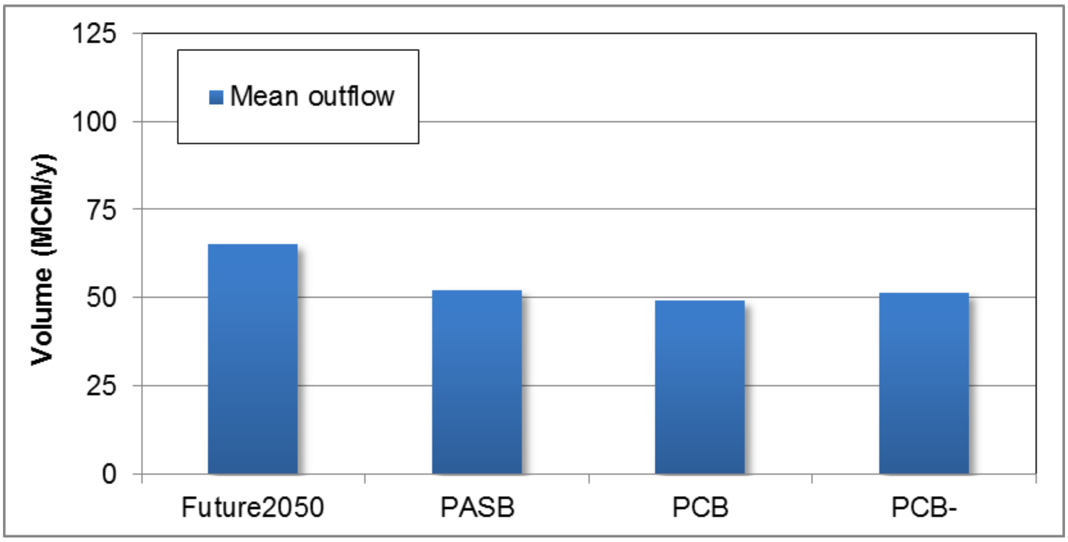


Figure 70. Mean outflow of the Sebeya. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

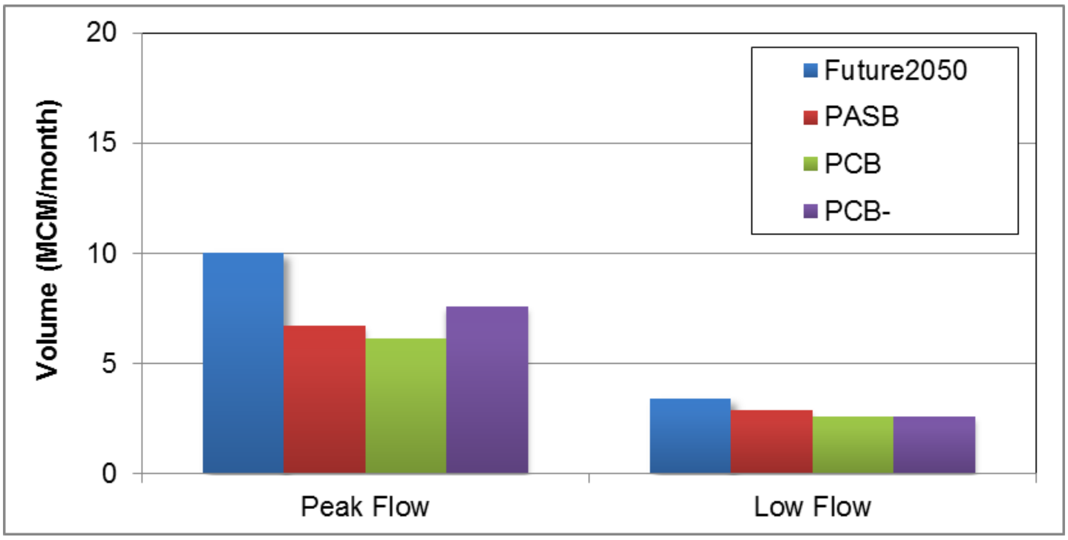


Figure 71. Peak and low flows of the Sebeya. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

8 Upper Nyabarongo Catchment: Water Balance and Allocation Modeling

8.1 Background

The Upper Nyabarongo catchment is a large catchment with a size of about 3,350 km^2 area, about 13% of RWanda. The catchment is part of the Nile basin and runs from south to north in the western part of Rwanda. The catchment is reputed to constitute the water tower of Rwanda and boosts a significant number of tributaries of which the most important are Mwogo River (length of (81 km), Rukarara River (length of 47 km), Mbirurume River (52 km) and Satinsyi River (60 km).

The Upper Nyabarongo springs from the confluence of the Mwogo and Mbirurume rivers and runs to the confluence with the Mukungwa River from where the Nyabarongo continues as the Lower Nyabarongo on its way to the Akagera River and Lake Victoria. A significant portion of the Upper Nyabarongo (particularly in the west of the catchment) is of high altitude (above 2000 m) with steep sloops, peaking at 2950 m. The outflow of the catchment is at 1410 m altitude (the confluence of the Upper Nyabarongo with the Mukungwa River).

A more detailed description of Muvumba can be found in the see Catchment Plan Report.

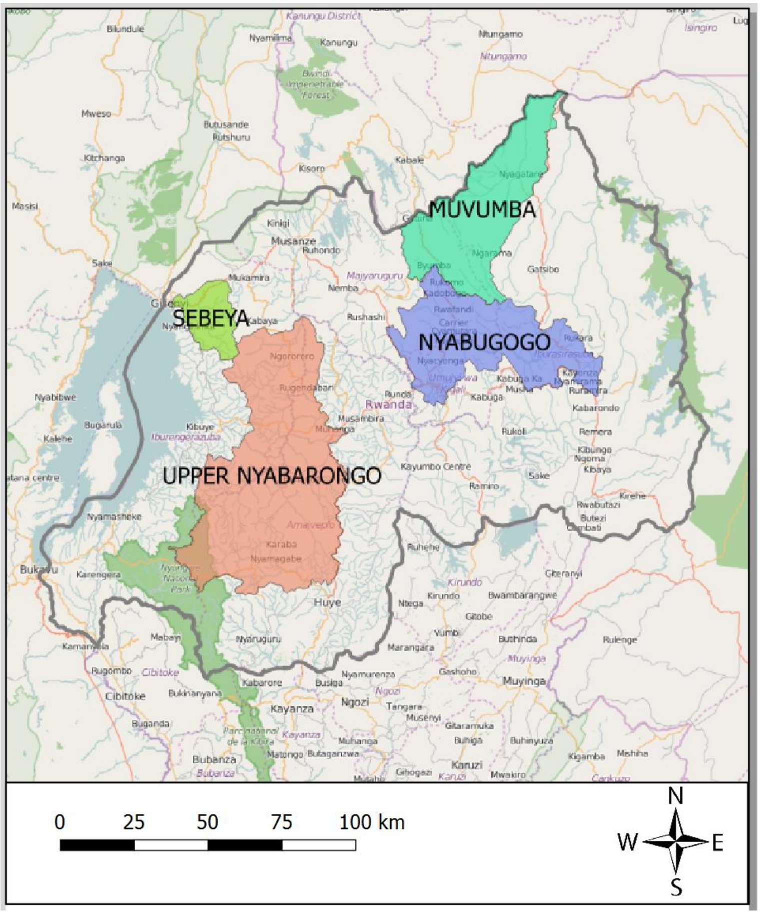


Figure 72. The four demonstration catchments of the Water for Growth Rwanda program.

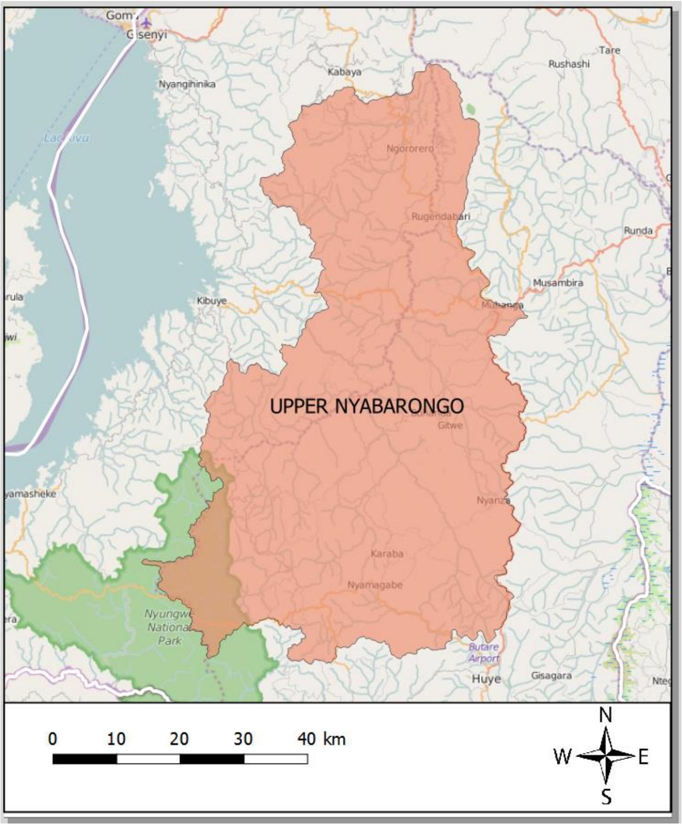


Figure 73. The Upper Nyabarongo Catchment in northern Rwanda.

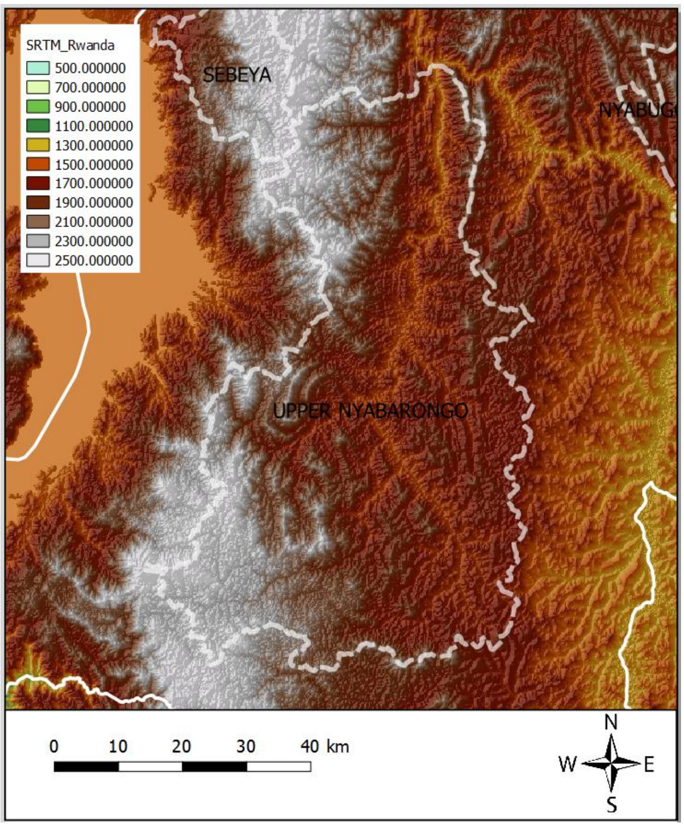


Figure 74. Elevation of the Upper Nyabarongo Catchment (in MASL).

8.2 Model development

8.2.1 Schematization

8.2.1.1 Catchments

The catchment has been divided into sub-catchment to be used in WEAP. The number of sub-catchments should be large enough to characterize the main features in the catchment, but small enough to have output at a level suited to the project requirements. In general a number of around five is sufficient. Each sub-catchment is divided into six land use classes, making a total of 30 units within the catchment.

Rwanda distinguishes four levels of Catchment planning. For the Upper Nyabarongo catchment the following number of sub-catchment at each level exists:

- Level 1: exactly 1 sub-catchment
- Level 2: 3 sub-catchments
- Level 3: 113 sub-catchments
- Level 4: 549 sub-catchments

It can be concluded that based on this analysis working at Level 2 does not provide the level of detail required for the schematization of WEAP. However, also the Level 3 sub-catchment will not work as for this the level of detail (113 sub-catchment) is too much for the project needs. It was therefore decided to create a new level of catchment detail using the DEM. A threshold level of 15,000 pixels resulted in 10 sub-catchments. These 10 were aggregated to six sub-catchments which were the base for the first WEAP model development, and were used for initial calibration, validation and scenario analysis.

During an expert knowledge driven approach it was decided to change sub-catchment boundaries to ensure a better linkage with existing and future planning procedures. This process resulted in a delineation existing out of five sub-catchments that can be seen in Figure 57.

8.2.1.2 Groundwater Node

For each sub-catchment a so-called Groundwater Node is defined. For each Groundwater Node recharge is calculated by WEAP and abstractions are based on the demand of users and the actual storage.

8.2.1.3 Demand Nodes

For each sub-catchment four so-called Demand Nodes are defined. Each demand node has a specific water user: domestic, industry (four sub-sectors), livestock, and irrigated agriculture. For domestic a sub-division between urban and domestic has been made. These water users can take water from surface water and from ground water.

Water demand per sector is taken from various sources such as Catchment Plans, National Water Resources Master Plan, Irrigation Master Plan and various data sources collected during the project. More importantly, expert knowledge was used to get the best estimates of water demand by various sectors. It is important to realize that if better data are available, these can be easily incorporated in the existing WEAP model (using the Key Assumptions approach).

In November 2016, a Water Users' Survey was carried out to get an overview of the water usage in each of the four studied catchments. The observed water users in this survey are: coffee washing stations, hydropower plants, water treatment plants, mineral extraction sites, dams, irrigation schemes, fishing farms, industries and land parcels above 100 ha. Incorporating the data from this survey in WEAP could support a well-founded and transparent view on the water allocating dynamics in each (sub-)catchment.

For domestic use, the water intake is expected to vary somewhere in the range of 40-80 L/cap/day. However, according to the Water Use Survey daily water intake per capita ranges between less than 2 L/cap/day for Muvumba up to 851 L/cap/day for Upper Nyabarongo. Possible explanations for the large difference in domestic water use between catchments could be the survey's inability to quantify small water using intakes for personal use and to focus mainly on large water users. Also, it might be possible that the large water intake for domestic use in the Upper Nyabarongo could to some extent be transported to other areas balancing the mutual differences between the catchments. As the Water Users' Survey appears to contain large uncertainties for domestic water consumption, it was selected not to use data from the Water Users' Survey for domestic use.

Instead, for domestic water demand the numbers from the Catchment Plan are used indicating that rural water demand is 40 l/cap/d and for urban 60 l/cap/d. Based on expert knowledge this number was considered outdated. Therefore in the WEAP model rural water demand was set at 80 l/cap/d and for urban 100 l/cap/d.

Water supply is considered to originate from the sub-catchments. For Ruhango and Nyanza towns an sub-catchment transfer has been included as these town obtain water from Mpanga water treatment plant.

For industrial water the Industrial water demand including mining is according to the National Water Resources Master Plan (p. 125) 3 l/cap/d. This number is outdated and data from the recently completed Water Users' Survey have been used. Exact distinction between various industrial uses was not completely clear from the data set. However, distinction between mining and other industrial use could be derived. The following data were derived and used in the WEAP models:

- Mining: 99 l/cap/d
- Coffee washing: 34 l/cap/d based on (50% of 69 l/cap/d)
- Tea factories: 17 l/cap/d based on (25% of 69 l/cap/d)
- Other: 17 l/cap/d based on (25% of 69 l/cap/d)

Data on water demand for irrigation varies substantial between different sources. It was therefore decided to follow the overall figures as mentioned in NWRMP as also done in the Catchment Plans. The average irrigation water demand depends on the type of irrigated land. Marshland irrigated areas requires between 200 and 250 mm irrigation per year, while hill side irrigated areas require 600 to 800 mm irrigation per year. Total irrigated areas where derived from the land use map. However, distinction between whether these areas are marshland or hill-side irrigated is not known. Therefore this distinction was done by taking the slopes in each sub-catchment. It was considered that if slopes are steeper than 10 degrees, hill-side irrigation is applied. Since average slopes for each sub-catchment were used, a linear interpolation was used (marshland% = 150 -10*slope). Field visits might be necessary to obtain a more accurate estimate for this. Obviously, if more detailed data will become available, this can be easily implemented in the existing WEAP model.

Water consumption by livestock is considered as well, given the importance in many parts of Rwanda. The National Water Resources Master Plan (p. 105) states however that "… the record of animals per administrative unit is notoriously inaccurate". Number of animals was therefore derived from the rural population. It was assumed that for each 5 people one animal (excluding chickens) is present. Water consumption was taken as 125 l/head/day. Obviously, if more accurate date are becoming available, these can be included in the model. Field visits might be required to get more accurate data.

Environmental flow requirements are defined according to the National Water Resources Master Plan (p. 143) as fraction of the total demand compared to "water surplus" in a particular month. A fraction of 1/3 was used. This so called "water surplus" is the "non-demanded" water. To translate this kind of cryptic wording one could say that the environmental flow requirement is not met as the total demand is more than 2/3 of the available water resources in a particular month. As example: if total water resources in a month are 100 MCM, environmental flow requirements are not met if demand in that month exceeds 66 MCM. Interesting in this definition is that the flow in a river is not considered as a criterion.

8.2.2 Land cover

Land class data is used in WEAP to imitate the hydrological relations between the soil, the atmosphere and runoff. For the WEAP models a list of 14 land cover classes is used:

- Agroforestry with progressive terraces
- Agroforestry with radical terraces
- Agroforestry without terraces
- Forest
- Grassland
- Irrigated marshland
- Irrigated hillslope
- Progressive terraces without agroforestry
- Radical terraces without agroforestry
- Rainfed agriculture
- River buffer zones
- Shrubs
- Urban
- Wetlands

A land cover map of Rwanda in 2015 is provided by the RNRA and used to calculate the land cover areas per sub-catchment. As information on terraces and irrigation is lacking from this map, these are added separately. A Google Earth exercise has been performed to quantify the currently terraced areas. Terraces are distinguished in four categories; radical terraces and progressive terraces both either with or without agroforestry. Terraces and agroforestry are forms of soil, water and crop management and therefore will also influence the WEAP soil and water retention characteristics accordingly. Furthermore, the soil and water retention characteristics also varies for each of the remaining land use classes and is stored in the WEAP models respectively.

In WEAP, these characteristics are defined by the root-zone conductivity, soil water capacity, preferred flow direction and the runoff-resistance factor. The runoff-resistance factor controls the amount of water that enters the upper soil layer, the soil water capacity determines the amount of water that can be stored in the upper soil layer and the root-zone conductivity and the preferred flow direction influence the water percolation from the upper soil layer to the deeper soil layer. For example, increasing the terraced area in a sub-catchment will increase the water retention capacity by enhancing the runoff-resistance, the soil water capacity, preferred flow direction and the root zone conductivity.

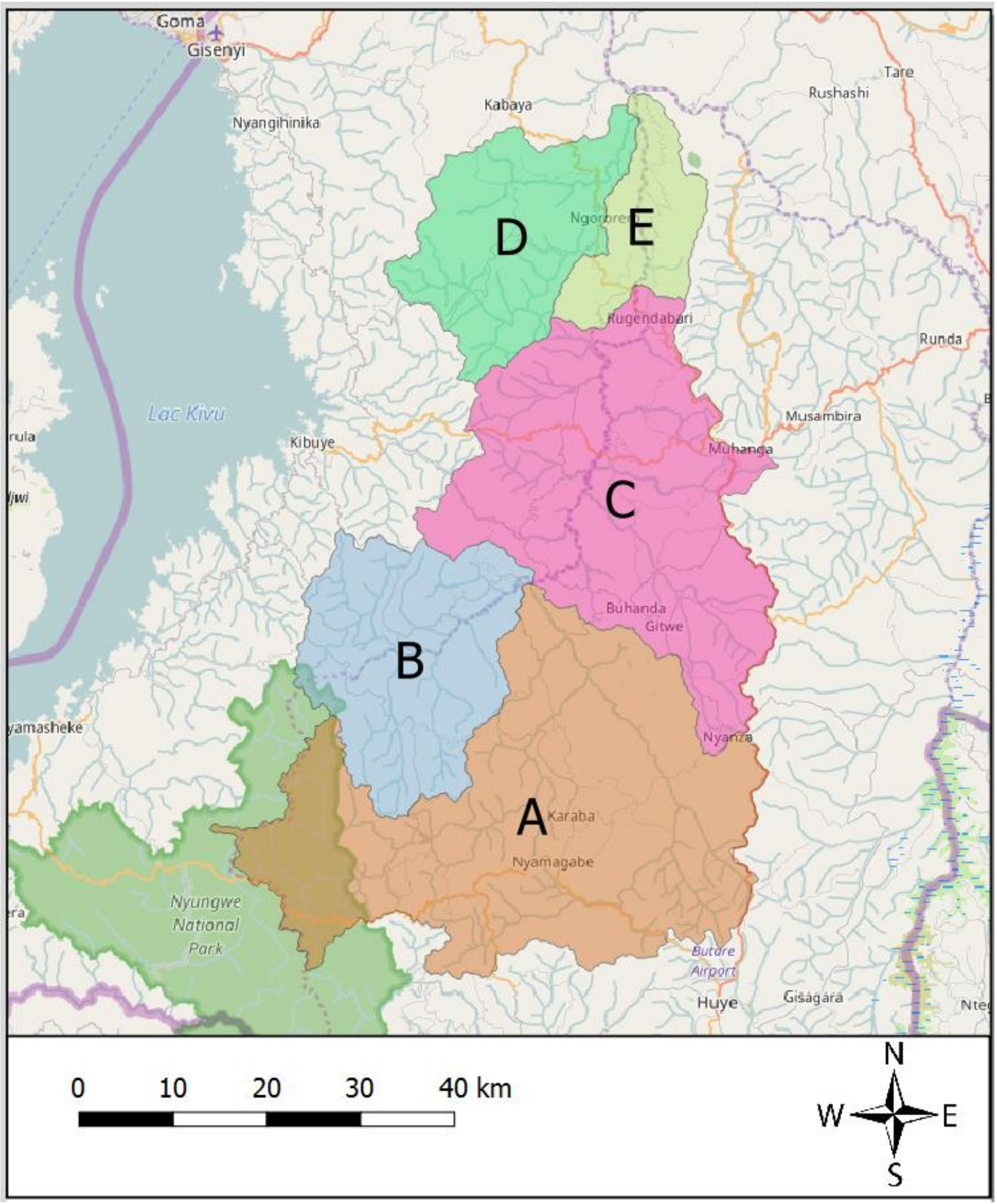


Figure 75. The five sub-catchments in Upper Nyabarongo as used in the WEAP model.

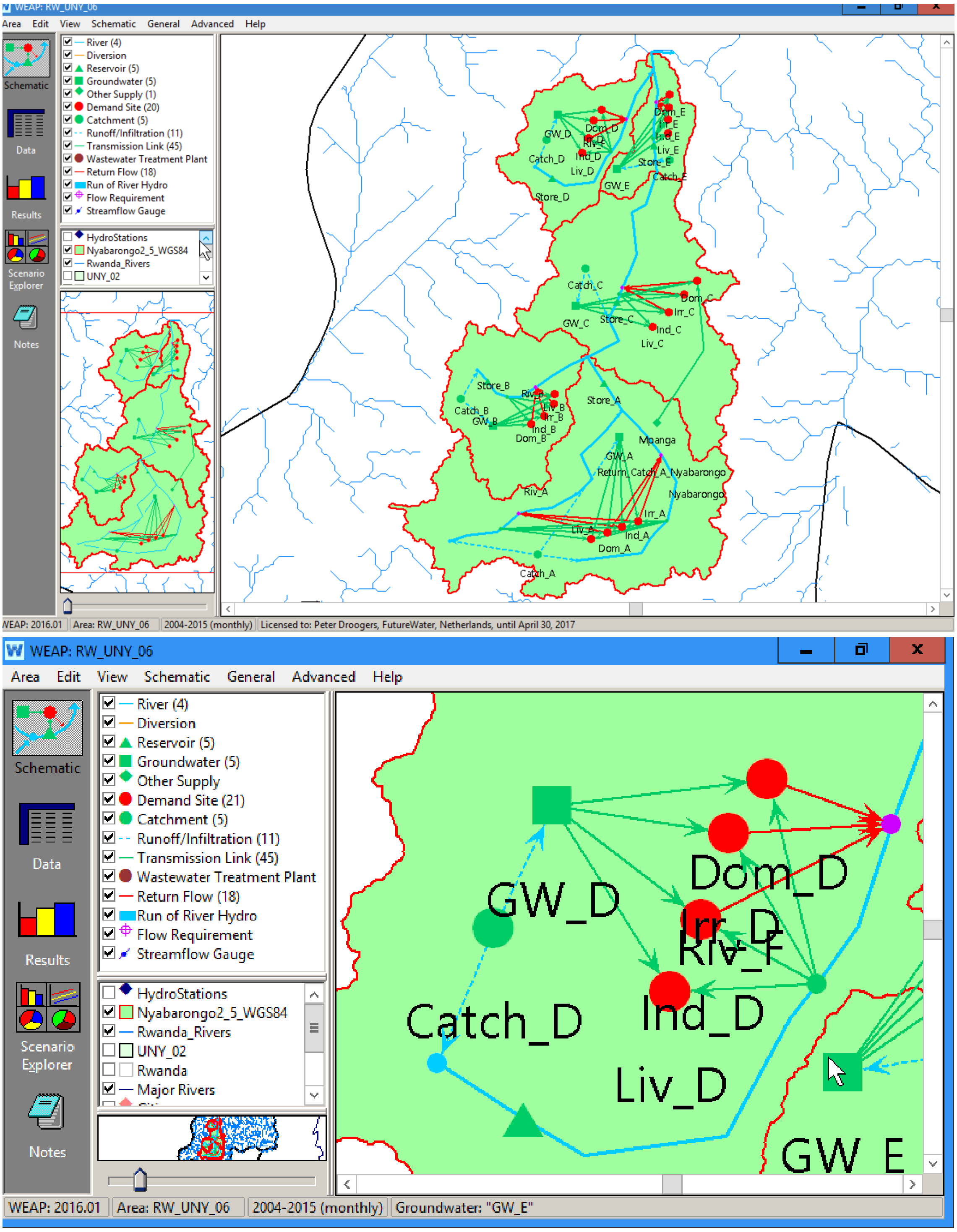


Figure 76. Schematization of Upper Nyabarongo in the WEAP model. Top: complete model. Bottom: detail for Sub-Catchment D.

8.2.3 Meteorological data

8.2.3.1 Rainfall

Meteorological data and especially rainfall data is essential to develop catchment planning. Quite some data are observed and available for Rwanda. However, recent data is difficult to obtain, spatial coverage is somewhat fragmented, and quality control has to be performed. Global initiatives of various research group around the world have resulted in consistent data sets of precipitation, based on using remote sensing, observations and advanced data assimilation techniques. One of the most commonly used and accepted as high quality is the so-called Chirps data set.

CHRIPS is the Climate Hazards Group InfraRed Precipitation with Station data and is a 30+ year quasi-global rainfall dataset. Spanning 50°S-50°N (and all longitudes), starting in 1981 to near-present, CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

Estimating rainfall variations in space and time is an important aspect of drought early warning and environmental monitoring. An evolving dryer-than-normal season must be placed in historical context so that the severity of rainfall deficits may be quickly evaluated. However, estimates derived from satellite data provide areal averages that suffer from biases due to complex terrain which often underestimate the intensity of extreme precipitations events. Conversely, precipitation grids produced from station data suffer in more rural regions where there are less rain gauge stations. CHIRPS was created in collaboration with scientists at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center in order to deliver reliable, up to date, and more complete datasets for a number of early warning objectives (such as trend analysis and seasonal drought monitoring).

Early research focused on combining models of terrain-induced precipitation enhancement with interpolated station data. More recently, new resources of satellite observations such as gridded satellite-based precipitation estimates from NASA and NOAA have been leveraged to build high resolution (0.05°) gridded precipitation climatologies. When applied to satellite-based precipitation fields, these improved climatologies can remove systematic bias, a key technique in the production of the 1981 to near-present CHIRPS dataset. The creation of CHIRPS has supported drought monitoring efforts by the USAID Famine Early Warning Systems Network (FEWS NET).

The CHIRPS data can be downloaded free of charge from http://chg.geog.ucsb.edu/data/chirps/. Data are delivered for the entire continent at a daily based. Using QGIS and python scripting these data were aggregated to monthly values for each sub-catchment.

8.2.3.2 Other climate variables

The Rwandan climate is quite constant during the year with the exception of the rainfall (as discussed in the previous section). For the WEAP model additional climate data are needed to estimate the potential evapotranspiration. For temperature the average monthly values of Kigali (elevation 1567 MASL) have been used and scaled to the average elevation using a lapse-rate. Lapse rates are in general between 0.6 and 1.0^{o}C depending on the stability of the air and the extent of high elevation plateaus. If air is not completely saturated and no extended plateaus exist a lapse rate of 1^{o}C per 100 meter applies. So taken Kigali elevation as reference the following equation applies: Tcorr (^{0}C) = 15.67 – 0.01*Elevation(m). For relative humidity also the average monthly data for Kigali have been used. Finally, cloudiness fraction has been derived from the monthly average rainfall records, where it was assumed that if rainfall exceeds 100 mm per month cloud fraction is 50%, and with lower rainfall linear scaled to 100%.

Obviously, if additional and more accurate climate data are becoming available, these can be easily included in the existing model.

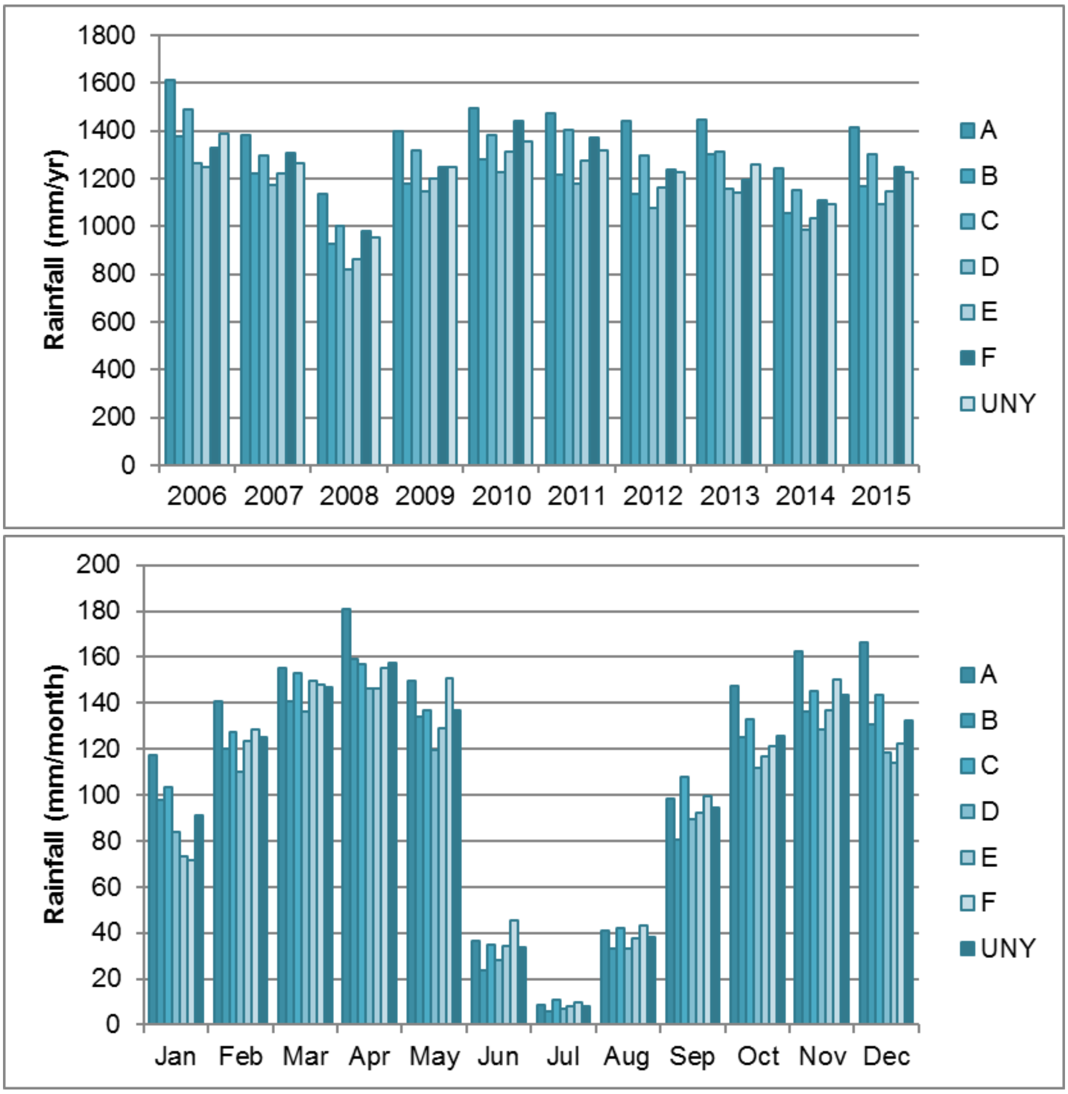


Figure 77. Rainfall data for Upper Nyabarongo catchment and the five sub-catchments as derived from the CHRIPS dataset. Top: total annual rainfall. Bottom: average monthly rainfall over 2006-2015. A-E are the sub-catchments; UNY is average entire Upper Nyabarongo Catchment.

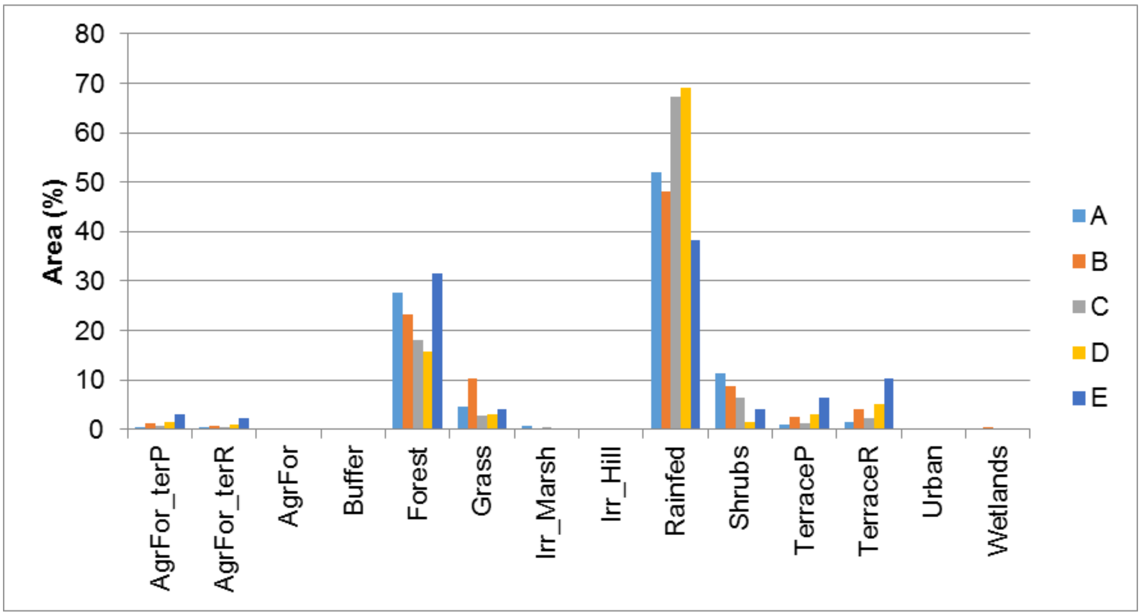


Figure 78. Land cover distribution in the Upper Nyabarongo sub-catchments.

8.3 Model Performance

The WEAP model has been widely applied in many regions across the globe. WEAP has proven to be a reliable tool for water balance and water allocation analysis. Obviously, quality of a model for s specific area depends completely on the accuracy of the available data. For this specific study it is important to realize the difference between “absolute” accuracy and “relative” accuracy. “Absolute” accuracy relates to how well the model represents reality; “relative” accuracy relates to the accuracy of comparing different scenarios. It has been proven that even if “absolute” accuracy is low, “relative” accuracy can be still high.

Nevertheless, it remains important to assess the performance of the model, even if data is scarce. This has been done using:

- Flow station data
- References such as NWRMP
- ET results from satellite information

For the Upper Nyabarongo data of various streamflow gauges are available (in brackets average flow). It was selected to use the most downstream station to assess model vs. observations.

Note that data of these stations are very fragmented and the derived stage-discharge relationships are for some of the stations based on limited data points. For each gauging station the graphs for flows, annual averages and monthly averages have been plotted. From these graphs it is clear that data is erratic in terms of available records as well as sudden unexplainable jumps. Therefore it was decided to focus on the Mwaka station for evaluating the model performance.

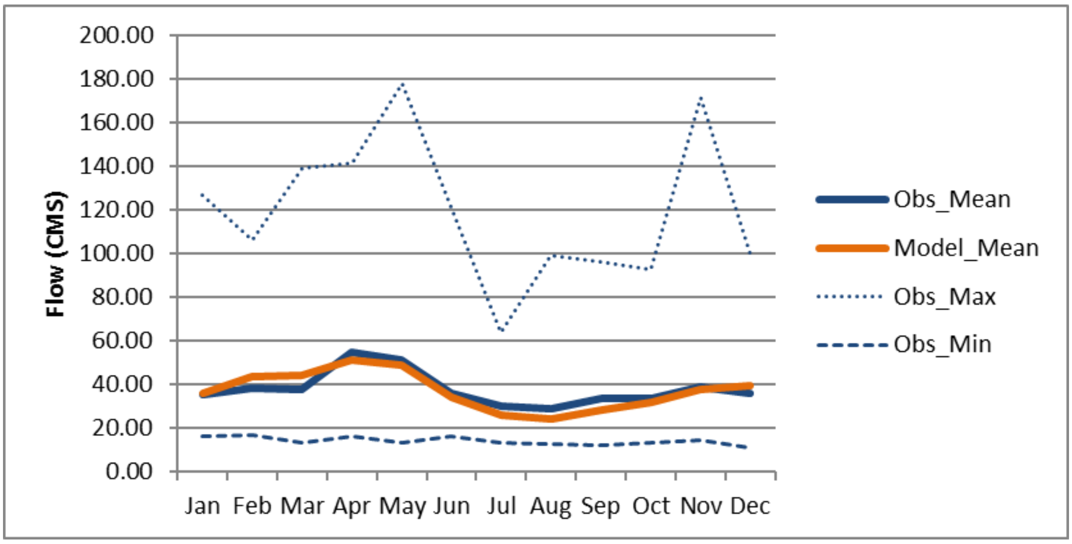


Figure 79. Observed and simulated mean, min and max flow for station Mwaka.

Table 12. Comparing water balance terms from NWRMP and WEAP model for Upper Nyabarongo.

	NWRMP	Model		
		AVG	Min	Max
Outflow basin (MCM/y)		4,113	3,178	4,633
Precipitation (MCM/y)	4,570	4,113	3,178	4,633
Actual evaporation (MCM/y)	3,281	2,077	1,971	2,141
Surface runoff (MCM/y)	1,289	1,498	1,201	1,753
Groundwater recharge (MCM/y)	1,000	519	443	582
Domestic use (MCM/y)	8.4	3.0	3.0	3.0
Irrigation use (MCM/y)	1.2	9.0	9.0	9.0
Industrial use (MCM/y)	N/A	62.0	62.0	62.0
Livestock use (MCM/y)	N/A	2.0	2.0	2.0

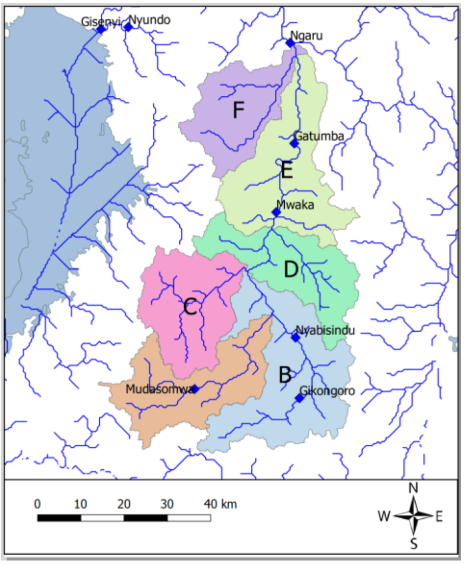


Figure 80. Flow gauging stations in the Upper Nyabarongo Catchment.

8.4 Baseline

The WEAP model was use to set the Baseline which can be considered as the current situation. This Baseline can be considered as the current situation and was analyzed by using data and information from a ten years period (2006-2015).

From the following Tables it is clear that most of the available water (= rainfall and inflow from Uganda) is evaporated by vegetation. Outflow from the catchment and groundwater recharge are other important components in the catchment. Interesting is that the so-called manageable water (sometimes referred to as Blue Water) is about 30% of total water resources. Only a small fraction is actually withdrawn for domestic, industry, irrigation and livestock.

These summary tables are essential to understand total water issues in the catchment. However, the WEAP models developed provide a wealth of more detailed information. The two screenshots hereafter on water demand and supply are shown as example of what can be obtained from the model.

Table 13. Summarized water balance for the entire basin for the baseline as 10 years average for the Upper Nyabarongo catchment.

IN	*(MCM/y)*	**OUT**	*(MCM/y)*
Precipitation	4,117	Evapotranspiration	2,077
Return flows	25	Withdrawals	42
Storage change	-23	Outflow	1,485
		Groundwater recharge	515
Total	*4,119*	*Total*	*4,119*

Table 14. Summarized water balance for the manageable water components (Blue Water) as 10 years average for the Upper Nyabarongo catchment.

IN	*(MCM/y)*	**OUT**	*(MCM/y)*
Runoff	402	Domestic	3
Baseflow	1,096	Industry	29
Groundwater	4	Irrigation	8
Return flows	25	Livestock	2
		Outflow	1,485
Total	*1,527*	*Total*	*1,527*

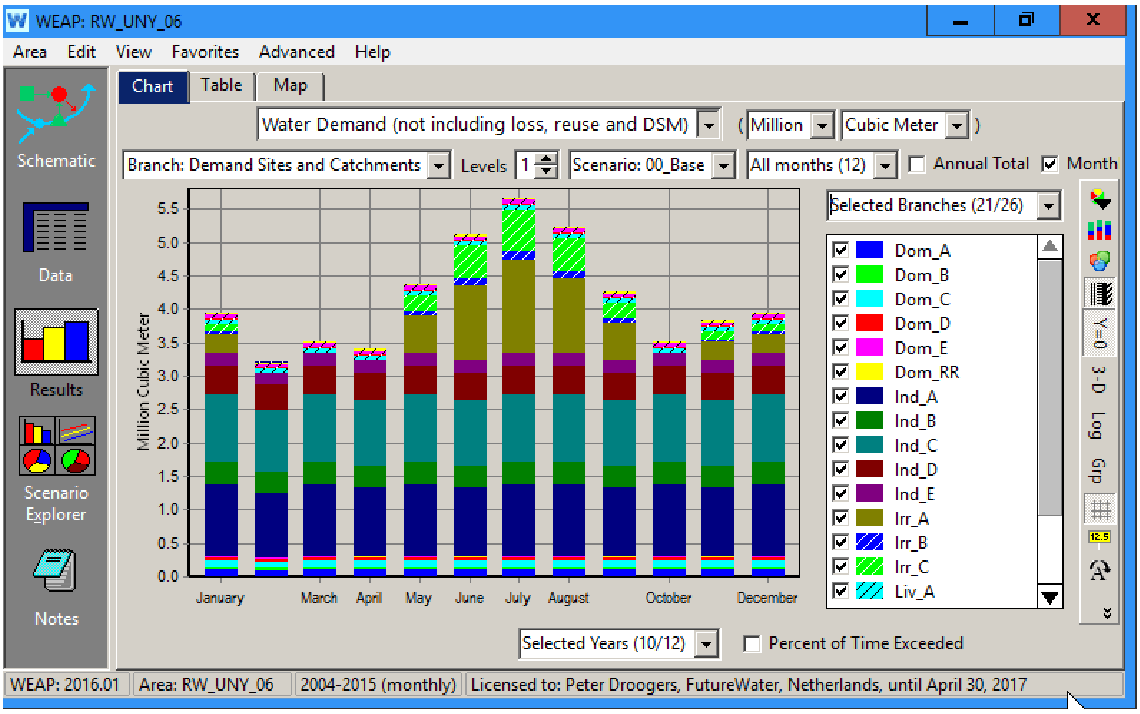


Figure 81. Example of WEAP results for the baseline: monthly average water demand.

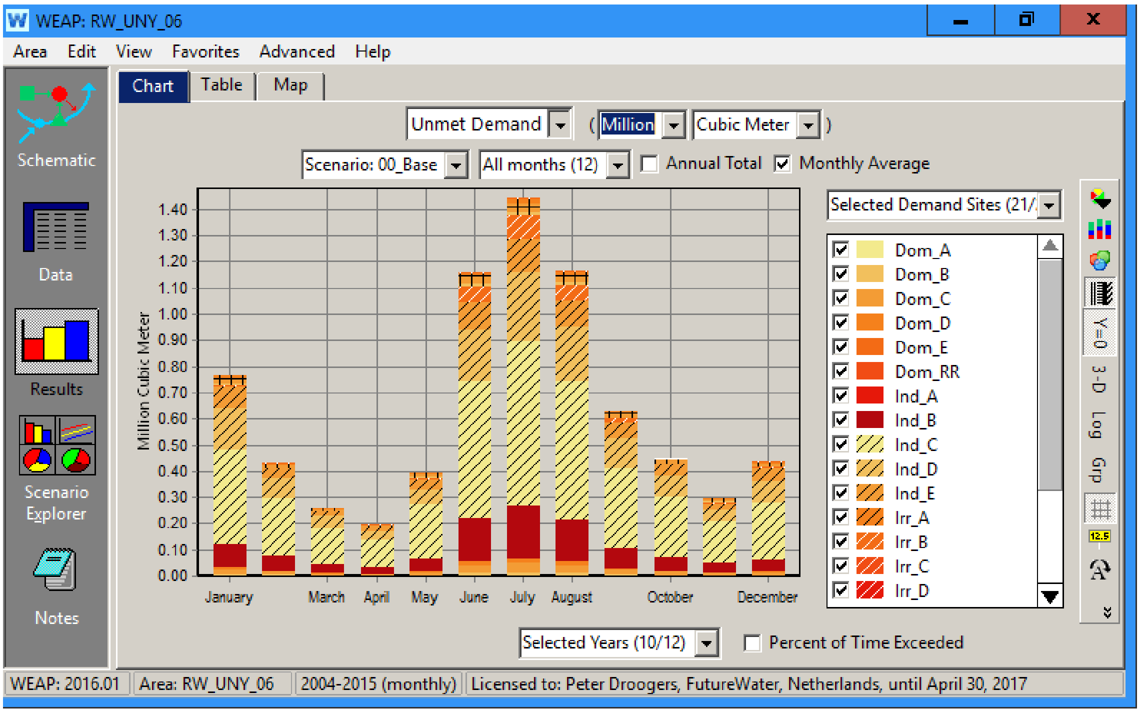


Figure 82. Example of WEAP results for the baseline: monthly average water shortages.

8.5 Scenarios: Projections and Alternatives

8.5.1 Projections

Projections (sometimes referred to as pathways or storylines) are future scenarios that can be hardly influenced by water planners and decision makers. Four different types of Projections were analyzed: climate change, population growth, and macro-economic development. For each of these three Projections a total of three time-horizons were considered (2023, 2030, 2050) as well as a low, medium and high impact projection. Moreover, as these Projections will not happen in isolation also nine combined groups were evaluated (three time horizons x three impacts)

Most important conclusions that can be drawn from these Projections as shown in the as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models.

Most relevant conclusions regarding these projections:

- Current water demand is quite modest at 50MCM/y, but already water shortages occur of about 10 to 15%. Water demand is expected to increase substantially in the future: from currently 50 MCM/y to 747 MCM/y in 2050, an increase of almost 15 times. Since the future has quite some uncertainty in climate, economic growth and population a low and a high-impact projection have been run as well. Results show that water demand by 2030 will be 10 to 30 times higher.
- Water shortage (unmet demand) is expected to increase substantially. Without proper actions taken it is expected that 25% of the demand by 2030 cannot be delivered.
- Changes in streamflow will be modest; the higher demand is compensated by an overall increase in precipitation. However, streamflow during dry months is projected to be lower and are somewhere between 85% and 70% compared to currently.

Further details and exact numbers can be obtained from the figures below and the appendix. Obviously, the WEAP model itself provide an unlimited number of results and options to plot figures for further analysis.

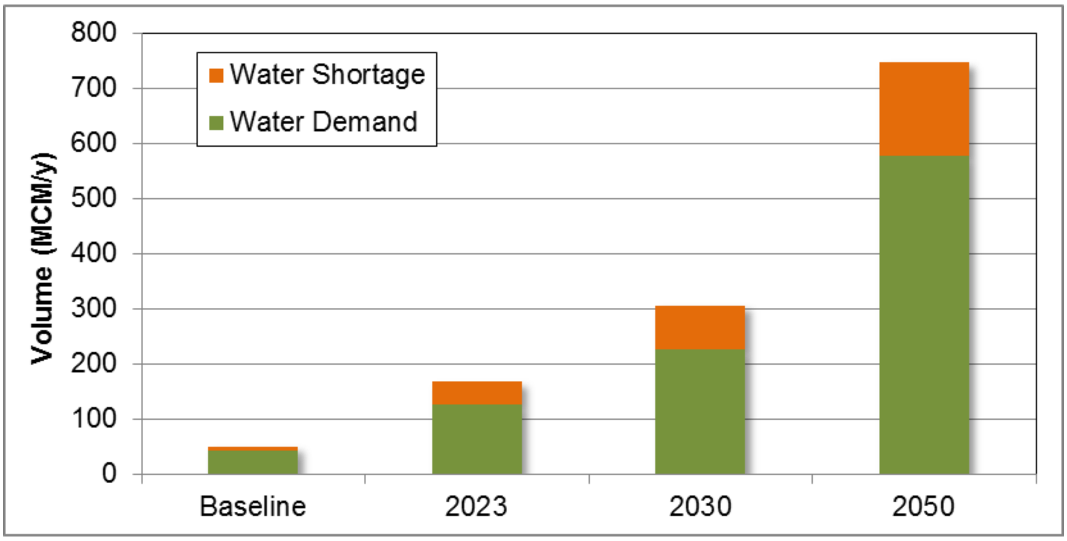


Figure 83. Water demand and shortage for the Upper Nyabarongo. Results are presented for the medium future projections.

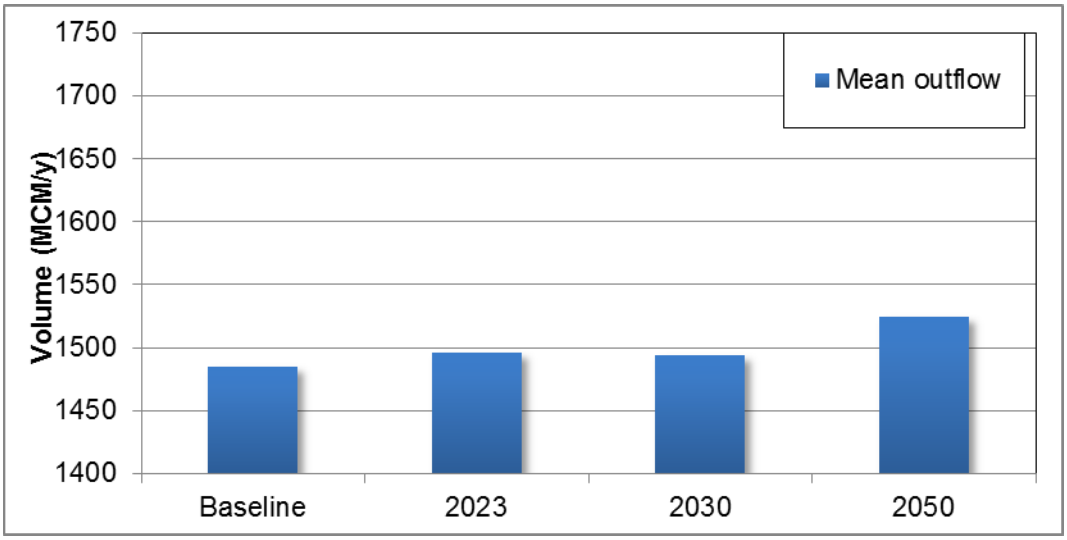


Figure 84. Mean outflow of the Upper Nyabarongo. Results are presented for the medium future projections.

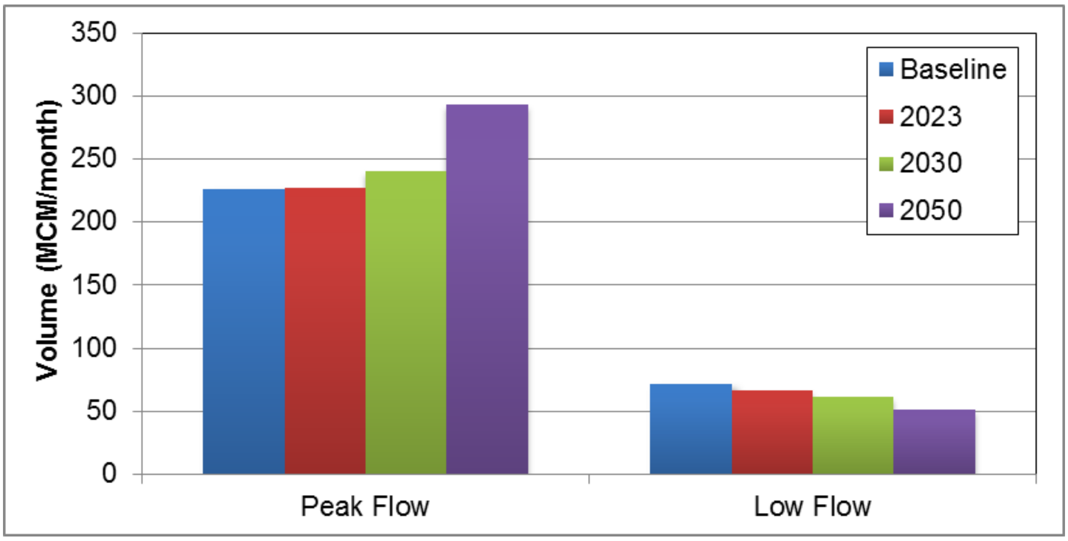


Figure 85. Peak and low flows of the Upper Nyabarongo. Results are presented for the medium future projections.

8.5.2 Alternatives

In contrast to the Projections as described above are the so-called Alternatives. Alternatives (sometimes referred to as interventions, adaptations, or implementation scenarios) are decisions initiated by policymakers and implemented by water managers that will optimize water resources management. Examples are constructing reservoirs, training farmers, irrigation planning, groundwater permits, erosion control, watershed conservation, amongst many others.

The Alternatives (interventions) are evaluated for 10 different options for each three time horizons. Note that the Table below where percentages and colors are presented is based on the comparing with the Future Medium Projection (and not with the Baseline). This was done as this Future Medium is the selected scenario for climate change, economic growth and population changes. So even for example as for the 2050 Alternative many water demands are green (lower than 100%) this demand compared with Baseline is still much higher.

Most important conclusions that can be drawn from these Alternatives as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models. Main conclusions regarding the results of these Alternatives:

- Most alternatives have a positive impact on the water demand, water shortage, streamflow and catchment hydrology.
- The alternative of Planning by Administrative and Sectoral Boundaries (PASB) is less effective compared to other alternatives, especially in the context of alleviation of water shortages and low flows.
- The alternative Planning by Catchment Boundaries (PCB), and its subs PCB+ and PCB- are the preferred alternatives. PCB- looks the most effective one, but is should be kept in mind that for this irrigation development is quite reduced, having impact on food security.
- PCB+ and PCB- are able to reduce projected water shortages by 40% to 45%.

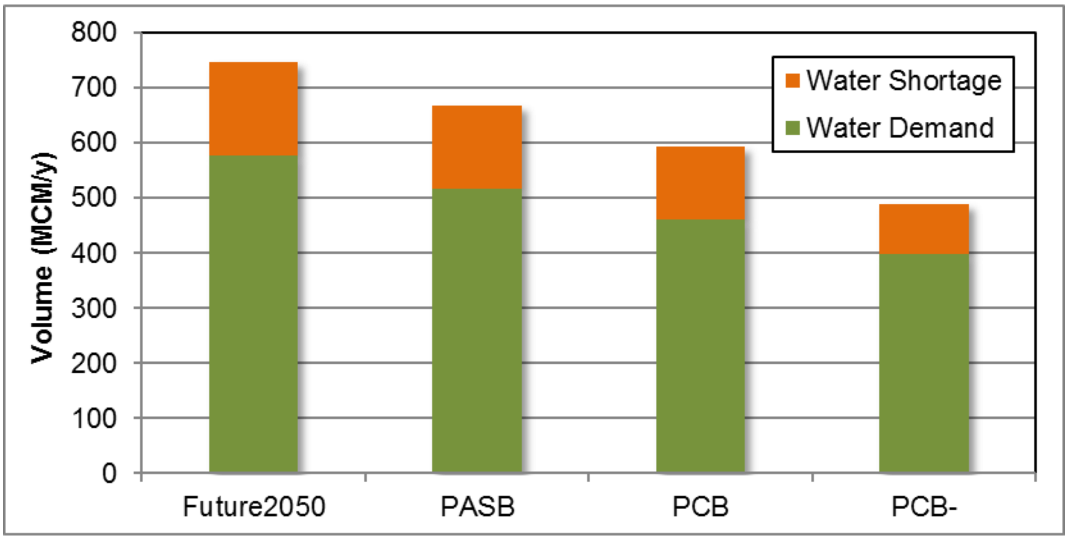


Figure 86. Water demand and shortage for the Upper Nyabarongo. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

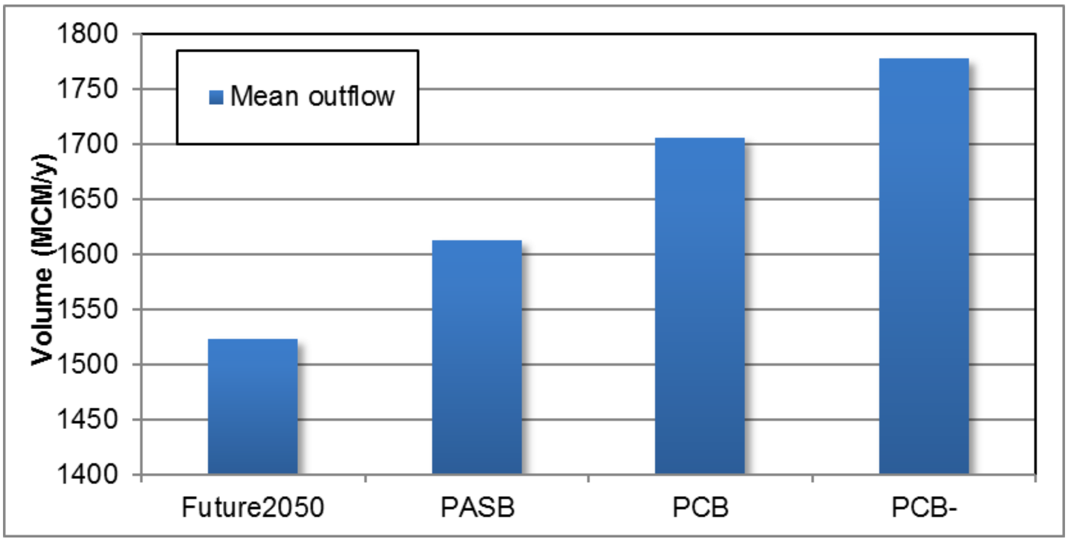


Figure 87. Mean outflow of the Upper Nyabarongo. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

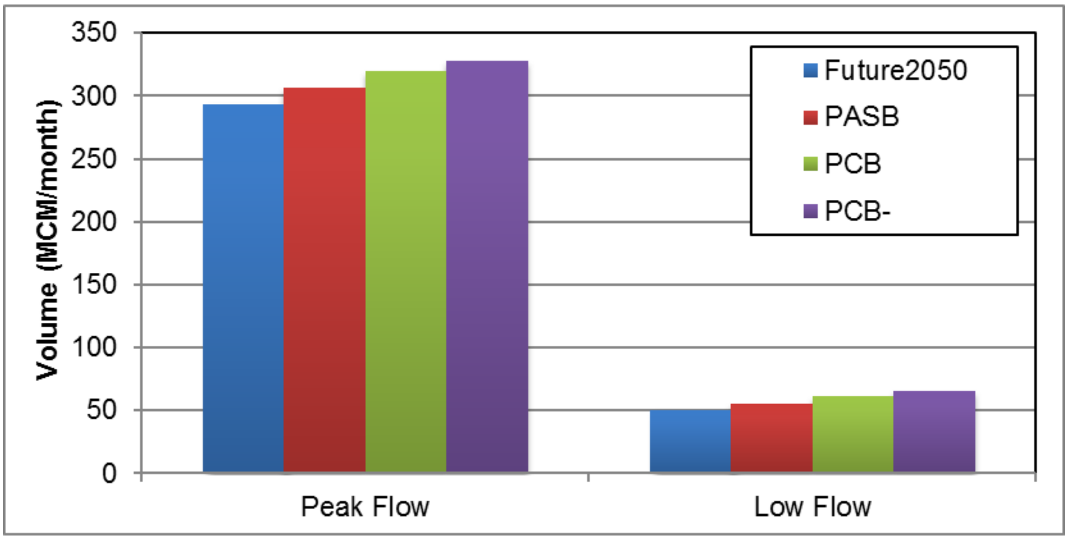


Figure 88. Peak and low flows of the Upper Nyabarongo. Results are presented for various selected Alternatives.

PASB = Planning by Administrative and Sectoral Boundaries. PCB = Planning by catchment Boundaries. PCB- = PCB with reduced implementation of irrigation.

9 Water budgets and planning in Rwanda using WEAP-R

9.1 Background

A nation-wide WEAP model (WEAP-R) has been built for the level-two catchments. The overall objective of this model is to support nation-wide water allocation and planning at a strategic level.

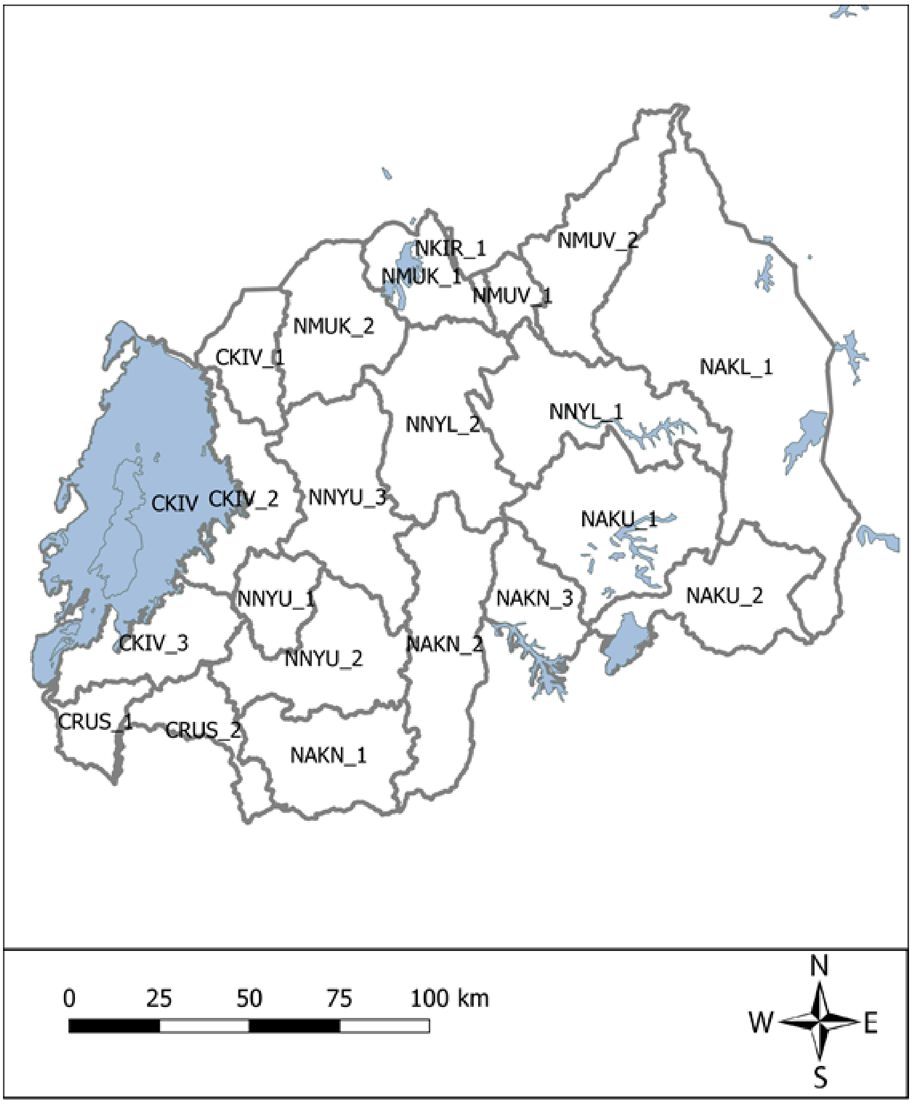


Figure 89. Level 2 Catchments in Rwanda.

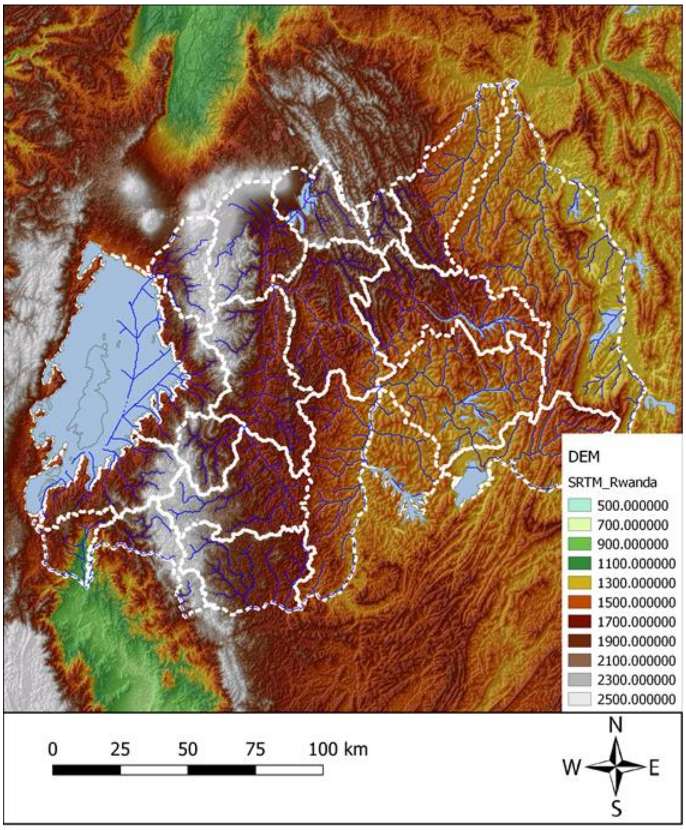


Figure 90. Elevations in Rwanda (in MASL).

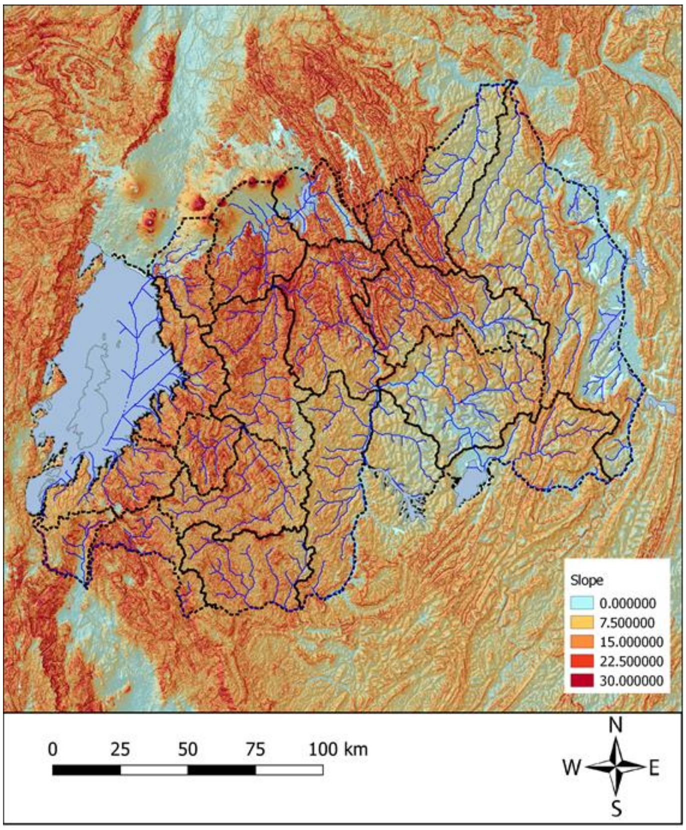


Figure 91. Slope map for Rwanda (in MASL).

9.2 Model development

9.2.1 Schematization

9.2.1.1 Catchments

In the NWRMP three levels of catchment delineation has been used. The nine Level 1 Catchments has been divided into smaller Level 2 catchments resulting in 20 Catchments. Each Catchment is divided into six land use classes, making a total of 120 units within the entire Rwanda model.

WEAP includes a so-called two layer approach to simulate hydrological processes. The first layer is the root zone and the second aquifer. Various data are needed to simulate those processes, which are linked to slope, soils and vegetation. The following data are used in the model.

9.2.1.2 River network

The river network as defined in WEAP is based on the catchments present in the country. For the Congo based catchments smaller streams flow into Lake Kivu contributing to the flow of the river Congo. Most catchments contribute through a series of streams to the Akagera, which flows through Uganda and emptying in Lake Victoria.

9.2.1.3 Groundwater Node

For each of the 20 catchment a so-called Groundwater Node is defined. For each Groundwater Node recharge is calculated by WEAP and abstractions are based on the demand of users and the actual storage.

9.2.1.4 Demand Nodes

For each catchment four so-called Demand Nodes are defined. Each demand node has a specific water user: domestic, industry (four sub-sectors), livestock, and irrigated agriculture. For domestic a sub-division between urban and domestic has been made. These water users can take water from surface water and from ground water.

Water demand per sector is taken from various sources such as Catchment Plans, National Water Resources Master Plan, Irrigation Master Plan and various data sources collected during the project. More importantly, expert knowledge was used to get the best estimates of water demand by various sectors. It is important to realize that if better data are available, these can be easily incorporated in the existing WEAP model (using the Key Assumptions approach).

In November 2016, a Water Users' Survey was carried out to get an overview of the water usage in each of the four studied catchments. The observed water users in this survey are: coffee washing stations, hydropower plants, water treatment plants, mineral extraction sites, dams, irrigation schemes, fishing farms, industries and land parcels above 100 ha. Incorporating the data from this survey in WEAP could support a well-founded and transparent view on the water allocating dynamics in each (sub-)catchment.

For domestic use, the water intake is expected to vary somewhere in the range of 40-80 L/cap/day. However, according to the Water Use Survey daily water intake per capita ranges between less than 2 L/cap/day for Muvumba up to 851 L/cap/day for Upper Nyabarongo. Possible explanations for the large difference in domestic water use between catchments could be the survey's inability to quantify small water using intakes for personal use and to focus mainly on large water users. Also, it might be possible that the large water intake for domestic use in the Upper Nyabarongo could to some extent be transported to other areas balancing the mutual differences between the catchments. As the Water Users' Survey appears to contain large uncertainties for domestic water consumption, it was selected not to use data from the Water Users' Survey for domestic use.

Instead, for domestic water demand the numbers from the Catchment Plan are used indicating that rural water demand is 40 l/cap/d and for urban 60 l/cap/d. Based on expert knowledge this number was considered outdated. Therefore in the WEAP model rural water demand was set at 80 l/cap/d and for urban 100 l/cap/d.

For industrial water the Industrial water demand including mining is according to the National Water Resources Master Plan (p. 125) 3 l/cap/d. This number is outdated and data from the recently completed Water Users' Survey have been used. Exact distinction between various industrial uses was not completely clear from the data set. However distinction between mining and other industrial use could be derived. The following data were derived and used in the WEAP models:

- Mining: 77 l/cap/d
- Coffee washing: 38 l/cap/d based on (50% van 77 l/cap/d)
- Tea factories: 19 l/cap/d based on (25% van 77 l/cap/d)
- Other: 19 l/cap/d based on (25% van 77 l/cap/d)

Data on water demand for irrigation varies substantial between different sources. It was therefore decided to follow the overall figures as mentioned in NWRMP as also done in the Catchment Plans. The average irrigation water demand depends on the type of irrigated land. Marshland irrigated areas requires between 200 and 250 mm irrigation per year, while hill side irrigated areas require 600 to 800 mm irrigation per year. Total irrigated areas where derived from the land use map. However, distinction between whether these areas are marshland or hill-side irrigated is not known. Therefore this distinction was done by taking the slopes in each sub-catchment. It was considered that if slopes are steeper than 10 degrees, hill-side irrigation is applied. Since average slopes for each sub-catchment were used, a linear interpolation was used (marshland% = 150 -10*slope). Field visits might be necessary to obtain a more accurate estimate for this. Obviously, if more detailed data will become available, this can be easily implemented in the existing WEAP model.

Water consumption by livestock is considered as well, given the importance in many parts of Rwanda. The National Water Resources Master Plan (p. 105) states however that "… the record of animals per administrative unit is notoriously inaccurate". Number of animals was therefore derived from the rural population. It was assumed that for each 5 people one animal (excluding chickens) is present. Water consumption was taken as 125 l/head/day. Obviously, if more accurate date are becoming available, these can be included in the model. Field visits might be required to get more accurate data.

Environmental flow requirements are defined according to the National Water Resources Master Plan (p. 143) as fraction of the total demand compared to "water surplus" in a particular month. A fraction of 1/3 was used. This so called "water surplus" is the "non-demanded" water.

To translate this kind of cryptic wording one could say that the environmental flow requirement is not met as the total demand is more than 2/3 of the available water resources in a particular month. As example: if total water resources in a month are 100 MCM, environmental flow requirements are not met if demand in that month exceeds 66 MCM. Interesting in this definition is that the flow in a river is not considered as a criterion.

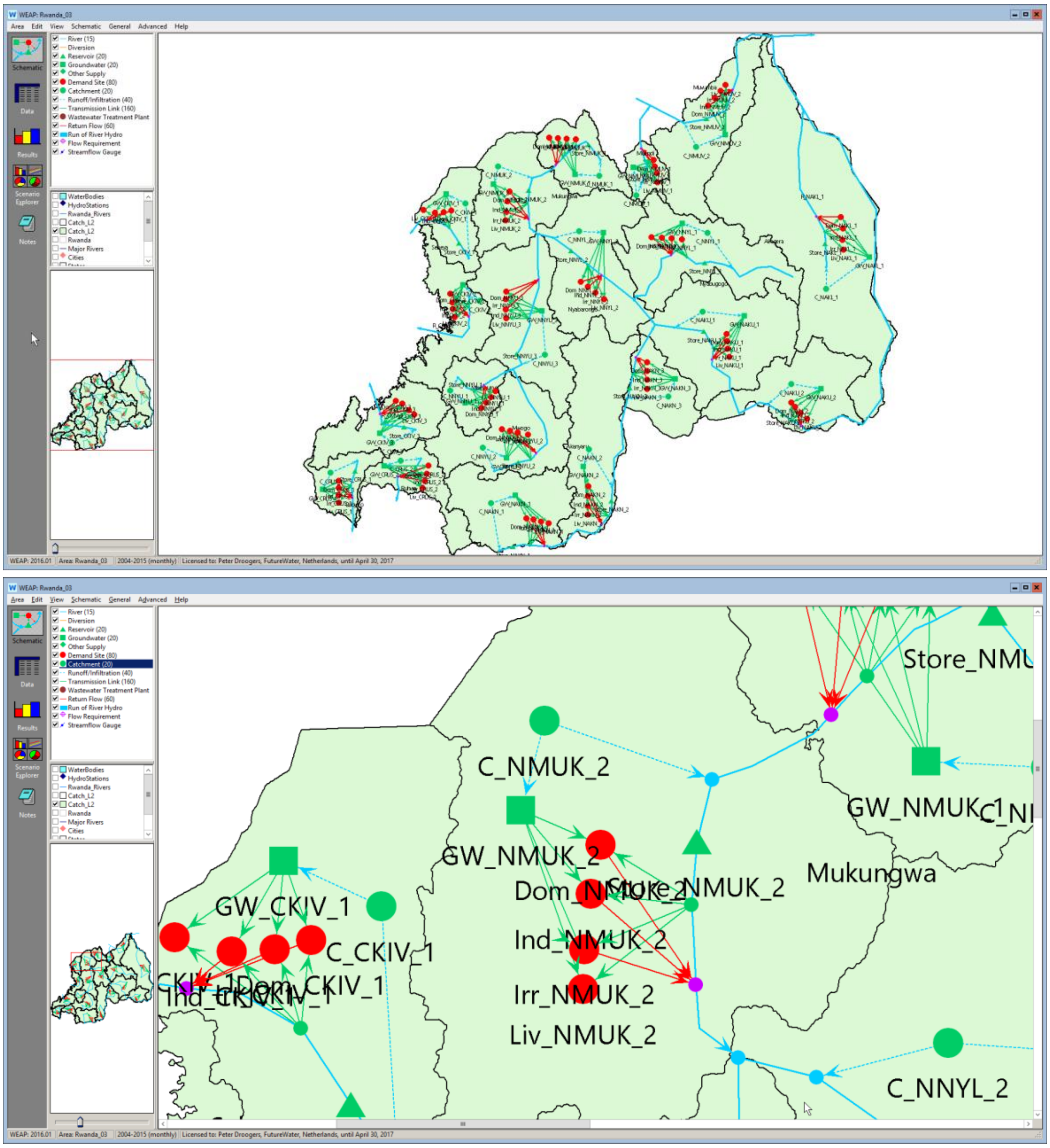


Figure 92. Schematization of Rwada in the WEAP model. Top: complete model. Bottom: detail.

9.2.2 Meteorological data

9.2.2.1 Rainfall

Meteorological data and especially rainfall data is essential to develop catchment planning. Quite some data are observed and available for Rwanda. However, recent data is difficult to obtain, spatial coverage is somewhat fragmented, and quality control has to be performed.

Global initiatives of various research group around the world have resulted in consistent data sets of precipitation, based on using remote sensing, observations and advanced data assimilation techniques. One of the most commonly used and accepted as high quality is the so-called Chirps data set.

CHRIPS is the Climate Hazards Group InfraRed Precipitation with Station data and is a 30+ year quasi-global rainfall dataset. Spanning 50°S-50°N (and all longitudes), starting in 1981 to near-present, CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

Estimating rainfall variations in space and time is an important aspect of drought early warning and environmental monitoring. An evolving dryer-than-normal season must be placed in historical context so that the severity of rainfall deficits may be quickly evaluated. However, estimates derived from satellite data provide areal averages that suffer from biases due to complex terrain which often underestimate the intensity of extreme precipitations events. Conversely, precipitation grids produced from station data suffer in more rural regions where there are less rain gauge stations. CHIRPS was created in collaboration with scientists at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center in order to deliver reliable, up to date, and more complete datasets for a number of early warning objectives (such as trend analysis and seasonal drought monitoring).

Early research focused on combining models of terrain-induced precipitation enhancement with interpolated station data. More recently, new resources of satellite observations such as gridded satellite-based precipitation estimates from NASA and NOAA have been leveraged to build high resolution (0.05°) gridded precipitation climatologies. When applied to satellite-based precipitation fields, these improved climatologies can remove systematic bias, a key technique in the production of the 1981 to near-present CHIRPS dataset. The creation of CHIRPS has supported drought monitoring efforts by the USAID Famine Early Warning Systems Network (FEWS NET).

The CHIRPS data can be downloaded free of charge from http://chg.geog.ucsb.edu/data/chirps/. Data are delivered for the entire continent at a daily based. Using QGIS and python scripting these data were aggregated to monthly values for each sub-catchment.

9.2.2.2 Other climate variables

The Rwandan climate is quite constant during the year with the exception of the rainfall (as discussed in the previous section). For the WEAP model additional climate data are needed to estimate the potential evapotranspiration. For temperature the average monthly values of Kigali (elevation 1567 MASL) have been used and scaled to the average elevation using a lapse-rate. Lapse rates are in general between 0.6 and 1.0^{o}C depending on the stability of the air and the extent of high elevation plateaus. If air is not completely saturated and no extended plateaus exist a lapse rate of 1^{o}C per 100 meter applies. So taken Kigali elevation as reference the following equation applies: Tcorr (^{0}C) = 15.67 – 0.01*Elevation(m). For relative humidity also the average monthly data for Kigali have been used. Finally, cloudiness fraction has been derived from the monthly average rainfall records, where it was assumed that if rainfall exceeds 100 mm per month cloud fraction is 50%, and with lower rainfall linear scaled to 100%.

Obviously, if additional and more accurate climate data are becoming available, these can be easily included in the existing model.

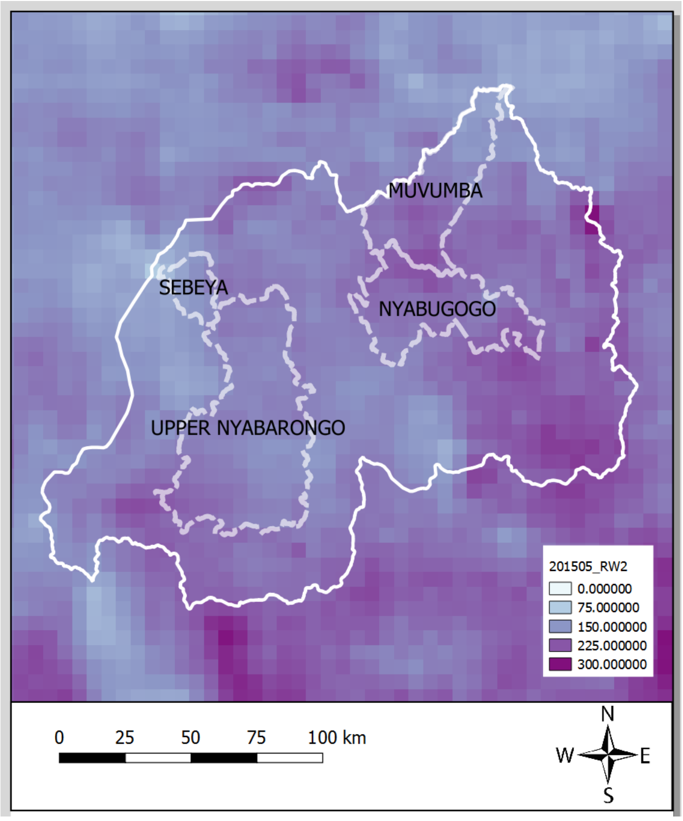
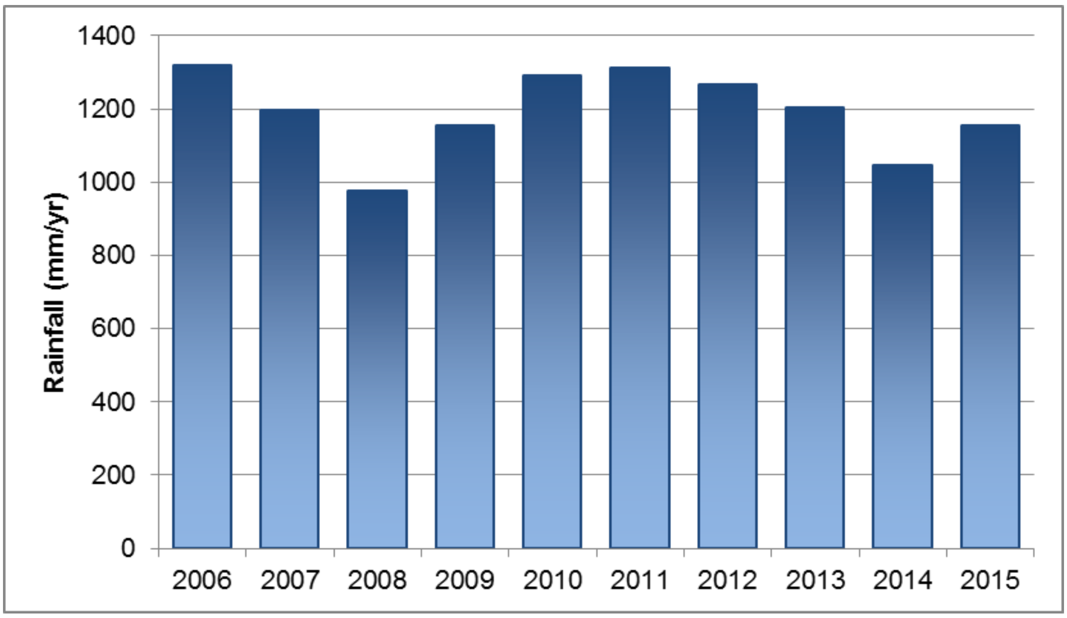


Figure 93. Example of rainfall data derived from the CHIRSP product. Data in mm for Apr-2015.



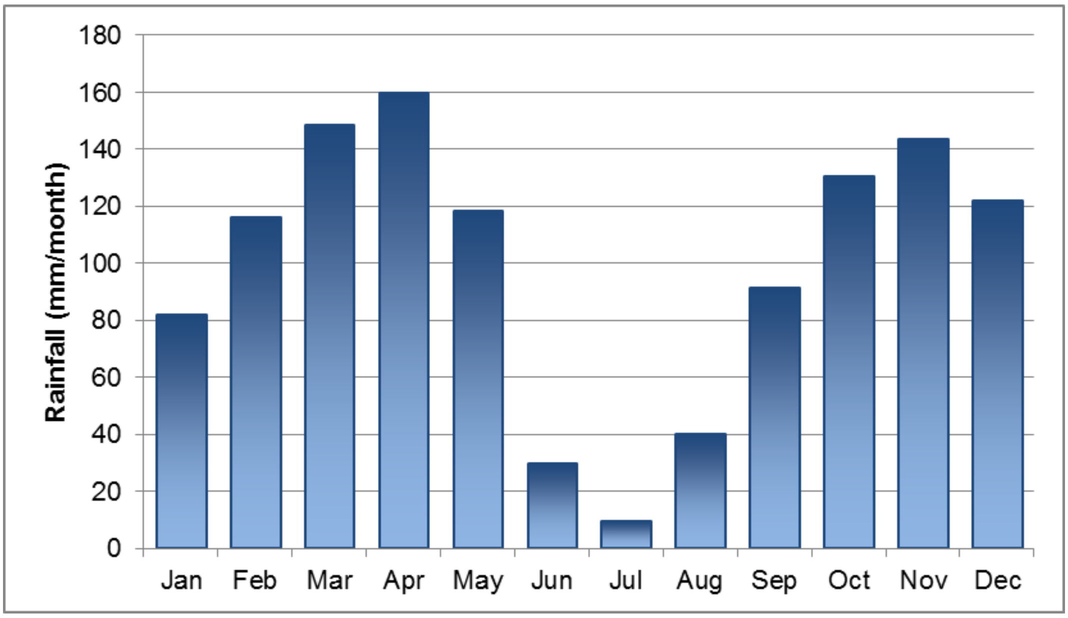


Figure 94. Average rainfall data for Rwanda as derived from the CHRIPS dataset. Top: total annual rainfall. Bottom: average monthly rainfall over 2006-2015.

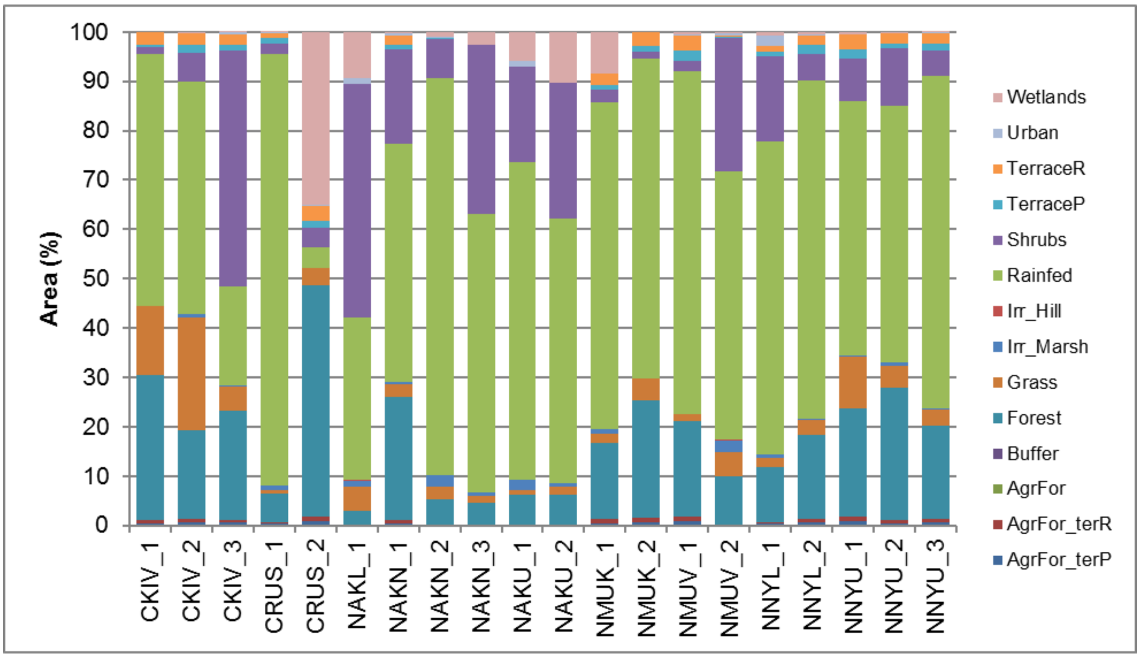


Figure 95. Land cover distribution for the 20 catchments in Rwanda.

9.3 Model Performance

The WEAP model has been widely applied in many regions across the globe. WEAP has proven to be a reliable tool for water balance and water allocation analysis. Obviously, quality of a model for s specific area depends completely on the accuracy of the available data. For this specific study it is important to realize the difference between “absolute” accuracy and “relative” accuracy. “Absolute” accuracy relates to how well the model represents reality; “relative” accuracy relates to the accuracy of comparing different scenarios. It has been proven that even if “absolute” accuracy is low, “relative” accuracy can be still high.

Nevertheless, it remains important to assess the performance of the model, even if data is scarce. This has been done using flow stations data from the following locations (in brackets the WEAP names):

- Kagitumba → Muvumba 10 (=NMUV_2, was used for MUV)
- Nemba → Nyabugogo 8 (=NNYL_1, was used for NYA)
- Nyundo → Sebeya 8 (=CKIV_1, was used for SEB)
- Mwaka → Mukungwa 16 (=NMUK_2, was used for YNU)

The satellite based estimates of evapotranspiration has been used as well for Intercomparison. It should be realized that the remote sensing as well as the WEAP model are both not true measurements. Nevertheless, both method provide quite similar results.

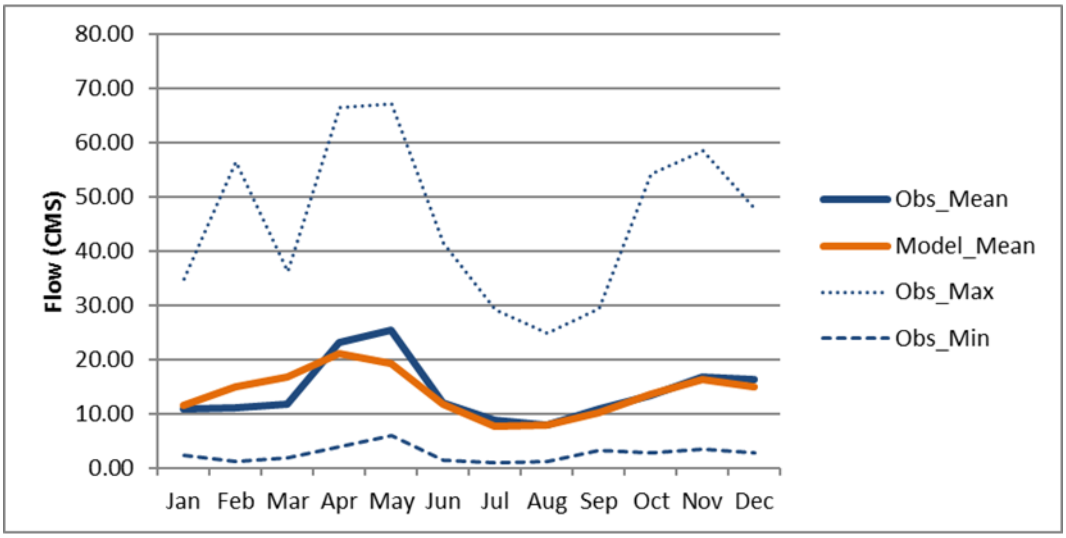


Figure 96. Observed and simulated mean, min and max flow for station Kagitumba.

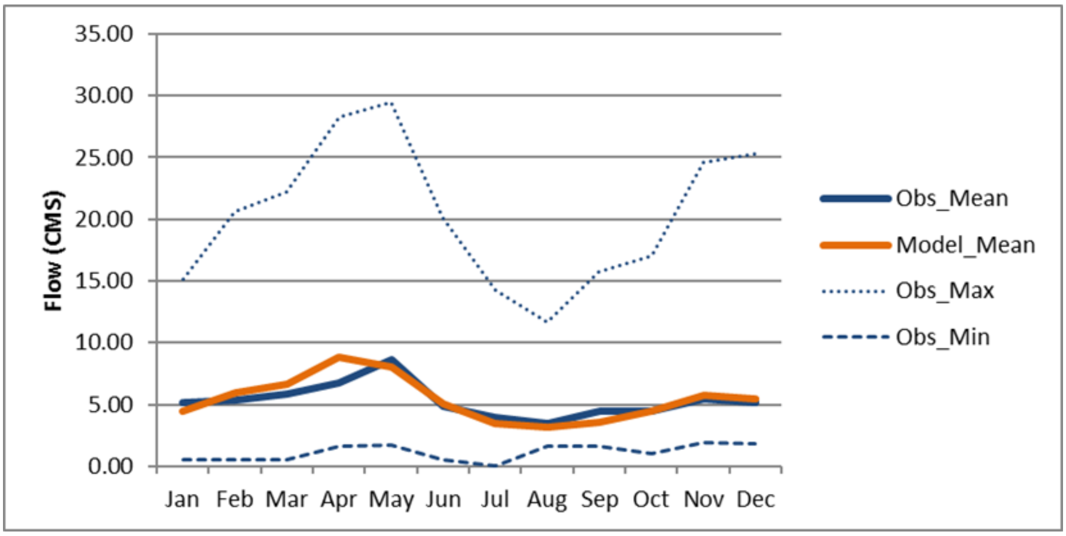


Figure 97. Observed and simulated mean, min and max flow for station Nemba.

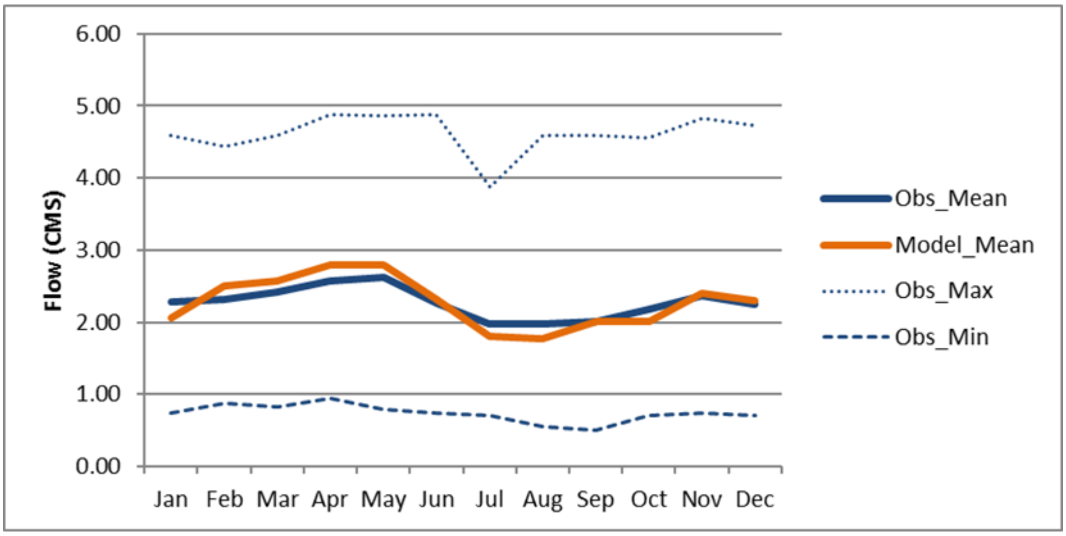


Figure 98. Observed and simulated mean, min and max flow for station Gisenyi.

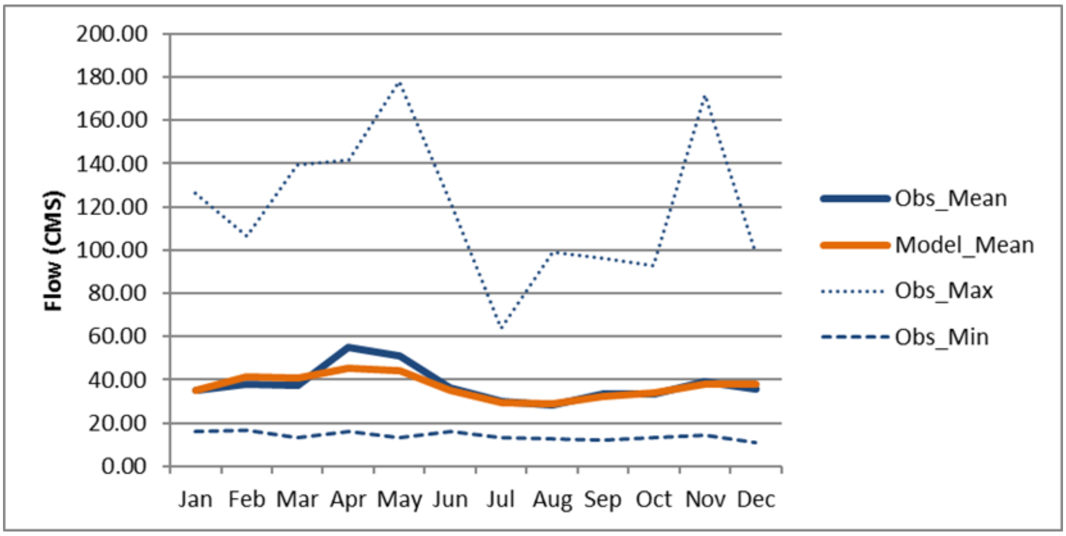


Figure 99. Observed and simulated mean, min and max flow for station Mwaka.

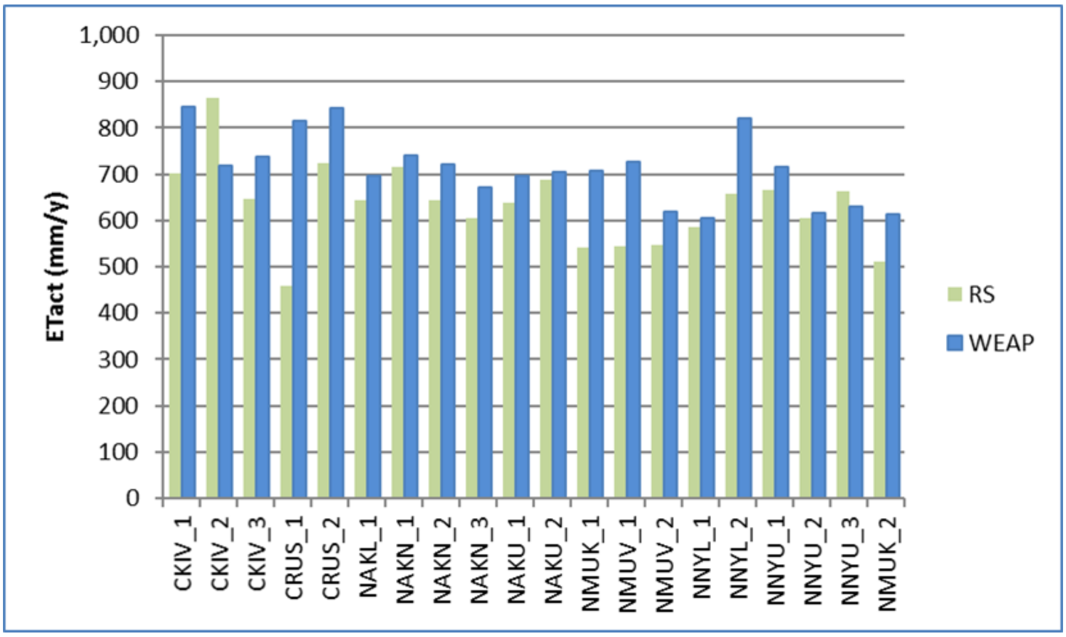


Figure 100. Actual evapotranspiration for the 20 catchments (averages for the years 2009, 2012, 2015).

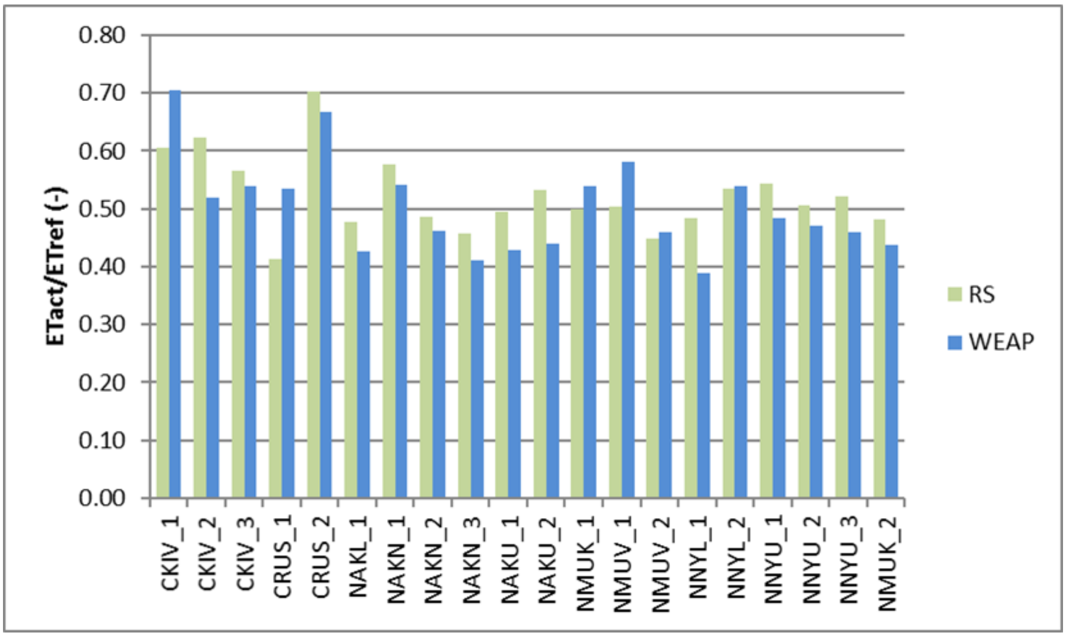


Figure 101. Relative evapotranspiration (=ETact/ETref) for the 20 catchments (averages for the years 2009, 2012, 2015).

9.4 Current situation

Most important conclusions that can be drawn from these Projections as shown in the as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models.

Most relevant conclusions regarding these projections:

- Water demand is projected to increase substantially. Uncertainty regarding this increase due to the differences between the low, medium and high impact, especially in the distant future.
- Water shortages in the dryer months are projected to be considerable in the future. It is clear that appropriate measures (alternatives) are essential to be taken.

Further details and exact numbers can be obtained from the figures below and the appendix. Obviously, the WEAP model itself provide an unlimited number of results and options to plot figures for further analysis.

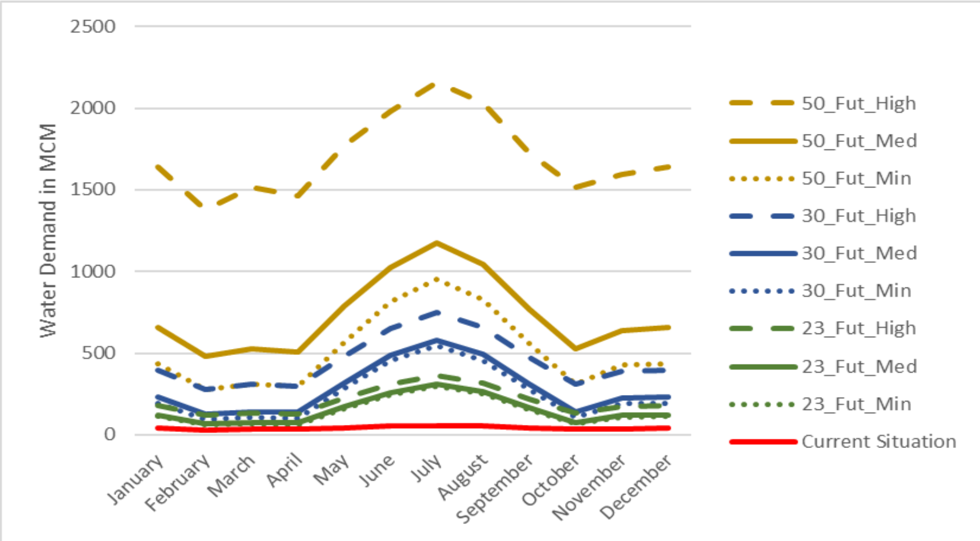


Figure 102 National water demand projections in MCM/month.

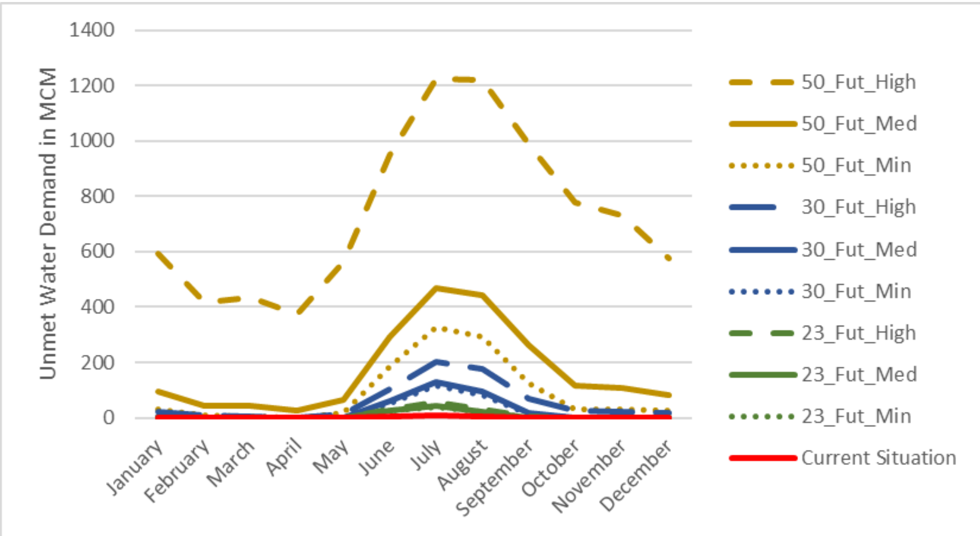


Figure 103 National unmet water demand projections in MCM/month.

9.4.1 Alternatives

The Alternatives (interventions) are evaluated for 10 different options for each three time horizons. Note that the Table below where percentages and colors are presented is based on the comparing with the Future Medium Projection (and not with the Baseline). This was done as this Future Medium is the selected scenario for climate change, economic growth and population changes. So even for example as for the 2050 Alternative many water demands are green (lower than 100%) this demand compared with Baseline is still much higher.

Most important conclusions that can be drawn from these Alternatives as shown in the Figures below. Detailed numbers and overviews are provided in the Appendix. Additional results can be obtained from the WEAP models. Main conclusions regarding the results of these Alternatives:

- The Alternatives to overcome water shortage are all effective to overcome especially water shortages during dryer months.
- The PCB (Planning by Catchment Boundary) are more effective compared to the PASB (Planning by Administrative and Sectoral Boundaries)
- The PCB+ Alternatives (more emphasize on catchment projection measures) is more effective in reducing water shortages. The PCB- (less irrigation development) is even more effective but has at the same time a negative impact on food production.
- Regulating flows and reducing low flows is best achieved by implementing the PCB+ Alternative.

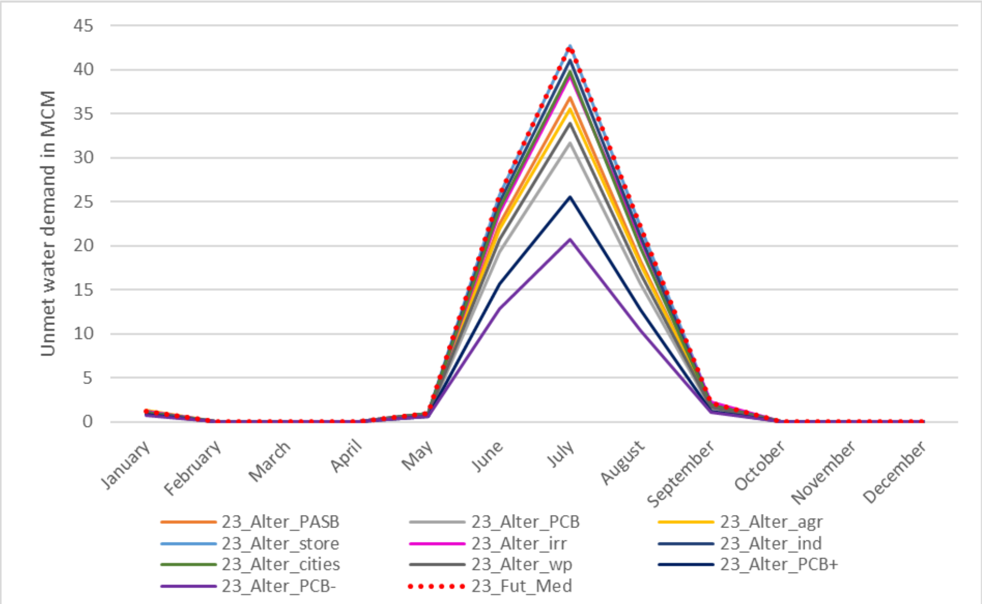


Figure 104 National unmet water demand for all 2023 alternatives and 2023 Future Medium in MCM/month.

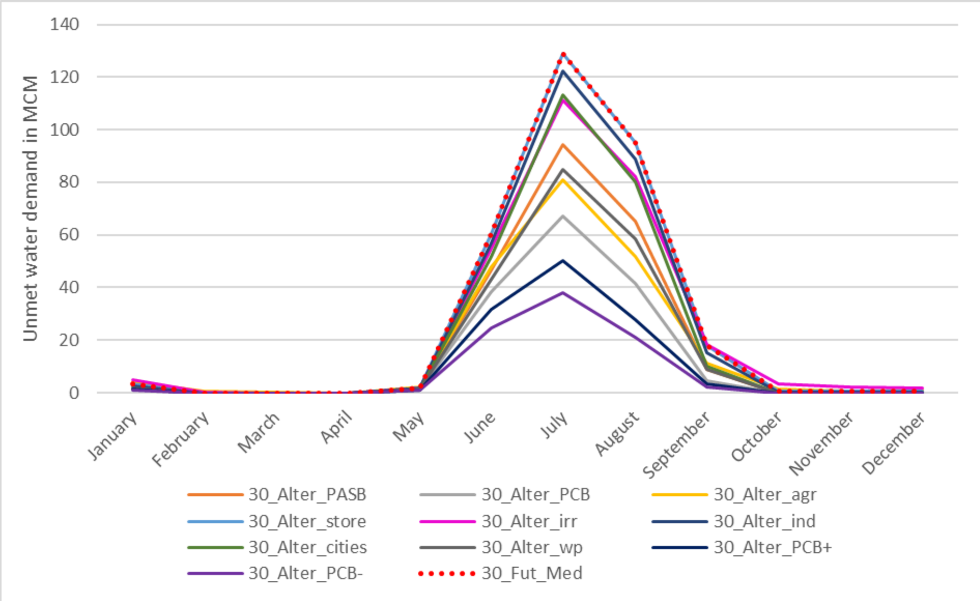


Figure 105 National unmet water demand for all 2030 alternatives and 2030 Future Medium in MCM/month.

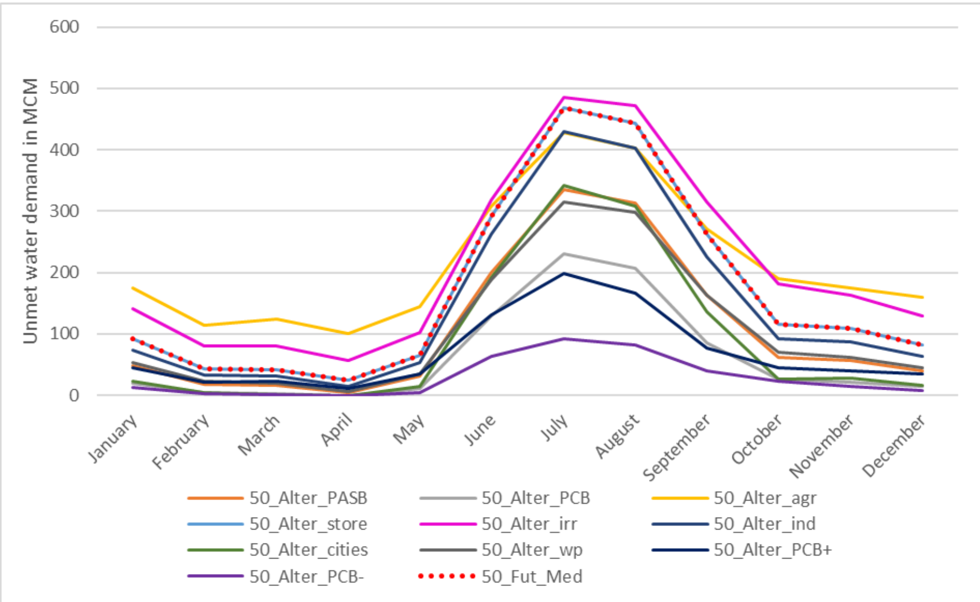


Figure 106 National unmet water demand for all 2050 alternatives and 2050 Future Medium in MCM/month.

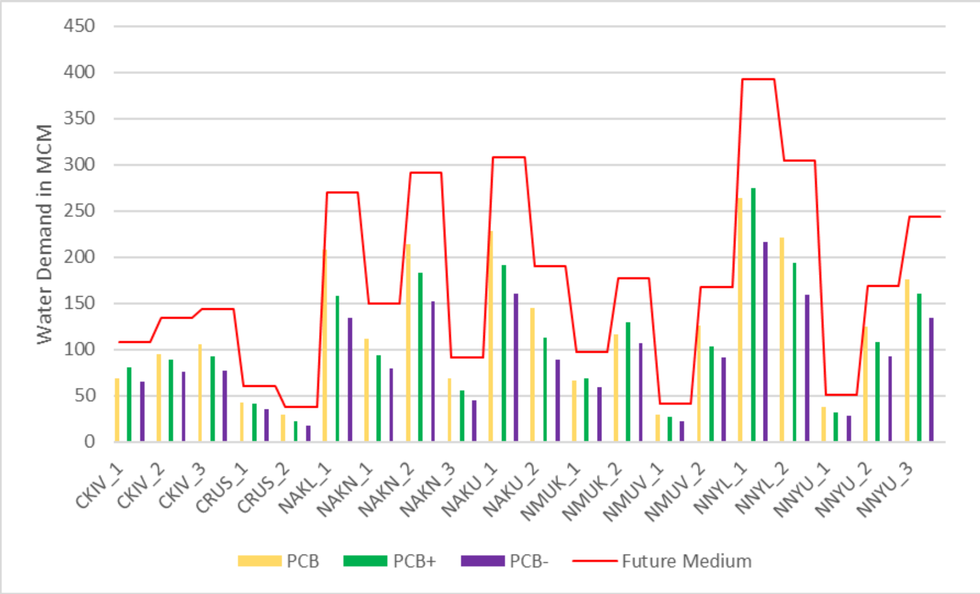


Figure 107 Average yearly water demand per catchment relative to the 2030 Future Medium for the 2030 PCB, PCB+ and PCB- scenarios in MCM/year.

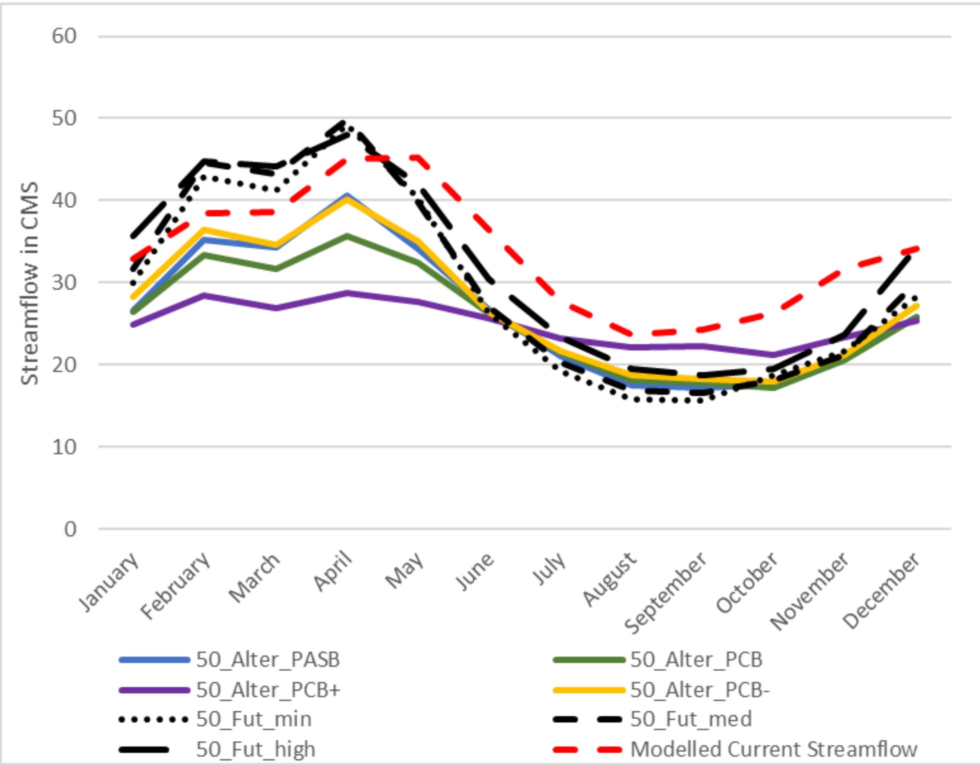


Figure 108 Streamflow of the Upper Nyabarongo Outlet point in several 2050 alternatives and the modelled Current Situation streamflow in CMS.

10 Conclusions and recommendations

The objectives of the W4GR (Water for Growth Rwanda) program can be summarized as "effectively manage water resources to contribute to sustainable socio-economic development and equitably improved livelihoods". A major unknown is what "effective management" is. Therefore, water planning tools have to be used to explore what the impact of effective management is on the overall water resources. In the current program component as described in this report a clear future focus was followed in two ways: Projections and Alternatives. Projections (sometimes referred to as pathways or storylines) are future scenarios that can be hardly influenced by water planners and/or decision makers. Alternatives (sometimes referred to as interventions, adaptations, or implementation scenarios) are decisions initiated by policymakers and implemented by water managers that will optimize water resources management.

For the four demonstration catchments (Muvumba (MUV); Nyabugogo (NYA); Sebeya (SEB); Upper Nyabarongo (UNY)) and for the entire country WEAP models were developed using the most recent data available. Obviously, during the W4GR program more data and information will become available. These new data can be included in the models and evaluations can be reanalyzed. Even if data is not complete, which will never be the case, important to realize is that relative model accuracy (comparing different scenarios with a baseline) is always more accurate than absolute model accuracy (comparing model results with observations).

Results for the four demonstration catchments and the entire country can be found in this report under the specific chapters. Overall recommendations in terms of model enhancement and on water policies and planning are provided here.

Recommendations regarding further enhancement of the analysis described in this report:

- The models as developed are state-of-the-art using the most recent data available.
- Proposed Alternatives might be refined and re-evaluated based on the current results.
- The models developed are quite sophisticated and extensive. However, improved data and changes in Projections and Alternatives can be entered reasonable easily as the models were developed to ensure easy updating of this type of information.
- Model updating should not be done for each potential small enhancement. It is strongly advised to use the current models and only after a certain time (6-12 months) incorporate all improved data, projections and alternatives in enhanced versions of the current models. Like normal model development stages, it is advisable to create a list of issues that can be incorporated in enhanced version of the models and prioritize this list.
- Models developed during this specific assignment can be the base to develop models to be applied at local scales and/or for other catchments. It should be emphasized that in situations where local scale issues should be analyzed the current models can be used as a template. It is not recommended to include more local details in the existing models given the already quite complex nature of the current models.
- Further enhancement of staff capacity to use the existing models and modify these is highly recommended. Besides "formal" capacity building "informal" practicing and using the models is essential in this respect.

- Governance (including ownership) of models and further model development should be developed in due time to ensure responsible and effective use, development and application.

Recommendation regarding water policy and implementation:

- Rwanda overall has abundant water resources. However, water scarcity has a strong spatial and time dimension as demonstrated by water scarcity issues occurring already in the country. In the near-future this water scarcity is expected to increase even further due to climate change, population growth and macro-economic development.
- Climate change impact can be quite severe, especially on more pronounced higher and lower flows. Economic development, including irrigation expansion, industrial development, and increased domestic demand, is having however more impact on water demand, supply and shortages.
- Alternatives are able to overcome to a large extent projected water shortages in the future. It is clear that Planning by Administrative and Sectoral Boundaries (referred to as PASB), which is in fact a continuation of planning and implementation as usual, is not the most effective Alternative.
- The Alternative of Planning by Catchment Boundaries (PCB) is based on plans that are developed in a participative and vertically and horizontally integrated manner, resulting in a coherent program of measures for each sub-catchment. Implementation is coordinated between implementing agencies, with support of the Catchment Coordination Office and overseen by RNRA and Catchment Task Forces. This PCB is considered to be the most effective Alternative to overcome water shortages.

11 APPENDIX: Detailed WEAP Output

11.1 Muvumba

Table 15. Summary of impact of Projections expressed as 10 years average for the Muvumba catchment for the three time horizons.

			CRITERIA											
			Water Demand (MCM/y)	Water Shortage (MCM/y)	Water Short Months (nr/yr)	Evaporation Demand (MCM/y)	Evaporation Shortage (MCM/y)	Mean Flow (m3/s)	Peak Flow (m3/s)	Low Flow (m3/s)	Fast Runoff (MCM/y)	Slow Runoff (MCM/y)	Groundwater Recharge (MCM/y)
		00_Base	40	10	5	1954	958	15.1	32.7	7.1	39	303	206
= = = 2023 = = =	Projections	01_23_CC_low	40	10	5	2237	1152	14.4	31.9	6.5	43	271	185
		02_23_CC_med	40	10	5	2308	1192	14.4	31.6	6.4	43	270	184
		03_23_CC_high	40	10	5	2381	1233	14.3	31.5	6.3	44	268	183
		04_23_Pop_low	44	10	5	2149	1102	14.3	31.3	6.6	40	273	186
		05_23_Pop_med	44	10	5	2149	1102	14.3	31.3	6.6	40	273	186
		06_23_Pop_high	44	10	5	2149	1102	14.3	31.3	6.6	40	273	186
		07_23_Econ_low	46	10	6	2149	1102	14.3	31.3	6.5	40	273	186
		08_23_Econ_med	49	10	6	2149	1102	14.2	31.2	6.5	40	273	186
		09_23_Econ_high	66	12	6	2149	1102	14.1	31.1	6.4	40	273	186
		10_23_Fut_min	191	60	6	2432	1307	11.8	26.2	2.1	42	243	170
		11_23_Fut_med	196	60	6	2510	1352	11.7	25.9	2.1	43	241	169
		12_23_Fut_high	217	63	6	2589	1399	11.5	25.6	2.1	44	240	168
= = = 2030 = = =	Projections	23_30_CC_low	40	11	5	2263	1164	14.5	32.5	6.5	46	274	186
		24_30_CC_med	40	10	4	2352	1210	14.6	32.2	6.4	47	274	186
		25_30_CC_high	40	10	4	2444	1259	14.6	31.9	6.3	49	273	186
		26_30_Pop_low	45	10	5	2149	1102	14.3	31.3	6.6	40	273	186
		27_30_Pop_med	46	10	6	2149	1102	14.3	31.3	6.5	40	273	186
		28_30_Pop_high	46	10	6	2149	1102	14.3	31.3	6.5	40	273	186
		29_30_Econ_low	55	11	6	2149	1102	14.2	31.2	6.5	40	273	186
		30_30_Econ_med	63	12	6	2149	1102	14.2	31.1	6.4	40	273	186
		31_30_Econ_high	104	15	6	2149	1102	13.9	30.8	6.2	40	273	186
		32_30_Fut_min	272	97	7	2588	1423	10.7	24.1	1.8	45	228	162
		33_30_Fut_med	285	99	7	2690	1482	10.7	24.2	1.8	46	227	162
		34_30_Fut_high	347	111	7	2795	1543	10.5	23.9	1.8	48	227	162
= = = 2050 = = =	Projections	45_50_CC_low	40	12	4	2339	1199	15.0	33.9	6.5	54	280	190
		46_50_CC_med	40	12	4	2479	1264	15.3	33.6	6.4	60	284	193
		47_50_CC_high	40	12	4	2625	1332	15.6	33.5	6.4	67	289	197
		48_50_Pop_low	50	10	6	2149	1102	14.2	31.2	6.5	40	273	186
		49_50_Pop_med	53	11	6	2149	1102	14.2	31.2	6.5	40	273	186
		50_50_Pop_high	54	11	6	2149	1102	14.2	31.2	6.5	40	273	186
		51_50_Econ_low	83	13	6	2149	1102	14.0	31.0	6.3	40	273	186
		52_50_Econ_med	116	16	6	2149	1102	13.8	30.7	6.2	40	273	186
		53_50_Econ_high	267	38	10	2149	1102	12.9	29.5	5.8	40	273	186
		54_50_Fut_min	391	157	8	2789	1559	10.3	24.9	1.9	53	217	158
		55_50_Fut_med	462	180	9	2956	1648	10.3	24.9	1.9	58	220	160
		56_50_Fut_high	783	355	12	3130	1740	10.0	23.4	2.3	64	223	162

Table 16. Summary of impact of Projections for the Muvumba catchment for the three time horizons. Results are provided as % changes from Baseline.

			CRITERIA										
			Water Demand (%)	Water Shortage (%)	Water Short Months (%)	Evaporation Demand (%)	Evaporation Shortage (%)	Mean Flow (%)	Peak Flow (%)	Low Flow (%)	Fast Runoff (%)	Slow Runoff (%)	Groundwater Recharge (%)
		00_Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
== = 2023 = ==	Projections	01_23_CC_low	100%	106%	100%	114%	120%	95%	97%	91%	108%	90%	90%
		02_23_CC_med	100%	105%	98%	118%	124%	95%	97%	90%	110%	89%	89%
		03_23_CC_high	100%	105%	92%	122%	129%	95%	96%	89%	112%	89%	89%
		04_23_Pop_low	108%	103%	108%	110%	115%	95%	96%	92%	101%	90%	90%
		05_23_Pop_med	110%	104%	108%	110%	115%	95%	96%	92%	101%	90%	90%
		06_23_Pop_high	110%	104%	108%	110%	115%	94%	96%	92%	101%	90%	90%
		07_23_Econ_low	115%	106%	112%	110%	115%	94%	96%	92%	101%	90%	90%
		08_23_Econ_med	123%	109%	114%	110%	115%	94%	95%	92%	101%	90%	90%
		09_23_Econ_high	164%	124%	118%	110%	115%	94%	95%	91%	101%	90%	90%
		10_23_Fut_min	475%	630%	124%	124%	136%	78%	80%	30%	107%	80%	82%
		11_23_Fut_med	487%	632%	128%	128%	141%	77%	79%	29%	109%	80%	82%
		12_23_Fut_high	541%	655%	128%	133%	146%	76%	78%	30%	111%	79%	81%
== = 2030 = ==	Projections	23_30_CC_low	100%	111%	94%	116%	121%	96%	99%	92%	115%	90%	90%
		24_30_CC_med	100%	110%	88%	120%	126%	96%	98%	91%	120%	90%	90%
		25_30_CC_high	100%	109%	88%	125%	131%	97%	98%	89%	124%	90%	90%
		26_30_Pop_low	112%	104%	108%	110%	115%	94%	96%	92%	101%	90%	90%
		27_30_Pop_med	114%	105%	110%	110%	115%	94%	96%	92%	101%	90%	90%
		28_30_Pop_high	115%	106%	112%	110%	115%	94%	96%	92%	101%	90%	90%
		29_30_Econ_low	138%	114%	114%	110%	115%	94%	95%	91%	101%	90%	90%
		30_30_Econ_med	157%	122%	116%	110%	115%	94%	95%	91%	101%	90%	90%
		31_30_Econ_high	260%	161%	126%	110%	115%	92%	94%	88%	101%	90%	90%
		32_30_Fut_min	678%	1017%	132%	132%	149%	71%	73%	25%	113%	75%	79%
		33_30_Fut_med	710%	1037%	134%	138%	155%	71%	74%	26%	118%	75%	79%
		34_30_Fut_high	863%	1160%	146%	143%	161%	69%	73%	25%	122%	75%	78%
== = 2050 = ==	Projections	45_50_CC_low	100%	125%	88%	120%	125%	99%	103%	92%	138%	92%	92%
		46_50_CC_med	100%	124%	88%	127%	132%	101%	103%	91%	152%	94%	94%
		47_50_CC_high	100%	123%	84%	134%	139%	103%	102%	90%	169%	96%	95%
		48_50_Pop_low	125%	110%	114%	110%	115%	94%	95%	92%	101%	90%	90%
		49_50_Pop_med	131%	112%	114%	110%	115%	94%	95%	92%	101%	90%	90%
		50_50_Pop_high	135%	113%	114%	110%	115%	94%	95%	92%	101%	90%	90%
		51_50_Econ_low	207%	141%	124%	110%	115%	93%	95%	89%	101%	90%	90%
		52_50_Econ_med	288%	172%	128%	110%	115%	92%	94%	87%	101%	90%	90%
		53_50_Econ_high	664%	403%	196%	110%	115%	86%	90%	82%	101%	90%	90%
		54_50_Fut_min	972%	1648%	158%	143%	163%	68%	76%	26%	134%	72%	76%
		55_50_Fut_med	1150%	1884%	180%	151%	172%	68%	76%	27%	148%	73%	78%
		56_50_Fut_high	1949%	3716%	240%	160%	182%	66%	71%	33%	163%	74%	79%

Table 17. Summary of impact of Alternatives expressed as 10 years average for the Muvumba catchment for the three time horizons.

Horizon			CRITERIA											
			Water Demand (MCM/y)	Water Shortage (MCM/y)	Water Short Months (nr/yr)	Evaporation Demand (MCM/y)	Evaporation Shortage (MCM/y)	Mean Flow (m3/s)	Peak Flow (m3/s)	Low Flow (m3/s)	Fast Runoff (MCM/y)	Slow Runoff (MCM/y)	Groundwater Recharge (MCM/y)
= = = 2023 = = =		11_23_Fut_med	196	60	6	2510	1352	11.7	25.9	2.1	43	241	169
	Alternatives	13_23_Alter_PASB	172	52	6	2353	1240	12.1	26.6	2.3	44	248	172
		14_23_Alter_PCB	151	46	6	2272	1165	13.0	28.2	3.6	45	272	185
		15_23_Alter_agr	145	42	6	2034	998	13.8	27.6	4.9	40	307	203
		16_23_Alter_store	196	60	6	2510	1352	11.7	25.9	2.2	43	241	169
		17_23_Alter_irr	196	60	6	2510	1352	11.7	25.9	2.1	43	241	169
		18_23_Alter_ind	191	60	6	2510	1352	11.7	26.0	2.1	43	241	169
		19_23_Alter_cities	195	60	6	2510	1352	11.7	25.9	2.1	43	241	169
		20_23_Alter_wp	156	48	6	2510	1352	12.1	26.9	2.7	43	241	169
		21_23_Alter_PCB+	112	34	6	2034	1021	13.5	27.0	4.4	40	294	196
		22_23_Alter_PCB-	105	30	6	2194	1108	14.0	30.4	5.4	45	287	192
= = = 2030 = = =		33_30_Fut_med	285	99	7	2690	1482	10.7	24.2	1.8	46	227	162
	Alternatives	35_30_Alter_PASB	252	79	6	2559	1373	11.2	24.8	2.4	47	241	169
		36_30_Alter_PCB	221	69	6	2428	1268	11.9	26.1	3.0	48	257	177
		37_30_Alter_agr	214	64	6	2165	1083	12.7	25.7	3.4	43	288	194
		38_30_Alter_store	285	89	6	2690	1482	10.5	24.2	2.0	46	227	162
		39_30_Alter_irr	285	99	7	2690	1482	10.7	24.2	1.8	46	227	162
		40_30_Alter_ind	277	98	6	2690	1482	10.7	24.2	1.8	46	227	162
		41_30_Alter_cities	285	99	7	2690	1482	10.7	24.2	1.8	46	227	162
		42_30_Alter_wp	228	76	6	2690	1482	11.2	24.7	2.1	46	227	162
		43_30_Alter_PCB+	164	50	6	2165	1120	12.3	25.5	4.1	43	272	185
		44_30_Alter_PCB-	169	49	6	2315	1183	13.1	28.7	3.9	49	276	187
= = = 2050 = = =		55_50_Fut_med	462	180	9	2956	1648	10.3	24.9	1.9	58	220	160
	Alternatives	57_50_Alter_PASB	410	136	8	2809	1524	10.7	25.6	2.9	59	234	167
		58_50_Alter_PCB	361	106	7	2662	1403	11.2	26.3	4.1	60	249	175
		59_50_Alter_agr	369	109	8	2367	1192	11.9	25.8	3.6	55	279	190
		60_50_Alter_store	462	165	9	2956	1648	10.1	22.3	1.9	58	220	160
		61_50_Alter_irr	462	180	9	2956	1648	10.3	24.9	1.9	58	220	160
		62_50_Alter_ind	435	170	9	2956	1648	10.4	25.1	1.8	58	220	160
		63_50_Alter_cities	459	179	9	2956	1648	10.3	24.9	1.9	58	220	160
		64_50_Alter_wp	370	134	8	2956	1648	10.8	25.2	2.6	58	220	160
		65_50_Alter_PCB+	271	77	6	2367	1241	11.2	23.1	4.8	55	260	181
		66_50_Alter_PCB-	265	65	6	2440	1234	13.3	29.2	4.5	62	287	195

Table 10. Summary of impact of Alternatives for the Muvumba catchment for the three time horizons. Results are provided as % changes from Medium_Future.

			CRITERIA										
			Water Demand (%)	Water Shortage (%)	Water Short Months (%)	Evaporation Demand (%)	Evaporation Shortage (%)	Mean Flow (%)	Peak Flow (%)	Low Flow (%)	Fast Runoff (%)	Slow Runoff (%)	Groundwater Recharge (%)
= = = 2 0 2 3 = = =		11_23_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	13_23_Alter_PASB	88%	87%	98%	94%	92%	103%	103%	111%	102%	103%	102%
		14_23_Alter_PCB	77%	76%	95%	91%	86%	111%	109%	175%	104%	113%	109%
		15_23_Alter_agr	74%	70%	97%	81%	74%	118%	107%	238%	93%	127%	120%
		16_23_Alter_store	100%	99%	100%	100%	100%	100%	100%	105%	100%	100%	100%
		17_23_Alter_irr	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		18_23_Alter_ind	98%	99%	97%	100%	100%	100%	100%	99%	100%	100%	100%
		19_23_Alter_cities	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		20_23_Alter_wp	80%	79%	97%	100%	100%	104%	104%	131%	100%	100%	100%
		21_23_Alter_PCB+	57%	56%	91%	81%	76%	115%	104%	214%	92%	122%	116%
		22_23_Alter_PCB-	54%	49%	92%	87%	82%	120%	117%	259%	105%	119%	114%
= = = 2 0 3 0 = = =		33_30_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	35_30_Alter_PASB	88%	79%	96%	95%	93%	105%	102%	131%	102%	106%	104%
		36_30_Alter_PCB	77%	69%	93%	90%	86%	112%	108%	166%	103%	113%	109%
		37_30_Alter_agr	75%	65%	96%	80%	73%	119%	106%	187%	93%	127%	119%
		38_30_Alter_store	100%	90%	96%	100%	100%	98%	100%	111%	100%	100%	100%
		39_30_Alter_irr	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		40_30_Alter_ind	97%	99%	96%	100%	100%	100%	100%	99%	100%	100%	100%
		41_30_Alter_cities	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		42_30_Alter_wp	80%	77%	96%	100%	100%	105%	102%	114%	100%	100%	100%
		43_30_Alter_PCB+	57%	51%	91%	80%	76%	115%	105%	227%	93%	120%	114%
		44_30_Alter_PCB-	59%	50%	91%	86%	80%	123%	119%	212%	105%	121%	116%
= = = 2 0 5 0 = = =		55_50_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	57_50_Alter_PASB	89%	76%	89%	95%	92%	104%	103%	153%	101%	106%	104%
		58_50_Alter_PCB	78%	59%	77%	90%	85%	109%	106%	213%	103%	113%	109%
		59_50_Alter_agr	80%	61%	83%	80%	72%	116%	104%	189%	94%	127%	119%
		60_50_Alter_store	100%	92%	96%	100%	100%	98%	89%	101%	100%	100%	100%
		61_50_Alter_irr	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		62_50_Alter_ind	94%	94%	97%	100%	100%	100%	101%	97%	100%	100%	100%
		63_50_Alter_cities	99%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		64_50_Alter_wp	80%	74%	90%	100%	100%	105%	101%	135%	100%	100%	100%
		65_50_Alter_PCB+	59%	43%	69%	80%	75%	109%	93%	249%	94%	118%	113%
		66_50_Alter_PCB-	57%	36%	68%	83%	75%	129%	117%	235%	106%	130%	122%

11.2 Nyabugogo

Table 18. Summary of impact of Projections expressed as 10 years average for the Nyabugogo catchment for the three time horizons.

			CRITERIA											
			Water Demand (MCM/y)	Water Shortage (MCM/y)	Water Short Months (nr/yr)	Evaporation Demand (MCM/y)	Evaporation Shortage (MCM/y)	Mean Flow (m3/s)	Peak Flow (m3/s)	Low Flow (m3/s)	Fast Runoff (MCM/y)	Slow Runoff (MCM/y)	Groundwater Recharge (MCM/y)
		00_Base	47	6	6	2936	1633	5.3	12.4	2.7	45	160	219
== = 2023 = ==	Projections	01_23_CC_low	47	6	5	3055	1695	5.4	12.9	2.7	48	162	221
		02_23_CC_med	47	6	5	3153	1755	5.4	12.9	2.7	48	160	219
		03_23_CC_high	47	6	5	3253	1817	5.4	13.0	2.7	49	159	217
		04_23_Pop_low	58	7	6	2936	1633	5.2	12.3	2.7	45	160	219
		05_23_Pop_med	59	7	6	2936	1633	5.2	12.3	2.7	45	160	219
		06_23_Pop_high	60	7	6	2936	1633	5.2	12.3	2.7	45	160	219
		07_23_Econ_low	66	8	6	2936	1633	5.2	12.2	2.7	45	160	219
		08_23_Econ_med	76	9	6	2936	1633	5.1	12.1	2.6	45	160	219
		09_23_Econ_high	127	13	6	2936	1633	4.7	11.6	2.4	45	160	219
		10_23_Fut_min	180	49	6	3243	1858	3.8	9.6	1.8	47	149	207
		11_23_Fut_med	195	50	6	3347	1924	3.6	9.4	1.8	48	148	205
		12_23_Fut_high	262	60	8	3453	1991	3.2	8.9	1.6	49	146	203
== = 2030 = ==	Projections	23_30_CC_low	47	6	5	3091	1705	5.6	13.5	2.7	50	165	225
		24_30_CC_med	47	6	5	3213	1775	5.6	13.6	2.7	51	164	224
		25_30_CC_high	47	6	5	3339	1849	5.6	13.6	2.7	53	163	222
		26_30_Pop_low	62	7	6	2936	1633	5.2	12.3	2.7	45	160	219
		27_30_Pop_med	64	8	6	2936	1633	5.2	12.2	2.7	45	160	219
		28_30_Pop_high	66	8	6	2936	1633	5.2	12.2	2.7	45	160	219
		29_30_Econ_low	94	10	6	2936	1633	5.0	11.9	2.6	45	160	219
		30_30_Econ_med	118	13	6	2936	1633	4.8	11.6	2.4	45	160	219
		31_30_Econ_high	245	28	10	2936	1633	3.9	10.3	1.9	45	160	219
		32_30_Fut_min	323	107	8	3472	2034	2.8	5.6	1.3	49	139	196
		33_30_Fut_med	363	115	9	3609	2119	2.6	5.5	1.0	50	138	195
		34_30_Fut_high	552	187	12	3750	2208	2.3	4.4	1.0	51	137	193
== = 2050 = ==	Projections	45_50_CC_low	47	7	5	3195	1736	6.0	14.8	2.7	56	173	235
		46_50_CC_med	47	7	5	3387	1835	6.2	15.2	2.7	60	175	237
		47_50_CC_high	47	7	5	3586	1937	6.4	15.8	2.6	64	177	239
		48_50_Pop_low	78	9	6	2936	1633	5.1	12.1	2.7	45	160	219
		49_50_Pop_med	85	9	6	2936	1633	5.1	12.0	2.6	45	160	219
		50_50_Pop_high	90	10	6	2936	1633	5.0	12.0	2.6	45	160	219
		51_50_Econ_low	180	18	7	2936	1633	4.3	11.0	2.2	45	160	219
		52_50_Econ_med	280	36	11	2936	1633	3.7	9.9	1.8	45	160	219
		53_50_Econ_high	745	304	12	2936	1633	3.3	5.2	1.9	45	160	219
		54_50_Fut_min	608	253	12	3785	2244	2.2	4.6	0.9	54	131	189
		55_50_Fut_med	827	413	12	4012	2376	2.4	4.1	1.1	58	132	191
		56_50_Fut_high	1809	1268	12	4249	2514	3.7	7.3	2.0	62	133	192

Table 19. Summary of impact of Projections for the Nyabugogo catchment for the three time horizons. Results are provided as % changes from Baseline.

Horizon			CRITERIA										
			Water Demand (%)	Water Shortage (%)	Water Short Months (%)	Evaporation Demand (%)	Evaporation Shortage (%)	Mean Flow (%)	Peak Flow (%)	Low Flow (%)	Fast Runoff (%)	Slow Runoff (%)	Groundwater Recharge (%)
		00_Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
= = = 2023 = = =	Projections	01_23_CC_low	100%	102%	88%	104%	104%	102%	104%	99%	105%	101%	101%
		02_23_CC_med	100%	101%	86%	107%	107%	102%	105%	98%	107%	100%	100%
		03_23_CC_high	100%	100%	84%	111%	111%	101%	105%	97%	108%	99%	99%
		04_23_Pop_low	121%	115%	102%	100%	100%	99%	99%	99%	100%	100%	100%
		05_23_Pop_med	125%	117%	104%	100%	100%	99%	99%	99%	100%	100%	100%
		06_23_Pop_high	126%	118%	104%	100%	100%	98%	99%	99%	100%	100%	100%
		07_23_Econ_low	139%	128%	104%	100%	100%	97%	98%	98%	100%	100%	100%
		08_23_Econ_med	160%	142%	104%	100%	100%	96%	98%	96%	100%	100%	100%
		09_23_Econ_high	267%	219%	104%	100%	100%	89%	93%	87%	100%	100%	100%
		10_23_Fut_min	380%	799%	107%	110%	114%	71%	77%	67%	104%	93%	94%
		11_23_Fut_med	411%	820%	105%	114%	118%	68%	76%	65%	106%	92%	93%
		12_23_Fut_high	552%	985%	135%	118%	122%	61%	72%	58%	107%	91%	93%
= = = 2030 = = =	Projections	23_30_CC_low	100%	104%	89%	105%	104%	105%	109%	100%	110%	103%	103%
		24_30_CC_med	100%	103%	84%	109%	109%	106%	110%	98%	113%	102%	102%
		25_30_CC_high	100%	102%	84%	114%	113%	106%	110%	97%	116%	102%	101%
		26_30_Pop_low	130%	120%	104%	100%	100%	98%	99%	99%	100%	100%	100%
		27_30_Pop_med	136%	125%	104%	100%	100%	98%	99%	98%	100%	100%	100%
		28_30_Pop_high	139%	127%	104%	100%	100%	98%	99%	98%	100%	100%	100%
		29_30_Econ_low	199%	170%	104%	100%	100%	93%	96%	93%	100%	100%	100%
		30_30_Econ_med	249%	206%	104%	100%	100%	90%	94%	89%	100%	100%	100%
		31_30_Econ_high	517%	467%	172%	100%	100%	74%	83%	70%	100%	100%	100%
		32_30_Fut_min	681%	1751%	139%	118%	125%	52%	45%	49%	108%	86%	89%
		33_30_Fut_med	766%	1890%	154%	123%	130%	49%	44%	37%	111%	86%	89%
		34_30_Fut_high	1163%	3068%	211%	128%	135%	43%	36%	35%	113%	85%	88%
= = = 2050 = = =	Projections	45_50_CC_low	100%	113%	84%	109%	106%	114%	119%	99%	123%	108%	107%
		46_50_CC_med	100%	112%	81%	115%	112%	117%	123%	98%	132%	109%	108%
		47_50_CC_high	100%	111%	81%	122%	119%	121%	127%	96%	142%	110%	109%
		48_50_Pop_low	165%	145%	104%	100%	100%	96%	98%	97%	100%	100%	100%
		49_50_Pop_med	179%	155%	104%	100%	100%	96%	97%	96%	100%	100%	100%
		50_50_Pop_high	190%	163%	104%	100%	100%	95%	97%	96%	100%	100%	100%
		51_50_Econ_low	380%	303%	116%	100%	100%	81%	89%	81%	100%	100%	100%
		52_50_Econ_med	590%	588%	198%	100%	100%	70%	80%	67%	100%	100%	100%
		53_50_Econ_high	1571%	4986%	211%	100%	100%	63%	42%	70%	100%	100%	100%
		54_50_Fut_min	1282%	4152%	211%	129%	137%	41%	37%	31%	119%	82%	86%
		55_50_Fut_med	1743%	6789%	211%	137%	146%	46%	33%	40%	128%	83%	87%
		56_50_Fut_high	3813%	######	211%	145%	154%	70%	59%	72%	137%	83%	88%

Table 20. Summary of impact of Alternatives expressed as 10 years average for the Nyabugogo catchment for the three time horizons.

			CRITERIA											
			Water Demand (MCM/y)	Water Shortage (MCM/y)	Water Short Months (nr/yr)	Evaporation Demand (MCM/y)	Evaporation Shortage (MCM/y)	Mean Flow (m3/s)	Peak Flow (m3/s)	Low Flow (m3/s)	Fast Runoff (MCM/y)	Slow Runoff (MCM/y)	Groundwater Recharge (MCM/y)
= = = 2 0 2 3 = = =		11_23_Fut_med	195	50	6	3347	1924	3.6	9.4	1.8	48	148	205
	Alternatives	13_23_Alter_PASB	173	43	6	3178	1785	4.1	10.1	2.0	49	160	218
		14_23_Alter_PCB	152	38	6	3009	1651	4.7	10.8	2.2	50	173	233
		15_23_Alter_agr	162	37	6	2670	1423	5.3	10.6	2.4	45	196	259
		16_23_Alter_store	195	49	6	3347	1924	3.2	8.0	1.9	48	148	205
		17_23_Alter_irr	179	43	6	3347	1924	3.8	9.5	1.8	48	148	205
		18_23_Alter_ind	179	48	6	3347	1924	3.7	9.5	1.8	48	148	205
		19_23_Alter_cities	191	50	6	3347	1924	3.7	9.4	1.8	48	148	205
		20_23_Alter_wp	156	39	6	3347	1924	4.0	9.9	1.9	48	148	205
		21_23_Alter_PCB+	115	28	6	2670	1472	2.7	6.3	0.3	45	177	236
		22_23_Alter_PCB-	114	23	6	2926	1582	5.3	12.5	2.6	50	181	242
= = = 2 0 3 0 = = =		33_30_Fut_med	363	115	9	3609	2119	2.6	5.5	1.0	50	138	195
	Alternatives	35_30_Alter_PASB	322	91	7	3422	1962	2.8	5.4	1.5	51	149	207
		36_30_Alter_PCB	283	74	6	3234	1809	3.3	10.2	2.0	52	162	222
		37_30_Alter_agr	301	76	7	2860	1556	3.9	9.8	1.8	47	182	244
		38_30_Alter_store	363	112	9	3609	2119	2.6	5.1	1.0	50	138	195
		39_30_Alter_irr	332	99	9	3609	2119	2.7	5.5	1.3	50	138	195
		40_30_Alter_ind	336	109	8	3609	2119	2.7	5.7	1.1	50	138	195
		41_30_Alter_cities	356	114	9	3609	2119	2.6	5.5	1.0	50	138	195
		42_30_Alter_wp	291	87	7	3609	2119	2.8	5.7	1.4	50	138	195
		43_30_Alter_PCB+	213	55	6	2860	1618	1.9	4.7	0.5	47	164	221
		44_30_Alter_PCB-	207	44	6	3066	1670	4.5	11.0	2.2	53	177	239
= = = 2 0 5 0 = = =		55_50_Fut_med	827	413	12	4012	2376	2.4	4.1	1.1	58	132	191
	Alternatives	57_50_Alter_PASB	735	311	12	3799	2194	2.5	3.5	1.1	59	143	203
		58_50_Alter_PCB	648	208	12	3586	2017	2.6	3.1	1.7	60	155	217
		59_50_Alter_agr	736	262	12	3160	1729	3.0	4.0	1.7	55	174	237
		60_50_Alter_store	827	415	12	4012	2376	2.5	3.9	1.1	58	132	191
		61_50_Alter_irr	781	371	12	4012	2376	2.5	4.1	1.1	58	132	191
		62_50_Alter_ind	735	339	12	4012	2376	2.3	4.2	1.0	58	132	191
		63_50_Alter_cities	795	388	12	4012	2376	2.4	4.2	1.1	58	132	191
		64_50_Alter_wp	662	272	12	4012	2376	2.4	4.2	1.0	58	132	191
		65_50_Alter_PCB+	490	146	12	3160	1810	2.0	2.4	1.4	55	155	213
		66_50_Alter_PCB-	495	108	12	3232	1724	3.8	10.4	1.8	62	189	253

Table 10. Summary of impact of Alternatives for the Nyabugogo catchment for the three time horizons. Results are provided as % changes from Medium_Future.

			CRITERIA										
			Water Demand (%)	Water Shortage (%)	Water Short Months (%)	Evaporation Demand (%)	Evaporation Shortage (%)	Mean Flow (%)	Peak Flow (%)	Low Flow (%)	Fast Runoff (%)	Slow Runoff (%)	Groundwater Recharge (%)
== = 2023 = ==		11_23_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	13_23_Alter_PASB	89%	86%	97%	95%	93%	113%	107%	112%	102%	108%	107%
		14_23_Alter_PCB	78%	76%	97%	90%	86%	128%	115%	126%	104%	117%	114%
		15_23_Alter_agr	83%	73%	97%	80%	74%	147%	113%	133%	94%	133%	126%
		16_23_Alter_store	100%	98%	98%	100%	100%	89%	85%	108%	100%	100%	100%
		17_23_Alter_irr	92%	87%	97%	100%	100%	104%	102%	104%	100%	100%	100%
		18_23_Alter_ind	92%	96%	100%	100%	100%	103%	102%	101%	100%	100%	100%
		19_23_Alter_cities	98%	100%	100%	100%	100%	101%	100%	101%	100%	100%	100%
		20_23_Alter_wp	80%	79%	97%	100%	100%	109%	105%	107%	100%	100%	100%
		21_23_Alter_PCB+	59%	56%	95%	80%	77%	75%	67%	14%	94%	120%	115%
		22_23_Alter_PCB-	59%	46%	95%	87%	82%	147%	133%	147%	105%	122%	118%
== = 2030 = ==		33_30_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	35_30_Alter_PASB	89%	79%	81%	95%	93%	109%	98%	145%	102%	108%	106%
		36_30_Alter_PCB	78%	64%	64%	90%	85%	126%	187%	195%	104%	117%	114%
		37_30_Alter_agr	83%	66%	77%	79%	73%	149%	180%	173%	95%	132%	125%
		38_30_Alter_store	100%	98%	98%	100%	100%	98%	94%	96%	100%	100%	100%
		39_30_Alter_irr	91%	86%	100%	100%	100%	103%	100%	131%	100%	100%	100%
		40_30_Alter_ind	92%	94%	92%	100%	100%	104%	104%	110%	100%	100%	100%
		41_30_Alter_cities	98%	99%	99%	100%	100%	101%	101%	101%	100%	100%	100%
		42_30_Alter_wp	80%	75%	84%	100%	100%	108%	105%	141%	100%	100%	100%
		43_30_Alter_PCB+	58%	48%	64%	79%	76%	73%	86%	44%	94%	119%	114%
		44_30_Alter_PCB-	57%	38%	64%	85%	79%	172%	201%	215%	105%	129%	123%
== = 2050 = ==		55_50_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	57_50_Alter_PASB	89%	75%	100%	95%	92%	103%	85%	101%	101%	108%	106%
		58_50_Alter_PCB	78%	50%	100%	89%	85%	106%	75%	159%	103%	117%	114%
		59_50_Alter_agr	89%	63%	100%	79%	73%	123%	98%	150%	95%	132%	124%
		60_50_Alter_store	100%	100%	100%	100%	100%	101%	95%	99%	100%	100%	100%
		61_50_Alter_irr	94%	90%	100%	100%	100%	102%	100%	102%	100%	100%	100%
		62_50_Alter_ind	89%	82%	100%	100%	100%	93%	102%	90%	100%	100%	100%
		63_50_Alter_cities	96%	94%	100%	100%	100%	98%	104%	97%	100%	100%	100%
		64_50_Alter_wp	80%	66%	100%	100%	100%	96%	102%	92%	100%	100%	100%
		65_50_Alter_PCB+	59%	35%	100%	79%	76%	83%	58%	124%	95%	117%	112%
		66_50_Alter_PCB-	60%	26%	99%	81%	73%	153%	256%	160%	107%	143%	133%

11.3 Sebeya

Table 21. Summary of impact of Projections expressed as 10 years average for the Sebeya catchment for the three time horizons.

			CRITERIA										
			Water Demand (MCM/y)	Water Shortage (MCM/y)	Water Short Months (nr/yr)	Evaporation Demand (MCM/y)	Evaporation Shortage (MCM/y)	Mean Flow (m3/s)	Peak Flow (m3/s)	Low Flow (m3/s)	Fast Runoff (MCM/y)	Slow Runoff (MCM/y)	Groundwater Recharge (MCM/y)
		00_Base	16	1	3	447	196	3.2	4.6	2.1	1	104	114
== 2023 ==	Projections	01_23_CC_low	16	1	3	467	205	3.2	4.9	2.0	1	104	114
		02_23_CC_med	16	1	3	483	212	3.2	5.0	2.0	1	104	114
		03_23_CC_high	16	1	3	500	220	3.2	5.0	2.0	1	104	114
		04_23_Pop_low	21	1	3	447	196	3.1	4.6	2.0	1	104	114
		05_23_Pop_med	21	1	3	447	196	3.1	4.6	2.0	1	104	114
		06_23_Pop_high	21	1	3	447	196	3.1	4.6	2.0	1	104	114
		07_23_Econ_low	24	1	3	447	196	3.1	4.6	2.0	1	104	114
		08_23_Econ_med	28	2	3	447	196	3.1	4.5	2.0	1	104	114
		09_23_Econ_high	48	3	3	447	196	2.9	4.3	1.8	1	104	114
		10_23_Fut_min	40	5	4	475	210	2.8	4.5	1.7	1	101	112
		11_23_Fut_med	46	5	4	492	217	2.8	4.5	1.6	1	101	112
		12_23_Fut_high	72	7	5	509	225	2.6	4.3	1.5	1	101	113
== 2030 ==	Projections	23_30_CC_low	16	1	3	473	207	3.2	5.2	2.0	1	105	115
		24_30_CC_med	16	1	3	493	215	3.3	5.2	2.0	1	106	116
		25_30_CC_high	16	1	3	515	224	3.3	5.3	2.0	1	107	116
		26_30_Pop_low	22	1	3	447	196	3.1	4.6	2.0	1	104	114
		27_30_Pop_med	23	1	3	447	196	3.1	4.6	2.0	1	104	114
		28_30_Pop_high	24	1	3	447	196	3.1	4.6	2.0	1	104	114
		29_30_Econ_low	35	2	3	447	196	3.0	4.4	1.9	1	104	114
		30_30_Econ_med	45	2	3	447	196	2.9	4.4	1.9	1	104	114
		31_30_Econ_high	95	7	9	447	196	2.6	4.0	1.5	1	104	114
		32_30_Fut_min	68	10	4	489	217	2.5	4.4	1.4	1	99	112
		33_30_Fut_med	84	11	6	511	225	2.4	4.4	1.3	1	100	113
		34_30_Fut_high	159	28	12	533	235	2.1	3.8	1.2	1	100	113
== 2050 ==	Projections	45_50_CC_low	16	1	3	491	213	3.3	5.8	1.9	1	108	118
		46_50_CC_med	16	1	3	523	224	3.4	6.1	1.9	1	111	121
		47_50_CC_high	16	1	3	558	235	3.6	6.5	1.8	2	115	124
		48_50_Pop_low	29	2	3	447	196	3.1	4.5	2.0	1	104	114
		49_50_Pop_med	32	2	3	447	196	3.1	4.5	2.0	1	104	114
		50_50_Pop_high	34	2	3	447	196	3.0	4.5	1.9	1	104	114
		51_50_Econ_low	69	4	4	447	196	2.7	4.1	1.7	1	104	114
		52_50_Econ_med	109	9	11	447	196	2.5	3.9	1.4	1	104	114
		53_50_Econ_high	293	94	12	447	196	2.2	3.0	1.6	1	104	114
		54_50_Fut_min	153	34	12	516	228	2.1	4.2	1.1	1	98	113
		55_50_Fut_med	241	73	12	551	240	2.1	3.8	1.3	1	101	116
		56_50_Fut_high	635	387	12	587	252	2.8	4.2	2.0	2	104	119

Table 22. Summary of impact of Projections for the Sebeya catchment for the three time horizons. Results are provided as % changes from Baseline.

			CRITERIA										
			Water Demand (%)	Water Shortage (%)	Water Short Months (%)	Evaporation Demand (%)	Evaporation Shortage (%)	Mean Flow (%)	Peak Flow (%)	Low Flow (%)	Fast Runoff (%)	Slow Runoff (%)	Groundwater Recharge (%)
		00_Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
= = = 2 0 2 3 = = =	Projections	01_23_CC_low	100%	112%	116%	105%	105%	100%	107%	98%	112%	100%	100%
		02_23_CC_med	100%	111%	116%	108%	108%	101%	107%	97%	116%	101%	100%
		03_23_CC_high	100%	111%	116%	112%	112%	101%	108%	96%	121%	101%	100%
		04_23_Pop_low	125%	125%	108%	100%	100%	99%	99%	99%	100%	100%	100%
		05_23_Pop_med	129%	129%	108%	100%	100%	99%	99%	98%	100%	100%	100%
		06_23_Pop_high	130%	130%	108%	100%	100%	99%	99%	98%	100%	100%	100%
		07_23_Econ_low	145%	145%	112%	100%	100%	98%	98%	97%	100%	100%	100%
		08_23_Econ_med	169%	169%	120%	100%	100%	97%	98%	96%	100%	100%	100%
		09_23_Econ_high	292%	292%	136%	100%	100%	92%	93%	89%	100%	100%	100%
		10_23_Fut_min	244%	521%	144%	106%	107%	90%	98%	81%	110%	97%	99%
		11_23_Fut_med	280%	557%	144%	110%	111%	88%	98%	78%	115%	98%	99%
		12_23_Fut_high	442%	761%	180%	114%	115%	82%	93%	70%	120%	98%	99%
= = = 2 0 3 0 = = =	Projections	23_30_CC_low	100%	122%	120%	106%	105%	102%	111%	97%	123%	101%	101%
		24_30_CC_med	100%	121%	116%	111%	110%	103%	113%	96%	133%	102%	102%
		25_30_CC_high	100%	120%	116%	115%	114%	104%	115%	96%	143%	103%	103%
		26_30_Pop_low	135%	135%	108%	100%	100%	99%	99%	98%	100%	100%	100%
		27_30_Pop_med	142%	142%	112%	100%	100%	98%	99%	98%	100%	100%	100%
		28_30_Pop_high	146%	146%	116%	100%	100%	98%	98%	97%	100%	100%	100%
		29_30_Econ_low	213%	213%	128%	100%	100%	95%	96%	93%	100%	100%	100%
		30_30_Econ_med	272%	272%	136%	100%	100%	93%	94%	90%	100%	100%	100%
		31_30_Econ_high	579%	761%	372%	100%	100%	81%	85%	73%	100%	100%	100%
		32_30_Fut_min	413%	1065%	160%	110%	110%	79%	95%	66%	120%	95%	99%
		33_30_Fut_med	511%	1269%	224%	114%	115%	77%	94%	64%	129%	96%	99%
		34_30_Fut_high	971%	3145%	480%	119%	119%	65%	83%	58%	138%	97%	100%
= = = 2 0 5 0 = = =	Projections	45_50_CC_low	100%	155%	136%	110%	108%	105%	125%	91%	162%	104%	104%
		46_50_CC_med	100%	153%	136%	117%	114%	109%	132%	90%	196%	108%	107%
		47_50_CC_high	100%	151%	132%	125%	120%	112%	140%	89%	238%	111%	110%
		48_50_Pop_low	177%	176%	120%	100%	100%	97%	97%	96%	100%	100%	100%
		49_50_Pop_med	193%	193%	120%	100%	100%	96%	97%	95%	100%	100%	100%
		50_50_Pop_high	206%	205%	124%	100%	100%	96%	96%	94%	100%	100%	100%
		51_50_Econ_low	422%	434%	176%	100%	100%	87%	89%	82%	100%	100%	100%
		52_50_Econ_med	662%	1000%	448%	100%	100%	78%	83%	68%	100%	100%	100%
		53_50_Econ_high	1790%	######	480%	100%	100%	71%	65%	79%	100%	100%	100%
		54_50_Fut_min	931%	3812%	472%	116%	116%	66%	90%	53%	153%	95%	100%
		55_50_Fut_med	1467%	8038%	480%	123%	122%	65%	82%	63%	185%	98%	102%
		56_50_Fut_high	3875%	######	480%	131%	128%	88%	91%	99%	223%	100%	105%

Table 23. Summary of impact of Alternatives expressed as 10 years average for the Sebeya catchment for the three time horizons.

			CRITERIA										
			Water Demand (MCM/y)	Water Shortage (MCM/y)	Water Short Months (nr/yr)	Evaporation Demand (MCM/y)	Evaporation Shortage (MCM/y)	Mean Flow (m3/s)	Peak Flow (m3/s)	Low Flow (m3/s)	Fast Runoff (MCM/y)	Slow Runoff (MCM/y)	Groundwater Recharge (MCM/y)
= = = 2023 = = =		11_23_Fut_med	46	5	4	492	217	2.8	4.5	1.6	1	101	112
	Alternatives	13_23_Alter_PASB	41	4	4	478	210	1.2	2.7	0.3	1	105	114
		14_23_Alter_PCB	37	4	4	465	203	1.2	2.8	0.4	1	109	116
		15_23_Alter_agr	42	4	4	439	192	3.3	4.4	2.4	1	116	119
		16_23_Alter_store	46	5	4	492	217	0.9	2.1	0.3	1	101	112
		17_23_Alter_irr	44	5	4	492	217	2.8	4.5	1.6	1	101	112
		18_23_Alter_ind	39	5	4	492	217	2.9	4.6	1.7	1	101	112
		19_23_Alter_cities	45	5	4	492	217	2.8	4.5	1.6	1	101	112
		20_23_Alter_wp	37	4	4	492	217	2.9	4.6	1.7	1	101	112
		21_23_Alter_PCB+	28	3	3	439	196	0.9	2.0	0.5	1	111	116
		22_23_Alter_PCB-	33	3	3	462	202	1.3	2.9	0.4	1	111	117
= = = 2030 = = =		33_30_Fut_med	84	11	6	511	225	2.4	4.4	1.3	1	100	113
	Alternatives	35_30_Alter_PASB	75	10	4	496	217	1.1	2.7	0.5	1	104	115
		36_30_Alter_PCB	67	8	4	481	209	1.1	2.8	0.5	1	108	117
		37_30_Alter_agr	77	9	4	451	197	3.0	4.2	2.0	1	115	120
		38_30_Alter_store	84	11	6	511	225	0.9	1.6	0.5	1	100	113
		39_30_Alter_irr	81	10	6	511	225	2.5	4.4	1.3	1	100	113
		40_30_Alter_ind	72	10	4	511	225	2.5	4.5	1.3	1	100	113
		41_30_Alter_cities	83	11	6	511	225	2.4	4.4	1.3	1	100	113
		42_30_Alter_wp	67	8	4	511	225	2.6	4.5	1.4	1	100	113
		43_30_Alter_PCB+	52	6	4	451	203	0.7	1.5	0.5	1	108	116
		44_30_Alter_PCB-	59	6	4	475	206	1.2	3.0	0.5	1	111	118
= = = 2050 = = =		55_50_Fut_med	241	73	12	551	240	2.1	3.8	1.3	1	101	116
	Alternatives	57_50_Alter_PASB	216	54	12	534	230	1.7	2.5	1.1	2	106	119
		58_50_Alter_PCB	192	40	12	516	220	1.6	2.3	1.0	2	110	121
		59_50_Alter_agr	230	52	12	482	207	2.4	3.6	1.7	1	117	124
		60_50_Alter_store	241	71	12	551	240	1.7	2.0	1.2	1	101	116
		61_50_Alter_irr	236	68	12	551	240	2.1	3.8	1.3	1	101	116
		62_50_Alter_ind	201	52	12	551	240	2.1	4.1	1.2	1	101	116
		63_50_Alter_cities	237	70	12	551	240	2.1	3.8	1.3	1	101	116
		64_50_Alter_wp	192	46	12	551	240	2.1	4.1	1.2	1	101	116
		65_50_Alter_PCB+	150	25	12	482	216	1.1	1.6	0.8	1	109	119
		66_50_Alter_PCB-	177	28	12	504	214	1.6	2.9	1.0	2	117	124

Table 10. Summary of impact of Alternatives for the Sebeya catchment for the three time horizons. Results are provided as % changes from Medium_Future.

			CRITERIA										
			Water Demand (%)	Water Shortage (%)	Water Short Months (%)	Evaporation Demand (%)	Evaporation Shortage (%)	Mean Flow (%)	Peak Flow (%)	Low Flow (%)	Fast Runoff (%)	Slow Runoff (%)	Groundwater Recharge (%)
= = = 2 0 2 3 = = =		11_23_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	13_23_Alter_PASB	90%	89%	97%	97%	97%	42%	60%	22%	111%	104%	102%
		14_23_Alter_PCB	80%	78%	97%	95%	94%	43%	62%	23%	125%	108%	103%
		15_23_Alter_agr	93%	83%	97%	89%	88%	118%	97%	147%	63%	115%	106%
		16_23_Alter_store	100%	100%	100%	100%	100%	32%	46%	21%	100%	100%	100%
		17_23_Alter_irr	96%	91%	97%	100%	100%	101%	100%	102%	100%	100%	100%
		18_23_Alter_ind	85%	92%	100%	100%	100%	102%	101%	103%	100%	100%	100%
		19_23_Alter_cities	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		20_23_Alter_wp	80%	80%	97%	100%	100%	103%	102%	105%	100%	100%	100%
		21_23_Alter_PCB+	62%	59%	92%	89%	90%	33%	44%	33%	62%	110%	103%
		22_23_Alter_PCB-	71%	57%	92%	94%	93%	47%	64%	24%	126%	109%	104%
= = = 2 0 3 0 = = =		33_30_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	35_30_Alter_PASB	90%	83%	75%	97%	96%	44%	61%	40%	112%	104%	102%
		36_30_Alter_PCB	80%	71%	68%	94%	93%	45%	65%	38%	127%	108%	104%
		37_30_Alter_agr	92%	75%	68%	88%	87%	121%	95%	153%	61%	115%	106%
		38_30_Alter_store	100%	99%	100%	100%	100%	37%	37%	40%	100%	100%	100%
		39_30_Alter_irr	96%	89%	100%	100%	100%	101%	100%	102%	100%	100%	100%
		40_30_Alter_ind	86%	87%	73%	100%	100%	103%	103%	101%	100%	100%	100%
		41_30_Alter_cities	99%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		42_30_Alter_wp	80%	74%	71%	100%	100%	105%	103%	105%	100%	100%	100%
		43_30_Alter_PCB+	62%	54%	64%	88%	90%	29%	34%	35%	61%	109%	103%
		44_30_Alter_PCB-	70%	50%	66%	93%	91%	50%	69%	38%	129%	111%	105%
= = = 2 0 5 0 = = =		55_50_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	57_50_Alter_PASB	90%	74%	100%	97%	96%	80%	67%	84%	114%	104%	102%
		58_50_Alter_PCB	80%	55%	100%	94%	92%	75%	61%	75%	131%	109%	104%
		59_50_Alter_agr	96%	72%	100%	87%	86%	115%	95%	131%	55%	115%	107%
		60_50_Alter_store	100%	98%	100%	100%	100%	82%	52%	93%	100%	100%	100%
		61_50_Alter_irr	98%	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		62_50_Alter_ind	84%	72%	100%	100%	100%	100%	108%	93%	100%	100%	100%
		63_50_Alter_cities	98%	97%	100%	100%	100%	100%	101%	99%	100%	100%	100%
		64_50_Alter_wp	80%	63%	100%	100%	100%	101%	109%	94%	100%	100%	100%
		65_50_Alter_PCB+	62%	35%	100%	87%	90%	55%	43%	58%	54%	107%	102%
		66_50_Alter_PCB-	74%	38%	99%	92%	89%	79%	76%	75%	136%	115%	106%

11.4 Upper Nyaburongo

Table 24. Summary of impact of Projections expressed as 10 years average for the Upper Nyaburongo catchment for the three time horizons.

			CRITERIA										
			Water Demand (MCM/y)	Water Shortage (MCM/y)	Water Short Months (nr/yr)	Evaporation Demand (MCM/y)	Evaporation Shortage (MCM/y)	Mean Flow (m3/s)	Peak Flow (m3/s)	Low Flow (m3/s)	Fast Runoff (MCM/y)	Slow Runoff (MCM/y)	Groundwater Recharge (MCM/y)
		00_Base	50	8	11	3767	1690	47.1	85.6	27.1	402	1096	519
= = = 2023 = = =	Projections	01_23_CC_low	50	7	10	3929	1750	48.5	89.3	26.6	429	1114	529
		02_23_CC_med	50	7	10	4062	1807	49.0	89.8	26.3	441	1118	531
		03_23_CC_high	50	7	10	4198	1866	49.4	90.8	26.1	452	1120	532
		04_23_Pop_low	60	9	11	3767	1690	47.0	85.5	27.1	402	1096	519
		05_23_Pop_med	62	10	11	3767	1690	47.0	85.5	27.1	402	1096	519
		06_23_Pop_high	63	10	11	3767	1690	47.0	85.5	27.1	402	1096	519
		07_23_Econ_low	69	11	11	3767	1690	47.0	85.4	27.0	402	1096	519
		08_23_Econ_med	78	13	11	3767	1690	46.9	85.3	27.0	402	1096	519
		09_23_Econ_high	129	22	11	3767	1690	46.6	84.8	26.8	402	1096	519
		10_23_Fut_min	152	40	11	3966	1772	47.1	85.9	25.4	425	1099	529
		11_23_Fut_med	167	42	11	4100	1830	47.4	86.2	25.0	437	1103	531
		12_23_Fut_high	235	53	11	4238	1890	47.4	86.4	24.4	448	1105	532
= = = 2030 = = =	Projections	23_30_CC_low	50	7	10	3978	1758	49.7	92.3	26.1	449	1133	539
		24_30_CC_med	50	7	9	4144	1824	50.7	94.4	25.8	469	1142	544
		25_30_CC_high	50	7	9	4315	1893	51.5	97.2	25.6	488	1150	548
		26_30_Pop_low	65	10	11	3767	1690	47.0	85.4	27.1	402	1096	519
		27_30_Pop_med	68	11	11	3767	1690	47.0	85.4	27.0	402	1096	519
		28_30_Pop_high	69	11	11	3767	1690	47.0	85.4	27.0	402	1096	519
		29_30_Econ_low	97	16	11	3767	1690	46.8	85.1	26.9	402	1096	519
		30_30_Econ_med	121	20	11	3767	1690	46.6	84.8	26.8	402	1096	519
		31_30_Econ_high	248	43	11	3767	1690	45.8	83.5	26.2	402	1096	519
		32_30_Fut_min	265	75	11	4053	1802	46.8	88.5	23.6	441	1103	540
		33_30_Fut_med	306	81	11	4222	1870	47.4	91.0	23.2	461	1112	545
		34_30_Fut_high	497	111	10	4397	1942	46.8	91.9	21.9	479	1119	549
= = = 2050 = = =	Projections	45_50_CC_low	50	7	9	4118	1784	53.0	112.6	24.5	505	1180	565
		46_50_CC_med	50	7	9	4380	1874	55.5	120.4	24.5	555	1210	582
		47_50_CC_high	50	7	8	4654	1966	58.1	128.5	24.4	608	1239	598
		48_50_Pop_low	82	13	11	3767	1690	46.9	85.3	27.0	402	1096	519
		49_50_Pop_med	89	15	11	3767	1690	46.8	85.2	26.9	402	1096	519
		50_50_Pop_high	94	15	11	3767	1690	46.8	85.1	26.9	402	1096	519
		51_50_Econ_low	183	31	11	3767	1690	46.2	84.2	26.5	402	1096	519
		52_50_Econ_med	283	49	11	3767	1690	45.5	83.1	26.0	402	1096	519
		53_50_Econ_high	750	132	12	3767	1690	42.4	78.2	23.9	402	1096	519
		54_50_Fut_min	523	137	10	4235	1852	47.5	105.9	20.4	492	1133	566
		55_50_Fut_med	746	170	10	4505	1946	48.3	111.3	19.3	540	1162	582
		56_50_Fut_high	1748	382	9	4787	2043	45.0	109.4	18.7	591	1189	599

Table 25. Summary of impact of Projections for the Upper Nyaburongo catchment for the three time horizons. Results are provided as % changes from Baseline.

			CRITERIA										
			Water Demand (%)	Water Shortage (%)	Water Short Months (%)	Evaporation Demand (%)	Evaporation Shortage (%)	Mean Flow (%)	Peak Flow (%)	Low Flow (%)	Fast Runoff (%)	Slow Runoff (%)	Groundwater Recharge (%)
		00_Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
= = = 2 0 2 3 = = =	Projections	01_23_CC_low	100%	97%	96%	104%	104%	103%	104%	98%	107%	102%	102%
		02_23_CC_med	100%	95%	92%	108%	107%	104%	105%	97%	110%	102%	102%
		03_23_CC_high	100%	93%	92%	111%	110%	105%	106%	96%	113%	102%	102%
		04_23_Pop_low	121%	124%	103%	100%	100%	100%	100%	100%	100%	100%	100%
		05_23_Pop_med	124%	128%	104%	100%	100%	100%	100%	100%	100%	100%	100%
		06_23_Pop_high	125%	129%	104%	100%	100%	100%	100%	100%	100%	100%	100%
		07_23_Econ_low	138%	144%	104%	100%	100%	100%	100%	100%	100%	100%	100%
		08_23_Econ_med	157%	166%	105%	100%	100%	100%	100%	100%	100%	100%	100%
		09_23_Econ_high	259%	285%	105%	100%	100%	99%	99%	99%	100%	100%	100%
		10_23_Fut_min	305%	526%	101%	105%	105%	100%	100%	93%	106%	100%	102%
		11_23_Fut_med	334%	553%	100%	109%	108%	101%	101%	92%	109%	101%	102%
		12_23_Fut_high	469%	693%	100%	112%	112%	101%	101%	90%	112%	101%	103%
= = = 2 0 3 0 = = =	Projections	23_30_CC_low	100%	96%	90%	106%	104%	106%	108%	96%	112%	103%	104%
		24_30_CC_med	100%	93%	88%	110%	108%	108%	110%	95%	117%	104%	105%
		25_30_CC_high	100%	91%	87%	115%	112%	109%	114%	94%	122%	105%	106%
		26_30_Pop_low	129%	134%	104%	100%	100%	100%	100%	100%	100%	100%	100%
		27_30_Pop_med	135%	141%	104%	100%	100%	100%	100%	100%	100%	100%	100%
		28_30_Pop_high	139%	145%	104%	100%	100%	100%	100%	100%	100%	100%	100%
		29_30_Econ_low	194%	210%	105%	100%	100%	99%	99%	99%	100%	100%	100%
		30_30_Econ_med	242%	266%	105%	100%	100%	99%	99%	99%	100%	100%	100%
		31_30_Econ_high	497%	563%	107%	100%	100%	97%	98%	97%	100%	100%	100%
		32_30_Fut_min	530%	985%	99%	108%	107%	99%	103%	87%	110%	101%	104%
		33_30_Fut_med	612%	1060%	99%	112%	111%	101%	106%	85%	115%	101%	105%
		34_30_Fut_high	994%	1451%	93%	117%	115%	99%	107%	81%	119%	102%	106%
= = = 2 0 5 0 = = =	Projections	45_50_CC_low	100%	95%	86%	109%	106%	113%	132%	90%	126%	108%	109%
		46_50_CC_med	100%	91%	80%	116%	111%	118%	141%	90%	138%	110%	112%
		47_50_CC_high	100%	88%	75%	124%	116%	123%	150%	90%	151%	113%	115%
		48_50_Pop_low	164%	174%	105%	100%	100%	100%	100%	99%	100%	100%	100%
		49_50_Pop_med	178%	191%	105%	100%	100%	99%	100%	99%	100%	100%	100%
		50_50_Pop_high	189%	203%	105%	100%	100%	99%	99%	99%	100%	100%	100%
		51_50_Econ_low	366%	411%	106%	100%	100%	98%	98%	98%	100%	100%	100%
		52_50_Econ_med	566%	644%	107%	100%	100%	97%	97%	96%	100%	100%	100%
		53_50_Econ_high	1500%	1734%	108%	100%	100%	90%	91%	88%	100%	100%	100%
		54_50_Fut_min	1047%	1798%	92%	112%	110%	101%	124%	75%	123%	103%	109%
		55_50_Fut_med	1493%	2229%	90%	120%	115%	103%	130%	71%	134%	106%	112%
		56_50_Fut_high	3495%	5015%	88%	127%	121%	96%	128%	69%	147%	108%	115%

Table 26. Summary of impact of Alternatives expressed as 10 years average for the Upper Nyaburongo catchment for the three time horizons.

Horizon	Group	Scenario	Water Demand (MCM/y)	Water Shortage (MCM/y)	Water Short Months (nr/yr)	Evaporation Demand (MCM/y)	Evaporation Shortage (MCM/y)	Mean Flow (m3/s)	Peak Flow (m3/s)	Low Flow (m3/s)	Fast Runoff (MCM/y)	Slow Runoff (MCM/y)	Groundwater Recharge (MCM/y)
			CRITERIA										
= = = 2023 = = =		11_23_Fut_med	167	42	11	4100	1830	47.4	86.2	25.0	437	1103	531
	Alternatives	13_23_Alter_PASB	149	37	11	3939	1741	49.6	89.6	26.6	457	1147	537
		14_23_Alter_PCB	132	33	11	3777	1655	52.0	93.2	28.3	479	1193	544
		15_23_Alter_agr	142	34	11	3454	1444	52.2	73.1	37.5	234	1447	580
		16_23_Alter_store	167	42	11	4100	1830	47.4	86.2	25.0	437	1103	531
		17_23_Alter_irr	155	38	11	4100	1830	47.6	86.5	25.2	437	1103	531
		18_23_Alter_ind	152	39	11	4100	1830	47.5	86.4	25.1	437	1103	531
		19_23_Alter_cities	167	42	11	4100	1830	47.4	86.2	25.0	437	1103	531
		20_23_Alter_wp	134	34	11	4100	1830	47.7	86.8	25.3	437	1103	531
		21_23_Alter_PCB+	101	25	10	3454	1465	48.4	64.1	34.8	153	1400	572
		22_23_Alter_PCB-	106	23	10	3761	1647	52.5	94.6	28.8	481	1201	543
= = = 2030 = = =		33_30_Fut_med	306	81	11	4222	1870	47.4	91.0	23.2	461	1112	545
	Alternatives	35_30_Alter_PASB	273	72	11	4055	1777	49.8	94.8	24.9	482	1156	551
		36_30_Alter_PCB	241	63	10	3887	1688	52.2	98.8	26.7	506	1204	558
		37_30_Alter_agr	259	64	10	3551	1471	52.2	75.1	36.2	249	1461	595
		38_30_Alter_store	306	81	11	4222	1870	47.4	91.0	23.2	461	1112	545
		39_30_Alter_irr	282	72	11	4222	1870	47.6	91.0	23.4	461	1112	545
		40_30_Alter_ind	278	76	11	4222	1870	47.6	91.2	23.3	461	1112	545
		41_30_Alter_cities	305	81	11	4222	1870	47.4	91.0	23.2	461	1112	545
		42_30_Alter_wp	245	65	10	4222	1870	47.9	91.3	23.7	461	1112	545
		43_30_Alter_PCB+	184	47	10	3551	1498	48.4	65.3	33.7	162	1411	585
		44_30_Alter_PCB-	189	42	10	3853	1670	53.3	100.0	27.6	510	1219	557
= = = 2050 = = =		55_50_Fut_med	746	170	10	4505	1946	48.3	111.3	19.3	540	1162	582
	Alternatives	57_50_Alter_PASB	668	151	10	4325	1846	51.1	116.3	21.2	566	1208	589
		58_50_Alter_PCB	594	134	10	4144	1751	54.1	121.5	23.2	593	1257	597
		59_50_Alter_agr	671	143	10	3783	1516	53.2	86.7	34.0	300	1538	638
		60_50_Alter_store	746	170	10	4505	1946	48.3	111.3	19.3	540	1162	582
		61_50_Alter_irr	709	157	10	4505	1946	48.6	111.3	19.6	540	1162	582
		62_50_Alter_ind	654	154	10	4505	1946	48.9	112.1	19.7	540	1162	582
		63_50_Alter_cities	742	169	10	4505	1946	48.4	111.3	19.3	540	1162	582
		64_50_Alter_wp	597	136	10	4505	1946	49.4	112.3	20.2	540	1162	582
		65_50_Alter_PCB+	459	102	9	3783	1550	48.8	69.9	3.2	186	1488	627
		66_50_Alter_PCB-	489	91	9	4073	1715	56.4	124.5	24.8	603	1291	596

Table 10. Summary of impact of Alternatives for the Upper Nyaburongo catchment for the three time horizons. Results are provided as % changes from Medium_Future.

Horizon			CRITERIA										
			Water Demand (%)	Water Shortage (%)	Water Short Months (%)	Evaporation Demand (%)	Evaporation Shortage (%)	Mean Flow (%)	Peak Flow (%)	Low Flow (%)	Fast Runoff (%)	Slow Runoff (%)	Groundwater Recharge (%)
= = = 2023 = = =		11_23_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	13_23_Alter_PASB	89%	89%	99%	96%	95%	105%	104%	106%	105%	104%	101%
		14_23_Alter_PCB	79%	78%	99%	92%	90%	110%	108%	113%	110%	108%	102%
		15_23_Alter_agr	85%	80%	100%	84%	79%	110%	85%	150%	54%	131%	109%
		16_23_Alter_store	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		17_23_Alter_irr	92%	90%	100%	100%	100%	100%	100%	101%	100%	100%	100%
		18_23_Alter_ind	91%	93%	99%	100%	100%	100%	100%	100%	100%	100%	100%
		19_23_Alter_cities	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		20_23_Alter_wp	80%	80%	99%	100%	100%	101%	101%	101%	100%	100%	100%
		21_23_Alter_PCB+	60%	59%	98%	84%	80%	102%	74%	139%	35%	127%	108%
		22_23_Alter_PCB-	63%	54%	98%	92%	90%	111%	110%	115%	110%	109%	102%
= = = 2030 = = =		33_30_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	35_30_Alter_PASB	89%	89%	100%	96%	95%	105%	104%	107%	105%	104%	101%
		36_30_Alter_PCB	79%	78%	99%	92%	90%	110%	109%	115%	110%	108%	102%
		37_30_Alter_agr	85%	79%	98%	84%	79%	110%	83%	156%	54%	131%	109%
		38_30_Alter_store	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		39_30_Alter_irr	92%	90%	100%	100%	100%	100%	100%	101%	100%	100%	100%
		40_30_Alter_ind	91%	94%	100%	100%	100%	100%	100%	101%	100%	100%	100%
		41_30_Alter_cities	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		42_30_Alter_wp	80%	80%	99%	100%	100%	101%	100%	102%	100%	100%	100%
		43_30_Alter_PCB+	60%	59%	96%	84%	80%	102%	72%	145%	35%	127%	108%
		44_30_Alter_PCB-	62%	52%	98%	91%	89%	113%	110%	119%	111%	110%	102%
= = = 2050 = = =		55_50_Fut_med	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Alternatives	57_50_Alter_PASB	90%	89%	100%	96%	95%	106%	104%	110%	105%	104%	101%
		58_50_Alter_PCB	80%	79%	100%	92%	90%	112%	109%	121%	110%	108%	102%
		59_50_Alter_agr	90%	84%	100%	84%	78%	110%	78%	176%	56%	132%	109%
		60_50_Alter_store	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		61_50_Alter_irr	95%	92%	100%	100%	100%	101%	100%	102%	100%	100%	100%
		62_50_Alter_ind	88%	91%	100%	100%	100%	101%	101%	102%	100%	100%	100%
		63_50_Alter_cities	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		64_50_Alter_wp	80%	80%	100%	100%	100%	102%	101%	105%	100%	100%	100%
		65_50_Alter_PCB+	61%	60%	99%	84%	80%	101%	63%	17%	34%	128%	108%
		66_50_Alter_PCB-	66%	54%	99%	90%	88%	117%	112%	129%	112%	111%	102%

12 APPENDIX: Flow Records

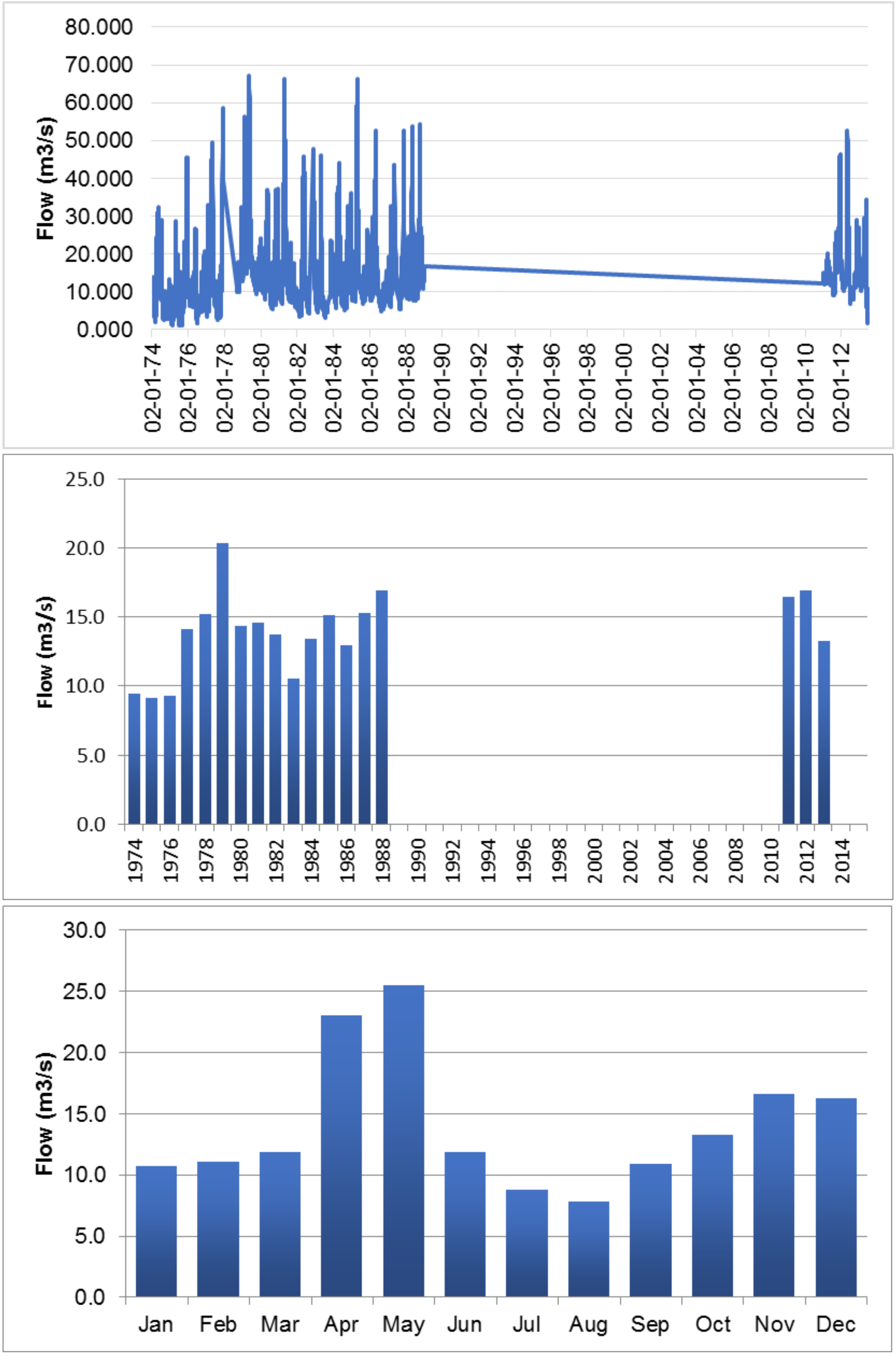


Figure 109. Observed (top), annual average (middle) and monthly average (bottom) discharge data for station Kagitumba (Muvumba).

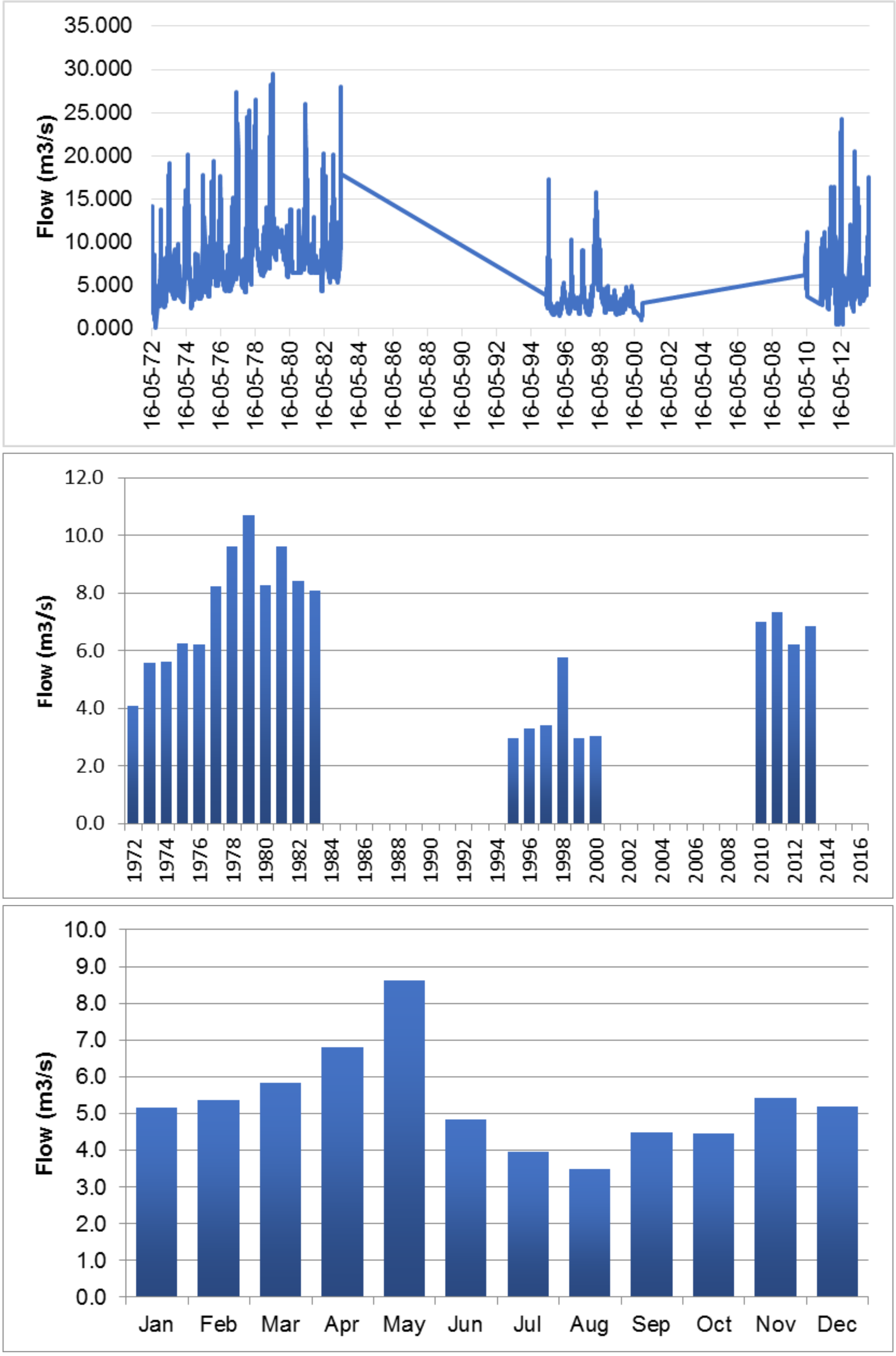


Figure 110. Observed (top), annual average (middle) and monthly average (bottom) discharge data for station Nemba in Nyabugogo Catchment.

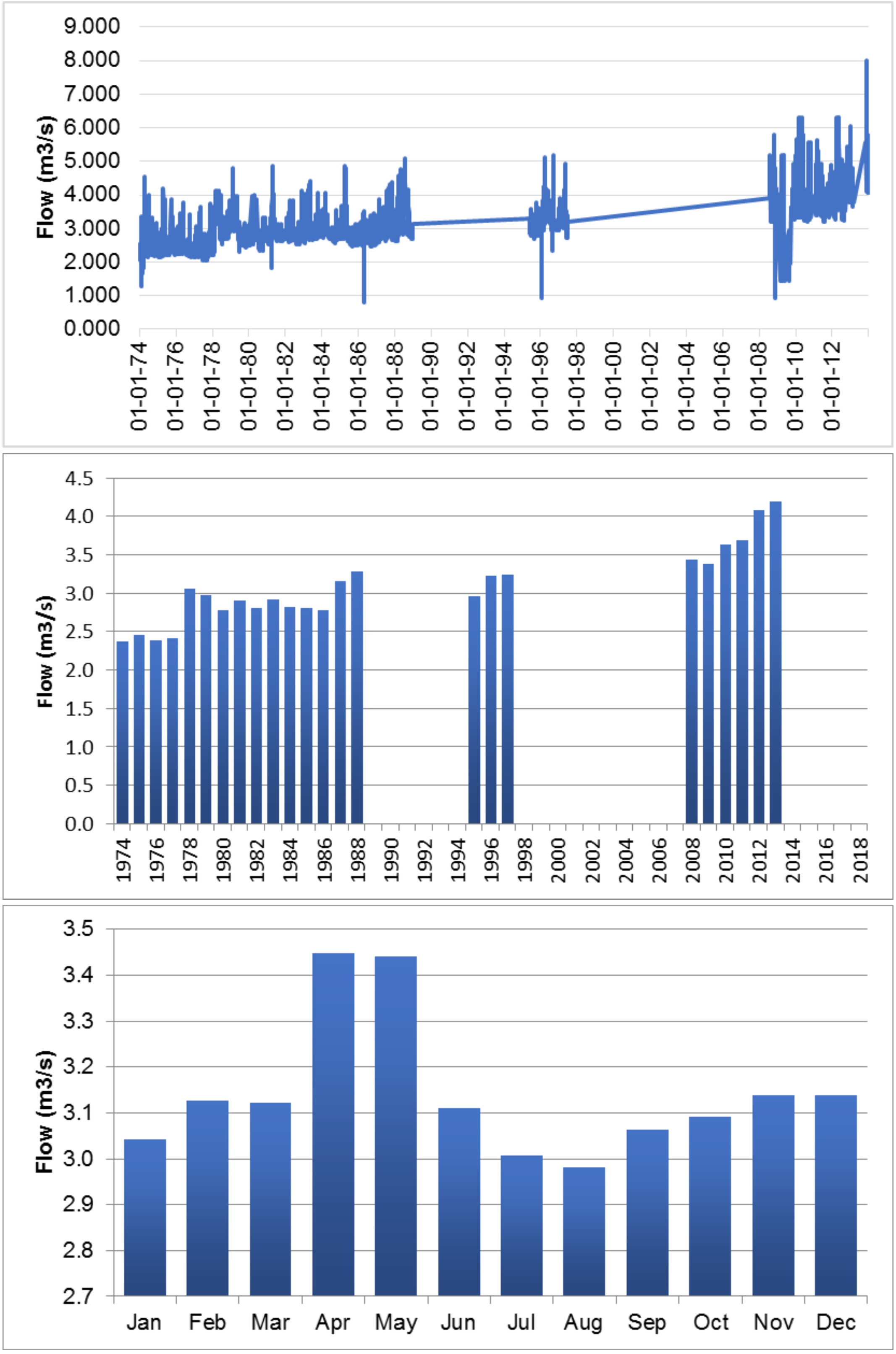


Figure 111. Observed (top), annual average (middle) and monthly average (bottom) discharge data for station Nyundo in Sebeya Catchment.

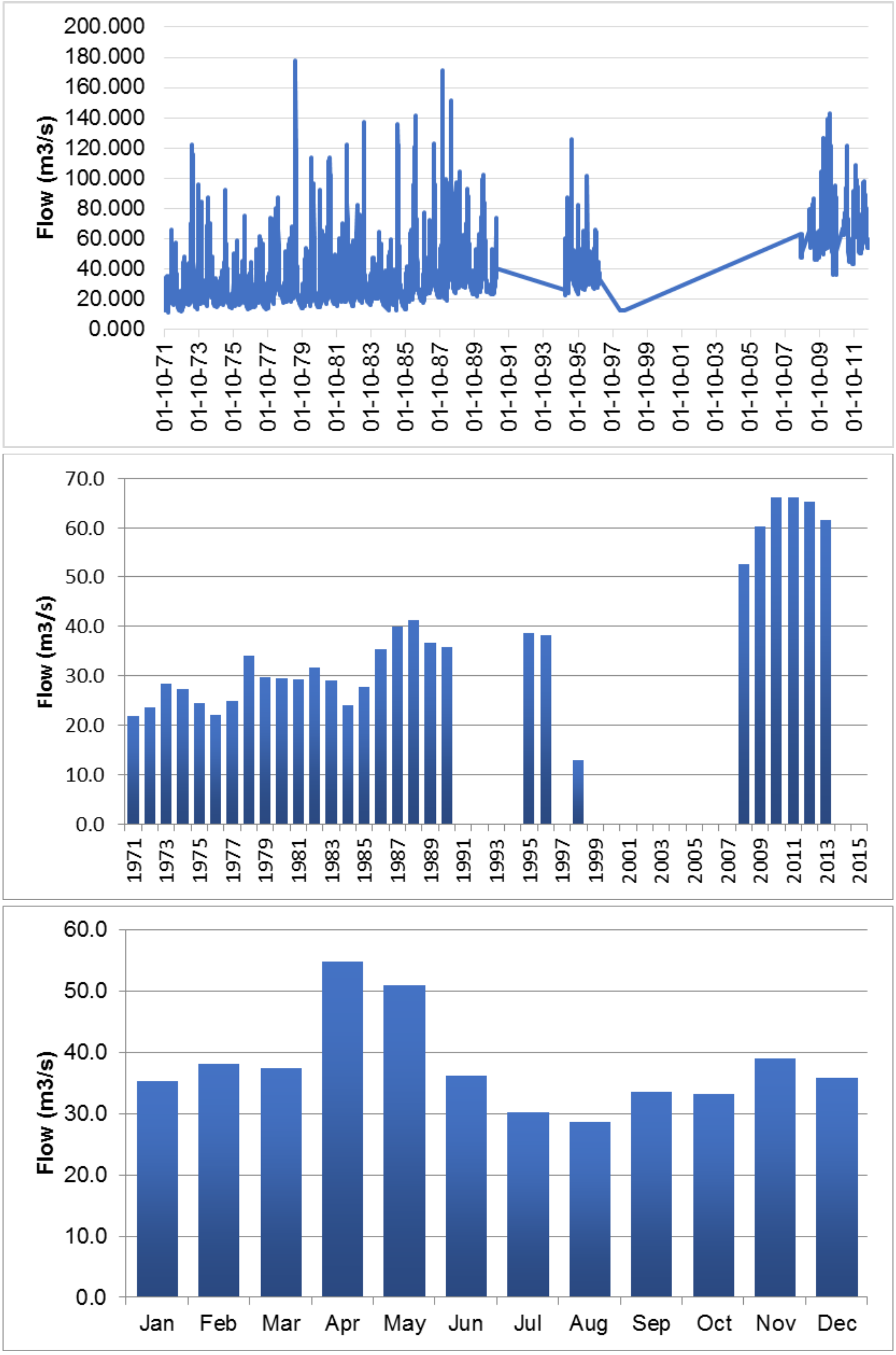


Figure 112. Observed (top), annual average (middle) and monthly average (bottom) discharge data for station Mwaka in Upper Nyabarongo Catchment.