# Water and Agriculture in Uganda

## Supporting a CLEW's assessment

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## Acronyms and abbreviation

| | |
|---|---|
| CLEW's | Climate, Land-use, Energy and Water strategies |
| CMS | Cubic Meter Per Second |
| El | Electricity |
| $ET_{ref}$ | Reference Evapotranspiration |
| FAO | Food and Agriculture Organization of the United Nations |
| GAEZ | Global Agro-Ecological Zones system |
| GHG | Green House Gases |
| GDP | Gross Domestic Product |
| GW | Ground Water |
| HPP | Hydropower Plant |
| IIASA | International Institute for Applied Systems Analysis |
| IRWR | Internal Renewable Water Resources |
| KTH | The Royal Institute of Technology |
| MCM | Million Cubic Meters |
| NWRA | National Water Resource Assessment |
| O&M | Operational and Maintenance |
| PP | Power Plant |
| RWR | Renewable Water Resources |
| R&D | Research and Development |
| UBOS | Uganda Bureau of Statistics |

| | |
|---|---|
| WEAP | Water Evaluation And Planning system |
| WTP | Water treatment plant |
| WWTP | Wastewater treatment plant |

## Abstract

This report presents a system analysis of the agricultural and water sector of Uganda. The overall objective is to identify areas where problems might arise in the future and see how these might affect the whole system.

In order to model and analyze these two sectors, two tools are being used; WEAP and GAEZ. WEAP (Water Evaluation And Planning system) is a program that enables modeling of a water system, including inflows, outflows, demand sites etc.
For certain climatic data and crop production analysis, the online database GAEZ (Global Agro-Ecological Zones system) is used. In this database, one may chose different time periods and extracts information based on the future IPCC climate scenarios.

For future years, different scenarios and combinations of them are investigated. This is done by among some; changing the precipitation, adding future hydropower plants and increasing the agriculture water demand. The latter due to increase of crop production and ensuring food security in the future by meeting the 2700 kcal/capita/day requirement. For climatic data and crop production, two different IPCC climate scenarios are used.

The results of the study show that there is a possibility of water deficit in certain areas and unmet hydropower demand in the future. Furthermore, there are crops that appear to be more resistible to climate change, but also require larger amount of irrigation in some cases. The extent of deficit, unmet demand and crop production show a variation between the different scenarios. However, these results will no matter scenario all affect each other and the system as a whole. Hence an integrated system approach is needed when planning and discussing future policy strategies.

**Keywords:** WEAP, GAEZ, Water, Agriculture, Climate change, Uganda, Sustainable development, CLEW

## Sammanfattning

Denna rapport presenterar en system analys av jordbruks- och vattensektorn i Uganda. Det övergripande syftet är att identifiera områden där problem kan uppstå i framtiden och se hur dessa kan komma att påverka systemet i stort.

För att modellera och analysera dessa två sektorer används två digitala verktyg; WEAP and GAEZ. WEAP (Water Evalutation and Planning system) är ett datorprogram som möjliggör modellering av ett vattensystem som inkluderar inflöden, utflöden och platser med efterfrågan på vatten.
För analys av viss klimatisk data och växtodling, används databasen GAEZ (Global Agri-Ecological Zones system) som är tillgänglig online. I denna databas är det möjligt att välja olika tidsperioder och erhålla information baserade på IPCC klimat scenarier.

För framtida år undersöks olika scenarier och kombinator av dessa. Detta görs genom att bland annat ändra nederbörden, inkludera framtida vattenkraftverk och öka efterfrågan på vatten inom jordbruket. Det sistnämnda sker pga. ökad växtodling och tillförsäkran om mat-säkerhet i framtiden genom att möta det dagliga kaloribehovet på 2700 kcal/capita. För klimatisk data och växtodling används två olika IPCC scenarier.

Resultatet av denna studie visar på en möjlig vattenbrist i vissa områden och ouppnådd efterfråga från vattenkraftverk i framtiden. Vidare finns det växter som ter sig ha större möjlighet att stå emot klimat förändringar, men kräver också större andel bevattning i vissa fall. Graden av vattenbrist, ouppnådd efterfråga och växtodling visar en variation emellan de olika scenarierna. Hursomhelst så kommer dessa resultat att visa på att de alla påverkar varandra och system i stort. Således är ett integrerat förhållningssätt med systemtänk nödvändigt vid planering och diskussion kring framtida policy strategier.

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## Disclaimer

This report represent a work in progress where methods and results will by most probable means come to be updated in the future. The document presents the views of the authors and may therefore not reflect or be supported by the parties whom are related to the project which this report is supporting.

Furthermore, it's advisable to read the report together with the report by Nilsson and Johansson; *Laying Foundation for energy policy making in Uganda by indicating the energy flow* (in press, July 2015) as they complement each other and are linked in terms of certain values and analysis. Together they give the overall perspective of the support to a CLEWs assessment. Hence when referring to results or values from OSeMOSYS, one should turn to the report done by Nilsson and Johansson in order to obtain the background for these values.

# 1. Introduction

One main issue that has been identified in many developing countries is the lack of efficient development policies (Division for Sustainable Development, 2014). The areas where this deficiency has been addressed are among others the acceleration of population growth, reduction of poverty, preservation and improvement of the environment and adaptation to climate changes. In order to address these matters, a consistent policy strategy that integrates economic, social and environmental sectors is required.

This way of integrated approach is being utilized in the project "*Supporting the Design of Sustainable Development Policies with Policy Modeling Tools 2014-2015"* (KTH, 2015b). One of the frameworks used in the project just mentioned, is CLEWs (Climate, Land-use, Energy and Water strategies), which provides an integrated system approach between its four constituents; climate, land, energy and water (KTH, 2015a). An integrated approach enables the possibility to visualize how changes in one sector may affect the others, hence one obtain a more coherent perspective when formulating the strategies that integrates economic, social and environmental dimensions. CLEW's incorporates local modelling along with analytical capacity that may allow the configuration of policy decision-making upon its result. Three countries today have agreed to be pilot countries; Bolivia, Nicaragua and Uganda.

This report presents the study of an integrated system analysis with Uganda as a case study.

## 1.1 Uganda

Uganda is located in the eastern part of Africa right by the equator with an altitude reaching up to 1 500 meter in the south and 1 000 meter in the north (NE, 2009). It was a British colony from year 1894 and was part of the British Empire until the independency in year 1962. Uganda has a history characterized by tyranny, both during the time of Idi Amin's regime and the ethnical violence of the Lord's Resistance Army (LRA). The current president, Yoweri Musevini, has had the power since 1985 when he unseated Milton Obote, who was the one to overthrow Amin. The next election will be held in February 2016.

Uganda has a total area that amounts to more than 241 550.7 $km^2$ out of which 15.1 % is open water bodies, 1.9 % wetlands and the rest (83.0 %) makes up the land area (UBOS, 2014). According to FAO (2015c) the population amounts to 37.5 million people today. In the year of 2010, 11 % of the population had access to electricity, the level of urbanization was estimated to 13 % and the per capita income was USD 506 (NPA, 2013). The number of people living in poverty reduced from 56 % in the year 1992-93 to 19.7 % in 2012-13 (World Bank, 2015a).

## 1.2 Agriculture sector

When the National Water Resource Assessment (NWRA) (MWE, 2013) was published in 2013, the crop farming was practiced on around 34 % of Uganda's total land area.
As for now, water supply for the production of agricultural commodities is primarily rain-fed with a non-market oriented approach. The technologies and machinery used in the production are of most basic condition and often practiced in a non-environmental friendly way. These factors contribute to a low volume and poor quality of production (MAAIF, 2009). According to the World Bank (World Bank, 2015a) the limitations within input (e.g. quality of seeds),

irrigation systems and mechanization in the agricultural production, will likely restrain the continued growth rate of the sector.
Due to the variability of the rainfall, soil moisture deficit occurs at times which may be critical for plant growth. All these factors results in a low crop yield in general throughout the whole of Uganda (MWE, 2013).

The agriculture sector contributes to around 53 % of the total export revenues of Uganda today, although slightly declining compared to other sectors. In the years of 2002/2003 it occupied 66 % of the population with work, increasing to over 73 % in the years of 2012/2013 (MAAIF, 2014). The sector recorded an annual growth rate of 1.5 % and contributed to 24 % of the country's GDP.

In Uganda there are 16 major crops being grown; cereals (maize, millet, sorghum and rice), root crops (cassava, sweet potatoes and Irish potatoes), pulses (beans, cow peas, field peas and pigeon peas), oil crops (groundnuts, soya beans and simsim), plantains and coffee (UBOS, 2014). To this, wheat may also be included, as it has become to increase in its production.

In 2013 the total area used for crop planting reached 5 745 000 hectare (UBOS, 2014). During this year the production of tea increased by 3.4 %, tobacco by 60.6 %, maize by 0.5 %, beans by 8.2 % and coffee by 11.5 % while production of banana decreased by 2.8 %. Coffee is the country's main foreign exchange earner and in 2013 its earning increased by 17.7 %. This led to an overall increase in formal export earnings by 2.4 percentage points from 2012 to 2013. The total contribution in 2013 for the agricultural sector to Uganda's GDP (at the current market prices) were 20.9 %.

As a large portion of the Ugandan population is involved in and depend on the harvest in agriculture, the government has recognized the sector as a key stone in order to mitigate poverty (MAAIF, 2009). Through the Poverty Eradication Action Plan (PEAP) the lead strategy of the modern farming shall make the opportunity to raise the income and improve livelihood of the poor. Within PEAP, the strategic framework Plan for the Modernization of Agriculture (PMA) has been developed in order to help the transformation of today's subsistence agriculture into a market-oriented sector.

### 1.3 Food scarcity

Different strategies and policies have been implemented in order to address the food security, nutrition and the right to food in Uganda. These include (FAO, 2013):

- Food and Nutrition Policy
- Food and Nutrition Strategy
- Health Sector Strategic Plan
- Agriculture Sector Development Strategy and Investment Plan
- National Development Plan
- Uganda Nutrition Action Plan

In the year of 2014, the number of low-birthweight infants amounted 11.8 %, which is a decrease from 2002's value of 12.3 % (FAO, 2014). The same report also concludes that underweight children under the age of five amounted to 15.4 % for boys and 12.8 % for girls in 2014. All anthropometric values are either higher or the same for boys compared to girls, except severe wasting children under the age of five where the value for girls amounts higher

than for boys. In year 2014, 9.7 million people were unnourished and the average food deficit amounted to 172 kcal/cap/day.

### 1.4 Water sector

Rainfall plays the most important role as contributor to ground and surface water recharge within Uganda (MWE, 2013). The total actual renewable water resources were in year 2014 60.1 $km^3$/year, which equals to about 1599 $m^3$/person and year (FAO, 2015c). In this aspect Uganda may be considered to obtain substantial fresh water resources. Though, it should be remarked that the spatial and time variations are substantial and therefore such conclusions are precarious. The rapid population growth that the country has experienced during the last decades, along with the increased urbanization as well as industrialization rates puts additional pressure on these resources (UNESCO, 2006).

Lake Victoria, the second largest fresh water body in the world is partly situated in Uganda (45 %) but also shared with Kenya (6%) and Tanzania (49 %) (MWE, 2013).
The number of water monitoring stations for surface- and groundwater within Uganda amounted 157 in June 2014. With 87 recorded as functional. 27 of the non-faulty once where set to monitor groundwater and 60 for surface water. This equals in average one monitoring station per 8941 $km^2$ for groundwater and 4024 $km^2$ for surface water (MWE, 2014)

Uganda's fresh water resources are regarded as abundant, and are prospected to contribute to a socioeconomic transformation. One third of Uganda's surface area is covered by fresh water, and the storage capacity that is provided by Lake Victoria, Albert Kyoga, George and Edward is significant. The substantial network of rivers that connect these reservoirs is also contributing to this potential. Of which one, the Nile River, the longest river in Africa, that serves water to 12 countries, has its source in Lake Victoria. This is both a beneficial position in regards of geo-political aspects as well as economical leverage. The Nile also provides the country a contingence to stimulate the economic growth by utilisation of water assets. Including irrigation schemes, fishery and aquaculture, industrial development, water transport as well as tourism (NPA, 2013).

The model which this report will present, is mostly based on data from the time period of 1953-1978, as this is the most recent data set with satisfactory quality and coverage available. Although being old data, it has been recognized to be representative of the long-term climatic conditions in Uganda (MWE, 2013).

In the year of 2012, the total area equipped for irrigation amounted to 11 140 hectare, which equals 0.1217 % of the total cultivated area (FAO, 2015c). Out of the area equipped for irrigation, 94.96 % was actually irrigated. Figure 1.4. shows the occurrence of irrigated cultivated area in Uganda, where the lack of it is highly evident.

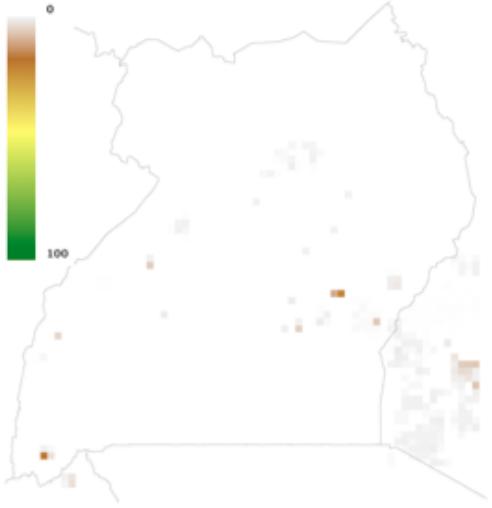



**Figure 1.4.** *Map over the of occurrence [%] of irrigated cultivated area extracted from GAEZ.*

The exact number of the irrigation potential has

not been established, but lies somewhat in the range between 186 000 to 410 000 hectares (MWE, 2013). The location of potential irrigation schemes involves mostly conversion of seasonal or permanent wetlands to cultivated land. For upland irrigation, there is a limitation of the exploitation due to lack of suitable dam sites in Uganda. The NWRA also states that developing the irrigation potential will most likely change the flows in the Nile River. From Lake Victoria it will be reduces with around 0.23 $km^3$/year and 1.0 $km^3$/year at the outlet of Lake Kyoga (MWE, 2013).

The water demand in Uganda is projected to increase rapidly due to population growth and consisting economic as well as agricultural development. A water scarcity may endanger food security as well as depress the future economy (MWE, 2013).

Only 10 % of the country, including the shores of Lake Victoria and the mountainous areas experience normally precipitation rates exceeding the potential evaporation. The remaining 90 % experience an annual deficit, ranging up to beyond 600 mm/year in parts of Rift Valley and the north-eastern part of the country (MWE, 2013).

### 1.5 Hydropower

The three major existing hydropower plants in Uganda lies along the Nile River; Kiira, Nalubaale and Bujagali. They amount to 630 MW out of the 2400 MW hydropower potential (MWE, 2013). As Lake Victoria is located at the beginning of the Nile, it serves as the principal reservoir. NWRA (2013) also identifies the limitation of the release of water from the lake in earlier years, which means that there's a great importance to ensure high water levels, else the potential hydropower may be affected. Furthermore, as the potential sites downstream the Nile River has a limited storage capacity, the existing power plants operate at a run-off-river basis.

The major factors that contributes to the inflow and outflow out of Lake Victoria are direct rainfall and evaporation. As the difference between them is generally small, the water balance is largely affected by climate change which may have an impact on the hydropower production (MWE, 2013).

### 1.6 Policies and Vision 2040

Today Uganda is seen as a primarily low-income country and the overall aim of the *Vision 2040* is to transform Uganda into a competitive upper middle-income country (NPA, 2013). In order to reinforce the growth progress of Uganda, the government in 2007 approved the Comprehensive National Development Planning Framework policy (CNCPF). It provides a 30-year Vision of development to the employed through: three 10-year plans, six 5-year National Development Plans (NDPs), Sector Investments Plans (SIPs), Local Government Development Plans (LGDPs), Annual work plans and Budgets. As of this, the National Planning Authority, along with other government institutions, has developed its new policy called *Uganda Vision 2040*. Its vision statement is *"A Transformed Ugandan Society from a Peasant to a Modern and Prosperous Country within 30 years"*. After this 30-year period starting at the baseline year of 2010, the per capita income is aimed to increase to USD 9,500 from the baseline year value of USD 506. The projections made further imply that Uganda will become a lower middle-income country by 2017 and moving towards an upper middle-income country by 2032. Hence, it will reach its goal of USD 9,500 in 2040. However, for the goal to be achieved, the GDP growth rate will have to be 8.2 % and consistent. In 2040 this

will lead to a total GDP of around USD 580.5 billion and a population of 61.2 million. The later by reducing today's populations annual growth rate of 3.03 % to 2.4 %.

Fundamental elements which the vision present that needs to be strengthen are among others; infrastructure, science, technology, engineering and innovation, land use and management, urbanisation, human resources and peace, defence and security.

### 1.6.1 Vision 2040-Agriculture

For agricultural production, the *Vision 2040* states the importance of continuing to stimulate the agriculture sector, as it will remain an important basin for growth in other sectors (NPA, 2013). Today small scale farmers, living in the rural areas, mainly dominate production.

Due to different factors, for instance limited application of technology and innovation, over dependency on rain-fed agriculture and land occupancy challenges, the productivity of the Ugandan agriculture has decreased. The *Vision 2040* emphasizes the significance of a transformation of today's subsistence farming to a market-oriented sector. The thought of this is to produce an agricultural sector which is profitable, competitive and sustainable and hence can provide food and income security. Not only shall it result in increase of employment opportunities along the entire commodity value chain (production, processing and marketing), but it will also improve Uganda's competitiveness on the world market. From a social perspective, it's been acknowledge that the effectiveness of the agricultural sector, resulting in higher and more intensive harvest, may improve the livings for low-income groups and empower other socially disadvantaged groups (e.g. women, disabled and young people).
To increase the total productivity in Uganda, some of the following commitments have been undertaken by the government in the *Vision 2040*:

- Invest in all major irrigation schemes and the development of them
- Continued investment in technology improvement which will be done by research for improved seeds, breeds and stocking materials
- Reduce the cost of fertilizer by invest in the development of the phosphate industry in Tororo
- Increase information access, knowledge and technologies to the farmers by reforming the country's extension system
- Reverse the land fragmentation to secure land for mechanization
- Improve the collection of appropriate statistics regarding the agriculture
- Improve information and its spreading of the weather
- Halt the relapse in soil fertility by more environmental control measurements
- Development and improve the human recourse in agriculture
- Develop the market access and value addition by for instance attracting private sector participants in activities and investments, improve market infrastructure etc.

### 1.6.2 Vision 2040-Water

According to the *Vision 2040* only 15 % of the potential hydropower is yet utilized (NPA, 2013). The remaining 85 % states the potential for the energy sector in the country and the vision from the government is to maximize the hydropower production by utilize all the potential hydropower in the various rivers, including hydropower plants ranging from small to large in size. Additionally the government aims to introduce mitigation measures, mainly

regarding protection of water catchments, in order to guarantee sufficient availability of water resources to produce the power, and enable the achievement of this goal.

Today, lack of sanitation and hygiene is liable for 70 % of the disease burden in the country. This is according to the *Vision 2040* expected to decrease during the vision period due to economic growth generated by revenues from the water sector. This will stimulate the labour market which will fuel the health level of the population. To address the health issues related to sanitation and hygiene, the government are henceforth aiming to construct and extend the piped water and sanitation system to cover all parts of Uganda.

According to the *Vision 2040* only 14.1 % of the IRWR (Internal Renewable Water Resources) will be utilized if a full exploitation of irrigation where to be established in Uganda. It should though be remarked that this is based on projections made by FAO from 1998. The Government aims to stimulate the agricultural sector during the vision period by developing bulk water transfer systems in order to increase the coverage for more areas within the country. The government also aims to lay foundation for development of both large and small-scale irrigation schemes in order to meet this goal.

The *Vision 2040* states that water recycling, re-use and increased efficiency are key factors for the future. Strategies regarding this will therefore be reinforced and will have to be taken into consideration in the design of future water supply systems.

### 1.7 WEAP

WEAP (Water Evaluation And Planning system) is a modelling-tool developed by SEI (Stockholm Environment Institute) for integrated planning of water resources. The software provides the user with a system for retaining water demand and resource information. It also enables the user to compare and manage different future scenarios in reference to first established base scenario (WEAP, 2012).

### 1.8 GAEZ

GAEZ refers to the Global Agro-Ecological Zones system and has been developed by the FAO in collaboration with IIASA (FAO, 2012a).
The database allows the user to quantify the crop production depending on the chosen agro-ecological context, level of input (high, intermediate and low) and management condition. Land resources are divided into the components of climate, soils and landform. These serves as the basis for the supply of water, energy, nutrients and physical support to plants.
GAEZ provides computations for different time periods, including individual historical years of 1961 to 2000, a 30-year average (average and variability results over the historical year 1961 to 1990), a baseline period (results over the mean climate data of year 1961 to 1990) as well as future time periods (2020, 2050 and 2080). The latter are based on IPCC:s emission scenarios that, may, affect future potential agricultural productivity (FAO, 2012b).

## 2. Objective

The objective with this report is to investigate and look into the synergies in between the water-, energy-, economy- and agricultural sector of Uganda and see how they depend and interrelate with one another. This will be done by performing an integrated analysis of the interrelationship between these four constituents where different potential climate change

scenarios will be evaluated, to see how these future changes may affect the sectors. The major factors that will be analysed are hydropower generation, water deficit and crop production and how they affect, and are affected by, the interlinked system.
The work will be performed with the aim to get a overview of the system, hence its aim is to work as a foundation for future studies with more detailed objective. The result may in the end work as substance for policy making in Uganda.

# 3. Methodology

The following sections presents the methodology which this study is based on. It is a quantitative study which is based on both calculations and assumptions but also existing values. WEAP is used to model the water system in Uganda and GAEZ is used both for input for WEAP, but also to analyze the agricultural production in the country.
The section starts by presenting an overview of the reference resource system; a schematic view of how water, agriculture, energy and economy are linked together.
A map over Uganda along with some basic characteristics for this study (e.g. sub-basins) is presented to give an overview of the study area.
The view of the area in WEAP is given along with an explanation of all the parameters needed as input. The following sections presents these parameters and how they have been obtained (either as existing numbers or calculations). Data from GAEZ works as input in WEAP for certain climatic parameters.
The end of the methodology describes applied future scenarios and how some of the parameters have been changed in accordance to the scenarios. GAEZ works both as an input in WEAP to recalculate some of the parameters, but also to generate other additional results.

## 3.1 Reference resource system

The Reference Resource System (Figure 3.1a) shows the two main areas; *Water* and *Agriculture & Land* and how they interact with each other as well as the other areas; *Energy* and *Economy*. The occurrence of future climate change with the main sub-categories; *Temperature & Sun and Rain* are also included with is potential affects on the system.

A simplified version of Figure 3.1a is presented below (Figure 3.1b) With only elements that direct affects Water and/or Agriculture & Land are included. The elements highlighted in this report is marked bold in the figure.

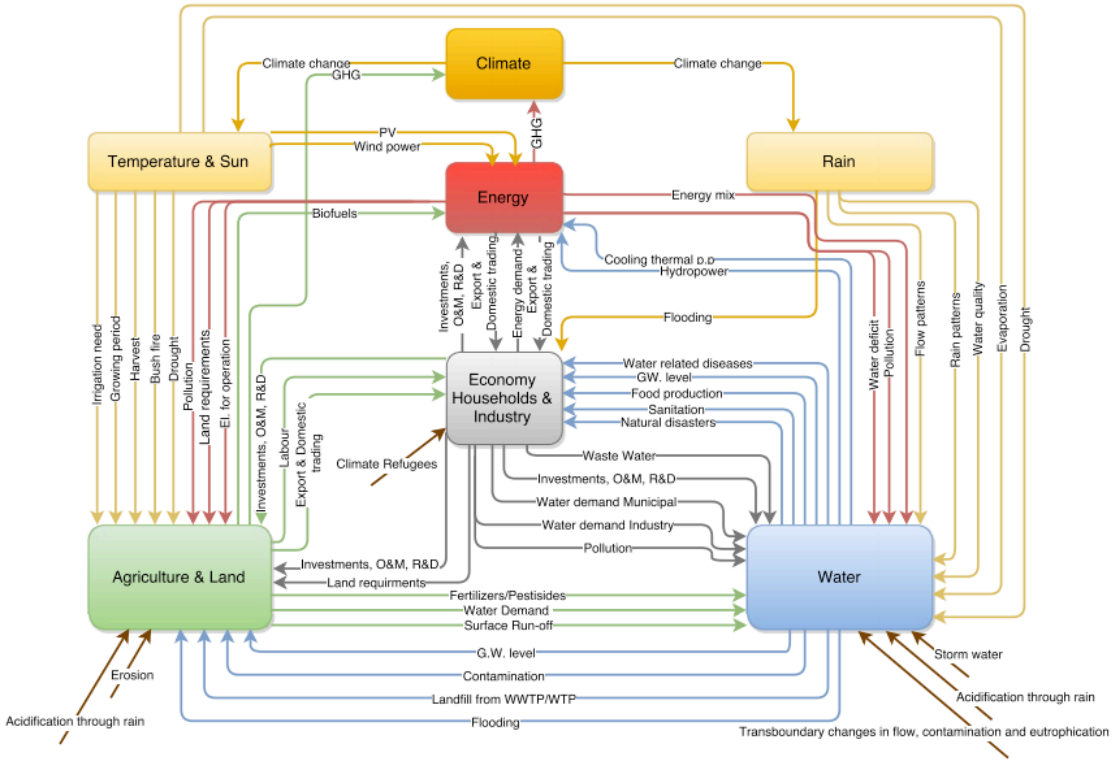



**Figure 3.1a.** *Reference Resource System*

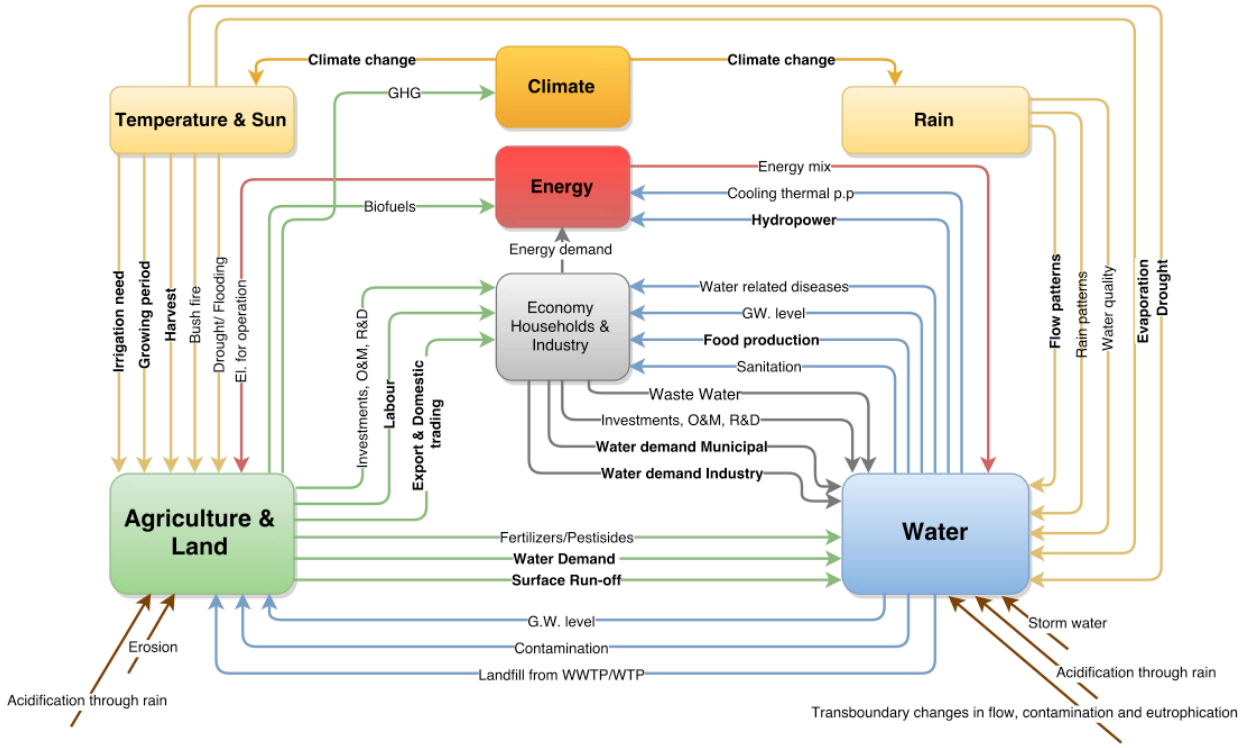



**Figure 3.1b** *Reference resource system with emphasise on the Water and Agriculture Sector; the areas highlighted in this report in bold.*

### 3.2 Area of study

To abridge the modelling in WEAP, the country is divided into eight sub-basins. They are as follows; Aswa, Kidepo, Albert Nile, Victoria Nile, Lake Kyoga, Lake Albert, Lake Edward and Lake Victoria, and are shown in Figure 3.2 (UNESCO, 2006).




**Figure 3.2.** *The eight sub-basins (UNESCO, 2006).*

The eight sub-basins contain the different source of water (MWE, 2013) listed in Table 3.2a. As there are no rivers located in the Kidepo river-basin it's assumed that it gets its water from River Pager.

**Table 3.2a.** *The eight sub-basin in Uganda (MWE, 2013)*

| Sub-basin | Lakes | Rivers |
|---|---|---|
| **Lake Victoria** | Lake Victoria | Nile River<br>River Katonga<br>River Kagera<br>Internal inflows (local inflows)<br>External inflows (international inflows) |
| **Lake Kyoga** | Lake Kyoga | Nile River<br>Internal inflows (local inflows) |
| **Victoria Nile** | - | Nile River |
| **Lake Edward** | Lake Edward<br>Lake George | Katonga<br>Semliki |
| **Lake Albert** | Lake Albert | Semliki |

| | | |
|---|---|---|
| | | Nile River |
| **Aswa** | - | Achwa |
| | | Pager |
| | | Agago |
| **Albert Nile** | - | Nile River |
| **Kidepo** | - | (Pager) |

The total area and land area (MWE, 2013) for each sub-basin is presented in Table 3.2b.

**Table 3.2b**. *The eight sub-basins and their areas (MWE, 2013).*

| Sub-basin | Total area [$km^2$] | Land area [$km^2$] |
|---|---|---|
| **Lake Victoria** | 61886 | 32924 |
| **Lake Kyoga** | 57236 | 53899 |
| **Victoria Nile** | 27961 | 27807 |
| **Lake Edward** | 18946 | 17855 |
| **Lake Albert** | 18079 | 14882 |
| **Aswa** | 27637 | 27635 |
| **Albert Nile** | 20727 | 20484 |
| **Kidepo** | 3229 | 3228 |
| **Miscellaneous** | 5716 | 5679 |

## 3.3 WEAP Model

The graphical view of the model developed in WEAP is presented in Figure 3.3. Each sub-basin has a set of nodes including:

- Demand Sites; Agriculture, Municipal and Industry (red dots)
- Catchment Sites (green dots)
- Groundwater (green squares)
- Run-of River Hydropower (blue rectangles)
- Reservoirs (blue triangles)

The nodes are connected by:

- Rivers (blue lines)
- Transmission Links (green lines)
- Runoff/infiltration (blue dotted lines)

- Diversions (orange lines)
- Return Flows (red lines)

Where Rivers are used to connect Reservoirs and Run-of River Hydropower plants. The other connections are used to interlink the remaining nodes with the rivers. Transmission Links indicates the inflow to demand sites and the Return Flow, the outflow. Runoff/infiltration are used to simulate the water from precipitation that either goes to ground water through infiltration or back to the rivers as surface run-off.
Finally one diversion is used, this is simply due to WEAP's inability to simulate two different outflows from a river. The Diversion therefore serves as a connection between the river and the reservoir.

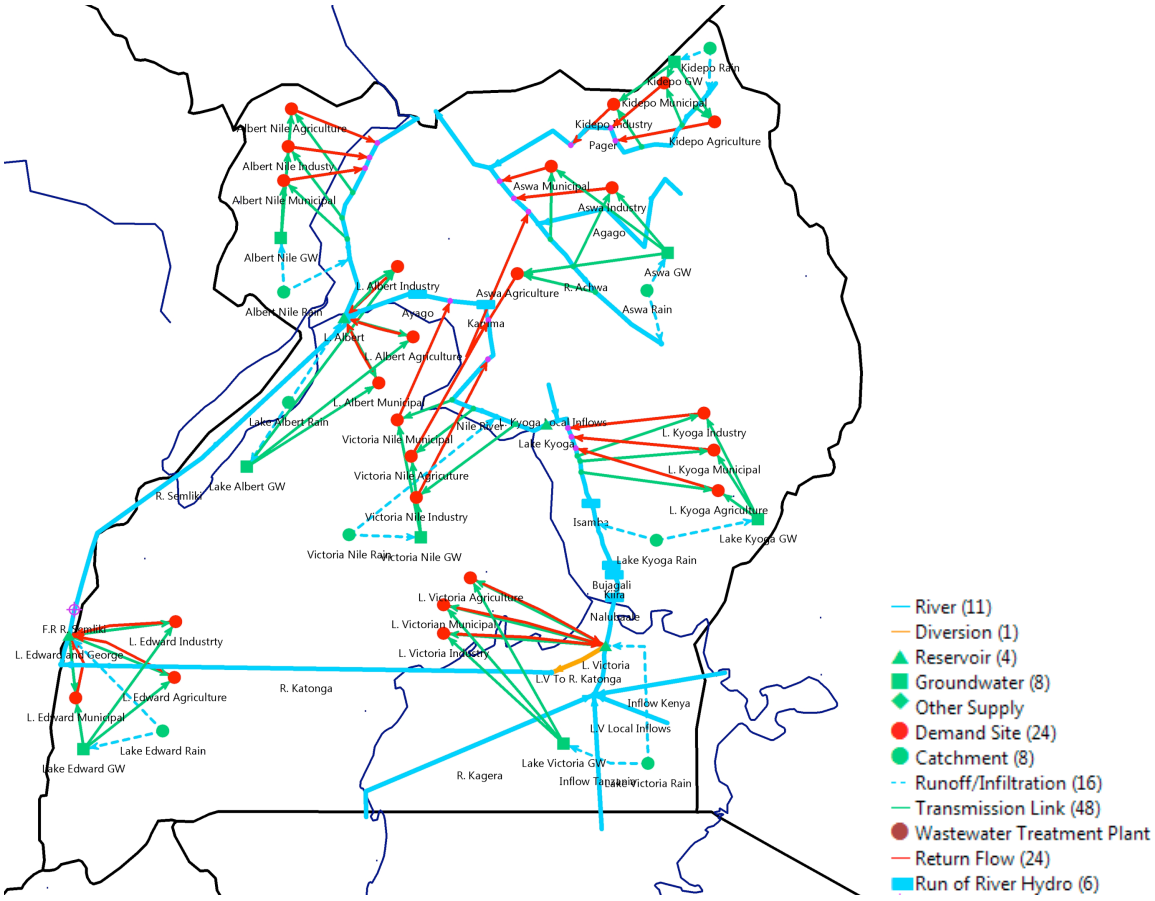



**Figure 3.3.** *Model of the water system in Uganda, generated in WEAP.*

For each of the eight river basins the major rivers and reservoirs are chosen. This in order to get a good geographical spread of the evaluated rivers, yet not exceeding the number of rivers that is considered a feasible amount as input for the model. The coherency of the data regarding stream flows is here also taken into consideration. The location of rivers and reservoirs are obtained from Google Earth on March 25th, 2015.

For the WEAP model, there are a number of parameters needed as input in order to run the model. For this study the parameters presented in Table 3.3 are used as input. The first column describes the input parameter along with its unit. The second column states in which section in this report the parameters are described in more detail, e.g. calculations made to

obtain these. The third column presents parameters that are used in order to calculate the input parameters. For instance, in order to calculate the net evaporation, the precipitation and evaporation is used. The fourth column shows in which section each of these parameters are being described.

***Table 3.3.*** *Description of parameters used as input in WEAP.*

| **Input in WEAP** | **Section** | ***Calculations based on*** | ***Section*** |
|---|---|---|---|
| Catchment area [$km^2$] | 3.2 | - | |
| Demography [capita] | 3.4 | *Land area [$km^2$]* | *3.2* |
| | | *Population density [capita/$km^2$]* | *3.4* |
| Precipitation [mm] | 3.5 | - | |
| Net evaporation [$m^3/s$] | 3.6 | *Precipitation [mm]* | *3.5* |
| | | *Evaporation [$m^3/s$]* | *3.6* |
| Municipal water demand [$m^3$/capita] | 3.7 | *Demography [capita]* | *3.4* |
| Industry water demand [$m^3$/capita] | 3.7 | *Demography [capita]* | *3.4* |
| Agriculture water demand [$m^3$/capita] | 3.7 | *Demography [capita]* | *3.4* |
| Water consumption [%] | 3.7 | - | |
| Water head [m] | 3.8 | - | |
| Plant factor [%] | 3.8 | - | |
| Maximum Turbine Flow [CMS] | 3.8 | - | |
| Generating efficiency [%] | 3.8 | - | |
| Annual demand [PJ] | 3.8 | *OSeMOSYS* | |
| Initial volume [MCM] | 3.9 | - | |
| Storage capacity [MCM] | 3.9 | *Initial volume [MCM]* | *3.9* |
| Observed volume [billion $m^3$] | 3.9 | *Initial volume [MCM]* | *3.9* |
| | | *Storage balance [MCM]* | *3.9* |
| River flows [$m^3/s$] | 3.10 | - | |
| Groundwater recharge [MCM] | 3.11 | *Precipitation [mm]* | *3.5* |
| Maximum groundwater withdrawal [MCM] | 3.11 | - | |
| Run-off fraction [%] | 3.12 | *Groundwater recharge [MCM]* | *3.11* |
| | | *Precipitation [mm]* | *3.5* |
| | | *Effective precipitation [mm]* | *3.13* |

| | | | |
|---|---|---|---|
| Crop coefficient | 3.13 | - | |
| Effective precipitation | 3.13 | *Run-off coefficient* | *3.13* |
| | | *Groundwater recharge [%]* | *3.11* |
| Reference evapotranspiration [mm] | 3.13 | - | |

## 3.4 Demography

The population of each sub-basin is calculated by using a density map obtained from the Ugandan National Water Ministry Water Atlas (MWE, 2012). From here, a mean value of the population density for each sub-basin is calculated. This was done visually; hence it's a rough estimation. The population for each of the eight sub-basins is thereafter calculated by multiplying the density with the land area for each sub-basin, see section 3.2, these values are presented in Table 3.4.

The total calculated population of the 8 sub-basins amounts to 38 877 996 people. However, the total population in Uganda today is 37 579 000 people (FAO, 2015c). Hence the population of each river basin is adjusted accordingly to the ratio between this real value and the total value calculated. The adjusted population of each river basin, which is used in the model, is presented in Table 3.4 in the column *"adjusted population"*.

**Table 3.4.** *Density and population, calculated and adjusted, for each sub-basin (FAO, 2015c).*

| Sub-basin | Land area ($km^2$) | Density ($cap/km^2$) | Population | Adjusted Population |
|---|---|---|---|---|
| **Lake Victoria** | 32924 | 262.25 | 8634319 | 8400006 |
| **Lake Kyoga** | 53899 | 182.5 | 9836568 | 9569628 |
| **Victoria Nile** | 27807 | 190 | 5283330 | 5139954 |
| **Lake Edward** | 17855 | 305 | 5445775 | 5297991 |
| **Lake Albert** | 14882 | 190 | 2827580 | 2750847 |
| **Aswa** | 27635 | 117.5 | 3247113 | 3158994 |
| **Albert Nile** | 20484 | 155 | 3175020 | 3088858 |
| **Kidepo** | 3228 | 55 | 177540 | 172722 |

## 3.5 Precipitation

In order to obtain the precipitation throughout the country, a map for year 2000 is extracted from GAEZ, see figure 3.5a.

When using GAEZ online, one may get specific values for each point at the map by simply clicking on the map. E.g.. One point gives the precipitation for that specific point in the country.
As the precipitation for each sub-basin is required, a certain amount of values for each sub-

basin is extracted from the map and then a mean value is calculated. The number of points is in relation to the sub-basin's area; 1 point for each 1000 $km^2$. For instance, for Kidepo with an area of 3229 $km^2$ (Table 3.2b), three points are used. From these points, a mean value for each sub-basin may be calculated.

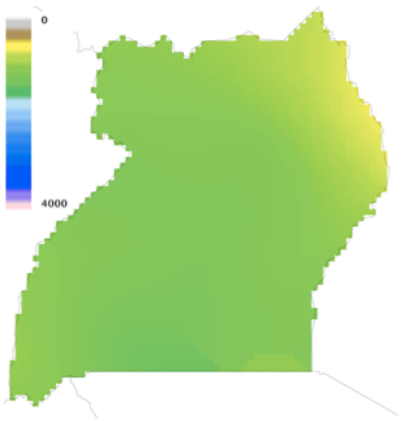



**Figure 3.5a.** *Map over the annual precipitation for year 2000 extracted from GAEZ.*

Using these mean values and calculating the total annual average for the country, this number differs from the 1180 mm that FAO (FAO, 2015c) has measured for year 2014. To meet this value, the ones calculated here are adjusted with the ratio between the official annual average and the calculated annual average. Then each value for the sub-basins are multiplied with this ratio to get the adjusted values, see Table 7a in Appendix.
In order to get the monthly variation, statistics from the World Bank (World Bank, 2015b) over the mean variation over the year was used, see Figure 3.5b. One should however note that this is a mean variation for the country, hence the same yearly variation will be assumed over the whole country. The calculated precipitation for each sub-basin is presented in Table 3.5.

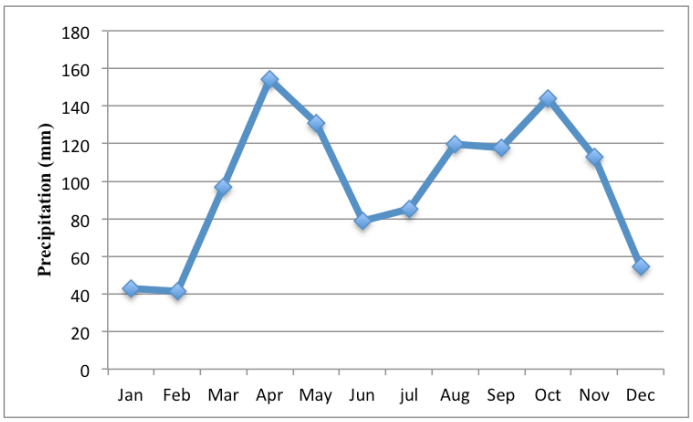



**Figure 3.5b.** *The monthly variation in precipitation (mm) (World Bank, 2015b).*

**Table 3.5.** *The calculated precipitation (mm) for different months for each sub-basin.*

| Sub-basin | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lake Victoria** | 49 | 48 | 112 | 177 | 150 | 91 | 98 | 138 | 136 | 165 | 130 | 63 | 1356 |
| **Lake Kyoga** | 40 | 39 | 91 | 144 | 122 | 74 | 80 | 112 | 110 | 134 | 106 | 51 | 1102 |
| **Victoria Nile** | 46 | 45 | 105 | 167 | 142 | 85 | 92 | 130 | 128 | 156 | 122 | 59 | 1277 |
| **Lake Edward** | 44 | 43 | 100 | 159 | 135 | 81 | 88 | 123 | 122 | 148 | 117 | 56 | 1218 |
| **Lake Albert** | 47 | 45 | 106 | 168 | 142 | 86 | 93 | 130 | 128 | 157 | 123 | 59 | 1284 |
| **Aswa** | 40 | 39 | 91 | 145 | 123 | 74 | 80 | 113 | 111 | 135 | 106 | 51 | 1110 |
| **Albert Nile** | 43 | 42 | 98 | 156 | 133 | 80 | 86 | 121 | 119 | 146 | 115 | 55 | 1194 |
| **Kidepo** | 33 | 31 | 74 | 117 | 100 | 60 | 65 | 91 | 90 | 110 | 86 | 42 | 899 |

## 3.6 Evaporation

Net evaporation for the reservoirs; Lake Victoria, Kyago, Albert, Edward and George are obtained by subtracting the precipitation over the lakes, Table 7b in Appendix, from the evaporation from the lakes, Table 7c in Appendix, (MWE, 2013). The monthly values for Lake Victoria is obtained (due to visual measurement) from a graph in NWRA. As the calculated mean value from these 12 monthly values don't coincide with the given mean value from the same source, the monthly values is therefore adjusted in accordance to the ratio between the given and calculated mean value. The monthly values are presented in Table 3.6.

**Table 3.6.** *Net Evaporation ($m^3/s$) (MWE, 2013).*

| Reservoirs (lakes) | Mean | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lake Victoria (adjusted)** | -374 | 464 | -214 | -1271 | -4226 | -1786 | 1095 | 1732 | 1543 | 1456 | -13 | -1775 | -1488 |
| **Lake Edward/ George** | 84 | 138 | 117 | 81 | 35 | 72 | 108 | 101 | 67 | 72 | 61 | 40 | 108 |
| **Lake Albert** | 250 | 382 | 368 | 291 | 115 | 200 | 281 | 212 | 207 | 237 | 183 | 180 | 346 |
| **Lake Kyoga** | 34 | 165 | 132 | 82 | -29 | -69 | 14 | -3 | -42 | -18 | 1 | 44 | 131 |

## 3.7 Demand sites

The total water demand for the whole population for each of the municipal, industry and agriculture area is obtained from the NWRA (MWE, 2013). The municipal demand is taken as the sum of urban and rural demand. The agriculture demand include both crop irrigation and livestock. The yearly per capita demand for year 2009, which is used as input in WEAP for year 2014 (assuming the same demand), is then calculated by dividing the demand by the adjusted population, see Table 3.4. These values are presented in Table 3.7.

**Table 3.7.** *The water demand ($m^3$/capita) for the different demand sites and sub-basins (MWE, 2013).*

| Sub-Basin | Municipal [$m^3$/cap] | Industry [$m^3$/cap] | Agriculture [$m^3$/cap] |
|---|---|---|---|
| **Lake Victoria** | 8.7 | 3.4 | 6.3 |
| **Lake Kyoga** | 3.1 | 0.1 | 9.1 |
| **Victoria Nile** | 1.9 | 0.2 | 4.5 |
| **Lake Edward** | 2.7 | 0.2 | 3.8 |
| **Lake Albert** | 2.2 | 0.1 | 4.5 |
| **Aswa** | 1.6 | 0.0 | 4.5 |
| **Albert Nile** | 2.7 | 0.1 | 5.1 |
| **Kidepo** | 1.7 | 0.0 | 15.1 |

The consumption is defined as the consumptive losses for the demand sites, i.e. water lost to evaporation. For the municipal and industrial demand sites it is chosen to 12.5 % and for Agriculture 71.2 % accordingly to estimation done by UNEP (UNEP, 2008).

## 3.8 Hydropower

The first parameter needed as input in WEAP for hydropower is the maximum turbine flow. For Bujagali this is obtained from the Clean Development Mechanism (CDM, 2013). As no reliable source is available for the maximum turbine flow for Kiira and Nalubaale, it will in this study be assumed that they have the same value as Bujagali.

The water head for Bujagali is obtained from Alstom which were a part of the construction of the hydro power plant (Alstrom, 2013). For Nalubaale and Kiira, there is a lack of reliable source for this parameter and the values used are from a presentation given by Nobert Matarutsi at the African Utility Week in Durban 2010 (Matarutse, N., 2010). However, as these values are likely realistic in their magnitude (when comparing with the value for Bujagali) they are used in the model.

Plant factor describes the portion of time during which the power plant is active. The Final Master Plan Report done by EAPP and EAC (EAC et al, 2011) gives the plant factor for each power plant.

The generating efficiency is defined as the electricity generated divided by the hydropower input. This is usually a generic value depending on power plant and for this study the value for a large scale hydropower is used, assuming all three hydro power plants are of large scale (Eurelectric, 2003).

Energy demand for year 2014 is here assumed to be the energy produced from each power plant, these values are obtained from OSeMOSYS.

All of these values for each hydropower plant are presented in Table 3.8.

**Table 3.8.** *Input data in WEAP for current hydro power plants (CDM, 2013; EAC et al, 2011; Eurelectric, 2003; Matarutse, N., 2010).*

| | Water Head (h) [m] | Plant Factor | Maximum Turbine Flow [CMS] | Generating Efficiency | Annual Demand [PJ] |
|---|---|---|---|---|---|
| **Nalubaale** | 18.9 | 0.49 | 1375 | 0.95 | 2.18 |
| **Kiira** | 20.8 | 0.43 | 1375 | 0.95 | 2.43 |
| **Bujagali** | 23 | 0.9 | 1375 | 0.95 | 5.05 |

## 3.9 Reservoir data

The reservoirs in the model includes Lake Victoria, Lake Edward, Lake George, Lake Albert and Lake Kyoga. However, Lake Edward and Lake George are added to work as one reservoirs as most data is given for them both together.

When starting to run the model, it is assumed that that the initial volume for the reservoirs equals the reservoirs volume, where the values are collected from NWRA (MWE, 2013). Furthermore, it is assumed that the storage capacity is ten times the volume of the reservoirs. This assumption is made without any source, but merely in order to ensure that the reservoirs do not get filled when running the model.

Storage capacity and initial storage is assumed to be constant throughout the whole year, as no data of yearly variation is available. These values are presented in Table 3.9a.

Observed volume is assumed to be the initial storage plus the storage balance (which may be negative). The storage balance is as well given by the NWRA. The observed volume for each reservoir is given in monthly values and yearly mean values in Table 3.9b.

**Table 3.9a.** *Storage capacity and initial storage (MCM) for the reservoirs (MWE, 2013).*

| Reservoirs (Lakes) | Storage Capacity [MCM] | Initial Storage [MCM] |
|---|---|---|
| **Lake Victoria** | 27 000 000 | 2 700 000 |
| **Lake Edward/George** | 787 000 | 78 700 |
| **Lake Albert** | 1 400 000 | 140 000 |
| **Lake Kyoga** | 160 000 | 16 000 |

**Table 3.9b**. *Monthly and mean values of the observed volume (b*illion $m^3$*) in the reservoirs (MWE, 2013).*

| Reservoir [$10^9$ $m^3$] | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lake Victoria** | 2699 | 2700 | 2702 | 2708 | 2704 | 2697 | 2696 | 2697 | 2697 | 2699 | 2703 | 2703 |
| **Lake Edward/ George** | 78.4 | 78.5 | 78.7 | 79.0 | 78.9 | 78.6 | 78.6 | 78.6 | 78.7 | 78.9 | 79.0 | 78.7 |
| **Lake Albert** | 139.4 | 139.3 | 139.6 | 140.2 | 140.3 | 140.2 | 140.4 | 140.4 | 140.3 | 140.4 | 140.3 | 139.7 |
| **Lake Kyoga** | 15.7 | 15.8 | 156.0 | 16.3 | 16.7 | 16.3 | 16.0 | 16.0 | 15.90 | 15.9 | 15.9 | 15.8 |

Loss to groundwater from the reservoirs is assumed to be included in the groundwater recharge, see section 3.11. This is due to the lack of sufficient data.

## 3.10 River data

Flows for the major rivers are collected from NWRA (MWE, 2013). Some values are given with their monthly variation, whereas some are only presented with their mean values.

For river Katonga, the monthly variation is calculated by using the same variation as local inflow to Lake Edward/George. The fraction for each month in the local inflow river (monthly divided by annual total) is then multiplied with the original value for the river flow in Katonga in order to get the monthly variation.

For inflows to Lake Victoria the same applies, but the NWRA presents the total monthly variation for all inflows to Lake Victoria. The same variation is assumed to be applied for all inflows to the lake (Kagera, inflow from Kenya and inflow from Tanzania).

For river Aswa, Pager and Agago it's more complexed as they have no nearby rivers and the error may be too big if using for instance the variation of Nile River. Therefore these rivers are assumed to have a constant flow for each month.

As this model is a simplified one, it is assumed that the only outflow from Lake Edward/George is River Semliki and its only inflow is River Katonga.

Local inflow indicates flows from rivers which are not drawn as separate rivers in the WEAP model. However, these have to be taken into consideration, to get the mass balance right. Therefore these are added as one single river, with the flow corresponding to the sum of the inflowing rivers that have not yet been included in the model.

The data for all the rivers and certain reaches (definition: a section of a river) are presented in Table 3.10. Rivers denoted with one asterix are rivers which have their monthly variation calculated based on a nearby river. Rivers denoted with two asterix are rivers which have no data regarding monthly variation, and hence they have the same value each month.
Note that neither Kidepo or Victoria Nile are included. For Kidepo this is simply because

there are no rivers in its basin, however for the model it is assumed that the water withdrawal is from river Pager. For Victoria Nile it is not necessary to have any input as the model itself ensure the water to flow through this basin via Nile River.
The other basins are stated in order to know in what parts of the rivers the values are being input.

If the same river is mentioned more than one time it is because the values differ along the river. This is generally always the case, however once again this is a simplified model so this variation is only taken into consideration for certain rivers and reaches.

**Table 3.10.** *Flows ($m^3/s$) in the different rivers and reaches (MWE, 2013).*

| Sub-basin | River | *Note* | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Aswa* | | | | | | | | | | | | | | |
| | Pager** | | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 |
| | Aswa(1)** | *Between Agago & Pager* | 48.6 | 48.6 | 48.6 | 48.6 | 48.6 | 48.6 | 48.6 | 48.6 | 48.6 | 48.6 | 48.6 | 48.6 |
| | Agago** | | 5.1 | 5.1 | 5.1 | 5.1 | 5,1 | 51 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 |
| | Aswa(2)** | *Before Agago inflow* | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 |
| *Albert Nile* | | | | | | | | | | | | | | |
| | Albert Nile | | 1194 | 1152 | 1122 | 1117 | 1135 | 1132 | 1126 | 1135 | 1181 | 1220 | 1260 | 1249 |
| *Lake Albert* | | | | | | | | | | | | | | |
| | Albert Nile | *Outflow L Albert* | 1194 | 1152 | 1122 | 1117 | 1135 | 1132 | 1126 | 1135 | 1181 | 1220 | 1260 | 1249 |
| | Semliki | *Inflow L. Albert* | 149 | 135 | 138 | 157 | 171 | 154 | 155 | 160 | 165 | 172 | 185 | 170 |
| *Lake Edward/ Geroge* | | | | | | | | | | | | | | |
| | Semliki | *Outflow from L. Edward* | 127 | 113 | 113 | 123 | 130 | 124 | 132 | 135 | 134 | 135 | 144 | 139 |
| *Lake Kyoga* | | | | | | | | | | | | | | |
| | Nile River | *Outflow L. Kyoga* | 1054 | 1018 | 999 | 1016 | 1100 | 1168 | 1190 | 1189 | 1179 | 1159 | 1141 | 1125 |
| | Local Inflows | | 68 | 34 | 25 | 41 | 162 | 121 | 58 | 44 | 66 | 76 | 137 | 146 |
| *Lake Victoria* | | | | | | | | | | | | | | |
| | Katonga* | *Outflow L. Victoria* | 3 | 3 | 4 | 5 | 6 | 4 | 3 | 3 | 5 | 6 | 7 | 5 |
| | Nile River* | *Outflow L. Victoria* | 1039 | 1031 | 1036 | 1065 | 1142 | 1182 | 1142 | 1088 | 1056 | 1025 | 1011 | 1039 |
| | Kagera * | *Inflow L. Victoria* | 200 | 167 | 234 | 334 | 401 | 234 | 167 | 200 | 200 | 167 | 267 | 401 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inflow Kenya* | 236 | 196 | 275 | 393 | 471 | 275 | 196 | 236 | 236 | 196 | 314 | 471 |
| | Inflow Tanzania* | 174 | 145 | 203 | 290 | 348 | 203 | 145 | 174 | 174 | 145 | 232 | 348 |
| | Local inflows* | 27.6 | 23.0 | 32.2 | 46.0 | 55.2 | 32.2 | 23.0 | 27.6 | 27.6 | 23.0 | 36.8 | 55.2 |

** Monthly variation based on nearby river*
*** No data regarding monthly variation*

## 3.11 Groundwater

Assessments of the groundwater in Uganda have been poor during recent years, which has resulted in inadequate data and resources (UNESCO, 2006). It has been estimated that the groundwater recharge in Uganda ranges between 7-20 % of the precipitation (UNESCO, 2006). For this study, the groundwater recharge is chosen to be 10 %. A lower value is chosen partly since that the saturation of the ground is not taken into consideration. Meaning that if a higher value is chosen it might be possible that for some areas, this amount of water might not be able to infiltrate due to saturated ground. Also, the area for which the recharge is calculated for, includes both land area as well as water area. The values obtained for precipitation in section 3.5 are adjusted with a factor of 0.1 in order to obtain the groundwater recharge. These values are presented in table 3.11a.

**Table 3.11a.** *Monthly ground water recharge for each sub-basin (MCM) (MWE, 2013).*

| River Basin | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lake Victoria** | 305 | 294 | 690 | 1097 | 931 | 562 | 607 | 851 | 839 | 1023 | 805 | 389 |
| **Lake Kyoga** | 229 | 221 | 519 | 824 | 700 | 422 | 456 | 640 | 630 | 769 | 605 | 292 |
| **Victoria Nile** | 130 | 125 | 294 | 467 | 396 | 239 | 258 | 362 | 357 | 435 | 342 | 165 |
| **Lake Edward** | 84 | 81 | 190 | 301 | 256 | 154 | 167 | 234 | 231 | 281 | 221 | 107 |
| **Lake Albert** | 84 | 81 | 191 | 303 | 258 | 155 | 168 | 235 | 232 | 283 | 223 | 108 |
| **Aswa** | 112 | 107 | 252 | 401 | 341 | 205 | 222 | 311 | 307 | 374 | 294 | 142 |
| **Albert Nile** | 90 | 87 | 204 | 323 | 275 | 166 | 179 | 251 | 247 | 302 | 237 | 115 |
| **Kidepo** | 11 | 10 | 24 | 38 | 32 | 19 | 21 | 29 | 29 | 35 | 28 | 13 |

The maximum withdrawal is assumed to be equal to the sustainable groundwater withdrawal, presented in table 3.11b, i.e. the proportion of the ground water recharge that can be exploited on a sustainable basis without unacceptable consequences (MWE, 2013).

**Table 3.11b.** *The Sustainable ground water withdrawal, yearly mean values for each sub-basin (MCM) (MWE, 2013).*

| Sub-Basin | Max withdrawal [MCM] |
|---|---|
| **Lake Victoria** | 813 |
| **Lake Kyoga** | 1946 |
| **Victoria Nile** | 1110 |
| **Lake Edward** | 362 |
| **Lake Albert** | 353 |
| **Aswa** | 478 |
| **Albert Nile** | 500 |
| **Kidepo** | 20 |

## 3.12 Runoff and infiltration

The parameter needed in WEAP for runoff and groundwater (GW) infiltration is the run-off fraction ($R_{frac}$). In reality the precipitation either goes to groundwater recharge, evapotranspiration (ET) or surface run-off. The latter is modelled to flow directly into the nearby rivers. In WEAP this is performed in two steps; first by calculating the evapotranspiration and then from the remainder the fraction going to GW infiltration ($GW_{inf.frac}$) and run-off. Hence, the percentage of the remainder that goes go groundwater has to be calculated. This is done by taking the ratio:

$$\text{(I)} \qquad GW_{inf.frac} = \frac{P \cdot 0.1}{P - ET}$$

As stated under groundwater, 10 % of the precipitation goes to groundwater recharge ($GW_{Re}$). The evapotranspiration can be calculated by multiplying the precipitation with the effective precipitation (see section 3.13). Therefore the following expressions can be used as input in WEAP:

$$\text{(II)} \qquad GW_{inf.frac} = \frac{GW_{Re}}{P(1 - P_{eff})}$$

The run-off fraction is then given by:

$$\text{(III)} \qquad R_{frac} = 100 - GW_{inf.frac}$$

## 3.13 Catchments

Input needed in WEAP for the catchment areas includes; catchment area, crop coefficient ($K_c$), effective precipitation and reference evapotranspiration.

Catchments areas are taken as the total area of each sub-basin, including both land area and rivers and lakes, see table 3.2b in section 3.2.

As the farming system is widely spread over the country (MWE, 2013) the crop coefficient is calculated as a national mean value, meaning that no account is taken to the variation of cropping throughout the country.
The crops are chosen accordingly to UBOS (Ugandan Bureau of Statistic, 2014) and the Ugandan government (NPA, 2013) statement of the country's major crops. These are listed in column one in Table 7d in Appendix. Sugarcane has also been added as a major crop. The second column shows a calculated mean value of the yearly crop coefficient for each crop, as it differs from the different stages of the growth (FAO, 2015a). From here, the national mean value of 0.87 is obtained and used as an input in WEAP.

Effective precipitation in WEAP is defined as the percentage of precipitation available for evapotranspiration, the remainder goes to runoff or groundwater recharge. For this parameter, the following relationship is assumed:

$$P_{eff} = 1 - (R_C + GW_{Re}) \quad \text{(IV)}$$

The runoff coefficient ($R_C$) is obtained from NWRA (MWE, 2013) and the groundwater recharge is defined as 10 % in section 3.11.
Since no data is available for Kidepo, it is here assumed to have the same value as the nearby river basin Aswa.

The reference evapotranspiration is also obtained from NWRA. These are given as mean values hence no monthly variation is assumed.

Table 3.13 present the crop coefficient (which is constant), effective precipitation and reference evapotranspiration ($ET_{ref}$) for each sub-basin.

**Table 3.13.** *Crop coefficient and effective precipitation for each sub-basin. (FAO, 2015; MWE, 2013).*

| Sub-basin | $K_c$ | $P_{eff}$ | $ET_{ref}$ [mm] |
|---|---|---|---|
| **Lake Victoria** | 0.87 | 0.86 | 1391 |
| **Lake Kyoga** | 0.87 | 0.86 | 1680 |
| **Victoria Nile** | 0.87 | 0.86 | 1560 |
| **Lake Edward** | 0.87 | 0.68 | 1277 |
| **Lake Albert** | 0.87 | 0.74 | 1455 |
| **Aswa** | 0.87 | 0.85 | 1720 |
| **Albert Nile** | 0.87 | 0.88 | 1530 |
| **Kidepo** | 0.87 | 0.85 | 1745 |

## 3.14 Scenarios

To evaluate how the occurrence of future climate changes may affect the system, the following scenarios are being evaluated; one reference scenario (A0) and three climate

scenarios (A1, A2 and A3) with different input levels see section 3.14.4 below. The major difference lies in the change of precipitation, which is based on the available IPCC scenarios in GAEZ.
One may chose different input levels in GAEZ; low, intermediate or high (see section 3.14.4 below). For A0, low input is assumed due to today's low level farming as discussed in section 1.2. For A1 low input is chosen and for A2 and A3 both low and high input are evaluated. How the parameters are changed and calculated are described in the following sections. The parameters not mentioned in the following sections are assumed to be the same as the current account year.

A summary of all scenarios is presented in Table 3.14.

**Table 3.14.** *The different scenarios used and their explanation and time period.*

| Scenario | Explanation | IPCC scenario in GAEZ | Input level | Time period climate data | Water Demand | Food Security | Hydropower | Population growth rate |
|---|---|---|---|---|---|---|---|---|
| **A0L** | Reference scenario | - | Low | 2014 | As current account year | Not included | Current and future HPP | 3.03 % |
| **A1L** | Historic scenario | - | Low | 1961-1990 | As current account year | 2700 kcal /capita,day for 2040 20 % meat | Current and future HPP | 3.03 % |
| **A2L** | Low increase of P and low input | CCCma CGCM2 A2 | Low | 2015-2040 | Linear increase between 2014 to 2040 | 2700 kcal /capita,day for 2040 20 % meat | Current and future HPP | 3.03 % |
| **A2H** | Low increase of P and high input | CCCma CGCM2 A2 | High | 2015-2040 | Linear increase between 2014 to 2040 | 2700 kcal /capita,day for 2040 20 % meat | Current and future HPP | 3.03 % |
| **A3L** | High increase of P and low input | CSIRO Mk2 B1 | Low | 2015-2040 | Linear increase between 2014 to 2040 | 2700 kcal /capita,day for 2040 20 % meat | Current and future HPP | 3.03 % |
| **A3H** | High increase of P and High input | CSIRO Mk2 B1 | High | 2015-2040 | Linear increase between 2014 to 2040 | 2700 kcal /capita,day for 2040 20 % meat | Current and future HPP included | 3.03 % |

### 3.14.1 Population growth rate

According to UBOS (Ugandan Bureau of Statistics, 2014) the population growth rate for Uganda has been estimated to 3.03 % between 2002 and 2014. The same percentage is used in order to obtain the population for each year, starting from today's population calculated in section 3.4 to year 2040.

### 3.14.2 Precipitation

Three different climate scenarios are evaluated using existing historic data (1969-1990) and the IPCC climatic data available in GAEZ. The two IPCC climatic scenario projections are CCCma CGCM2 A2 and CSIRO Mk2 B1. For these three scenarios, the precipitation is extracted from GAEZ; for the historic time period and year 2050 for the two IPCC scenarios, see Figure 3.14.2.

The mean annual precipitation for the historic, CCCma CHCM2 A2 and CSIRO Mk2 B1 scenarios are 1329 mm, 1284 mm and 1422 mm respectively. For the historic time period it is assumed that this precipitation is valid for year 2040 as well. However, in order to obtain the values for the IPCC scenarios for year 2040, a rough estimation of a linear increase is assumed between 2040 and 2050, linear interpolation is therefore used to calculate the value for year 2040. For the CCCma CHCM2 A2 scenario the interpolated value is 1291.5 mm and 1406.5 mm for CSIRO Mk2 B1.

The precipitation for each month and sub-basin is calculated by taking the ratio between the annual precipitation values obtained from GAEZ for current account (Section 3.5) and the interpolated mean value for 2040. This ratio is then multiplied with the adjusted precipitation for each sub-basin, Table 7e in Appendix, and the monthly fraction for that particular month, obtained from the World Bank, see Figure 3.5b. Hence the same variation is assumed in the future.
Finally the annual mean change in rainfall is calculated from these values in reference to the precipitation for current account. The following equation is used to calculated the annual change:

$$\text{(V)} \quad Precipitation_{2040} = Precipitation_{2014} \cdot k^t$$

Where k is the annual change and t is the time in years between 2014 and 2040. Solving for k for each sub-basin and scenario gives the input needed. These are also used to calculate a starting value for year 2015, which also serves as an input in WEAP in order for the model to run the linear interpolation up to year 2040.
The annual change in percentage as well as the starting value for 2015 is then used as input in WEAP, Table 7k in Appendix presents these along with the values for year 2040.

There are predications (MWE, 2013), which says that the rain patterns will change in the sense that there will be more intense rainfall in December to February and less in June to August. However, due to lack of data regarding how much this change amounts to, this is out of the scope of this report.

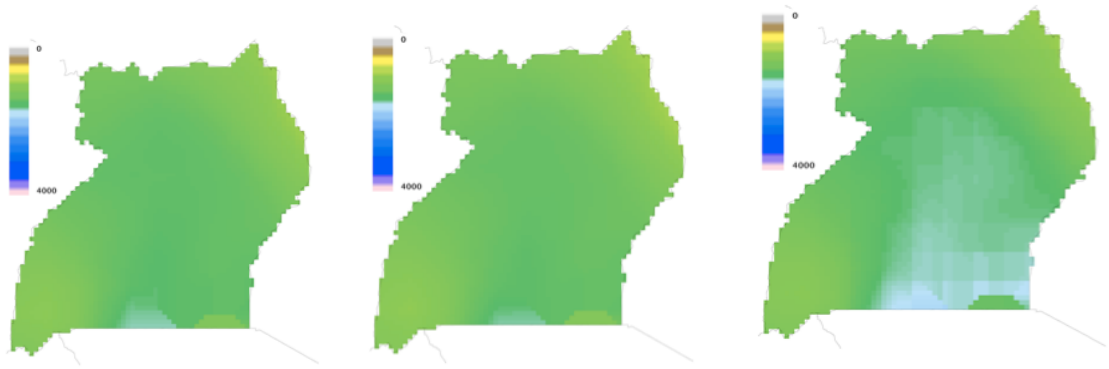



**Figure 3.14.2.** *Annual precipitation for the different scenarios extracted from GAEZ. From the left: historic time period (scenario A1), IPCC's climate scenario CCCma CHCM2 A2 (scenario A2) and IPCC's climate scenario CSIRO Mk2 B1 (scenario A3), extracted from GAEZ (mm).*

### 3.14.3 Evaporation & Evapotranspiration

It is valid to think that the temperature will come to change in the future as well. In this study this change will be included in the change of evapotranspiration. From GAEZ, one may obtain the reference evapotranspiration, see Figure 3.14.3. Once again it is assumed that the change is linear from today to 2040, and linear interpolation is used to get the annual percental change for the two IPCC scenarios. For historic time period the obtained value is assumed to apply for 2040 as well.

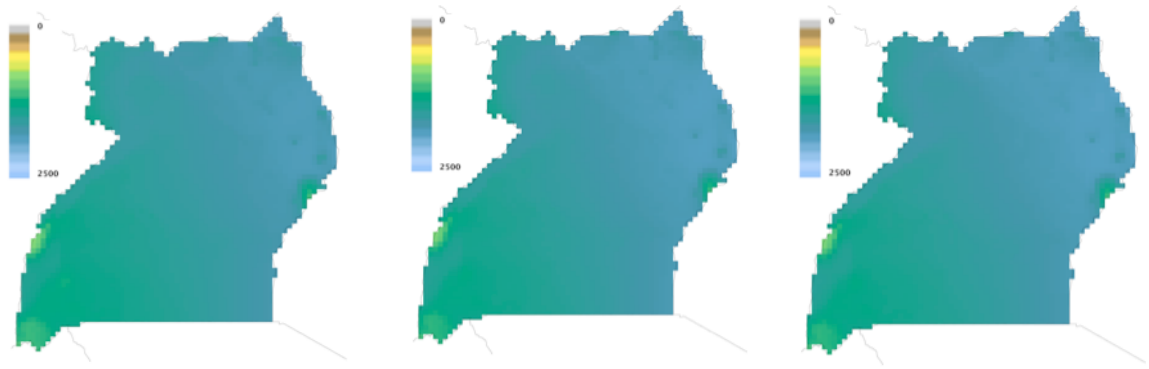



**Figure 3.14.3.** *Reference evapotranspiration extracted from GAEZ; from the left: historic period (scenario A1), CCCma CHCM2 A2 (scenario A2) and CSIRO Mk2 B1 (scenario A3), extracted from GAEZ. (mm)*

Table 7b in Appendix present the reference evapotranspiration for each scenario for 2015 and 2040 as well as the percental annual change. The latter one is used together with the starting value of year 2015, as input in WEAP to get the values for each year in between 2015 and 2040. As GAEZ only provides a national mean value, the same variation for each sub-basin as year 2014 is assumed to apply for the future as well.

It is assumed that the affects on the evaporation coincides with the affects on the reference evapotranspiration, therefore the percental change of the reference evapotranspiration from 2014 until 2040 is applied on the evaporation. The change is assumed to be equal for all sub-basins. The reference evapotranspiration is obtained for 2050 in GAEZ, linearity is assumed, whereas the 2040 value is obtained by linear interpolation. To finally calculate the 2040 value for the net evaporation for each sub-basin, the precipitation for 2040 (Appendix, Table 7e) and the evaporation (Appendix Table 7f) for the same year is used. A linear increase from 2014 until 2040 is then assumed, and a starting value for 2015 along with an annual increase is calculated and later used in WEAP as input, the table 7g in Appendix.

### 3.14.4 Input level

As mentioned earlier it's possible to choose the input level in GAEZ. The input level refers to the amount of fertilizers used, type of farming system, level of mechanization etc.
Hence low level means low/no fertilizer use, labour intensive techniques, low level management and largely subsistence based. High level on the other hand is the high use of fertilizers, fully mechanized, high-level management and to a great extent market oriented.

### 3.14.5 Municipal and Industry demand

For the municipal and industry demand, the estimations of NWRA for year 2030 is used. Using linear interpolation, the values for 2040 are obtained. The input in WEAP is the value for year 2015 (as this is the beginning of the scenarios) and the annual change in percentage. For this change, the same equation (V) as for the annual change of precipitation, see section 3.14.2, is used. The values for year 2040 and 2015 as well as the annual change for each sub-basin and scenario is presented in table 7h in Appendix.

### 3.14.6 Agriculture demand

#### *3.14.6.1 Crops*

The harvested area for the historic scenario, A1, has been taken as what FAO (FAO, 2015b) calculated the harvested area to be for year 2013 (there are no documented values yet for 2014). The harvested area for the future scenarios A2 and A3 is based on the increase of the land extent of cultivated area between the historic period of 1969-1990 to 2050, meaning that the harvested area for each crop increases with the ratio between the extent of cultivated area for historic time period and the land extent of cultivated area for the given scenario. The harvested area for all scenarios is presented in Table 7i in Appendix.

Note that *extent of cultivated area* does not equal the *cultivated area* here. The cultivated area is the total area used for cultivation, however not all this land may be cultivated at the time or for crops. Hence the land extent refers to the actual cultivated area at the time.
As it may be difficult to see a pattern for how the cultivated area increases, this parameter (i.e. harvested area) is not linearly interpolated to year 2040. Instead it is assumed that the value for year 2050 applies for year 2040.

The harvested area is used in order to calculate the maximum yield one may get for each crop by multiplying the maximum yield (ton/hectare) obtained through GAEZ with the harvested area. This results in the total amount (ton) that is possible to harvest for the actual cultivated area.

For all of these crops, GAEZ assumes that all the actual cultivated area, i.e. extent of cultivated area, is used for each crop when calculating its values. Therefore one cannot add the values together to get a total that would add up to a too high number.

To illustrate how irrigation demand increases over time, the water deficit (mm) output from GAEZ is used as an input in WEAP. Water deficit is defined as the difference between rain-fed water supply and the optimal crop water requirements and is therefore a measurement of the irrigation need.
As just mentioned, it is not possible to add the water deficit for all crops, hence maize has been taken as a reference crop. Using the total average water deficit and multiplying it with the total suitable area for maize (assuming all area is used), one obtains the total water deficit in MCM for the whole country.

As the demand sites are divided into sub-basins, it's required to calculate the water deficit for each demand site. This is done by a percental allocation which is based on the amount of cultivated area for each sub-basin. This is in its turn calculated by multiplying the area for

each sub-basin with the percentage of land extent of cultivated area ($A_{cult}$) (percentage of actual cultivated area). Now, the irrigation need ($I_i$) (water deficit) for each sub-basin is calculated by multiplying the water deficit for maize ($I_{maize}$) with the share of cultivated area:

$$(VI) \qquad I_i = \frac{I_{Maize} \cdot A_{cult}}{A_{cult,tot}}$$

Where i stands for the different sub-basins and $A_{cult,tot}$ is the total cultivated area of all sub-basins.

These values obtained from this equation is then used as the input for irrigation in the agriculture demand in WEAP.

As all these values are based on year 2050, they are linearly interpolated to year 2040. The cultivated area and irrigation need for each sub-basin and year 2040 are presented in Table 3.14.6.1. Scenario A0L does not have any values for cultivated area as the values for its water deficit has not been calculated (and hence not dependent on the cultivated area) but are given values, as described in section 3.7.

**Table 3.14.6.1.** *Cultivated area and water deficit for each sub-basin.*

| | **A0L** | | **A1L** | | **A2L** | | **A2H** | | **A3L** | | **A3H** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sub-Basin** | Cultivated Land [ha] | Water Deficit [mm] | Cultivated Land [ha] | Water Deficit [mm] | Cultivated Land [ha] | Water Deficit [mm] | Cultivated Land [ha] | Water Deficit [mm] | Cultivated Land [ha] | Water Deficit [mm] | Cultivated Land [ha] | Water Deficit [mm] |
| **Lake Victoria** | - | 10.9 | 9552 | 43.9 | 13604 | 35.0 | 13604 | 85.6 | 13605 | 41.1 | 13604 | 58.1 |
| **Lake Kyoga** | - | 11.1 | 15638 | 71.9 | 22271 | 55.5 | 22271 | 138.3 | 22271 | 86.2 | 22271 | 93.2 |
| **Victoria Nile** | - | 0 | 8068 | 37.1 | 11490 | 27.0 | 11490 | 69.7 | 11490 | 44.5 | 11490 | 46.5 |
| **Lake Edward** | - | 2.2 | 5180 | 23.8 | 7378 | 18.0 | 7378 | 45.4 | 7378 | 28.6 | 7378 | 30.5 |
| **Lake Albert** | - | 0 | 4318 | 19.9 | 6149 | 14.5 | 6149 | 37.3 | 6149 | 23.8 | 6149 | 24.9 |
| **Aswa** | - | 0 | 8018 | 36.9 | 11419 | 26.9 | 11419 | 69.3 | 11419 | 44.2 | 11419 | 46.2 |
| **Albert Nile** | - | 0 | 5943 | 27.3 | 8464 | 19.9 | 8464 | 51.4 | 8464 | 32.8 | 8464 | 34.2 |
| **Kidepo** | | 0 | 937 | 4.3 | 1334 | 3.1 | 1334 | 8.1 | 1334 | 5.2 | 1334 | 5.4 |

### *3.14.6.2 Livestock*

Food security as an objective is included in the agriculture water demand as the water demand for livestock.
For year 2014 the average daily caloric intake (DCI) for a Ugandan person was estimated to 2242 kcal/capita (FAO, 2014). In order to ensure food security, the caloric intake should be 2700 kcal/cap/day (Mugisha et al, 2014). Furthermore, the diet of a person living in a developing country today has been estimated to be composed of 12.5 % of meat (Rockström, 2003) and the water need for each calorie of meat is 0.004 $m^3$. Rockström further presents that in the future the share of meat is likely to increase to 20 %.
Using these numbers and multiplying them, one gets the total water need per month and capita, these values are presented in Table 3.14.6.2.

**Table 3.14.6.2.** *Today's and future water demand for livestock (FAO, 2014; Mugisha et al, 2014; Rockström, 2003).*

| Year | Caloric intake [Kcal/cap/day] | Share of meat [%] | Water need for meat [$m^3$/kcal] | Water need for DCI of meat [$m^3$] | Water need per month and capita [$m^3$] | Increase from 2014 [%] |
|---|---|---|---|---|---|---|
| **2014** | 2242 | 12.5 | 0.004 | 1.121 | 34.1 | - |
| **2040** | 2700 | 20 | 0.004 | 2.16 | 65.7 | 1.93 |

When the water demand for crops (see section 3.14.6.1) and livestock are obtained, these values are added in order to get the total water need for agriculture. As done for the municipal and industry demand, the annual increase between year 2014 and 2040 is calculated by using equation V. Using this calculated number, the total agriculture water demand for year 2015 is obtained and input in WEAP along with the percental increase. These are presented in Table 7j in Appendix.

Figure 3.14.6.2. shows the increase of water demand for all demand sites between year 2014 and year 2040, for the different scenarios. The graph is extracted from WEAP.

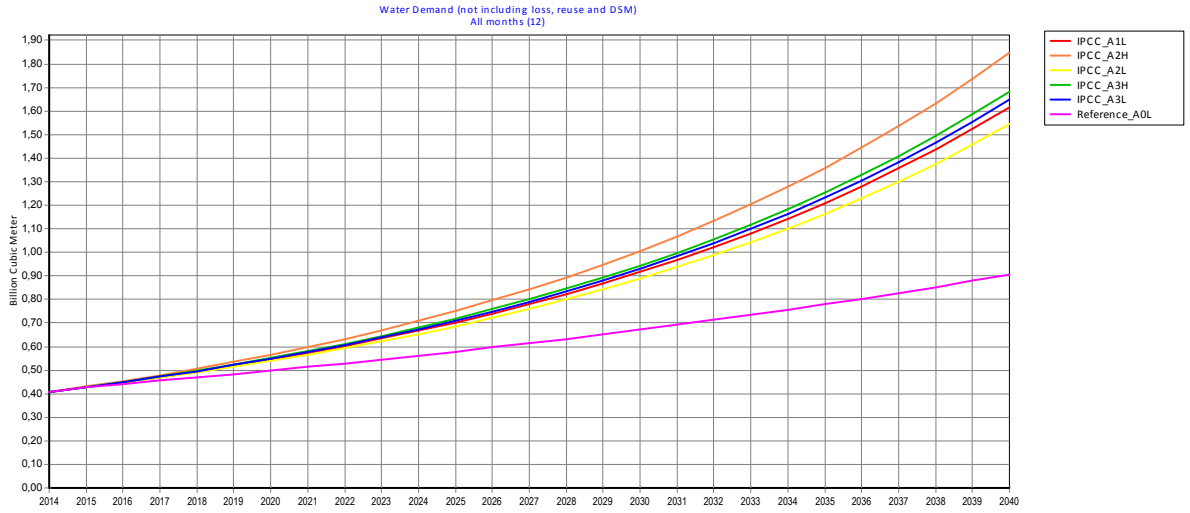



**Figure 3.14.6.2**. *Water demand for all demand sites for all scenario from year 2014 to 2040 (MCM) (WEAP)*

### 3.15.1 Hydropower

Three planned future hydropower plants have been added to the model; Isimbia, Karuma and Ayago.

The same parameters as for the current hydropower plants are required as input in WEAP.

The maximum turbine flow is obtained from NEMA Uganda (NEMA Uganda, 2015) for Karuma. Due to lack of data, both Isimbia and Ayago are assumed to have the same value.

Data regarding the water head for the future power plants are not available, instead the following energy equation is used in order to calculate them (Electropedia, 2015):

$$P_{max} = \eta \cdot \rho \cdot g \cdot h \cdot Q_{mean} \quad \text{(VII)}$$

Solving for the water head (h):

$$h = \frac{P_{max}}{\eta \cdot \rho \cdot g \cdot Q_{mean}} \quad \text{(VIII)}$$

Where P is set to 600 MW for both Karuma and Ayago and 188 MW for Isambia (UEGCL, 2014) $Q_{mean}$ is calculated in WEAP for the period 2014-2040 and equals 1049.33 $m^3/s$ for Karuma, 1049.62 $m^3/s$ for Ayago and 926.05 $m^3/s$ for Isimbia. The generating efficiency ($\eta$) equals 95 % (see Table 18 below), gravity constant (g) is taken to 9.8 $m/s^2$ and the value used for the density of water ($\rho$) is 1000$kg/m^3$ for all three hydro power plants.

The generating efficiency is assumed to be the same as for the current ones (Eurelectric, 2003), as they are also assumed to be large hydropower plants. The plant factor is obtained from the report done by EAC and EAPP (EAC et al, 2011).

These four parameters are presented in table 3.15.1 along with year of installation.

**Table 3.15.1.** *Year of installation and technical parameters for the future hydropower plants. (EAC et al, 2011; Eurelectric, 2003; UEGCL, 2014; Electropedia, 2015; NEMA Uganda, 2015)*

| HPP | Year of installation | Water head (h) [m] | Plant factor | Maximum turbine flow [CMS] | Generating efficiency |
|---|---|---|---|---|---|
| **Karuma** | 2017 | 61.4 | 0.9 | 1128 | 0.95 |
| **Isimbia** | 2015 | 21.8 | 0.9 | 1128 | 0.95 |
| **Ayago** | 2018 | 61.4 | 0.9 | 1128 | 0.95 |

For the hydropower demand, demand projections from OSeMOSYS are used and are presented in Table 7k in Appendix. The table also contains the demand projections for the current hydropower plants for future years.
These are up to the year of 2035 and for the last five years to 2040, it is assumed that the demand is constant.

# 4. Results

## 4.1 Crop production

For each of the crop, the water deficit and maximum yield is obtained. The water deficit (i.e. irrigation requirement) is, as mentioned under section 3.14.6.1, used as an input in WEAP under agriculture demand. However, it also shows how the water deficit varies for the different crops, see Figure 7a in Appendix. This figure shows that the greatest deficit is for Maize whereas it's zero for tobacco, this applies for all scenarios.

Figure 4.1b present the maximum yield (in ton) for the cultivated area in 2040 for the chosen crops. Maize gives the highest yield for scenario A2H and B1H. Sweet Potato amounts to around half the yield of Maize for the same scenarios, closely followed by Cassava.

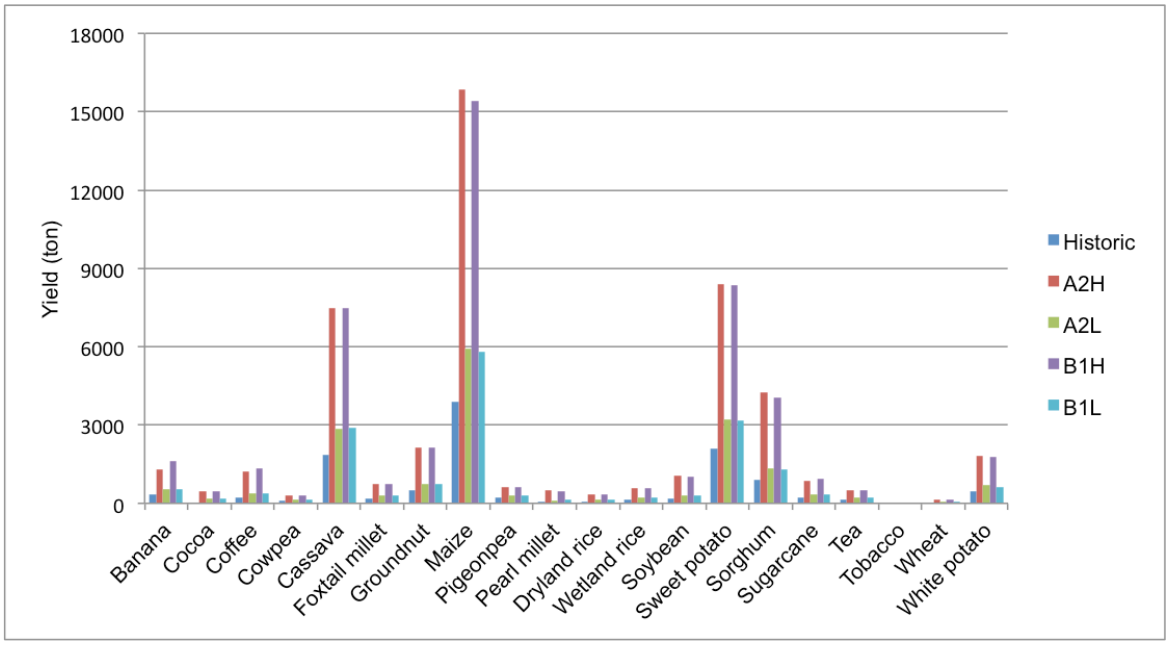



**Figure 4.1a**. *Total yield in tonnes for the different crops and scenarios, values extracted from GAEZ.*

Cassava, groundnut, maize, sorghum and sweet potato are the five crops which gives the highest yield. For these five crops their suitability maps are presented in figures 4.1b-4.1f.

The legend next to the map shows the suitability index (SI) which indicate the amount of maximum attainable yield. For instance, SI > 85 means that it's possible to attain more than 85 % of the yield, hence a very high suitability.
Note that for sorghum and scenario A3L, no data is available in GAEZ and no map can be extracted.

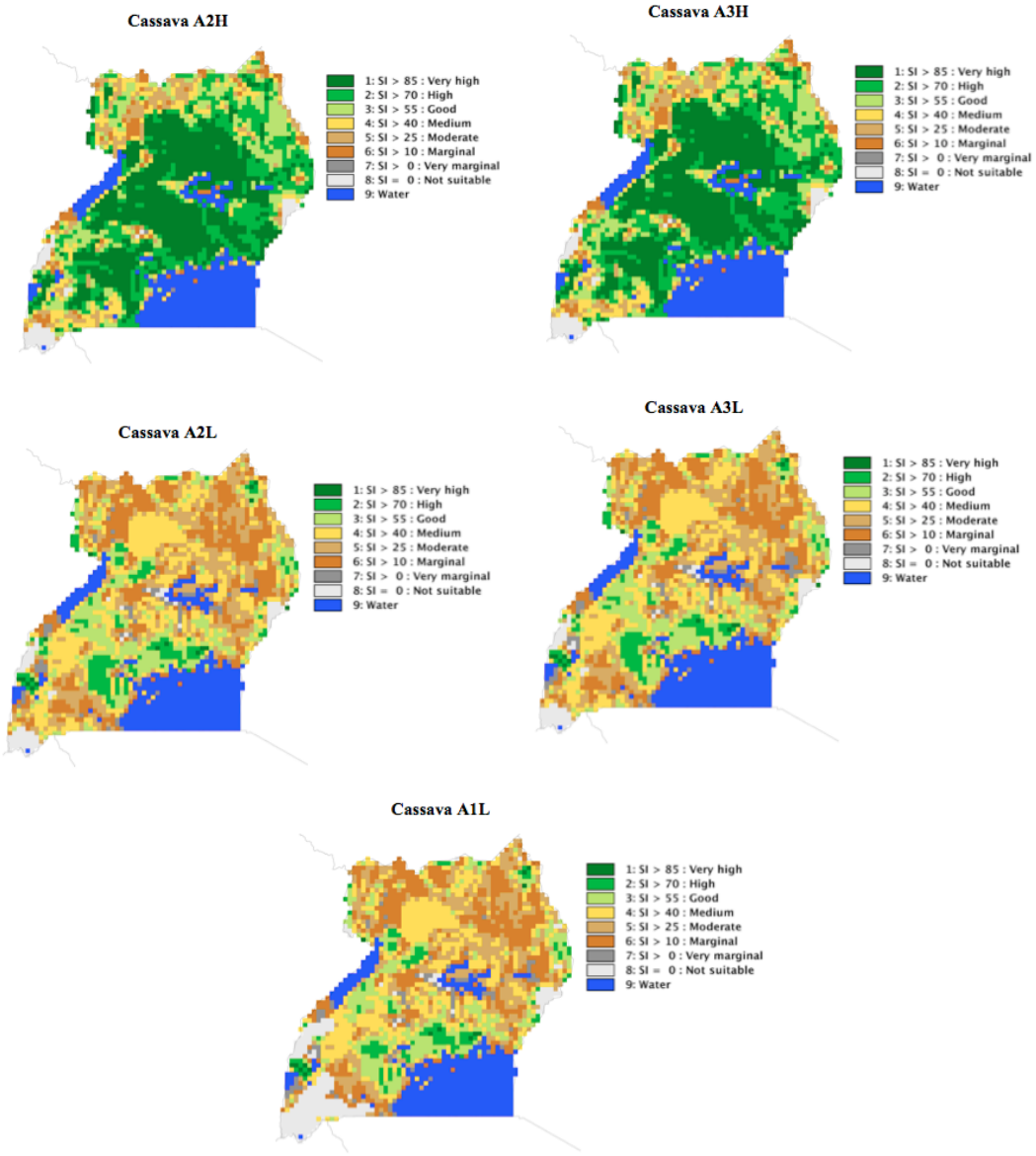
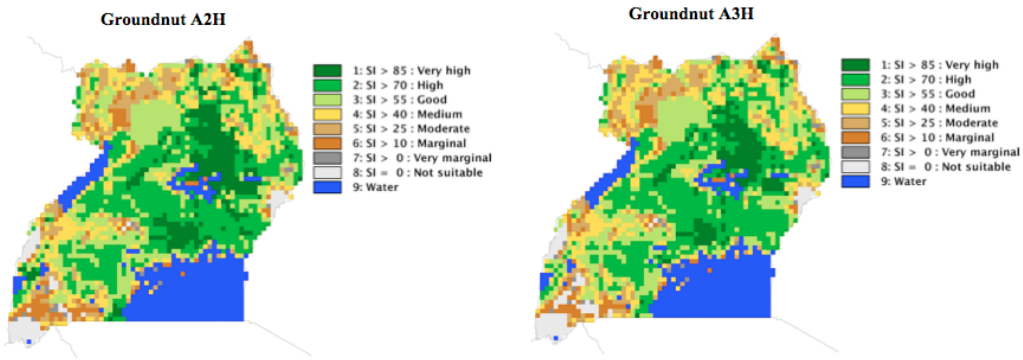



**Figure 4.1b.** *Land suitability for rain-fed cassava for different scenarios, extracted from GAEZ.*



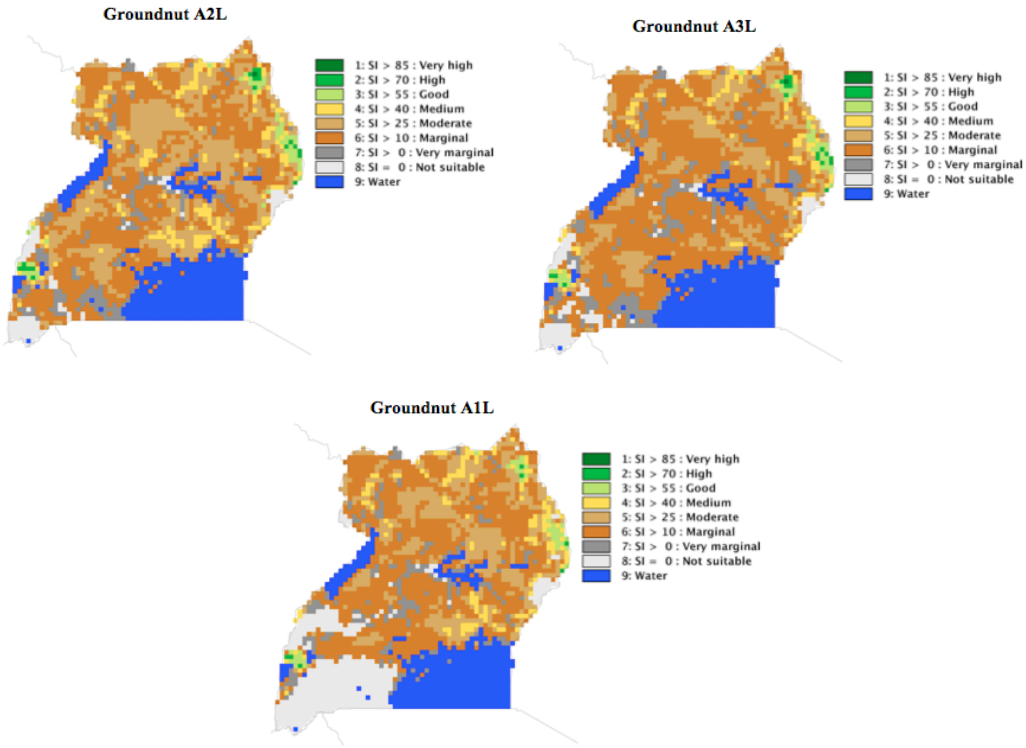
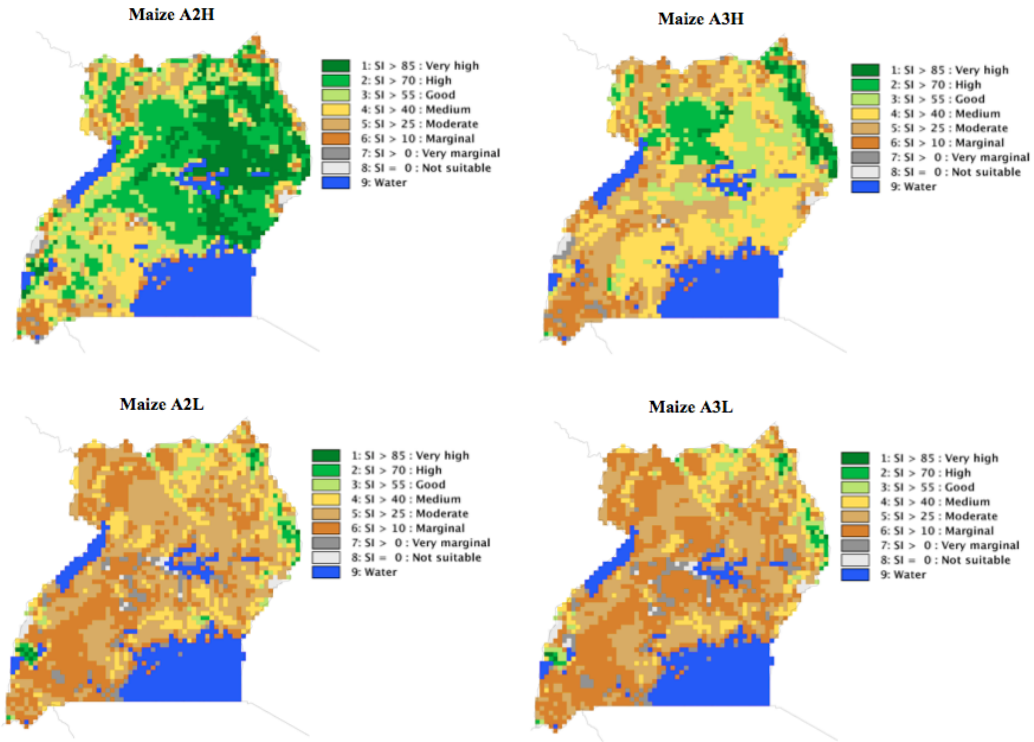



**Figure 4.1c.** *Land suitability for rain-fed groundnut for different scenarios, extracted from GAEZ.*



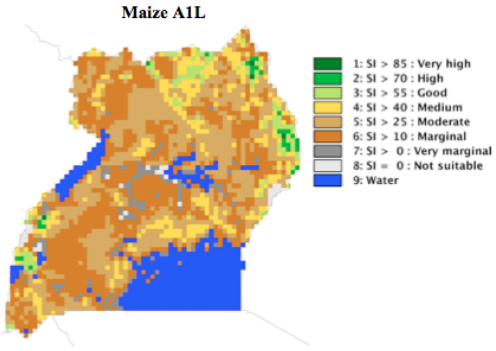



**Figure 4.1d.** *Land suitability for rain-fed maize for different scenarios, extracted from GAEZ.*

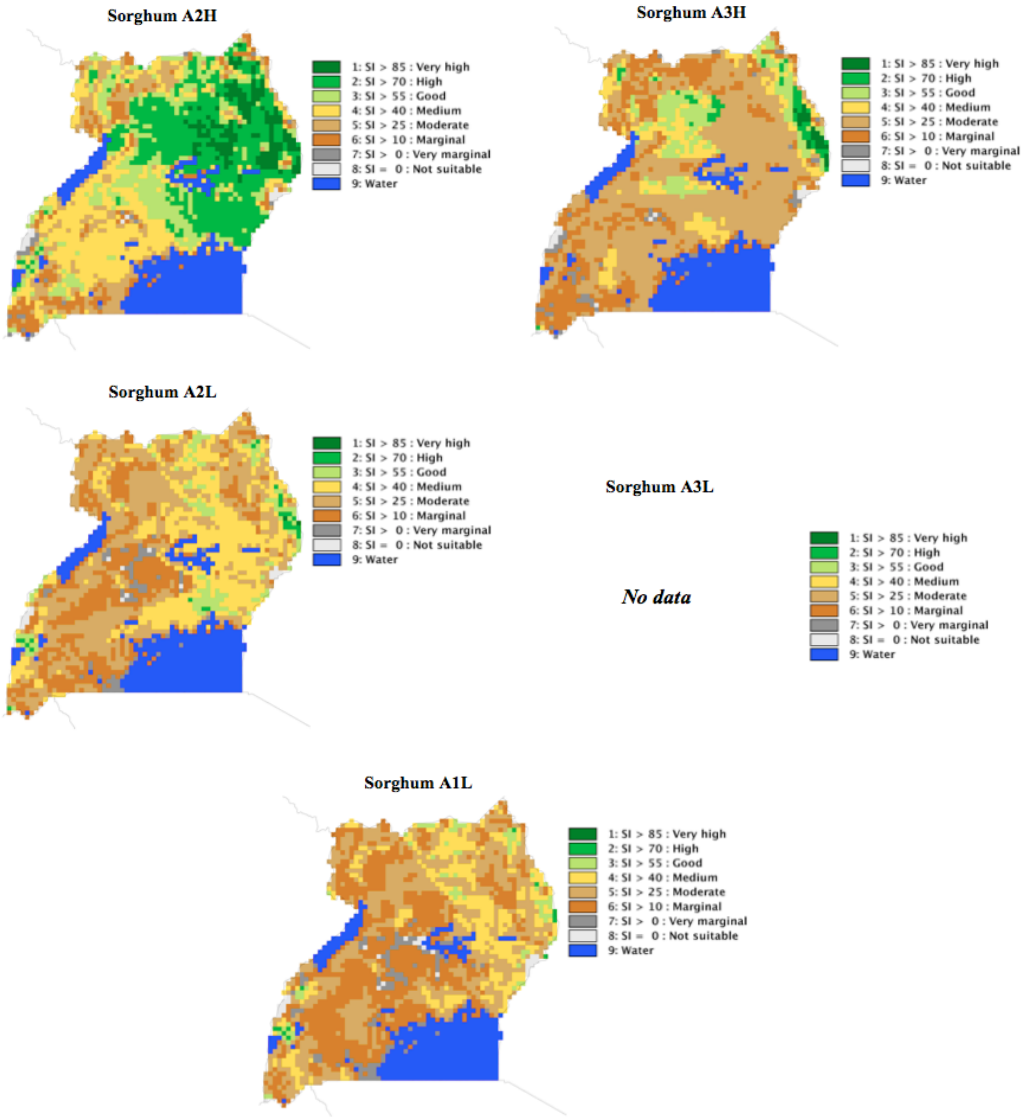



**Figure 4.1e.** *Land suitability for rain-fed sorghum for different scenarios, extracted from GAEZ.*

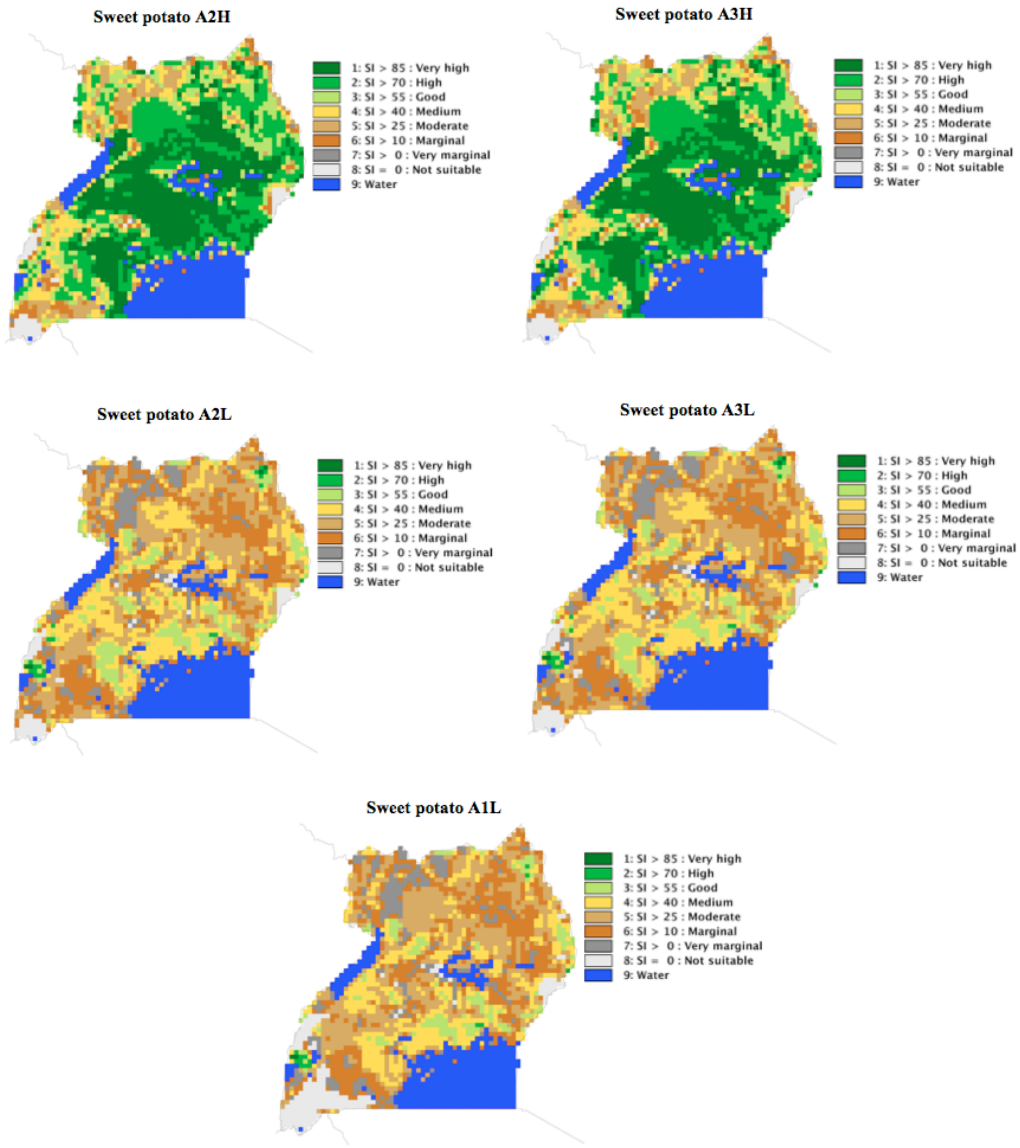



**Figure 4.1f.** *Land suitability for rain-fed sweet potato for different scenarios, extracted from GAEZ.*

## 4.2 Hydropower

### 4.2.1 Demand and generation - all scenarios

The total calculated hydropower generation (2015-2040) is very similar between the different scenarios and different power plants (Figure 4.2.1a). Karuma and Ayago have the biggest projected generation with the mean values of 400.1 million GJ and 416.4 million GJ respectively. The lowest generation is projected for Kiira and Nalubaale with the mean values of 59.5 million GJ and 62.2 million GJ respectively.

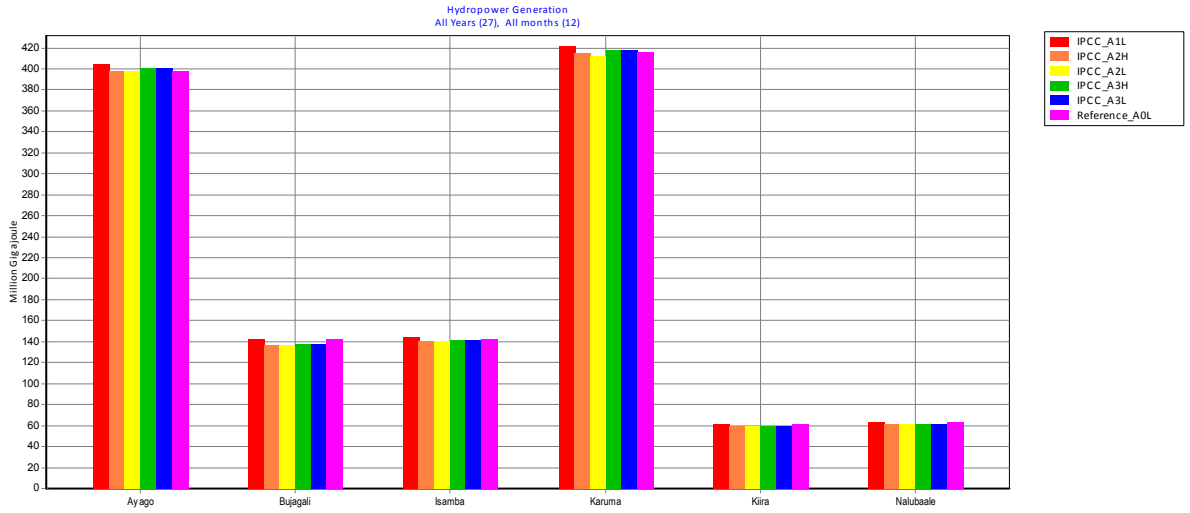



**Figure 4.2.1a**. *Hydropower generation for the different power plants for all scenarios (million GJ) (WEAP).*

The total hydropower demand for each of the different hydropower plants and scenarios for the whole evaluated time period are presented in Figure 7b in Appendix. It reflects the generation fairly well, With Ayago and Karuma having the greateast and Kirira and Nalubalee the least.
When comparing this hydropower demand and generation (Figure 4.2.1b) one can see that the national generation exceeds the national demand for all years but 2015 and 2016, where there during some parts of the years are an deficit observed.

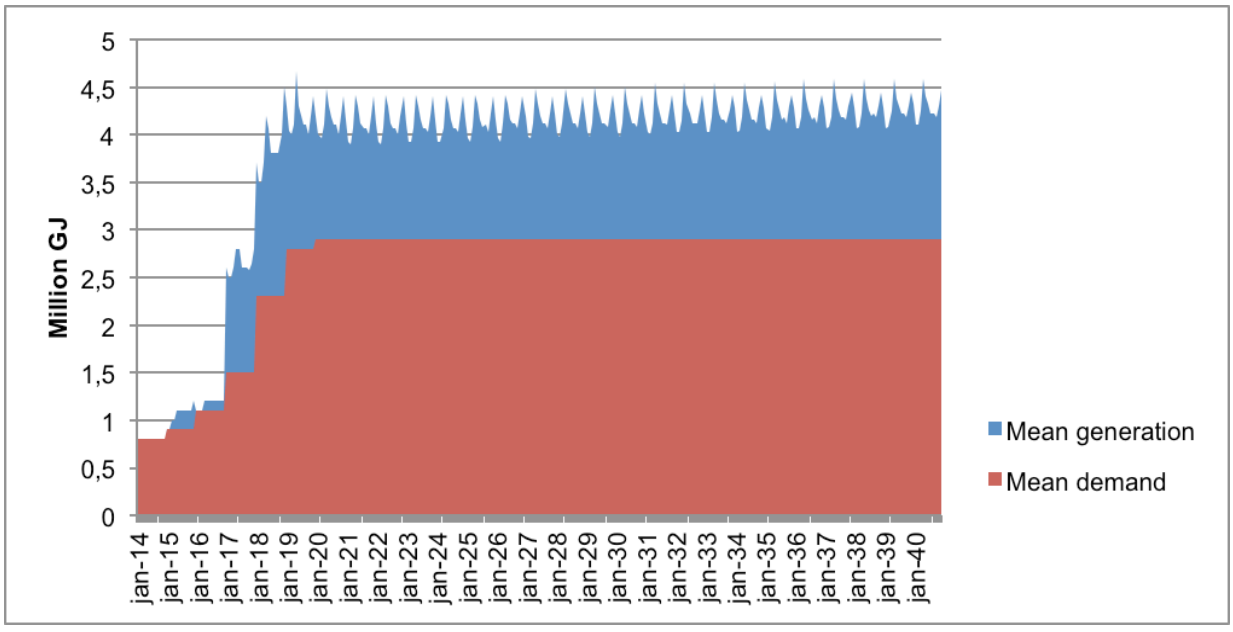



**Figure 4.2.1b.** *The total hydropower demand and generation based on mean values for all scenarios (million GJ) (WEAP).*

As seen in Table 4.2.1c, the generation exceeds the generation for all hydropower plants but Kiira, which experience a total shortage of 5.38 Million GJ for the time period of 2015-2040.

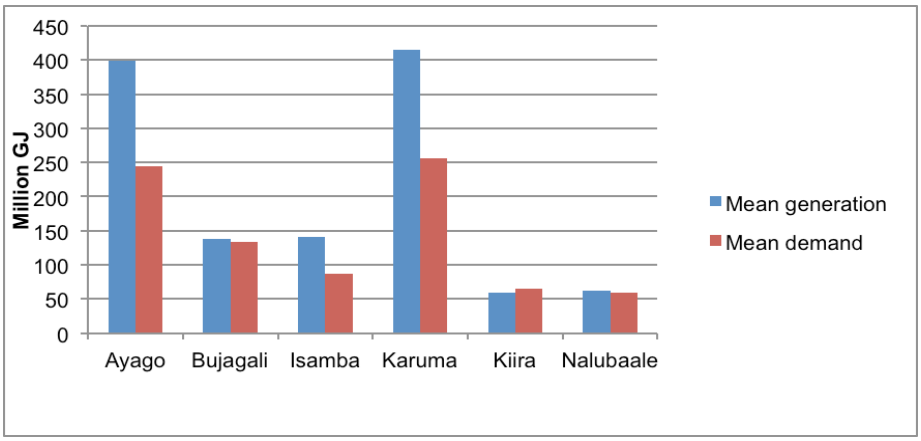



**Figure 4.2.1c.** *The total mean generation and mean demand for all the scenarios and each respective hydropower plant from 2015-2040 (million GJ) (WEAP).*

The gap between the generation and demand for Kiira varies throughout the years. The biggest gap and highest inability to meet the demand is observed in the beginning of the time period where the biggest variations are also seen (Figure 7c in Appendix). The values stabilizes towards the end of the time period, in similarity to the same values on a National total level (Figure 7c Appendix).

### 4.2.2 Demand and generation – monthly distribution

The monthly mean values of the generation for the A0L scenario from today until year 2040 is project to have its highest peak in May and a lower peak in October, coinciding with the two rain seasons. The calculated seasonal variation ranges between around a minimum of 3300 and maximum 4300 Thousand GJ, see Figure 4.2.2a.

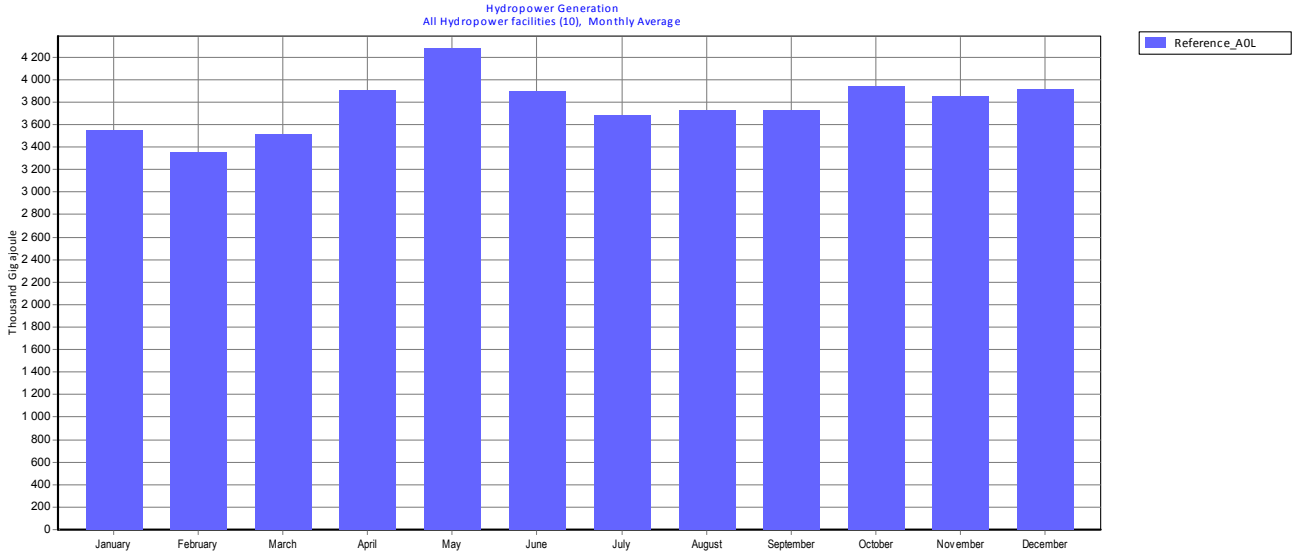



**Figure 4.2.2a.** *The average monthly generation for the A0L Scenario for year 2015-2040 (thousand GJ) (WEAP).*

The monthly patterns for the monthly generation is projected to change in the future, with a decrease of the total hydropower generation during April, May, October and November for all

scenarios in reference to the A0L scenario, and the generation of today. There will also be a decrease for the A2H, A2L and A3H scenarios in August, September and November. Furthermore there is an observed decrease in November for A1L. There is an observed increase during all other months and for all other scenarios. The highest decrease is observed in April, May and October and highest increase in January and February (Figure 4.2.2b). The monthly values are mean values from 2015-2040 projected values. The total annual generation is though projected to increase (Figure 4.2.1c).

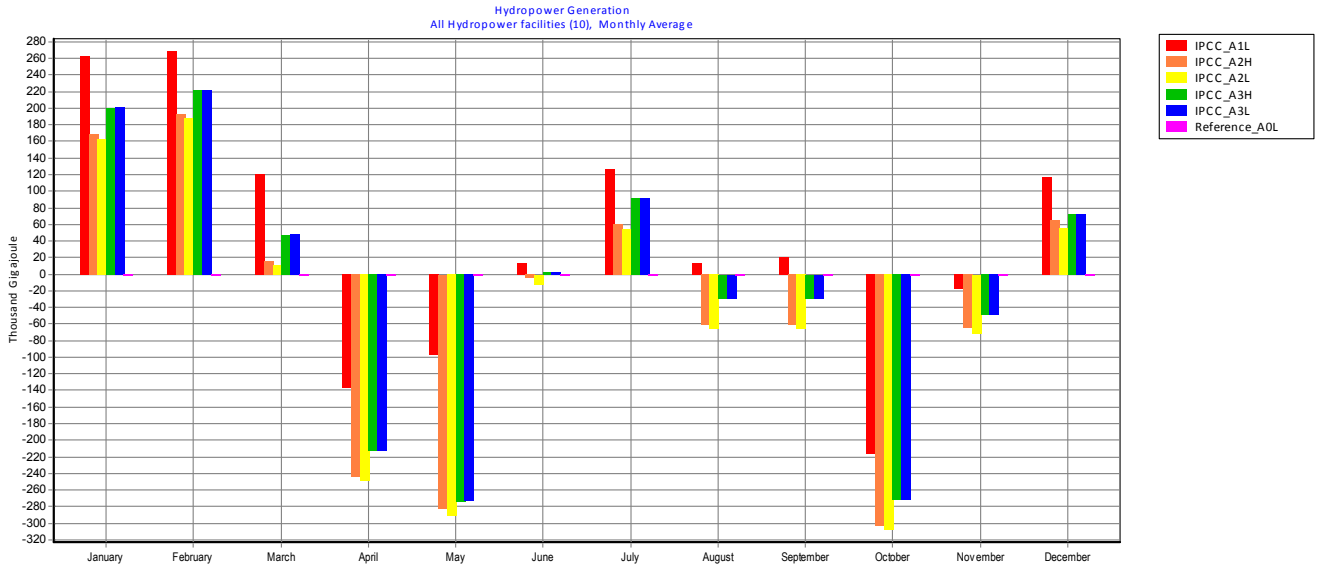



**Figure 4.2.2b.** *The average monthly generation for all scenarios in reference to the A0L Scenario for year 2015-2040 (thousand GJ) (WEAP).*

## 4.3 Unmet water demand

There is a water deficit observed in the end of the evaluated time period for both the municipal as well as the agriculture demand sites in the Lake Kyoga sub-basin. This inability to meet the water demand starts in year 2036 for A1L (Figure 4.3a) and A2L (Figure 4.3b), 2032 for A2H (Figure 4.3c) and 2035 for A3H (Figure 4.3d) and A3L (Figure 4.3e).

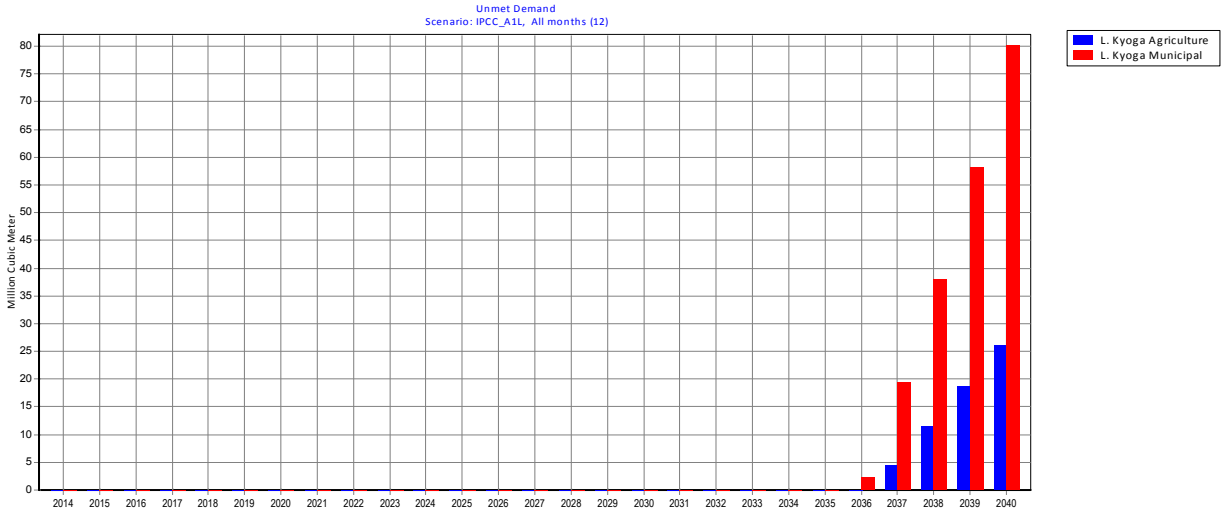



**Figure 4.3a.** *Unmet water demand for all demand sites for the A1L scenario for year 2014-2040 (MCM) (WEAP).*

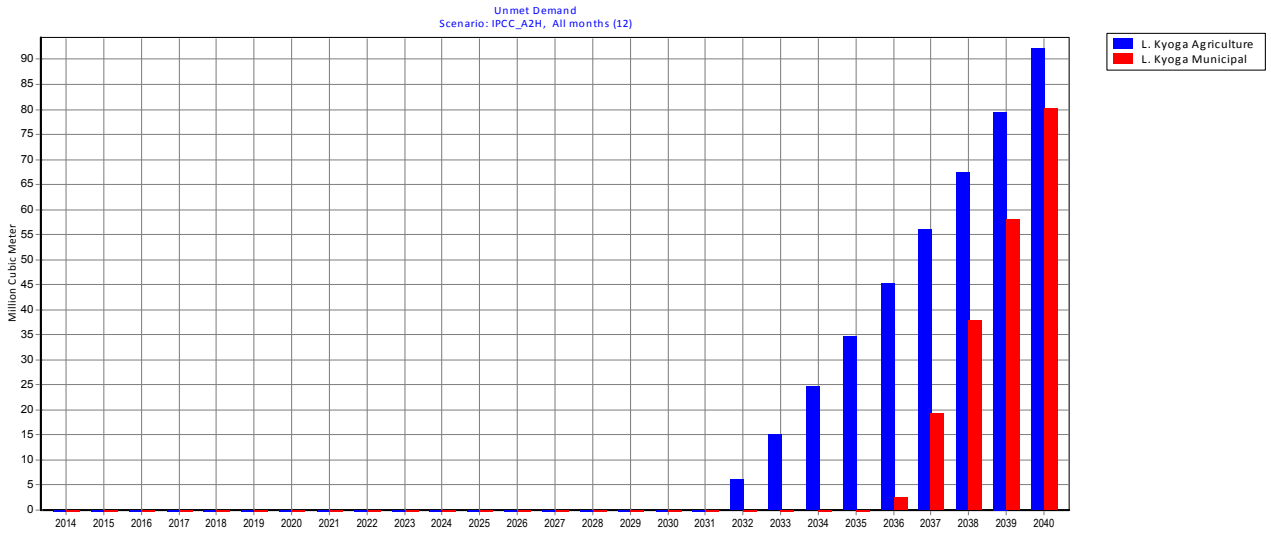



**Figure 4.3b.***Unmet water demand for all demand sites for the A2H scenario for year 2014-2040 (MCM) (WEAP).*

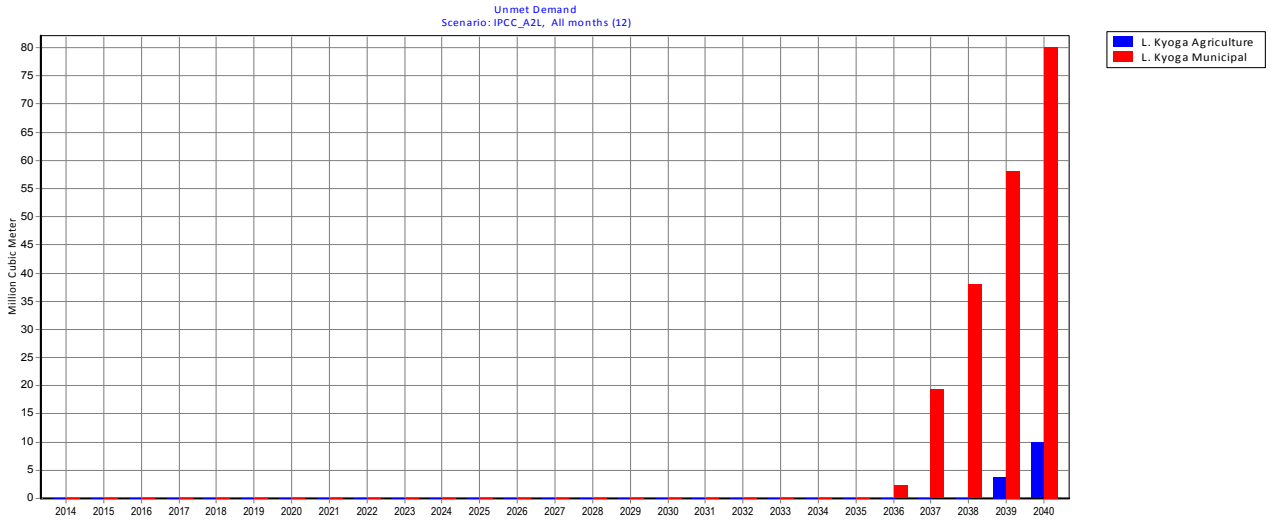



**Figure 4.3c.***Unmet water demand for all demand sites for the A2L scenario for year 2014-2040 (MCM)(WEAP).*

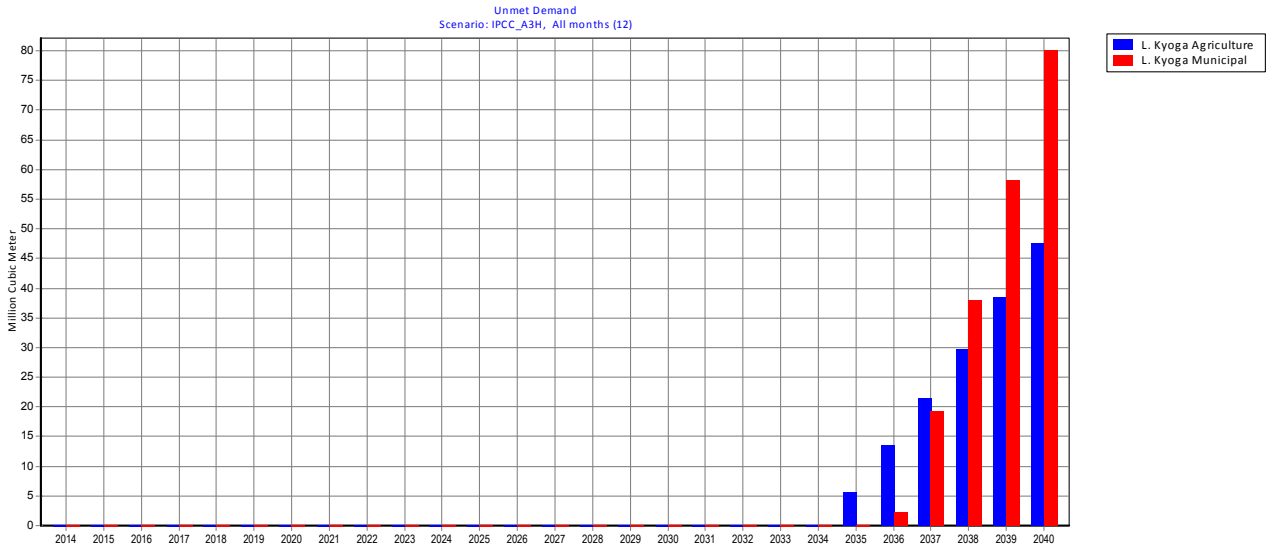



**Figure 4.3d.** *Unmet water demand for all demand sites for the A3H scenario for year 2014-2040 (MCM) (WEAP).*

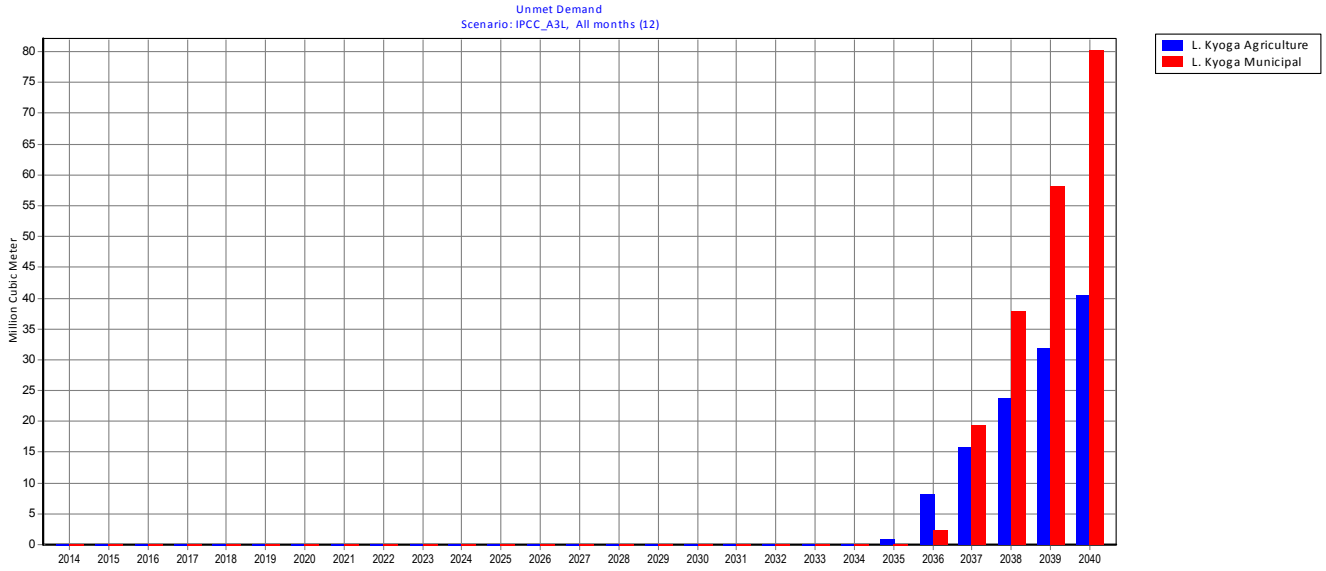



**Figure 4.3e**. *Unmet water demand for all demand sites for the A3L scenario for year 2014-2040 (MCM) (WEAP).*

As observed in table 4.3f. the unmet demand is, given by the method used, equal for all scenarios for the municipal demand sites. For the agriculture demand sites a significant variation is observed for the different scenarios. The greatest is projected for A2H (156.6 MCM) and the least for A2L (13.6 MCM). With an average deficit for all scenarios of 155.6 MCM.

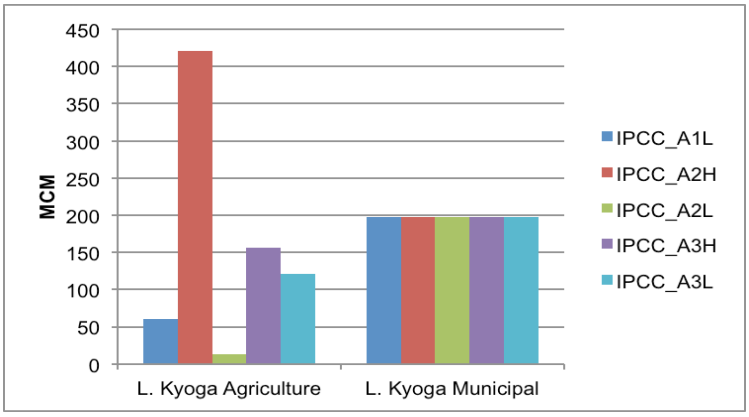



**Figure 4.3f.** *Unmet water demand for Lake Kyoga Agriculture and Municipal demand sites for all scenarios in MCM (WEAP).*

# 5. Discussion, Conclusion & Future Work

## 5.1 Unmet Water demand

There is an observed inability to meet the water demand for both municipal and agriculture in the Lake Kyoga river basin in the future. The Lake Kyoga's main water assets are Lake Kyoga and the Nile River. The latter is both the main contributory inflow and outflow to the lake, which has already been identified by the Ministry of Water and Environment as presented in section 1.6. This means that all the hydropower stations along the Nile are in one way or another interlinked and may be causing or affected by this water deficit. This highlight the importance of a broader systematic approach, when planning for both hydropower stations and their reservoirs as well as laying foundation for water strategies for demand sites including irrigation schemes. In this area it is therefore necessary to look into alternatives when trying to meet both electricity and water demand. This could for instance be the

integration of small-scale hydropower in reservoirs that also serves as irrigations schemes for crop production.

By looking at the *Reference Resource System* (Figure 3.1b), one can see that this inability to meet the water demand could lead to firstly an inability to supply water for irrigation need, which will affect the crop production. This in its turn will affect the economy, both through reduction of national and international trading but also the social dimension which food scarcity might cause. Secondly, this deficit could as discussed above lead to consequences for the hydropower generation. This would by all means lead to consequences for the energy sector and there through affect the economy, industries and households as well. If Uganda choses to develop their hydropower, this deficit has to be considered and planned for in order to prevent it.
By looking at the consequences in a wider perspective, it is also evident that even though this deficit is limited to a certain area, it will have affects on all sub-basins. I.e. one area of the country may not experience the deficit, but it may be affected by one of the possible consequences. For instance, a water deficit may result in less crop production which may either compromise the countries food supply or a decline in domestic and international trading with commodities. The latter affecting the countries economy.

Furthermore, an increase in temperature will likely affect the evapotranspiration. This means that the water deficit for crops will increase as well, hence there will be a greater need for irrigation. Meaning that if this irrigation need cannot be meet naturally (e.g. rain), irrigation schemes will need to be exploited, as discussed above. As can be seen in Figure 4.3f, the water deficit ranges between the different scenarios. This implies that the future climate needs to be taken into consideration when planning for the future farming system.

### 5.2 Crop suitability & Water deficit

It is evident by looking at figure 4.1a, that there are certain crops that are more resistible to the future potential climate changes. Maize gave the highest yield in all scenarios, showing that this is a resistant crop which can stand climatic changes. Cassava, Sorghum and Sweet Potato are close behind, also showing potential in high yield in the future. Whereas other food security crops as rice, seem to be largely affected by this in the future.

However, looking at these numbers together with the suitability maps one may also distinguish the difficulty in finding suitable areas for farming. Out of the five major ones here chosen, it seems like Cassava has the most suitable area for all future scenarios. For all crops, the scenarios with high input as a parameter, the yield and suitable area increase the most. Even though Maize being the crop with the highest yield, it also results in the crop with the highest irrigation need, as can be seen in Figure 4.1a. Evidently, looking at Figure 4.1a and 7a (in Appendix), the crops with the highest yield result in the ones with the highest irrigation need. This does not necessarily mean a problem, as has been presented earlier in this report there is a great potential in irrigation schemes and development of these.
Although, as discussed in the previous section there is an unmet demand in the agriculture site in Kyoga. For this sub-basin it may not be as easy to development the irrigation schemes needed for the crops with highest yield. But it's not advisable to evaluate the irrigation need, as these may not result in a high enough yield for the production to be profitable. Using the suitability maps, maize and sorghum does not seem to qualify as most suitable.
However, in order to give a definite answer on which crops are the most suitable for this area a further and more detailed study need to be done. But what can be pointed out from this study is that the Kyoga region show high yield for the two scenarios with high input. This

urge for a change in the farming system and management to bring in better input (seeds etc.), techniques and management with supervision and an ambition to make it more market oriented.

By looking at the *Reference Recourse System* (Figure 3.1b), increasing from *low* to *high* input would mean increased cost for Labor, Investments, O&M (Operational & Maintenance) and R&D (Resource & Development). However, this investment may result in an increase in yield, which this report has shown. However, the high input also means an increase in use of fertilizers and pesticides, which may have a negative effect on the water system. Looking at Figure 3.1b again, one may identify one possible consequence of this to be contaminated water or eutrophication.

One important thing to emphasize is not to look at these results in a too narrow perspective. Meaning that if you are just focus on one crop, you may face depletion and the soil becomes useless. Instead one possibility could be to look at how one can optimize the arable land in terms of having different crops at the same location but during different times of the year. This could be done by looking at the growing period of each crop and trying to map them together. This of course requires good knowledge regarding whether it's possible to grow the different crops at one location, meaning still not reaching depletion or such.

### 5.3 Population growth rate

One main thing that should be pointed out is the population rate used in this report. As stated, it is based on UNEP's calculations for year 2014. However as this is only an assumption that this will be constant for future year, it may be the case that this number becomes significantly different. As the Government's vision is to reduce this rate to 2.4 %, this will by most definite means change the results obtained in this study. It will mean that the demand for water will decrease as well as total electricity demand. Imagine if the municipal water demand decreases the most, that will mean that there will be more water for irrigation. Adding a decrease in electricity demand will result in having to generate less electricity and hence more water is available for irrigation.
Hence it is important to have in mind that the population has a big impact on the results and trying to get the growth to stagnate could be a major key factor to mitigate water scarcity, and of course food scarcity as well.

### 5.4 Hydropower generation

The electricity demand will be met for all hydropower plants but Kiira, the deficit exists for all months of the year. The exceed in generation in all other hydropower plants is though potentially able to compensate for this inability to meet the demand. Especially from the nearby powerplants; Nalubaale and Bujagali.

The substantial potential excess electricity generation could, even though development has been included in these demand projections already, give room for even greater development in all sectors until 2040 with an increased electricity demand as result. This puts Uganda in a beneficial position, as lack of access to electricity is essential for development of an economy. It is essential to emphasize the importance of an improved distribution network, that can secure the distribution with a wider spatial spread. This in order to lay foundation for this mentioned development.

The potential excess generation is not only a keystone for the country's direct development, it also opens the doors for an international market. Excess electricity could be sold to nearby countries, preferably countries with an other energy-mix that has other monthly and or daily availability to generate electricity.

The monthly patterns observed in reference to todays generation (A0L) is assumed to change in the future. The highest decrease of generation occurs during the wet months of April, May and October. It should though be pointed out that the occurrence of changed rain patterns that are likely to appear in the future, is not taken into consideration in this report, so the result may change when that is included in the calculations.

In Figure 3.1b it's apparent that a change in the rainfall will affect the flow patterns in rivers. Hence, the increase of precipitation that occurs according to the IPCC scenarios, may have a positive impact on the hydropower generation as for instance more water may be stored in reservoirs. However if the case is that there are periods with higher flows in the future, it may not be possible to utilize the increased flow as there is a maximum flow which the power plant can let through. In the same sense it may be the case that there won't be enough flow during dry periods to meet the demand.
Increase in rain may also result in less need for irrigation, if the evapotranspiration does not increase too much. Although, as there is both a partly unmet hydropower generation demand as well as water deficit, an increase in precipitation may not mitigate them both.

### 5.5 Conclusion

What can be concluded from the above discussion and overall from this report, is that there is a possibility of water deficit and inability to meet the hydropower demand in the future. What may also be concluded is that in order to ensure food security, a thorough planning on the farming system is needed. There are certain crops which are more suitable and resistible to the future climate change.
Furthermore the consequences for these three will stretch beyond their own boundaries and they will have an affect on other parts in the different sectors; water, agriculture, energy and economy. Hence, the results obtained in this study may be kept in mind when planning for the future and developing policy strategies within this field.

### 5.6 Future work

The model and methods used in this study is of more basic condition, meaning it has been composed to give an overview where a deeper and wider analysis may and should be taken on from here. The following areas have been identified by the authors to be of most interest and need of further study in order to get better results:

- Expand the hydrology; add more rivers, include groundwater calculations in the model, include more updated values etc.
- Include water quality, fertilizers and pesticides in the model and analysis
- Sanitation and health; refers to the previous point.
- Expand demand sites; divide municipal into urban and rural, find more coherent values for each demand-sites usage etc.
- Add thermal power plants and small scale hydropower plants (both current and future)

# 6. References


Alstrom, 2013. *Bujagali: Powering Uganda from the Nile.* [pdf]
Available at: http://www.alstom.com/Global/Power/Resources/Documents/Brochures/bujagali-uganda-kaplan-hydro-plant-advertorial.pdf [Accessed 2015-05-05].

CDM, 2013. Monotoring Report Form" [pdf]
Available at:
http://cdm.unfccc.int/filestorage/K/F/G/KFGZ6WB0DJN4XTEV753A298LOP1CIM/MR%20-%20Bujagali.pdf?t=VFl8bm56MnV0fDDIMo8w-_XDIzRvekz3Yd4m [Accessed on 2015-04-06]

Division for Sustainable Development, 2014. *Prototype Global Sustainable Development Report* [pdf]
Available at:
https://sustainabledevelopment.un.org/content/documents/1454Prototype%20Global%20SD%20Report.pdf [Accessed: 2015-05-05].

EAC., EAPP, 2011. *Regional Power System Master Plan and Grid Code Study* [pdf]
Available at:
http://www.eac.int/energy/index.php?option=com_docman&task=doc_view&gid=89&tmpl=component&format=raw&Itemid=70 [Accessed 2015-04-02]

Electropedia, 2015. *Hydroelectric Power* [online]
Available at: http://www.mpoweruk.com/hydro_power.htm [Accessed 2015-05-15]

Eurelectric, 2003. *Efficiency in Electricity Generation* [pdf] Available at:
www.eurelectric.org/Download/Download.aspx? [Accessed 2015-05-15]

FAO, 2013. *Uganda - Integrating Food and Nutrition Security and the Right to Food in Local Government Development Planning and Budgeting* [pdf] Available at:
http://www.fao.org/docrep/019/i3295e/i3295e.pdf [Accessed 2015-05-10]

FAO, 2014. *Food and Nutrion in Numbers* [pdf] Available at: http://www.fao.org/3/a-i4175e.pdf [Accessed 2015-05-10]

FAO, 2012a. *Frequently Asked Questions (FAQ)* [pdf]
Available at: http://www.fao.org/fileadmin/user_upload/gaez/docs/FAQ_EN.pdf [Accessed 2015-05-10]

FAO, 2012b. Global Agro-ecological Zones – Model Documentation [pdf]
Available at: http://www.fao.org/fileadmin/user_upload/gaez/docs/GAEZ_Model_Documentation.pdf [Accessed 2015-04-09]

FAO, 2015a. Crop coefficients for different growing stages [pdf]
Available at: http://www.fao.org/nr/water/aquastat/water_use_agr/Annex1.pdf [Accessed 2015-05-15]

FAO, 2015b. *Harvested area* [online]
Available at: http://faostat3.fao.org/download/Q/QC/E [Accessed 2015-10-18]

FAO, 2015c. *Aquastat- Country Fact Sheet: Uganda*. [pdf] Available at:
http://www.fao.org/nr/water/aquastat/data/cf/readPdf.html?f=UGA-CF_eng.pdf [Accessed: 2015-05-22]

KTH, 2015a. *CLEWs- Climate, Land, Energy and Water strategies to navigate the nexus [Online]* Available at: http://www.kth.se/en/itm/inst/energiteknik/forskning/desa/researchareas/clews-climate-land-energy-and-water-strategies-to-navigate-the-nexus-1.432255 [Accessed 2015-05-05].

KTH, 2015b. *Supporting the Design of Sustainable Development Policies with Policy Modelling Tools 2014-2015 [Online]* Available at: https://www.kth.se/en/itm/inst/energiteknik/forskning/desa/projects/ongoing-projects/supporting-the-design-of-sustainable-development-policies-with-policy-modelling-tools-2014-2015-1.563606 [Accessed 2015-05-05].

MAAIF, 2009. *Uganda National Rice Development Strategy* [pdf] Available at: http://www.riceforafrica.org/downloads/NRDS/uganda_en.pdf [Accessed 2015-04-30]

MAAIF, 2015. *About us* [online] Available at: http://www.agriculture.go.ug/About-Us [Accessed 2015-04-10]

MAAIF, 2014. *Policy Statement for The Ministry of Agriculture, Animal Industry and Fisheries For the Financial Year 2014/15* [pdf] Available at: http://www.agriculture.go.ug/userfiles/Ministry%20Policy%20statement%20FY%202014-15.pdf [Accessed 2015-04-05]

Matarutse, N., 2010. *Successes achieved in terms of maintenance planning and implementationHydro Power Plants on the Nile River.* [pdf] Available at: http://www.esi-africa.com/wp-content/uploads/Nobert_Matarutse.pdf [Accessed 2015-04-02].

Mugisha M., F., Fenner, A., R., 2014. *The influence of water, land, energy and soil-nutrient resource interactions on the food system in Uganda* [pdf] Available at: http://www.sciencedirect.com/science/article/pii/S030691921400195X [Accessed 2015-05-15]

MWE., 2012. *05-Water Supply Atlas National Report* . [pdf] Available at: http://mwe.go.ug/index.php?option=com_docman&task=cat_view&gid=12&Itemid=223 [Accessed 2015-05-16].

MWE, 2013. *Uganda National Water Resources Assessment*. Ministry of Water and Environment (MWE). P.O. Box 20026, Kampala, Uganda.

MWE, 2014. *Water and Environment Sector Performance Report 2014.* pdf] Available at: http://rural-water-supply.net/fr/resources/details/627 [Accessed: 2015-05-06]

National Planning Authority (NPA), 2013. *Uganda Vision 2040* [pdf] Available at: http://npa.ug/wp-content/themes/npatheme/documents/vision2040.pdf [2015-04-15]

NE (Nationalencyklopedin AB), 2009. *Nationalencyklopedin.* Volume 19. Mohn Media Print GmbH, Germany.

NEMA Uganda, 2015. *Executive Summary* [pdf] Available at: http://www.nemaug.org/E_i_a_documents/Executive_summary.pdf [Accessed 2015-05-15]

Nilsson, A., Johansson, I., In Press. *Laying Foundation for energy policy making in Uganda by indicating the energy flow*. Stockholm: Royal Institute of Technology

Rockström, J., 2003. *Water for food and nature in drought-prone tropics: vapour shift in rain-fed agriculture* [pdf] Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1693286/ [Accessed 2015-05-15]

UEGCL, 2014 *Uganda Electricity Generation Company Limited. "Projects in progress"* [Online] Available at: http://uegcl.com/projects-in-progress.html [Accessed: 2015-04-29]

UBOS, 2014. *Statistical Abstract 2014* [pdf] Available at: http://www.ubos.org/onlinefiles/uploads/ubos/statistical_abstracts/Statistical_Abstract_2014.pdf [Accessed 2015-04-05]

UNEP, 2008. *Vital Water Graphics* [online] Available at: http://www.unep.org/dewa/vitalwater/article43.html [Accessed 2015-05-15]

UNESCO, 2006. *National Development Report: Uganda* [pdf] Available at: http://unesdoc.unesco.org/images/0014/001467/146760e.pdf [Accessed: 2015-05-01]

WEAP, 2012. *WEAP in an hour.* [pdf] Available at: http://www.weap21.org/downloads/WEAP_Tutorial.pdf [Accessed 2015-05-05].

World Bank, 2015a. *Uganda overview* [online] Available at: http://www.worldbank.org/en/country/uganda/overview [Accessed 2015-04-10]

World Bank, 2015b. *Average monthly temperature and rainfall for Uganda from 1960-1990* [online] Available at: http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Africa&ThisCCode=UGA [2015-04-15]

# 7. Appendix

**Table 7a**. *Withdrawal points from GAEZ for precipitation for the different sub-basins.*

| Point | Albert Nile | Victoria Nile | Lake Albert | Lake Edward | Lake Victoria | Lake Kyoga | Aswa | Kidepo |
|---|---|---|---|---|---|---|---|---|
| **1** | 1001 | 1029 | 1107 | 995 | 1007 | 1058 | 1015 | 731 |
| **2** | 993 | 1088 | 1190 | 1029 | 1019 | 1036 | 1010 | 766 |
| **3** | 992 | 1065 | 1085 | 1074 | 1078 | 966 | 1039 | 821 |
| **4** | 968 | 1076 | 1114 | 1097 | 1064 | 1066 | 1051 | |
| **5** | 1001 | 1049 | 1138 | 1042 | 1146 | 1066 | 1080 | |
| **6** | 1019 | 1051 | 1131 | 1006 | 1175 | 1050 | 1054 | |
| **7** | 1021 | 1070 | 1121 | 1062 | 1203 | 1075 | 1021 | |
| **8** | 1030 | 1083 | 1105 | 1148 | 1121 | 1071 | 1088 | |
| **9** | 1021 | 1092 | 1102 | 1180 | 1166 | 1105 | 1070 | |
| **10** | 1028 | 1078 | 1082 | 1188 | 1207 | 1105 | 1061 | |
| **11** | 1013 | 1094 | 1093 | 982 | 1153 | 1126 | 1065 | |
| **12** | 1030 | 1099 | 1102 | 1015 | 1158 | 1130 | 1009 | |
| **13** | 1021 | 1115 | 1116 | 1034 | 1210 | 1125 | 1033 | |
| **14** | 1066 | 1120 | 1193 | 981 | 1207 | 1139 | 1070 | |
| **15** | 1062 | 1123 | 1077 | 973 | 1257 | 839 | 962 | |
| **16** | 1099 | 1132 | 1060 | 1009 | 1253 | 944 | 893 | |
| **17** | 1083 | 1135 | 1045 | 996 | 1284 | 1085 | 837 | |
| **18** | 1054 | 1110 | 1013 | 1032 | 1301 | 839 | 829 | |
| **19** | 1022 | 1119 | | 1049 | 1330 | 782 | 700 | |
| **20** | 1015 | 1131 | | | 1307 | 804 | 751 | |
| **21** | 1029 | 1141 | | | 1151 | 964 | 831 | |
| **22** | | 1156 | | | 1167 | 962 | 874 | |
| **23** | | 1135 | | | 1174 | 1002 | 942 | |
| **24** | | 1078 | | | 1187 | 1067 | 986 | |
| **25** | | 1085 | | | 1193 | 1065 | 956 | |
| **26** | | 1044 | | | 1208 | 1038 | 867 | |
| **27** | | 1126 | | | 1229 | 1075 | 839 | |
| **28** | | 1124 | | | 1215 | 1081 | 800 | |
| **29** | | | | | 1272 | 1090 | | |
| **30** | | | | | 1314 | 1104 | | |
| **31** | | | | | 1330 | 1097 | | |
| **32** | | | | | 1330 | 1105 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **33** | | | | | 1191 | 1115 | | |
| **34** | | | | | 1169 | 1112 | | |
| **35** | | | | | 1203 | 1075 | | |
| **36** | | | | | 1169 | 1017 | | |
| **37** | | | | | 1204 | 947 | | |
| **38** | | | | | 1149 | 840 | | |
| **39** | | | | | 1190 | 731 | | |
| **40** | | | | | 1154 | 740 | | |
| **41** | | | | | 1288 | 846 | | |
| **42** | | | | | 1117 | 860 | | |
| **43** | | | | | 1076 | 765 | | |
| **44** | | | | | 1129 | 693 | | |
| **45** | | | | | 1086 | 601 | | |
| **46** | | | | | 1141 | 591 | | |
| **47** | | | | | 1094 | 680 | | |
| **48** | | | | | 1094 | 813 | | |
| **49** | | | | | 968 | 775 | | |
| **50** | | | | | 968 | 700 | | |
| **51** | | | | | 1050 | 632 | | |
| **52** | | | | | 1067 | 636 | | |
| **53** | | | | | 1076 | 700 | | |
| **54** | | | | | 1086 | 1097 | | |
| **55** | | | | | 1092 | 1055 | | |
| **56** | | | | | 1109 | 972 | | |
| **57** | | | | | 1094 | 962 | | |
| **58** | | | | | 1087 | | | |
| **59** | | | | | 1191 | | | |
| **60** | | | | | 1259 | | | |
| **61** | | | | | 1211 | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sum** | 21568 | 30748 | 19874 | 19892 | 71128 | 54016 | 26733 | 2318 |
| **Average** | 1027.1 | 1098.1 | 1104.1 | 1047.0 | 1166.0 | 947.7 | 954.8 | 772.7 |
| **Adjusted average** | 1194.4 | 1277.1 | 1284.0 | 1217.5 | 1356.0 | 1102.1 | 1110.3 | 898.6 |

**Table 7b.** *Precipitation over lakes (m3/s) (MWE, 2013).*

| Reservoirs (Lakes) | Mean | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lake Victoria** | 3742 | 2800 | 3600 | 5000 | 7500 | 5000 | 2100 | 1500 | 1800 | 2100 | 3500 | 5200 | 4800 |
| **Lake Victoria adjusted** | 3652 | 2733 | 3513 | 4880 | 7319 | 4880 | 2049 | 1464 | 1757 | 2049 | 3416 | 5075 | 4684 |
| **Lake Edward/George** | 72 | 29 | 46 | 82 | 119 | 83 | 41 | 38 | 84 | 94 | 90 | 112 | 50 |
| **Lake Albert** | 165 | 47 | 81 | 162 | 305 | 228 | 116 | 144 | 172 | 175 | 238 | 229 | 80 |
| **Lake Kyoga** | 133 | 20 | 55 | 98 | 189 | 221 | 138 | 151 | 198 | 187 | 170 | 122 | 46 |

**Table 7c.** *Evaporation (m3/s) (MWE, 2013).*

| Reservoirs (Lakes) | Mean | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lake Victoria** | 3179 | 3100 | 3200 | 3500 | 3000 | 3000 | 3050 | 3100 | 3200 | 3400 | 3300 | 3200 | 3100 |
| **Lake Victoria adjusted** | 3278 | 3196 | 3299 | 3609 | 3093 | 3093 | 3145 | 3196 | 3299 | 3506 | 3403 | 3299 | 3196 |
| **Lake Edward/George** | 156 | 167 | 163 | 163 | 154 | 155 | 149 | 139 | 151 | 166 | 151 | 152 | 158 |
| **Lake Albert** | 415 | 429 | 449 | 453 | 420 | 428 | 397 | 356 | 379 | 412 | 421 | 409 | 426 |
| **Lake Kyoga** | 167 | 184 | 187 | 180 | 159 | 152 | 152 | 148 | 156 | 170 | 171 | 166 | 176 |

**Table 7d.** *Major crops and their mean crop coefficient value (FAO, 2015a)*

| Crop | Initial | Development | Mid | Late | $K_c$ (mean value) |
|---|---|---|---|---|---|
| **Banana** | 1.00 | 1.00 | 1.00 | 1,00 | 1,00 |
| **Cassava** | 0.60 | 0.85 | 1.10 | 0.90 | 0.86 |
| **Coffee** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Cotton** | 0.35 | 0.78 | 1.20 | 0.60 | 0.73 |
| **Groundnut** | 0.40 | 0.78 | 1.15 | 0.60 | 0.73 |
| **Maize** | 0.30 | 0.75 | 1.15 | 0.60 | 0.70 |
| **Millet** | 0.30 | 0.65 | 1.00 | 0.30 | 0.56 |
| **Oil crops (Simsim)** | 0.35 | 0.75 | 1.15 | 0.35 | 0.65 |
| **Plantain** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Potatoes** | 0.50 | 0.83 | 1.15 | 0.75 | 0.81 |

| | | | | | |
|---|---|---|---|---|---|
| **Pulses** | 0.40 | 0.78 | 1.15 | 0.55 | 0.72 |
| **Rice** | 1.20 | 1.15 | 1.10 | 0.80 | 1.06 |
| **Sorghum** | 0.30 | 0.70 | 1.10 | 0.55 | 0.66 |
| **Soybean** | 0.40 | 0.78 | 1.15 | 0.50 | 0.70 |
| **Sugarcane** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Sweet potatoes** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Tea** | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| **Tobacco** | 0.50 | 0.85 | 1.20 | 0.80 | 0.83 |
| **Wheat** | 0.40 | 0.78 | 1.15 | 0.30 | 0.66 |
| **National mean value** | | | | | 0.87 |

**Table 7e**. *Precipitation (mm) for year 2015 and 2040 as well as annual increase, for each sub-basin and scenario, based on extraction from GAEZ.*

| | **A0L** | **A1L** | **A2L** | **A2H** | **A3L** | **A3H** |
|---|---|---|---|---|---|---|
| **Lake Victoria** | | | | | | |
| **Year 2015 [MCM]** | 1356 | 1370.2 | 1368.7 | 1368.7 | 1373.2 | 1373.2 |
| **Year 2040 [MCM)** | 1356 | 1776.1 | 1726.0 | 1726.0 | 1879.7 | 1879.7 |
| **Annual increase [%]** | 0 | 1.04 | 0.93 | 0.93 | 1.26 | 1.26 |
| **Lake Kyoga** | | | | | | |
| **Year 2015 [MCM]** | 1102 | 1113.6 | 1112.3 | 1112.3 | 1116.0 | 1116.0 |
| **Year 2040 [MCM]** | 1102 | 1443.5 | 1402.7 | 1402.7 | 1527.6 | 1527.6 |
| **Annual increase [%]** | 0 | 1.04 | 0.93 | 0.93 | 1.26 | 1.26 |
| **Victoria Nile** | | | | | | |
| **Year 2015 [MCM]** | 1277 | 1290.4 | 1289.0 | 1289.0 | 1293.2 | 1293.2 |
| **Year 2040 [MCM)** | 1277 | 1672.7 | 1625.5 | 1625.5 | 1770.2 | 1770.2 |
| **Annual increase [%]** | 0 | 1.04 | 0.93 | 0.93 | 1.26 | 1.26 |
| **Lake Edward** | | | | | | |
| **Year 2015 [MCM]** | 1218 | 1230.2 | 1228.9 | 1228.9 | 1232.9 | 1232.9 |
| **Year 2040 [MCM)** | 1218 | 1594.7 | 1549.7 | 1549.7 | 1687.7 | 1687.7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Annual increase [%]** | 0 | 1.04 | 0.93 | 0.93 | 1.26 | 1.26 |
| **Lake Albert** | | | | | | |
| **Year 2015 [MCM]** | 1284 | 1297.4 | 1296.0 | 1296.0 | 1300.2 | 1300.2 |
| **Year 2040 [MCM)** | 1284 | 1681.8 | 1634.3 | 1634.3 | 1779.8 | 1779.8 |
| **Annual increase [%]** | 0 | 1.04 | 0.93 | 0.93 | 1.26 | 1.26 |
| **Aswa** | | | | | | |
| **Year 2015 [MCM]** | 1110 | 1121.9 | 1120.7 | 1120.7 | 1124.6 | 1124.6 |
| **Year 2040 [MCM)** | 1110 | 1454.3 | 1413.3 | 1413.3 | 1539.1 | 1539.1 |
| **Annual increase [%]** | 0 | 1.04 | 0.93 | 0.93 | 1.26 | 1.26 |
| **Albert Nile** | | | | | | |
| **Year 2015 [MCM]** | 1194 | 1206.9 | 1205.5 | 1205.5 | 1209.5 | 1209.5 |
| **Year 2040 [MCM)** | 1194 | 1564.4 | 1520.3 | 1520.3 | 1655.6 | 1655.6 |
| **Annual increase [%]** | 0 | 1.04 | 0.93 | 0.93 | 1.26 | 1.26 |
| **Kidepo** | | | | | | |
| **Year 2015 [MCM]** | 899 | 907.9 | 901.7 | 901.7 | 909.9 | 909.9 |
| **Year 2040 [MCM)** | 899 | 1176.9 | 1143.7 | 1143.7 | 1245.6 | 1245.6 |
| **Annual increase [%]** | 0 | 1.04 | 0.93 | 0.93 | 1.26 | 1.26 |
| | | | | | | |

**Table 7f.** *Reference evapotranspiration (mm) for year 2015 and 2040 as well as the annual change, for each sub-basin and scenario, based on extractions from GAEZ.*

| | A0 | | | A1 | | | A2 | | | A3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2015** | **2040** | **Annual Change [%]** | **2015** | **2040** | **Annual Change [%]** | **2015** | **2040** | **Annual Change [%]** | **2015** | **2040** | **Annual Change [%]** |
| **National** | | | | | 1587 | | | 1619.5 | | | 1627 | |
| **Lake Victoria** | 1391 | 1391 | 0 | 1392.4 | 1429.0 | 0.10 | 1447.1 | 1458.3 | 4.03 | 1447.4 | 1465.1 | 4.05 |
| **Lake Kyoga** | 1680 | 1680 | 0 | 1681.7 | 1726.0 | 0.10 | 1747.7 | 1761.3 | 4.03 | 1748.1 | 1769.5 | 4.05 |
| **Victoria Nile** | 1560 | 1560 | 0 | 1561.6 | 1602.7 | 0.10 | 1622.9 | 1635.5 | 4.03 | 1623.2 | 1643.1 | 4.05 |
| **Lake Edward** | 1277 | 1277 | 0 | 1278.3 | 1311.9 | 0.10 | 1328.5 | 1338.8 | 4.03 | 1328.7 | 1345.0 | 4.05 |
| **Lake Albert** | 1455 | 1455 | 0 | 1456.5 | 1494.8 | 0.10 | 1513.7 | 1525.4 | 4.03 | 1513.9 | 1532.5 | 4.05 |
| **Aswa** | 1720 | 1720 | 0 | 1721.8 | 1767.0 | 0.10 | 1789.4 | 1803.2 | 4.03 | 1789.7 | 1811.6 | 4.05 |
| **Albert Nile** | 1530 | 1530 | 0 | 1531.6 | 1571.9 | 0.10 | 1591.7 | 1604.0 | 4.03 | 1592.0 | 1611.5 | 4.05 |
| **Kidepo** | 1745 | 1745 | 0 | 1746.8 | 1792.7 | 0.10 | 1815.4 | 1829.4 | 4.03 | 1815.7 | 1837.9 | 4.05 |

**Table 7g.** *Net evaporation for year 2015 and 2040 as well as annual increase, for each sub-basin and scenario, based on extractions from GAEZ.*

| | **A0L** | **A1L** | **A2L** | **A2H** | **A3L** | **A3H** |
|---|---|---|---|---|---|---|
| **Lake Victoria** | | | | | | |
| **Year 2015 [m³/s]** | -4483.2 | -395.0 | -391.0 | -391.0 | -391.1 | -391.1 |
| **Year 2040 [m³/s]** | -4483.2 | -19105.1 | -14534.9 | -14534.9 | -14730.9 | -14730.9 |
| **Annual increase [%]** | 0 | 5.73 | 4.64 | 4.64 | 4.68 | 4.68 |
| **Lake Edward/George** | | | | | | |
| **Year 2015 [m³/s]** | 1000 | 82.8 | 83.5 | 83.5 | 83.9 | 83.9 |
| **Year 2040 [m³/s]** | 1000 | 681.4 | 853.6 | 853.6 | 981.7 | 981.7 |
| **Annual increase [%]** | 0 | -1.46 | -0.61 | -0.61 | -0.07 | -0.07 |
| **Lake Kyoga** | | | | | | |
| **Year 2015 [m³/s]** | 3002 | 247.3 | 249.0 | 249.0 | 250.3 | 250.3 |
| **Year 2040 [m³/s]** | 3002 | 2257.0 | 2703.5 | 2703.5 | 3083.3 | 3083.3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Annual increase [%]** | 0 | -1.09 | -0.40 | -0.40 | 0.10 | 0.10 |
| **Lake Albert** | | | | | | |
| **Year 2015 [$m^3$/s]** | 406.7 | 32.5 | 31.7 | 31.7 | 32.5 | 32.5 |
| **Year 2040 [$m^3$/s]** | 406.7 | -140.6 | 68.4 | 68.4 | 130.4 | 130.4 |
| **Annual increase [%]** | 0 | -4.00 | -6.62 | -6.62 | -4.28 | -4.28 |

**Table 7h.** *Municipal and Industry water demand for year 2015 and 2040 as well as annual increase, for each sub-basin and scenario (MWE, 2013).*

| | **A0L** | | **A1, A2 & A3** | |
|---|---|---|---|---|
| | **Municipal** | **Industry** | **Municipal** | **Industry** |
| **Lake Victoria** | | | | |
| **Year 2015 [$m^3$/cap]** | 8.7 | 3.4 | 9.0 | 3.3 |
| **Year 2040 [$m^3$/cap]** | 8.7 | 3.4 | 16.5 | 1.6 |
| **Annual increase [%]** | 0 | 0 | 2.5 | (-2.94) |
| **Lake Kyoga** | | | | |
| **Year 2015 [$m^3$/cap]** | 3.1 | 0.1 | 3.3 | 0.1 |
| **Year 2040 [$m^3$/cap]** | 3.1 | 0.1 | 13.1 | 0.1 |
| **Annual increase [%]** | 0 | 0 | 5.7 | (-2.94) |
| **Victoria Nile** | | | | |
| **Year 2015 [$m^3$/cap]** | 1.9 | 0.2 | 2.0 | 0.1 |
| **Year 2040 [$m^3$/cap]** | 1.9 | 0.2 | 8.6 | 0.2 |
| **[%]** | 0 | 0 | 5.9 | (-2.94) |
| **Lake Edward** | | | | |
| **Year 2015 [$m^3$/cap]** | 2.7 | 0.2 | 2.8 | 0.1 |
| **Year 2040 [$m^3$/cap]** | 2.7 | 0.2 | 8.2 | 0.2 |
| **Annual increase [%]** | 0 | 0 | 4.4 | (-2.94) |
| **Lake Albert** | | | | |
| **Year 2015 [$m^3$/cap]** | 2.2 | 0.1 | 2.3 | 0.1 |
| **Year 2040 [m3/capita]** | 2.2 | 0.1 | 7.7 | 0.1 |
| **Annual increase [%]** | 0 | 0 | 5.0 | (-2.94) |
| **Aswa** | | | | |
| **Year 2015 [$m^3$/cap]** | 1.6 | 0 | 1.7 | 0 |
| **Year 2040 [$m^3$/cap]** | 1.6 | 0 | 4.1 | 0 |

| | | | | |
|---|---|---|---|---|
| **[%]** | 0 | 0 | 3.6 | 0 |
| **Albert Nile** | | | | |
| **Year 2015 [$m^3$/cap]** | 2.7 | 0.1 | 2.8 | 0.1 |
| **Year 2040 [m3/capita]** | 2.7 | 0.1 | 11.2 | 0.1 |
| **Annual increase [%]** | 0 | 0 | 5.7 | (-2.94) |
| **Kidepo** | | | | |
| **Year 2015 [$m^3$/cap]** | 1.7 | 0 | 1.9 | 0 |
| **Year 2040 [$m^3$/cap]** | 1.7 | 0 | 11.2 | 0 |
| **Annual increase [%]** | 0 | 0 | 7.4 | 0 |

**Table 7i.** *Harvested area (ha) for each scenario and crop (FAO, 2015b).*

| | **A1** | **A2 & A3** |
|---|---|---|
| **Banana** | 136.0 | 193.6 |
| **Cocoa** | 48.0 | 68.4 |
| **Coffee** | 312.0 | 444.3 |
| **Cowpea** | 75.0 | 106.8 |
| **Cassava** | 435.0 | 619.5 |
| **Foxtail millet** | 90.0 | 128.2 |
| **Groundnut** | 420.0 | 598.2 |
| **Maize** | 1000.0 | 1424.2 |
| **Pigeonpea** | 105.0 | 149.5 |
| **Pearl millet** | 90.0 | 128.2 |
| **Dryland rice** | 46.5 | 66.2 |
| **Wetland rice** | 46.5 | 66.2 |
| **Soybean** | 160.0 | 227.9 |
| **Sweet potato** | 550.0 | 783.3 |
| **Sorghum** | 350.0 | 498.5 |
| **Sugarcane** | 50.0 | 71.2 |
| **Tea** | 280.0 | 398.8 |
| **Tobacco** | 20.0 | 28.5 |
| **Wheat** | 14.2 | 20.2 |
| **White potato** | 106.0 | 151.0 |

**Table 7j.** *Agriculture water demand for year 2015 and 2040 and annual increase, for each sub-basin and scenario, partly based on extractions from GAEZ (FAO, 2014; Mugisha et al, 2014; Rockström, 2003).*

| | A0L | A1L | A2L | A2H | A3L | A3H |
|---|---|---|---|---|---|---|
| **Lake Victoria** | | | | | | |
| **Year 2015 [$m^3$/cap]** | 6.3 | 6.4 | 6.3 | 6.4 | 6.4 | 6.4 |
| **Year 2040 [$m^3$/cap]** | 6.3 | 6.9 | 6.4 | 9.2 | 6.7 | 7.7 |
| **Annual increase [%]** | 0 | 0.3 | 0.03 | 1.4 | 0.2 | 0.7 |
| **Lake Kyoga** | | | | | | |
| **Year 2015 [$m^3$/cap]** | 9.1 | 9.1 | 9.1 | 9.2 | 9.1 | 9.2 |
| **Year 2040 [$m^3$/cap]** | 9.1 | 10.5 | 9.7 | 13.7 | 11.2 | 11.5 |
| **Annual increase [%]** | 0 | 0.6 | 0.3 | 1.6 | 0.8 | 0.9 |
| **Victoria Nile** | | | | | | |
| **Year 2015 [$m^3$/cap]** | 4.5 | 4.6 | 4.6 | 4.7 | 4.6 | 4.6 |
| **Year 2040 [$m^3$/cap]** | 4.5 | 7.3 | 6.4 | 10.2 | 8.0 | 8.2 |
| **Annual increase [%]** | 0 | 1.9 | 1.4 | 3.2 | 2.2 | 2.3 |
| **Lake Edward** | | | | | | |
| **Year 2015 [$m^3$/cap]** | 3.8 | 3.9 | 3.9 | 3.9 | 4.0 | 3.9 |
| **Year 2040 [$m^3$/cap]** | 3.8 | 5.1 | 4.6 | 7.0 | 5.5 | 5.7 |
| **Annual increase [%]** | 0 | 1.1 | 0.7 | 2.3 | 1.4 | 1.5 |
| **Lake Albert** | | | | | | |
| **Year 2015 [$m^3$/cap]** | 4.5 | 4.6 | 4.6 | 4.7 | 4.6 | 4.7 |
| **Year 2040 [m3/cap]** | 4.5 | 7.4 | 6.5 | 10.3 | 8.0 | 8.2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Annual increase [%]** | 0 | 1.9 | 1.6 | 3.2 | 2.2 | 2.3 |
| **Aswa** | | | | | | |
| **Year 2015 [$m^3$/cap]** | 4.5 | 4.6 | 4.6 | 4.7 | 4.6 | 4.7 |
| **Year 2040 [m3/cap]** | 4.5 | 9.4 | 7.9 | 14.1 | 10.4 | 10.7 |
| **Annual increase [%]** | 0 | 2.9 | 2.2 | 4.5 | 3.3 | 3.4 |
| **Albert Nile** | | | | | | |
| **Year 2015 [$m^3$/cap]** | 5.1 | 5.2 | 5.1 | 5.2 | 5.2 | 5.2 |
| **Year 2040 [$m^3$/cap]** | 5.1 | 8.6 | 7.4 | 12.1 | 9.4 | 9.6 |
| **Annual increase [%]** | 0 | 2.1 | 1.5 | 3.4 | 2.4 | 2.5 |
| **Kidepo** | | | | | | |
| **Year 2015 [$m^3$/cap]** | 15.1 | 15.4 | 15.3 | 15.6 | 15.4 | 15.4 |
| **Year 2040 [$m^3$/cap]** | 15.1 | 24.8 | 21.7 | 34.9 | 27.1 | 27.7 |
| **Annual increase [%]** | 0 | 1.9 | 1.4 | 3.3 | 2.3 | 2.4 |

**Table 7k.** *Demand projections (from OSeMOSYS)*

| Hydropower plant | Kiira | Bujagali | Nalubaale | Isambia | Karuma | Ayago |
|---|---|---|---|---|---|---|
| **2014** | 2.43 | 5.05 | 2.18 | - | - | - |
| **2015** | 2.43 | 5.05 | 2.18 | 1.70 | - | - |
| **2016** | 2.43 | 5.05 | 2.18 | 3.41 | - | - |
| **2017** | 2.43 | 5.05 | 2.18 | 3.41 | 5.44 | - |
| **2018** | 2.14 | 3.64 | 2.18 | 3.41 | 10.87 | 5.44 |
| **2019** | 2.40 | 4.07 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2020** | 2.43 | 5.04 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2021** | 2.43 | 4.92 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2022** | 2.43 | 4.82 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2023** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **2024** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2025** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2026** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2027** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2028** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2029** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2030** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2031** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2032** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2033** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2034** | 2.43 | 5.05 | 2.18 | 3.41 | 10,87 | 10.87 |
| **2035** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2036*** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2037*** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2038*** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2039*** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |
| **2040*** | 2.43 | 5.05 | 2.18 | 3.41 | 10.87 | 10.87 |

**The demand for 2036-2040 are assumed to be the same as the demand for 2035.*

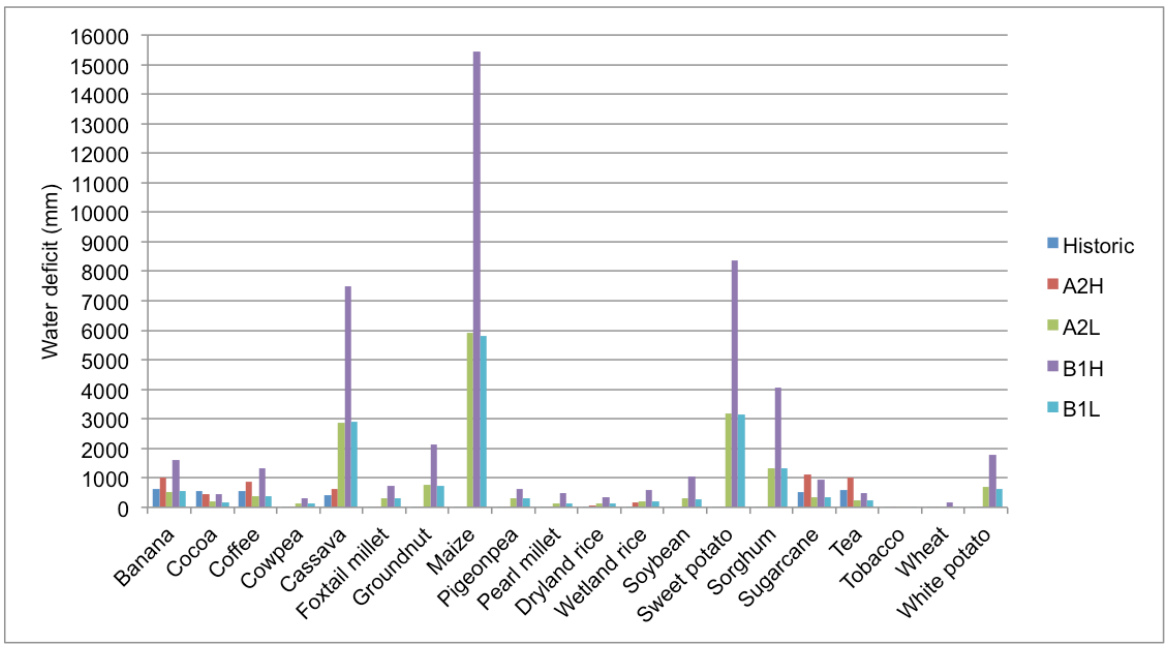



**Figure 7a.** *Total average water deficit (mm) for each crop and scenario, extracted from GAEZ (mm).*

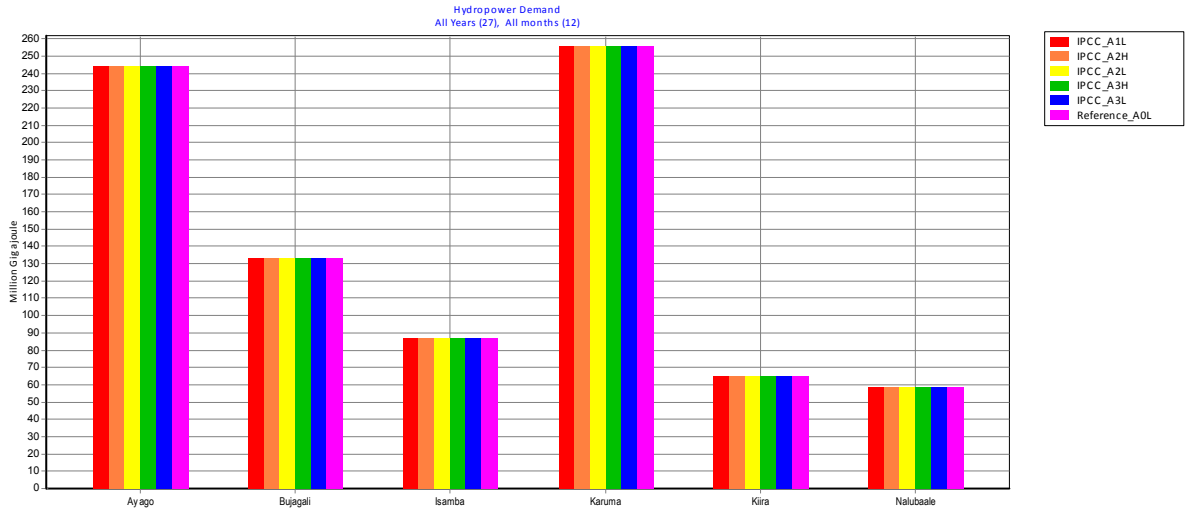



**Figure 7b.** *Hydropower demand for the different power plants for all scenarios (million GJ) (WEAP).*




**Figure 7c.** *The total mean generation and demand for the different scenarios for Kiira hydropower plant from 2015-2040 (million GJ) (WEAP).*