Economic Assessment of the Impacts of Climate Change in Uganda

Data Water Sector Report

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LIST OF ACRONYMS

Acronym	Definition
CRU	Climate Research Unit
DSM	Demand Side Management
FAO	Food and Agricultural Organization of the United Nations
GDP	Gross Domestic Product
GNI	Gross National Income
GoU	Government of Uganda
IPCC	International Panel for Climate Change
IRWR	Internal Renewable Water Resources
MCM/y	Millions of cubic meters per year
MWE	Ministry of Water and Environment
NDP	National Development Plan
NPV	Net Present Value
PPP	Purchasing Power Parity
SSP	Socioeconomic Scenarios
RCC	Reinforced Cement Concrete
RCP	Representative Concentration Pathways
US CPI	United States Consumer Price Index
VSL	Value of a Statistical Life
WEAP	Water Evaluation and Planning

EXECUTIVE SUMMARY

Climate change and variability are already affecting the availability of water in Uganda and this is expected to increase over time. The main economic sectors directly affected by water supply and variability are agriculture and livestock, fisheries, aquaculture, forestry and tourism. Complementary sectors include lake transport and energy production; social sectors that are impacted are health and nutrition and water and sanitation.

In this report an estimate is made of water demand by sector (agriculture, households and industry) in each of the eight watersheds in the country. This is compared with the supply likely to be available. From the two an estimate is arrived at of the unmet demand, now and in the future under given climate scenarios. This unmet demand (part of which arises from climatic factors and part from socioeconomic changes) is then valued in monetary terms. In addition to looking at 'normal' conditions in the future the report also analyses the situation in the case of a drought and how that would translate into losses in the future.

The basic tool that has been used to undertake the analysis is the Water Evaluation and Planning tool (WEAP). This matches water supplies and competing demands, and thus assesses the upstream–downstream links for different management options in terms of their resulting water sufficiency, and unmet demands, costs, and benefits. The model has been calibrated to reproduce water runoff in each of the watersheds and the resulting fit provides a basis for making projections into the future.

Estimates have been made of water demand by sector (households, industry, livestock and agriculture) for each of the watersheds from 1981-2010. During this period average availability was sufficient in most months to meet supply although there were some periods when unmet demand was as high as 5% of total demand. In the future, however, projections are for a much greater level of demand and some potential reductions in supply. Total demand is expected to increase from 408 million cubic meters a year (MCM/y) in 2010 to 3,963 MCM/y in 2050. Total unmet demand will then rise from 3.7 MCM/y to 1,651 MCM/y in this period. In most months water shortages will be enormous.

The unmet demand has been valued in money terms based on methods that are widely used in this field. These methods elicit the willingness to pay of different water users (households, farmers, industry representatives) for additional amounts of water by using sophisticated techniques involving questionnaires developed following careful protocols on research in this area. Overall, the expected cost in 2050 is anticipated to be of the order of 14,558 billion shillings (US$5.5 billion). This is a conservative estimate and the figure could be as much as ten times higher if income effects on willingness to pay are taken into account. Domestic consumption is likely to be impacted in three watersheds: Lake Victoria, Aswa and Kidepo. The largest overall economic losses are anticipated to be in the Lake Victoria, Albert Nile and Lake Kyoga watersheds. These values underline the need for further investment in the water supply infrastructure in Uganda. With or without climate change the economic losses are of a significant magnitude.

In addition to unmet demand under average conditions the report has also looked at droughts. Past extreme events of water shortage have had major impacts, with two droughts in the past decade (in 2005-6 and 2010-11) resulted in losses of $250 million and $1174 million respectively. Each drought lasts about 3 years representing an average annual damage per drought event in the last decade of $237 million.

Adaptation measures to deal with these serious problems include those that improve efficiency on the demand side, those that improve water storage and increase availability and those that reduce losses from extreme events. The report has looked at the costs of proposed actions documented in the Government's Costed Implementation Strategy and compared them to the potential benefits in terms of reducing unmet demand or in reducing losses from droughts. Three programmes, which account for 92% of the Government's strategy were examined: Programme A focuses on improvements in water use efficiency, Programme B addresses water supply issues for agriculture and industry and Programme C sets up an Integrated Water Resources Management system that would help reduce losses from droughts and floods.

In each case the model calculates the minimum reduction in damages required for the project to generate a 10% rate of return. The results indicate that even with a very small impact on unmet demand programmes A and B would generate this return. For programme A it requires a mere 0.5% reduction (i.e. just of one half of one percent) for the programme to reach this return. For programme B the required reduction is even smaller – only 0.4% of the unmet demand in agriculture and industry. Finally for programme C the required reduction in damages from droughts is only 4.5%.

The implications of such a preliminary analysis are that the benefits of action to adapt in the water sector are very high and further investments may well be justified. Of course, the latter is not proven and more work is needed to link the programmes to reductions in damages but there is some a priori evidence to support the case. This could be undertaken as part of the MWE World Bank mandate.

Further work on adaptation in the sector requires detailed data at the local level. Such data should be available from the case studies to be carried out. Once available their findings can be added to this report

1. INTRODUCTION

Climate change and variability are already affecting the availability of water in Uganda and this is expected to increase over time. In recent years the country has be subjected to the La Niña drought event of 1998-2000 and the El Niño-Southern Oscillation (ENSO) wet phase and floods event of 1997-1998, both of which caused considerable loss and disruption.

The sources of the effects include changes in precipitation patterns, increased frequency of floods and droughts, and changes in evaporation due to higher temperatures. All of these affect the amount of water available, both directly and through its impacts on infrastructure related to water. At the same time the country is facing major socioeconomic change, especially population growth and increasing incomes, that is resulting in an increased demand for water in the country. Since water is a key base for almost all human activity the consequences of these changes are very significant throughout the economy and society. As the Government's Water Adaptation Strategy Report (GoU, 2011) notes the main economic sectors that are directly affected by water supply and variability are agriculture and livestock, fisheries and aquaculture, forestry and tourism. Complementary sectors include lake transport and energy production. Social sectors that are impacted include health and nutrition and water and sanitation.

This report does not attempt to model the complex linkages between water availability and economic activity in the various sectors. That would require more resources and time than was available for the assignment. Instead what has been undertaken is an estimate of water demand by sector (agriculture, households and industry) in each watershed. This is compared with the supply that is likely to be available and from the two an estimate is arrived at of the unmet demand, now and in the future under given climate scenarios. This unmet demand (part of which arises from climatic factors and part from socioeconomic changes) is then valued in monetary terms. In addition to looking at 'normal' conditions in the future the report also analysis the situation in the case of a drought and how that would translate into losses in the future.

These estimates provide the basic information for the assessment of different policies and measures that can reduce the unmet demand and address drought conditions. A number of these have been identified in the government's adaptation strategy and in the Costed Implementation Strategy (GoU, 2012). Unfortunately that report does not provide an indication of how much of the gap is reduced by particular measures and so a full cost benefit assessment cannot be carried out. Nevertheless an attempt is made to relate the measures to the benefits of reducing unmet demand and to provide a partial assessment of the rates of return that the measures would give at different levels of efficiency. Further information on adaptation options will come from the case studies that are yet to be carried out.

The report is structured as follows. Section 2 presents the current water supply and demand situation in Uganda. Section 3 gives an overview of the methodology employed. Section 4 discusses the scenarios used in the analysis. Section 5 develops the modelling framework. Section 6 presents evidence on the climate change impacts and Section 7 discusses the allocation rules for water in Uganda. Section 8 presents estimates of the unmet demand by user type, with Section 9 discussing the methods to value these impacts. Section 10 presents the estimated economic losses. Section 11 presents a case study of the costs of an extreme event – the drought in 2010-2011. Section 12 gives an overview of adaptation options in the water sector, and finally Section 13 presents the conclusions.

This report was written by Tim Taylor and Anil Markandya of Metroeconomica, Peter Droogers of Future Water and Albert Rugumayo. We gratefully acknowledge the helpful comments and suggestions provided on initial results by Government of Uganda officials and others during the mission to Uganda in September 2014.

2. CURRENT WATER DEMAND AND SUPPLY

2.1. General Overview of Water Issues

Uganda[1] is a landlocked country located at the equator. The total population of the country is estimated at 34.9 million, of which 88 percent is rural. The annual population growth rate is 2.8 percent. The national average population density is 188 inhabitants/km^2 (Source: World Bank). About 54 percent of the population is concentrated on the shores of Lake Victoria and in the southern part of the country. Uganda has a total area of 241,040 km^2, a north-south extent of about 650 km and a maximum east-west extent of about 500 km. Much of the country lies at an altitude of 900 to 1,500 m, with an average altitude of 1,200 m. About 18 percent of the total area of the country is open water, and large areas are covered by swamps. The highest mountains of the country are Mount Stanley, 5,109 m, at the border with the Democratic Republic of Congo followed by Mount Elgon, 4,321 m, at the border with Kenya.

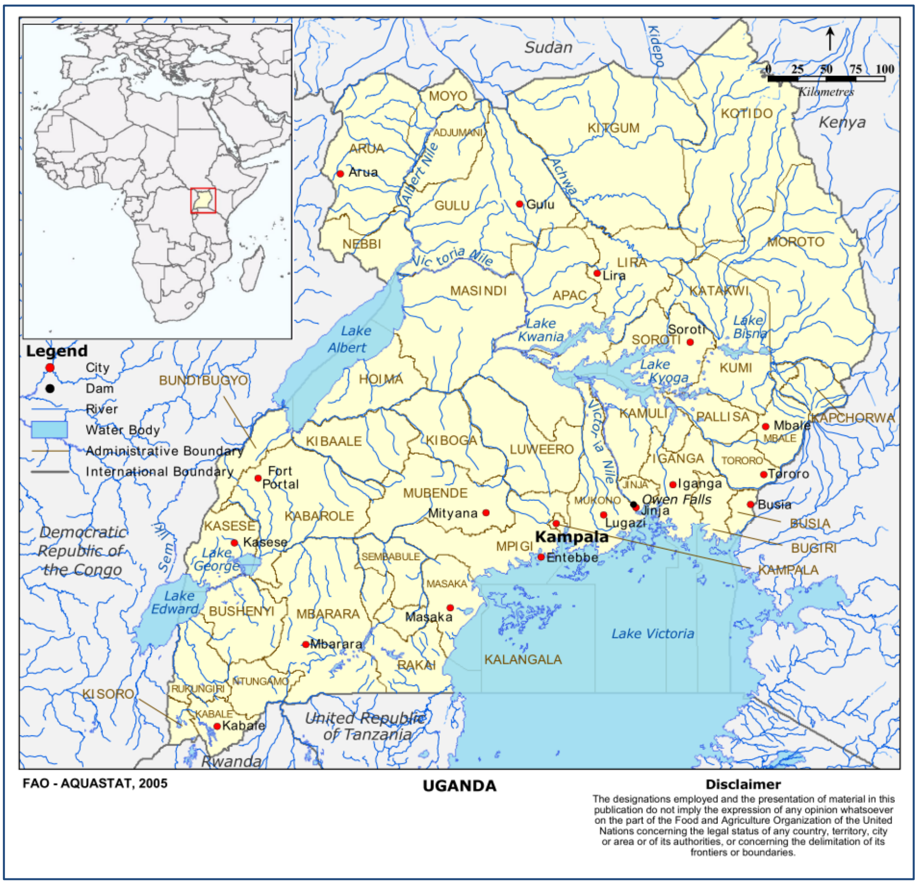
Uganda has an equatorial climate with small regional variations in annual temperature and humidity. Precipitation varies from 750 mm/yr in the Karamajong pastoral areas in the northeast to 1,500 mm/yr in the high rainfall areas on the shores of Lake Victoria, around the highlands of Mount Elgon in the east, the Ruwenzori Mountains in the southwest, Masindi in the west and Gulu in the north. Mean annual rainfall is estimated at 1,180 mm. The southern part of the country is generally well-watered with two rainfall peaks occurring in March-May and August-November without any pronounced dry season in between, whereas in the north there is a marked dry season from November to March. Figure 1 shows the main rivers in the country. Figure 2 & Figure 3 indicate the temporal and spatial variation in rainfall.

Seasonal and spatial variability of precipitation causes specific problems as the country encompasses both humid and semi-arid areas. There are not only differences between distinct wet and dry years, but there are also considerable variations in the timing of the onset of seasons and in the amount of rainfall and hence stream flow. Even in the high rainfall areas around Lake Victoria there is a moisture deficit during the periods December-February and June-September. The mean annual temperature over most of the country is in the range of 18 °C to 35 °C and the mean monthly evaporation rates are between 125 and 200 mm.

Climate change is a potential threat to the country's freshwater resources and the socio-economic activities depending on those freshwater resources. While the general warming trend of the global climate, predicted by all global circulation models would lead to an increase in the evaporation rate, its possible impact on rainfall on the equatorial plateau is not yet completely understood. The latest projections made as part of this project indicate that there may be a slight decrease in annual precipitation. However climate change is expected to increase climatic variability by shifting and intensifying extremes, which could lead to more severe drought and flood events. For this too, however, there are no firm predictions.

[1] Summarized from FAOs AquaStat

Figure 1. Overview of main rivers in Uganda.



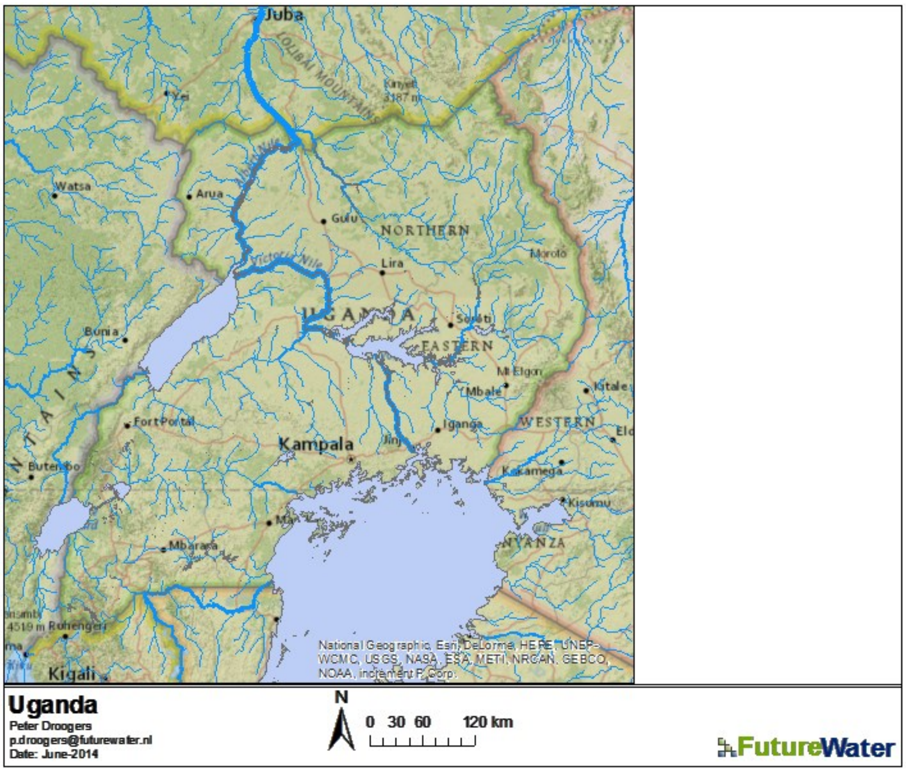
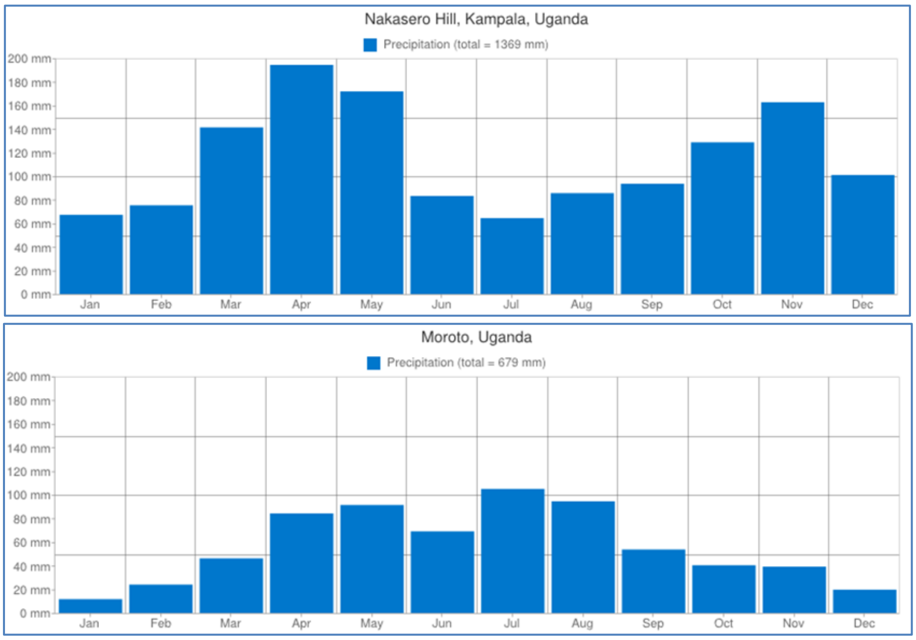
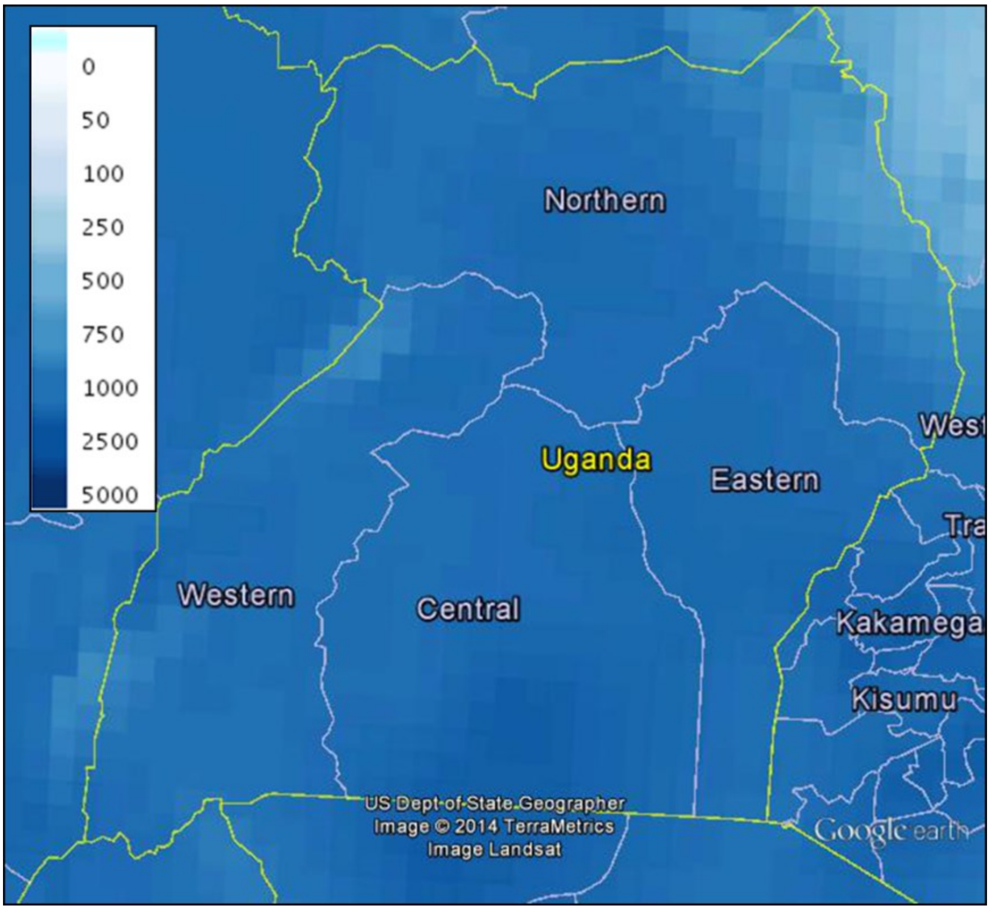


Figure 2. Typical example of precipitation variation within Uganda: Kampala (top) and Moroto (bottom) in the North-East of the country.



Source: www.SamSamWater.com

Figure 3. Annual precipitation across Uganda.



Source: CRU CL2.0 (New et al., 2000)

2.2. Water Supply and Demand

As noted, average precipitation in Uganda is 1180 mm/yr; which totals to about 280 km^3/yr over the entire country. Most of this rainfall is evaporated and does not enter streams or deep groundwater. Internal surface water resources are therefore only a fraction of the total precipitation and are estimated to be 39 km^3/yr, while groundwater is believed to be around 29 km^3/yr. Since this groundwater is considered to be overlapping with surface water, the total Internal Renewable Water Resources (IRWR) are estimated to be 39 km^3/yr (Table 1**Error! Reference source not found.**). External water resources of 27 km^3/yr comprise inflow from Lake Victoria (25 km^3/yr) as well as inflow via Lake Edward and Lake Albert from the Democratic Republic of Congo. The total renewable water resources of the country are estimated to be 66 km^3/yr. (Source: AquaStat)

Total water withdrawal of the country was 300 million m^3 in 2002, representing 0.4 percent of total renewable water resources. The greatest water user was the domestic sector with 134 million m^3, followed by irrigation and livestock with 120 million m^3, and industry with 46 million m^3 (Table 2).

The main hydropower facility is the Naluballe Power station (formerly Owen Falls Dam) located at the outlet of Lake Victoria. Completed in 1954, it has an installed hydropower capacity of 180 MW. The Kiira plant has an installed capacity of 200MW. ,. The construction of the 250 MW Bujagali hydropower plant near Jinja, about 8 km north of Lake Victoria, was completed in 2012. Its reservoir has a capacity of 750 000 m^3. Other projected schemes located along the Nile downstream of Owen Falls include the Isimba power station (183MW) now under construction (planned to enter in operation in 2018) and the planned Ayago (600 MW) and Karuma (600 MW) projects.

Table 1. Renewable water resources in Uganda. Source: Aquastat

Renewable water resources			
Average precipitation		1 180	mm/yr
		284.4	10^9 m^3/yr
Internal renewable water resources		39	10^9 m^3/yr
Total actual renewable water resources		66	10^9 m^3/yr
Dependency ratio		40.9	%
Total actual renewable water resources per inhabitant	2004	2 472	m^3/yr
Total dam capacity	2002	1	10^6 m^3

Table 2. Water withdrawal in Uganda. Source: Aquastat

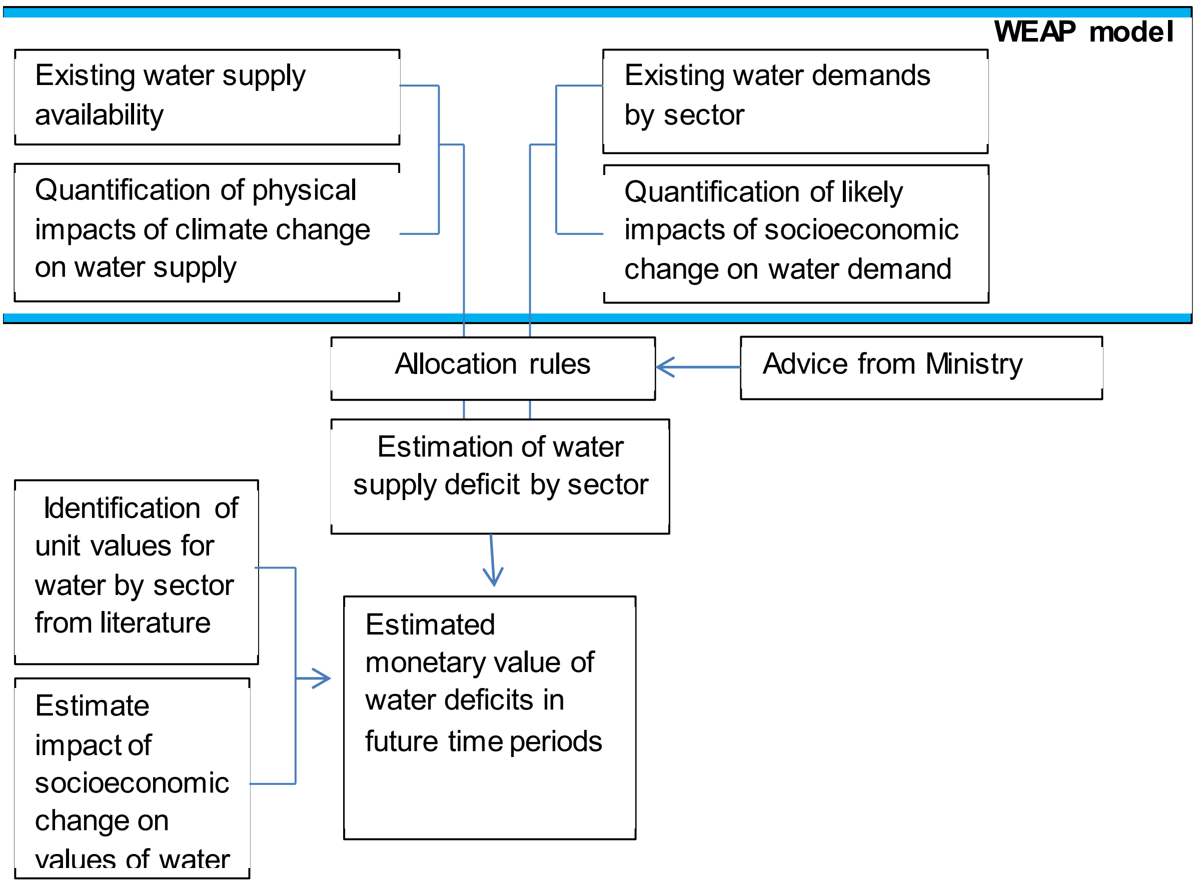
Water withdrawal			
Total water withdrawal	2002	300	10^6 m^3/yr
- irrigation + livestock	2002	120	10^6 m^3/yr
- municipalities	2000	134	10^6 m^3/yr
- industrial	2000	46	10^6 m^3/yr
• per inhabitant	2002	12	m^3/yr
Surface water and groundwater withdrawal	2002	300	10^6 m^3/yr
• as % of total actual renewable water resources	2000	0.5	%

3. METHODOLOGY

An overview of the methodology employed is given in Figure 4. We follow the standard approach of first estimating the physical impacts of climate change and then placing monetary values on these impacts using appropriate existing literature. The Water Evaluation and Planning (WEAP) model takes existing water sources and estimates of supply by watershed. It takes the information on demand by sector and watershed and compares the two. Where deficits are found the model takes an allocation rule (based on government advice) and applies it to estimate the deficit by sector. The economic component of the model then values the resulting deficits.

One complication for water is the significant impact that socioeconomic change will have on water demand and hence on future water shortages. Socioeconomic change will significantly increase water demands, and given that the modelling used in this chapter balances demand and supply, it is difficult to disentangle the impact of each. As such we have not attempted to separate the signal for climate change from that for socioeconomic change – i.e. in this report we consider the adaptation deficit alongside the climate change impact.

Figure 4. Overview of methodology



4. Baseline Scenarios

Before going into the details of the estimates it is essential to lay out the forecasts for Gross Domestic Product (GDP) and the climate scenarios that underlie the forecasts. The results presented here combine two Socioeconomic Scenarios (SSP), as defined by IPCC, with two Representative Concentration Pathways (RCP), also defined by IPCC. The SSP scenarios chosen are SSP1 and SSP5 and are described as follows.[2]

SSP1 assumes that: "relatively good progress is made towards sustainability, with sustained efforts to achieve development goals, while reducing resource intensity and fossil fuel dependency. There is rapid development of low-income countries, a reduction of inequality (globally and within economies), rapid technology development, and a high level of awareness regarding environmental degradation. The world is characterized by an open, globalized economy, with relatively rapid technological change."

SSP5 stresses conventional development oriented toward economic growth as the solution to social and economic problems through the pursuit of enlightened self-interest. The preference for rapid conventional development leads to an energy system dominated by fossil fuels, resulting in high GHG emissions and challenges to mitigation.

The corresponding GDP estimates for Uganda are given in Table 3.

The RCP pathways chosen for the climate assessment are RCP4.5 and RCP8.5. RCP 4.5 is associated with a +4.5 W.m-2 radiative forcing (≈553 ppm CO_2) in 2100. RCP 8.5 is a more extreme concentration pathway, which is associated with a +8.5 W.m-2 radiative forcing (≈1284 ppm CO_2) in 2100. Further details of the RCP scenarios can be found in Baastel Consortium (2014b). The national temperature and precipitation for Uganda are given in that report and the relevant sections for this analysis are reproduced below as Table 4.

In this analysis SSP1 has been combined with RCP4.5 and SSP5 with RCP8.5. Although the two are not proven to go together there is a strong presumption that SSP1 is consistent with the more climate friendly RCP and SSP5 is consistent with the less climate friendly RCP.

Table 3. GDP Projections for Uganda to 2050 US$2005 Billion.

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
SSP1	38.4	50.6	71.1	105.1	159.6	243.7	366.8	540.3	776.1
Growth % p.a.		5.7%	7.0%	8.1%	8.7%	8.8%	8.5%	8.1%	7.5%
SSP5	38.4	50.6	71.3	108.2	173.3	281.4	445.1	681.7	1009.9
		5.7%	7.1%	8.7%	9.9%	10.2%	9.6%	8.9%	8.2%

Source: OECD, taken from IIASA

Table 4. Comparison of results under the RCP 4.5 and RCP 8.5 concentration pathways for Uganda.

Parameter	RCP 4.5	RCP 8.5
Annual temperature changes from the median	In +50 years to present: +1.5ºC to +2ºC in most continental parts of Uganda In +80 years from present: +2ºC to +2.5ºC in most of Uganda.	In +50 years to present: +2ºC to +3ºC in most continental parts of Uganda In +80 years from present: +4ºC to +5ºC in most of Uganda.
Annual rainfall	In both +50 and +80 years: -5 mm (mostly in the northern half) to -10mm per month (mostly in the	In both +50 and +80 years: -10mm to -20mm (mostly in the northern half) to -30mm per month (mostly in the

[2] Further details of the projections are available from https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=series. When you get to the site you need to log in as a guest.

changes from the median	southern half). Up to -70mm per month over lake Victoria.	south). Over -100mm per month over lake Victoria.

Source: Rautenbach, 2014

5. MODELLING FRAMEWORK

5.1. WEAP overview

In this analysis, we use the WEAP model. The Water Evaluation and Planning tool (WEAP) has been developed to meet this need. It uses the basic principle of water balance accounting: total inflows equal total outflows, net of any change in storage (in reservoirs, aquifers and soil). WEAP represents a particular water system, with its main supply and demand nodes and the links between them, both numerically and graphically.

The WEAP model was populated by data from Uganda. The most relevant data sources are:

- Water demand: originating from data documented by the Ministry of Water and Environment, Directorate of Water Resources Management (MWE, 2013).
- Precipitation is obtained from the Climate Research Unit (CRU) data set over the period 1980-2010.
- Runoff coefficients were used as presented by MWE, 2013.

Some limited tests of model performance were conducted, which suggests the model performs fairly well. However, it should be noted that full calibration and validation of the model was beyond the scope of this project. Further detail on the WEAP model set up is given in the annex.

6. CLIMATE CHANGE IMPACTS

This Chapter presents an analysis of the impact of climate change and socio-economic development on the water resources in Uganda. First the current water demand, supply and shortages are analyzed, followed by future changes. The third section will explore some potential adaptation strategies. All analysis has been done using the WEAP modelling framework as discussed in the previous Chapter.

6.1. Current water demand, supply and shortages

The WEAP modelling framework as introduced in the previous Chapter is used to analyse current and recent historic water demand, supply and shortages. For this a period of 30 years (1981-2010) has been used to ensure that annual variability will be included in the analysis. Moreover, the model was setup on a monthly basis to ensure that within-year variations can be captured as well.

The most important results can be summarized as follows:

- Total water demand in the country is 408 million cubic metres per year(MCM/y);Water demand is highest in the Lake Kyoga and Lake Victoria watersheds (Figure 5);
- Water demand per sector differs for each watershed substantially;
- Total unmet demand is on average 3.7 MCM/y. Maximum unmet demand in one particular year was as high as 19.9 MCM/y (Figure 6);
- In most months sufficient water can be delivered but there have been periods when supply met as little as 50% or 75% of demand (Table 5 and Figure 6). Note these do not consider loss, reuse and demand side management (DSM).
- The figures in the graphs are averages for the reference period (1981-2010)

Figure 5: Total annual demand for the eight watersheds (top) and per sector for Lake Victoria (bottom-left) and Lake Kyoga (bottom-right).

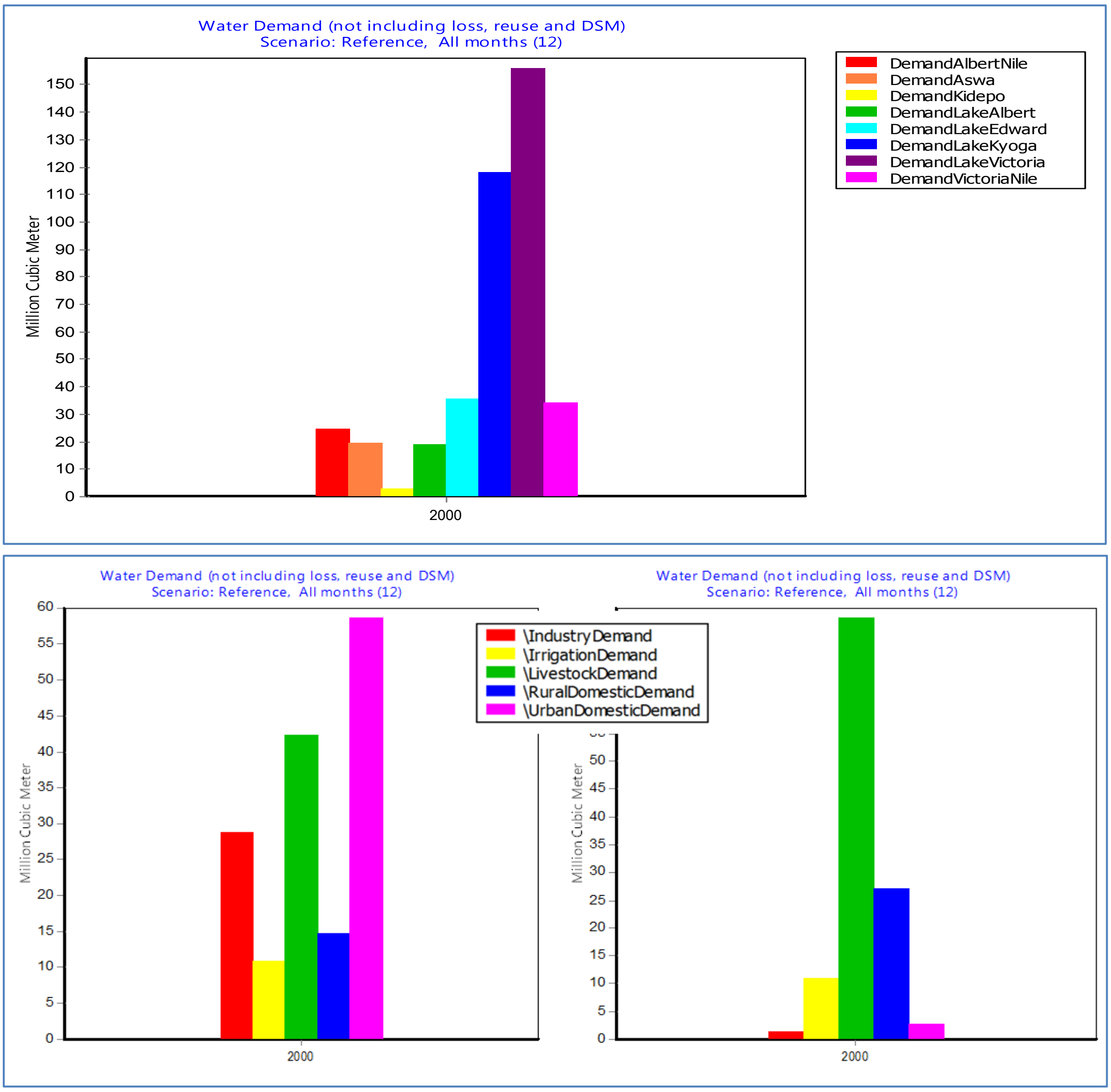
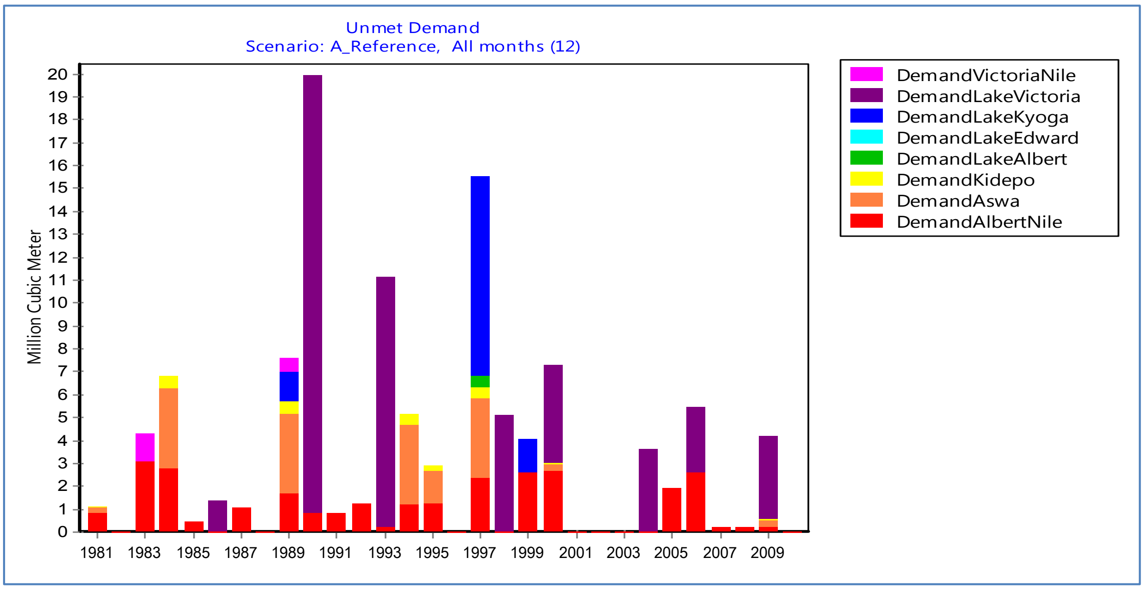


Figure 6: Unmet demand (water shortage) for the eight watersheds as total per year (top) and monthly average coverage (bottom) for the period 1981-2010 as calculated using WEAP.



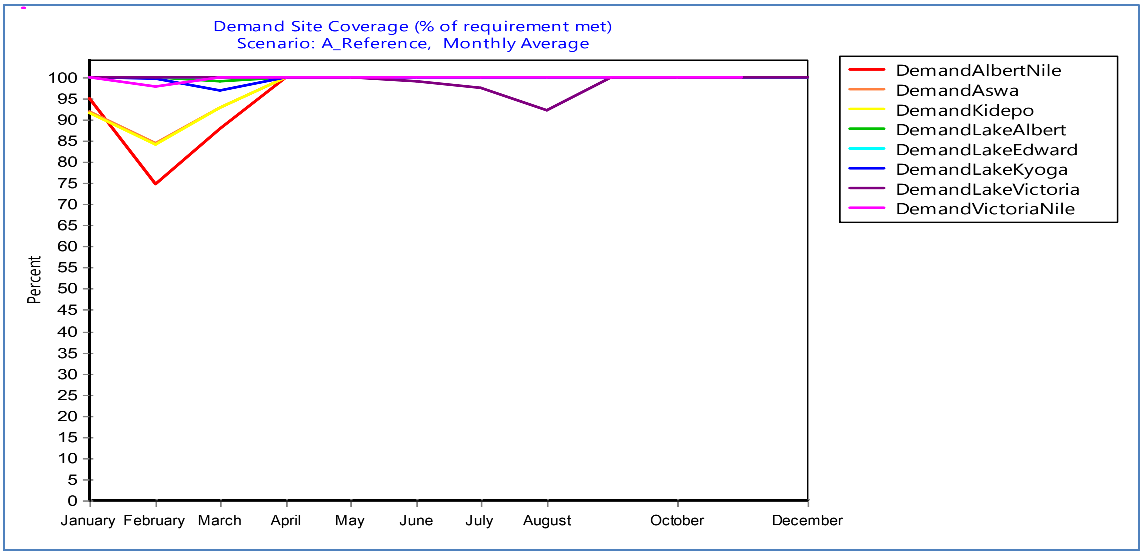
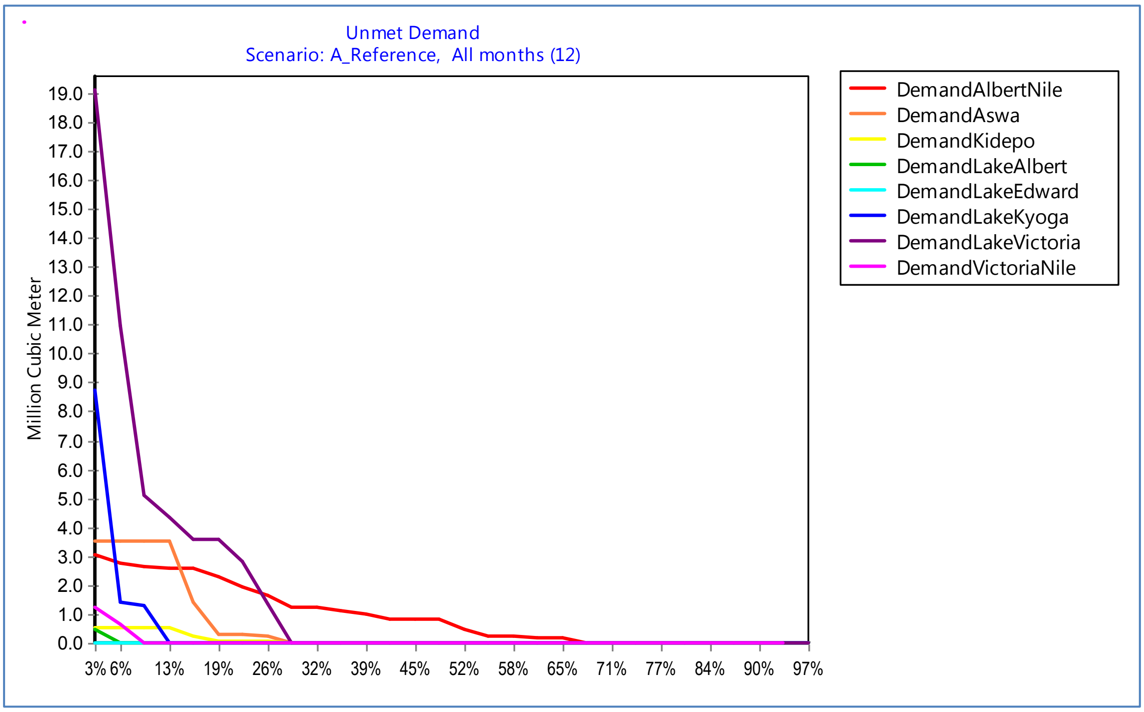


Table 5: Coverage of water demand per month. Results show number of months (out of 360) when water demand is not covered for 99%, 90%, 75% and 50% for the reference period (1981-2010).

	Months (in 30 year) where coverage of XXX% is met			
	99%	90%	75%	50%
Lake Victoria	11	10	6	2
Lake Kyoga	3	3	1	1
Victoria Nile	2	2	1	0
Lake Edward	0	0	0	0
Lake Albert	1	1	1	0
Aswa	13	13	10	9
Albert Nile	27	22	21	10
Kidepo	13	13	10	9

Figure 7. Unmet demand (water shortage) for the eight watersheds plotted as percent of time exceeded per year for the period 1981-2010.



6.2. Future water demand, supply and shortages

6.2.1. Setup

Future water resources will be influenced by: (i) climate change as well as (ii) socio-economic developments. Climate change projections can be obtained from various sources preliminary based on the IPCC 5^{th} assessment report and the associated CMIP5 database covering output of the major GCMs. It is important to note that instead of having one climate projection the IPCC defined a set of most likely scenarios (pathways) based on expected changes in greenhouse gas emission. The four Representative Concentration Pathways (RCPs) are RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively). Downscaled projections for Uganda for RCP4.5 and RCP8.5 were given in Table 4.

A detailed discussion on socio-economic development and the impact on water resources are provided in the study described in the 2013 report National Water Resources Assessment (MWE, 2013). Results of this study are summarized in Table 6 toTable 9, indicating that especially water demanded by the irrigation sector will increase substantially. Total water demand will increase from 414 MCM/year to 2,222 MCM/y, an increase of over 400% in a period of 20 years (2009 to 2030). These numbers are used to derive total water demands as well as demands by sector in 2050 by assuming that the trend from current to 2030 will continue. Table 9shows these projected water demands in 2050, indicating that total demand will increase from 414 MCM/y to 4,030 MCM/y in that year, almost a 10-fold increase.

The above changes in water demands should be considered in terms of potential changes in water resources. Water resources are a function of two major processes: changes in precipitation (total and extremes), and changes in evaporation due to higher temperatures. These two main changes should be considered in the context of the highly non-linear processes in hydrology (e.g. a change of 10% in rainfall will often lead to a substantial higher change in runoff). To evaluate those changes in a proper way a sophisticated hydrological model is recommended to provide most accurate results. In the context of this study we use a proxy of these complex processes by changing the monthly rainfall and the runoff coefficients in the WEAP modelling framework.

Sources of the exact impact of climate change on water resources are somewhat scarce. The 2013 report National Water Resources Assessment (MWE, 2013) states that an increase in annual rainfall of 10-20% during the 21st century and a change in the seasonal distribution of rainfall can be expected. Rainfall is projected to increase from December to February and decrease from June to August. The major impact of climate change is an increase in the frequency of intense rainfall events resulting from increased water vapor in the atmosphere, as a consequence of higher evaporation rates over the oceans. Rising temperatures will particularly affect the semi-arid areas because deficits in atmospheric moisture vapor pressure at the planetary boundary layer cannot be met by water stored in the soil. This will change conditions in the drier north-eastern and south-western areas but are of less concern around Lake Victoria. However, in contradiction to this, the same report also assumed that internal renewable water resources will remain the same (Table 8-2 in MWE, 2013).

Probably the most accurate and up-to-date information on changes in water supply can be obtained from Water2Invest (Figure 9). This project, funded by the European Commission through its Climate-KIC initiative, provides a global overview of water supply and demand till the end of this century based on advanced hydrological and water resources modelling. Results are based on analyses using advanced models running at daily and monthly time-scales and covering a broad set of climate (RCPs) and socio-economic projections (SSPs). Uganda is covered by three so-called Water Provinces and the monthly changes in Internal Renewable Water Resources are shown in Table 10 and Figure 10. The big advantage of using the results of Water2Invest is that not only are changes in rainfall considered, but also changes in evaporation and therefore runoff.

Other sources of information, although often based on the outdated IPCC projections, are (amongst some others):

- World Bank Climate Change Knowledge Portal
- The Nature Conservancy Climate Change Knowledge Portal
- WeADAPT
- UNDP Climate Change Country Profiles

The WEAP modelling framework has been expanded by including above information to analyse changes in water demand, supply and shortages. In summary, the model has been expanded by:

- Changing the water demand according to the numbers as shown in Table 9.
- Changing the water supply according the Water2Invest numbers by altering the runoff numbers according to Table 10.

Figure 8. Global average surface temperature change

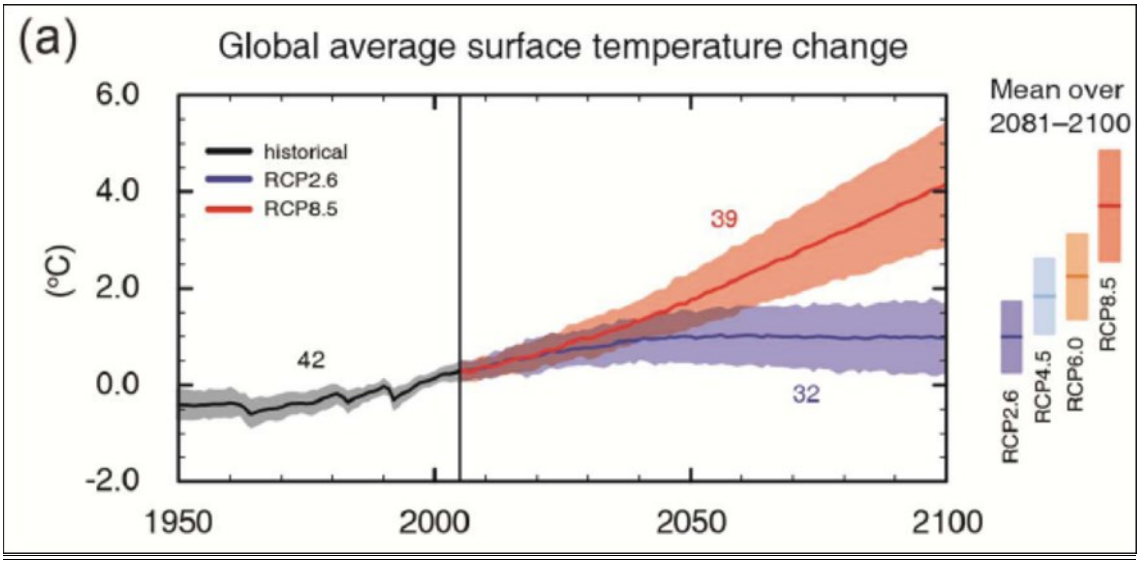


Table 6. The current (2009) water demand (MCM/y) in each basin in Uganda. IRWR = Internal renewable water resources, EI = exploitation index (= demand/IRWR)*100.

Current								
Watershed	Urban Domestic	Rural Domestic	Industrial	Livestock	Irrigation	Total	IWRW	EI
Lake Victoria	58.6	14.8	28.9	42.3	10.9	155.5	1,680	9.3
Lake Kyoga	2.6	27.1	1.3	75.7	11.1	117.8	2,320	5.1
Victoria Nile	1.6	8.3	0.8	23.2		33.9	1,440	2.4
Lake Edward	1.8	12.5	0.9	18.1	2.2	35.5	4,470	0.8
Lake Albert	0.8	5.2	0.4	12.5		18.9	2,890	0.7
Aswa		5.1		14.2		19.3	1,770	1.1
Albert Nile	0.5	7.8	0.3	15.6		24.2	450	5.4
Kidepo		0.3		2.6		0.3	210	1.4
Misc		1		8.2		9.2	360	2.5
Total	65.9	82.1	32.6	212.4	24.2	414.6	15590	2.8

Table 7. The projected (2030) water demand (MCM/y) in each basin in Uganda. IRWR = Internal renewable water resources, EI = exploitation index (= demand/IRWR)*100.

2030								
Watershed	Urban Domestic	Rural Domestic	Industrial	Livestock	Irrigation	Total	IWRW	EI
Lake Victoria	136.2	77.4	28.9	42.3	232	516.8	1,680	30.7
Lake Kyoga	49.7	129.3	1.3	75.7	678	934	2,320	40.3
Victoria Nile	21.5	41.1	0.8	23.2	109	195.6	1,440	13.6
Lake Edward	17.7	46.6	0.9	18.1	68	151.3	4,470	3.4
Lake Albert	6.2	24.5	0.4	12.5		43.6	2,890	1.5
Aswa	15.2	3.9		14.2	26	79.3	1,770	4.5
Albert Nile	15.8	33.8	0.3	15.6	214	279.5	450	62
Kidepo		2.7		2.6		5.3	210	2.5
Misc	2.6	6.2		8.2		17	360	4.7
Total	264.9	365.5	32.6	212.4	1327	2222.4	15590	14.3

Table 8. Changes (in %) between current (2009) and projected (2030) water demand (MCM/y) in each basin in Uganda. Note: N/A means no percentage could be calculated as current demand was 0.

Changes in %								
Watershed	Urban Domestic	Rural Domestic	Industrial	Livestock	Irrigation	Total	IWRW	EI
Lake Victoria	132	423	0	0	2028	232	0	230
Lake Kyoga	1812	377	0	0	6008	693	0	690
Victoria Nile	1244	395	0	0	N/A	477	0	467
Lake Edward	883	273	0	0	2991	326	0	325
Lake Albert	675	371	0	0	N/A	131	0	114
Aswa	N/A	-24	N/A	0	N/A	311	0	309
Albert Nile	3060	333	0	0	N/A	1055	0	1048
Kidepo	N/A	800	N/A	0	N/A	1667	0	79
Misc	N/A	520	N/A	0	N/A	85	0	88
Total	302	345	0	0	5383	436	0	411

Table 9. The projected (2050) water demand (MCM/y) in each basin in Uganda, based on the extrapolation of the current and 2030 projection.

2050								
Watershed	Urban Domestic	Rural Domestic	Industrial	Livestock	Irrigation	Total	IWRW	EI
Lake Victoria	213.8	140.0	28.9	42.3	453.1	878.1	1680.0	52.1
Lake Kyoga	96.8	231.5	1.3	75.7	1344.9	1750.2	2320.0	75.5
Victoria Nile	41.4	73.9	0.8	23.2	218.0	357.3	1440.0	24.8
Lake Edward	33.6	80.7	0.9	18.1	133.8	267.1	4470.0	6.0
Lake Albert	11.6	43.8	0.4	12.5	0.0	68.3	2890.0	2.3
Aswa	30.4	2.7	0.0	14.2	52.0	139.3	1770.0	7.9
Albert Nile	31.1	59.8	0.3	15.6	428.0	534.8	450.0	118.6
Kidepo	0.0	5.1	0.0	2.6	0.0	10.3	210.0	3.6
Misc	5.2	11.4	0.0	8.2	0.0	24.8	360.0	6.9
Total	463.9	648.9	32.6	212.4	2629.8	4030.2	15590	14.3

Figure 9. Screenshot of Water2Invest website with the three Water Provinces located in Uganda.

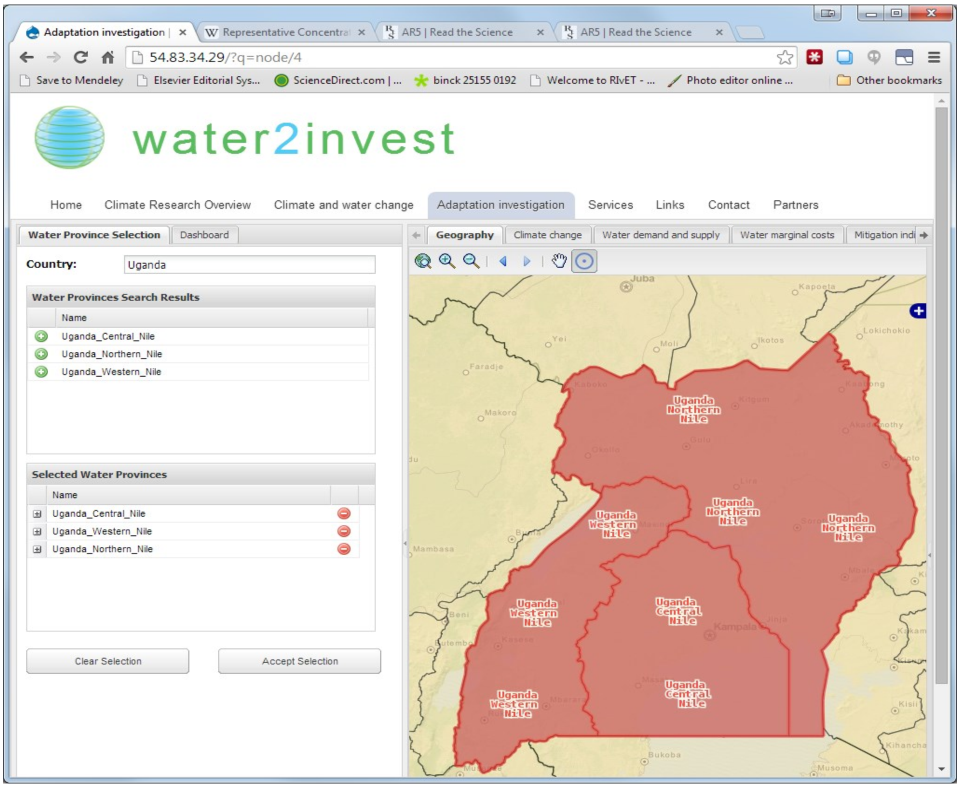
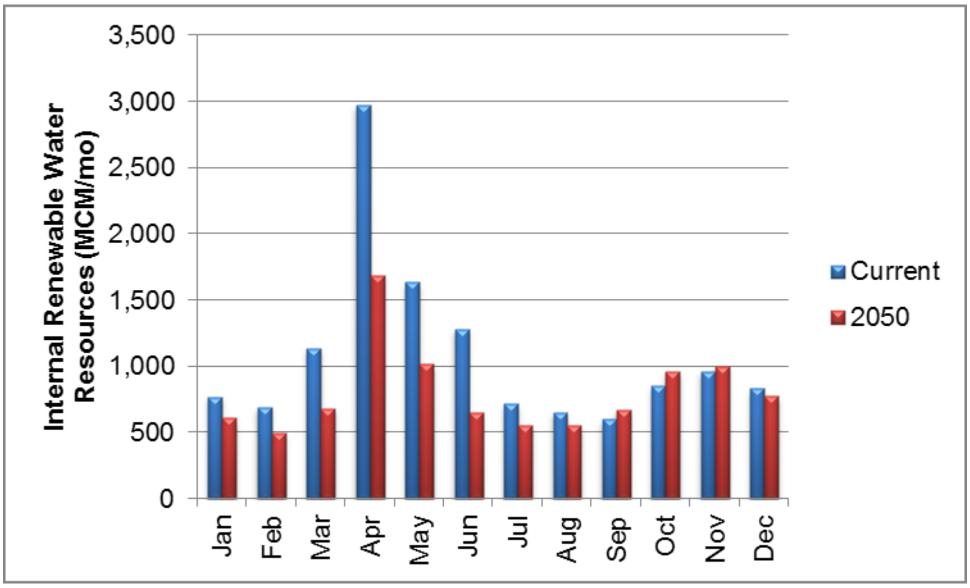


Table 10. Changes in Internal Renewable Water Resources for Uganda (RCP8.5 - SSP5). Source: Water2Invest.

	Current	2050	Change (%)
Jan	771	613	-20.4
Feb	694	497	-28.4
Mar	1,139	686	-39.8
Apr	2,976	1,692	-43.1
May	1,636	1,019	-37.7
Jun	1,285	653	-49.2
Jul	717	558	-22.1
Aug	655	553	-15.6
Sep	601	675	12.2
Oct	852	964	13.2
Nov	965	1,002	3.8
Dec	835	774	-7.3
Sum	13,127	9,686	-26.2

Figure 10. Current (1981-2000) and future (2041-2060) Internal Renewable Water Resources for Uganda for the RCP8.5 and SSP5.



Source: Water2Invest

6.2.2. Results Climate Change Analysis

The WEAP modelling framework has been adjusted to include the impact of changes in climate and socio-economic developments as presented in the previous section. Again a period of 30 years has been used to reflect the variability up to the year 2050.

The most important results can be summarized as:

- Total water demand is projected to increase from 408 MCM/y currently to 3,963 MCM/y in 2050 (Figure 11)
- Total unmet demand is on average 3.7 MCM/y currently and is expected to be 1,651 MCM/y. Maximum unmet demand in one particular year is 1,966 MCM/y (Figure 12)

- Unmet demand is high in all months and for most watersheds (Figure 12)
- In most months projected water shortage is enormous (Table 11)

In summary both water demands and the unmet demand for water are massive. It should be considered that these results are based assuming that no investments in the water sector would take place. In reality, expanding demand will be combined with various investments such as pumping schemes, canal infrastructure, etc.

Figure 11. Annual average water demand for the eight watersheds currently ("A_Reference Scenario") and around 2050 ("B_Climate_Change" Scenario).

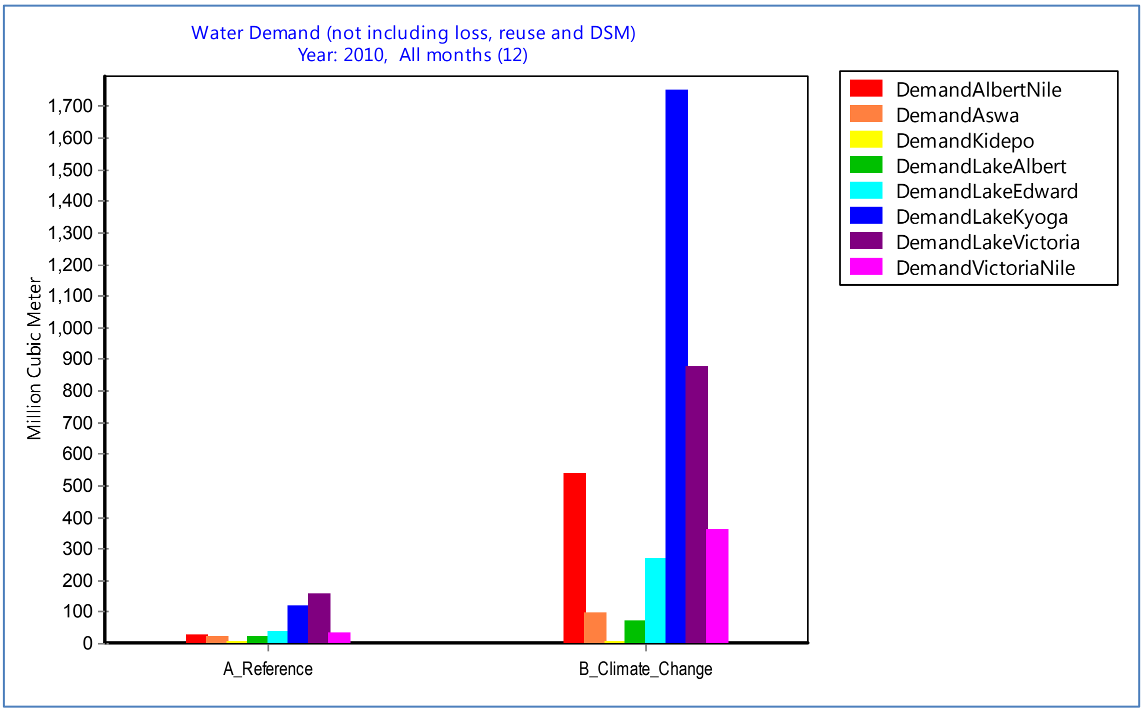
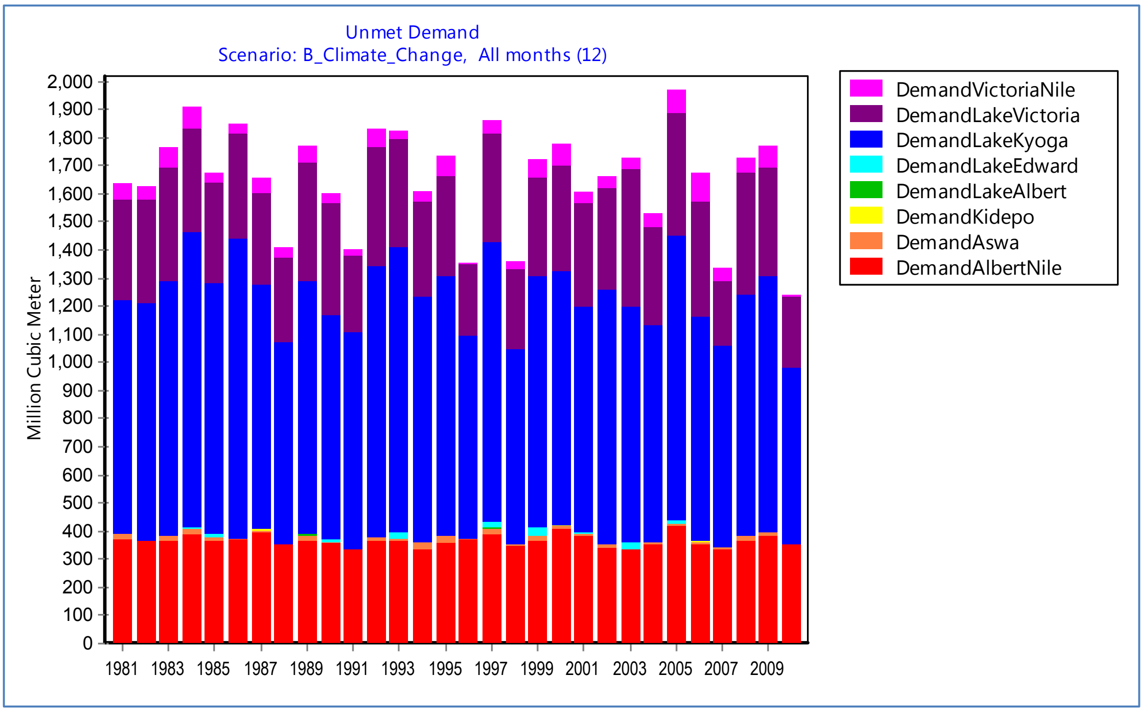


Figure 12. Unmet demand (water shortage) for the eight watersheds as total per year (top) and monthly average coverage (bottom) for the period around 2050.



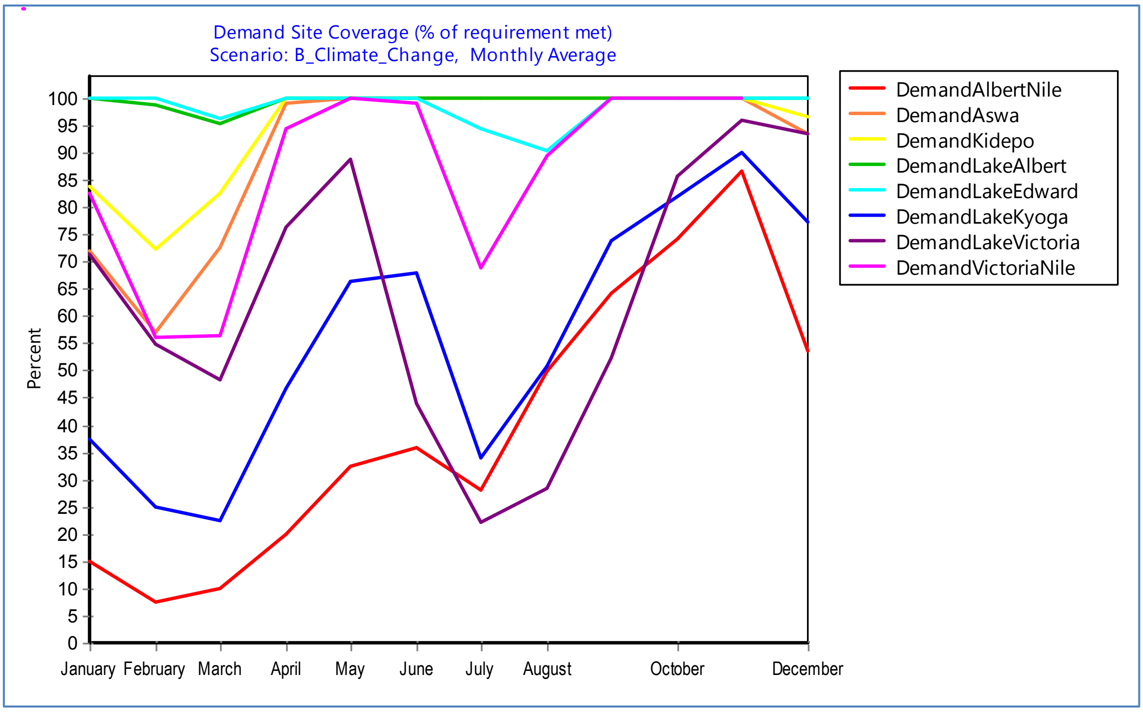


Table 11. Coverage of water demand per month. Results show number of months (out of 360) when water demand is not covered for 99%, 90%, 75% and 50% for the period around 2050.

	Months (in 30 year) where coverage of XX% is met			
	99%	90%	75%	50%
Lake Victoria	273	254	210	134
Lake Kyoga	319	303	260	156
Victoria Nile	119	102	76	38
Lake Edward	13	12	10	5
Lake Albert	3	3	3	2
Aswa	59	52	46	32
Albert Nile	336	330	310	247
Kidepo	35	32	26	20

7. ALLOCATION RULE

To value the impact of climate change on water resources in Uganda, we need to identify the values placed on different water uses. For the purposes of this study, based on discussions with the Ministry of Water and Environment, we assume a hierarchy of allocation, with the following demands being met sequentially:

- Consumption demand – urban and rural;
- Irrigation water demand;
- Industry water demand; and
- Livestock consumption demand.

8. ESTIMATION OF UNMET DEMAND BY USER TYPE

The estimated unmet demand by user type in 2050 is presented in Table 12. As can be seen from the table, the impacts differ significantly by region and consumer type.

Table 12. Estimated unmet demand by consumer type under climate change (millions litres per yr, 2050)

	Domestic	Irrigation	Industry	Livestock
Lake Victoria	97,788.1	360,057.3	28,900.0	42,300.0
Lake Kyoga	0.0	127,868.7	433.3	26,477.9
Victoria Nile	0.0	12,286.5	200.0	6,839.4
Lake Edward	0.0	0.0	0.0	1,298.5
Lake Albert	0.0	0.0	0.0	1,078.1
Aswa	1,613.3	28,160.6	0.0	13,848.0
Albert Nile	0.0	179,593.3	300.0	15,600.0
Kidepo	129.3	0.0	0.0	857.2

These results identify major problems in the future regarding sufficient water availability by 2050, especially in the Lake Victoria, where all sectors of demand have deficits. Water for irrigation will be in deficit in 5 of the 8 watersheds and water for livestock will be in deficit in all 8 watersheds. Values of these shortages are discussed in the next section.

9. MONETARY VALUATION

In order to place monetary values on water shortages, we first present a review of previous studies that have attempted to place a value on water supply in Uganda. From this literature unit values are then derived.

9.1. Review of previous studies valuing water in Uganda

Davis et al (2001) examined willingness to pay for improved water supply in Uganda by micro and small enterprises. Surveys were conducted with enterprise owners, owners' spouses or managers in two towns, Wobulenzi and Lugazi, in January 1999. In one of the towns, Wobulenzi, a new piped supply had already been installed before the survey. In Lugazi, 60% suggest they were willing to pay 125 shillings per jerrican for kiosk water (or 17.18 shillings per litre, 2013 prices) . In Wobulenzi only 40% of respondents were willing to pay 3,000 shillings in rental surcharge for a private connection.

Whittington et al (1998) conducted a contingent valuation study in 1994 to assess preferences for water supply in Lugazi, a small town. This assessed willingness to pay on a jerrican basis or on a monthly payment basis. The main results are shown in Table 13, along with the contingent valuation questions posed. It can be seen that even at rates of 100 shillings per jerrican in 1994 (359 shillings 2013 prices), 49 percent were willing to pay this for a public tap supply. This equates to 17.9 shillings per litre.

Table 13. Household willingness to pay for public tap in Lugazi

Percent of respondents who indicated they would use the public taps at different prices/monthly fees			
Contingent valuation question: Suppose the price of water per jerrican at the public tap were [25, 50, 100] shillings. Would your household decide to buy most of your water from the public taps, or would you decide to continue using vendors and/or springs?			
First price: pay by the jerrican	Public Taps	Existing sources	Don't know
25 sh. Per jerrican	89%	10%	1%
50 Sh. Per jerrican	78%	19%	3%
100 Sh. Per jerrican	49%	51%	0%

Source: Whittington et al (1998)

Angella, Dick and Fred (2014) investigate willingness to pay for irrigation water by rice farmers at the Doho Rice Irrigation Scheme in Uganda. A contingent valuation survey of 200 households was conducted in September 2012. The survey was based around a bidding game, with 5000 shillings/acre/season as the starting bid. This study is weak in that it does not use multiple start bid values to control for starting bid bias, however, it does give useful insights. The study suggests that rice farmers are willing to pay an average of 20,000 shillings per acre (21,094 shillings, 2013 prices). Estimating the willingness to pay per litre requires evaluation of the demand for irrigation water by rice production. Based on data from 2000-2004 for Uganda presented in Chapagain and Hoekstra (2010), the total water footprint of production was 158 Mm^3 per year and percolation 122 Mm^3, implying total water consumption of 280 Mm^3 for a crop area of 81,400 acres, implying an average water footprint of 785.51 m^3/acre/year. Using this as an estimate of demand for water per acre this suggests a willingness to pay per litre of 15.15 shillings.

Wright (2012) used the contingent valuation method to value water supply in Kigisu and Rubona, two rural villages in Mubende District. Using a sample of 122 households, a mean willingness to pay of 286 shillings per 20 litres from a public tap was estimated. This equates to 15.08 shillings per litre (2013 prices). This study did not find a relationship between willingness to pay and income. Significant determinants of willingness to pay include distance to existing source which had a positive impact and number of children which had a negative impact. The latter may be due to either impacts on disposable income or the impact of the availability of 'free' labour for water collection. It should be noted that this study is not published in a peer reviewed journal – but the values are similar in magnitude to others presented in this section.

9.2. Summary: Unit values

Based on these studies, we are able to place willingness to pay estimates on losses in water supply. Adjusting for inflation, the 2013 prices are shown in Table 14. In terms of allocating between urban and rural demand, we assumed that the water was allocated proportionately to demand in each location – and so estimated a weighted willingness to pay for water in the different water catchments as a result.

Table 14. Unit value estimates

User category	Willingness to pay (shillings/litre, 2013 prices)	Source
Urban domestic	17.97	Based on Whittington et al (1998), updated for inflation
Rural domestic	15.08	Based on Wright (2012), updated for inflation
Industry	17.18	Based on Davis et al (2001), updated for inflation
Irrigation	15.15	Based on Angella et al (2014), updated for inflation
Livestock	15.15	Based on irrigation

10. ESTIMATED ECONOMIC LOSSES

10.1. Valuation of water supply shortage: Results

Table 15 presents the estimated economic losses with an income elasticity of zero – i.e. if willingness to pay is not impacted by increases in income as a result of socioeconomic change. The costs are most significant in Lake Victoria, Albert Nile and Lake Kyoga. Overall we estimate 14,558 billion shillings ($5.5 billion) due to water shortages.

Table 15. Economic losses due to water supply shortages in 2050 under climate change – income elasticity of demand zero (Billions of Ugandan Shillings)

	Domestic	Irrigation	Industry	Livestock	Total
Lake Victoria	1,645.6	5,456.0	496.6	641.0	8,239.3
Lake Kyoga	0.0	1,937.6	7.4	401.2	2,346.3
Victoria Nile	0.0	186.2	3.4	103.6	293.3
Lake Edward	0.0	0.0	0.0	19.7	19.7
Lake Albert	0.0	0.0	0.0	16.3	16.3
Aswa	28.6	426.7	0.0	209.8	665.2
Albert Nile	0.0	2,721.4	5.2	236.4	2,963.0
Kidepo	1.9	0.0	0.0	13.0	14.9
Total	1676.1	10,728.0	512.7	1,641.1	14,558.0

10.2. Sensitivity – Income elasticity of willingness to pay assumption

Estimation of future incomes in Uganda requires use of scenarios from the OECD for both GDP and population, which when combined suggest GDP per capita will rise from the modelled current level of $1,315 to $10,612 and $13,485 under SSP1 and SSP5 respectively by 2050[3].

[3] Note here we do not use the real Ugandan data, to be consistent with the modelled futures under the SSP scenarios. Real GDP per capita is much lower in Uganda, but the SSPs using purchasing power parity adjusted GDP values, which take account of local prices and adjust the exchange rate accordingly. Hence there is a variation between modelled and actual data using market exchange rates.

The proportionate change in willingness to pay in response to a change in income could have a significant effect on the values attributed to water shortages. In general, we assume willingness to pay values may rise with improvements in income – and use the following equation to estimate the willingness to pay in different time periods:

$$WTP_{t+1} = WTP_t * \left(\frac{Y_{t+1}}{Y_t}\right)^e$$

Where WTP_t is willingness to pay in time t, Y_t is income in time t and e is the elasticity of willingness to pay in response to price.

There are issues with this analysis – as little is known about the inter-temporal transfer of values, and some might suggest it is best to simply consider the case where e=0, particularly given the finding of some of the reviewed studies that willingness to pay was insensitive to income in Uganda. However, in general, studies suggest values of between e=0 and e=1, so we use e=0.3 and e=1 to show the responsiveness of economic losses in Table 16.

It can be seen from Table 16 that the estimated economic losses are significantly related to the income elasticity of willingness to pay – ranging from 12,812 billion shillings to 132,002 billion shillings ($4.9 billion to $50.2 billion) depending on the scenario and the elasticity.

Table 16. Sensitivity of economic losses from water shortage in 2050 to income elasticity of willingness to pay for water under different socioeconomic scenarios

	Base	SSP1		SSP5	
	e=0	e=0.3	e=1	e=0.3	e=1
Lake Victoria	8,239.3	15,213.0	63,626.6	16,560.4	84,429.8
Lake Kyoga	2,346.3	4,332.2	18,118.9	4,715.9	24,043.0
Victoria Nile	293.3	541.5	2,264.6	589.4	3,005.1
Lake Edward	19.7	36.3	152.0	39.5	201.6
Lake Albert	16.3	30.2	126.2	32.8	167.4
Aswa	665.2	1,228.2	5,136.8	1,337.0	6,816.3
Albert Nile	2,963.0	5,470.8	22,881.0	5,955.4	30,362.1
Kidepo	14.9	27.6	115.4	30.0	153.1
Total	14,558.0	23,784.7	99,477.1	25,891.4	132,001.9

11. The Cost of Water Shortages: Case Study of an Extreme Event

Current climatic variation may provide useful evidence as to potential future impacts of climate change. Recent droughts have had significant impacts on Uganda, as have flooding related events. We discuss the impacts of flooding events in a related study on infrastructure, but here we present a case study based on the 2010-2011 drought event in Uganda. A previous drought event in 2005-2006 was estimated to have caused damages and losses of 627 billion shillings (US$250.3 million) (Department of Disaster Management, 2012).

The 2010-2011 event was experienced across the Great Horn of Africa, with the impacts being felt more acutely in neighbouring countries to Uganda. Although Uganda experienced some rainfall deficits, no State of Emergency was declared. An overview of rainfall data in the period is given in Table 17 below.

Table 17. Number of months with rainfall below long term average (Jan 2010 to July 2011)

Location	Number of months having rainfall below average	Percentage of time below average
Arua	12	63
Gulu	11	57
Jinja	11	57
Kasese	10	52
Mbarara	7	36
Soroti	11	57

The costs of the 2010-11 drought were estimated in a recent study by the Department for Disaster Management, which utilised the DaLA (Damage, Loss and Needs Assessment) methodology (Department for Disaster Management). Table 18 presents a summary of the damages and losses of the 2010-2011 event, showing that this event had very significant impacts. Overall the costs were estimated to be 2,796.6 billion shillings (US$1.2 billion) – with the most significant effects on crops and livestock.

Clearly water shortages do have a significant impact on the Ugandan economy and society – and as noted above water shortages may become more common under climate change.

Table 18. Summary of damage and losses caused by the 2010-2011 rainfall deficit

Sector	Damage	Production losses	Higher costs	Total
Crops		1034.7		1034.7
Livestock	106.2	934.9	85.4	1126.5
Agro Industry		278		278
Commerce		39.2	130.7	169.9
Electricity			106.3	106.3

Water		0.6	1.3	1.9
Health			14.9	14.9
Education			48.6	48.6
Food Aid			16.9	16.9
Total (Bn Shs)	**106.2**	**2287.3**	**404.1**	**2797.6**
Total (million US$)	**44.6**	**959.9**	**169.6**	**1174.1**

Source: Department of Disaster Management, 2012

12. ADAPTATION OPTIONS

The above analysis has shown there are significant costs when water supply shortages occur in Uganda – in part due to socioeconomic development, in part due to climate change. The same applies to droughts, for which there may be an increase in frequency, although that is not part of the climate model predictions.

In order to evaluate different options for addressing these shortages we have to compare the costs of the options with the value of the reduction in unmet demand. This is difficult to do at the national level as the data needed are for individual measures in different watersheds as well as the costs at that level and these were not available. Instead what we have done is compare the items in the aggregate programme for adaptation with potential benefits assuming different levels of effectiveness of these programmes in reducing unmet demand.

In the Costed Implementation Strategy (GoU, 2012) the Government of Uganda has identified eight programs to address water problems in the next 15 years (i.e. to about 2030). These have a total cost of $203 million, with $36 million in the short term (1-5 years), $67 million in the medium term (6-10 years) and $99 million in the medium term (10-15 years). Not all the options can be informed by the analysis described above but some of them can. In particular the following have been analysed in this manner:

A. Promote and encourage water harvesting and efficient water utilisation among individuals, households, institutions and sectors ($11.8 million over the next 15 years).
B. Ensure availability of water for production in water dependent sectors in order to increase their resilience to climate change impacts ($69.5 million over the next 15 years).
C. Promote integrated Water resources Management (including underground water resources) including contingency planning for extreme events such as floods and droughts ($105.9 million over the next 15 years).

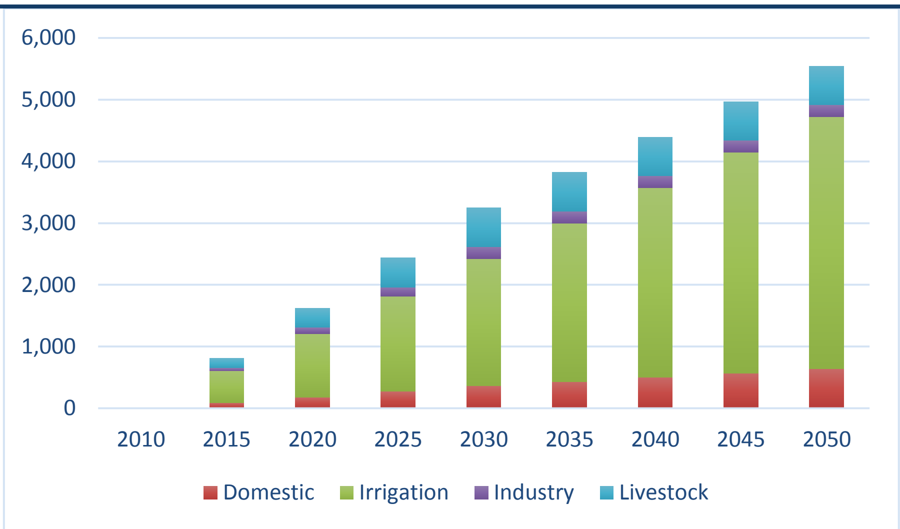
Together they account for 92 percent (in value) of the proposed programme for adaptation in the water sector. In order to carry out the analysis a number of additional assumptions had to be made.

In case A we assumed that the programme will improve water efficiency in households and the benefits will be a reduction in unmet demand from that sector. The value of unmet demand for 2050 has been estimated conservatively in Table 15. We took those estimates and derived figures for earlier years in the following way. First, estimates of the value of unmet demand for 2030 were made using the data on the size of unmet demand in 2030 and in 2050 from Table 7 and Table 9. Based on these numbers, urban and rural household demand deficit in 2030 is 630.4 MCM, while in 2050 it is 1,112.8MCM. At the same time the value of the household deficit in 2050 is 1,676.1 billion shillings (Table 15). Hence the value of the deficit in 2030 is taken as

(630.4/1,112.8)*1676.1 shillings. For years in between the deficit is interpolated assuming a linear increase between these two values and for years before 2030 a linear decline is assumed. The assumed values of unmet demand in years 2010 to 2050 are given in Table 19.

Table 19 (and graph below). Summary of damage and losses by sector 2010:2050 ($Mn.)

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
Domestic	0	91	182	273	364	432	501	569	638
Irrigation	0	515	1 030	1 545	2 060	2 565	3 070	3 576	4 081
Industry	0	49	98	146	195	195	195	195	195
Livestock	0	158	315	473	630	629	627	626	624
Total	0	1 625	1 625	2 437	3 249	3 821	4 393	4 965	5 538



In case B we assume that the measures are targeted to increase supply capacity and improved infrastructure for agriculture and livestock and for meeting any deficits in industrial demand. The value of unmet demand back to 2010 is as given in Table 19 and, as for case A, the programme is assumed to start having an effect in 2020.

In case C the assumption is that the programme reduces losses from droughts through water management. As we saw in Section 11 there were two droughts in the last decade (in 2005-6 and 2010-11) with losses of $250 million and $1,174 million respectively. The exact frequency of such droughts has been increasing in recent years. It is striking that 8 out of the 10 most severe floods and droughts in terms of numbers affected since 1900 have occurred within the last 20 years (CRED, 2014). This supports claims that extreme weather events have been increasing in recent years. In particular, the evidence suggests that droughts are becoming more frequent and more severe with major events occurring in 2001, 2002, 2005 and 2008 (UNDP, 2013). In Karamoja severe droughts are now occurring every two to three years as opposed to approximately every five years in the past (USAID, 2011). In the analysis we assume that with climate change such events will occur every three years but that there will be no further increase in frequency over the period to 2030.The average damage from each event is taken as the average annual damage from the last two major events will be $237 million (i.e. ((250+1174/2)/3). Future damages are difficult to predict as the agricultural sector faces two opposing trends. On the one hand yields will decline for some crops due to climate change and on the other the production will increase as a result of better techniques to manage inputs and investment in mechanisation. As the Agricultural Sector report shows the net effect on output is likely to be small. Hence no change is assumed in the value of expected damages from a given event.

The results of making the comparison are shown in Table 20. The table shows the Net Present Value (NPV) of the cost of each programme in the government adaptation strategy, the assumed benefits that have been quantified and the minimum percentage reduction in damages that the programme needs to achieve to obtain a 10 percent rate of return on investment (i.e. the reduction in damages that gives a zero Net Present Value with a 10 percent discount rate).

Table 20. Net benefits of adaptation options in the water sector

Programme	Present Value of Costs @ 10% Discount Rate ($Mn.)	Impact of Programme that has been assessed	Minimum % Reduction in Damage to give a 10% Return
Efficient water utilisation among households	$4.7	Reduced unmet demand in household sector	0.51%
Increased water availability for agriculture and industry	$32.7	Reduced unmet demand in agriculture, livestock and industry	0.4%
Integrated water resource management to deal with extreme events	$42.8	Reduced damages from future droughts	4.5%

The results indicate that even with a very small impact on unmet demand programmes A and B would generate this return. For programme A it requires a mere 0.5% reduction (i.e. just of one half of one percent) for it to get this return. For programme B the required reduction is even smaller – only 0.4% of the unmet demand in agriculture and industry. Finally for programme C the required reduction in damages from droughts is only 4.5%.

The implications of such a preliminary analysis are that the benefits of action to adapt in the water sector are very high and that further investments may well be justified. Of course the latter is not proven and more work is needed to link the programmes to reductions in damages but there is some a priori evidence to support the case.

Further work on adaptation in the sector requires, as noted above, detailed data at the local level. Some such data should be available from the case studies to be carried out. Once available their findings can be added to this report. Among the measures that can be analysed in such cases there are some on the demand side and some on the supply side.

Demand side management options include:

- Water pricing
- Permits for abstraction for irrigation
- Permits for abstraction for other purposes
- Leak reduction
- Improved regulation/control of illegal connections

Supply side options include:

- Increased storage or supply capacity through improved infrastructure
- Rural areas: Development of groundwater wells

- Rural areas: Shifting from surface water to deep bore wells
- Increase in rainwater harvesting structures

13. CONCLUSIONS

This report presents the results of modelling of the impact of climate change on water supply shortages in Uganda. Climate change and future socioeconomic development is likely to have a significant impact on water demand and supply – with shortages likely in many watersheds.

Domestic consumption will be impacted in three watersheds: Lake Victoria, Aswa and Kidepo. The largest overall economic losses are anticipated to be in the Lake Victoria, Albert Nile and Lake Kyoga watersheds. Overall, the expected cost in 2050 is anticipated to be of the order of 14,558 billion shillings (US$5.5 billion). This is a conservative estimate and the figure could be as much as ten times higher if income effects on willingness to pay are taken into account. This underlines the need for further investment in the water supply infrastructure in Uganda. With or without climate change the economic losses are of a significant magnitude.

Past extreme events of water shortage have had major impacts, with two droughts in the past decade (in 2005-6 and 2010-11) with losses of $250 million and $1174 million respectively representing an average damage in the last decade of $475 million.

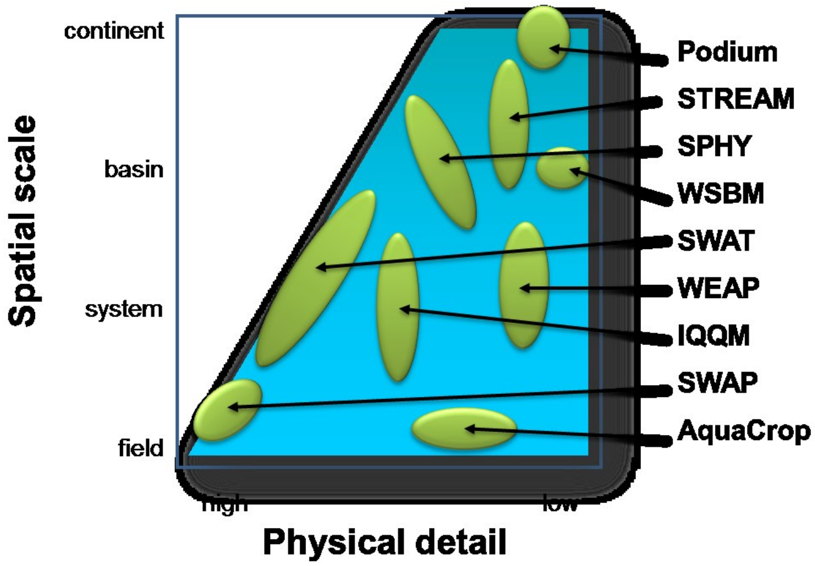
Adaptation measures to deal with these serious problems include those which improve efficiency on the demand side, those that improve water storage and increase availability and those that reduce losses from extreme events. The report has looked at the costs of proposed actions in all three areas and compared them to potential benefits in terms of reducing the estimated unmet demand.

The results indicate that even with a very small impact on reducing unmet demand these programmes would generate a rate of return of 10%. The same applies to measures that would tackle drought through Integrated Water Resource Management. The implications of such a preliminary analysis show the benefits of action to adapt in the water sector to be very high and further investments may well be justified. The latter, however, needs more work, to link the programmes to reductions in damages.

ANNEX: WEAP MODELLING

Water managers and decision makers are confronted with the challenges to cope with changes in water both due to the natural and socio-economic developments. Competing demands, an intensified hydrological cycle and more extremes require supporting tools for those water managers and decision makers. Depending on the nature of the questions to be answered a range of tools is available to support decision making, operational as well as strategic (Figure 13**Error! Reference source not found.**).

Figure 13. Relation between spatial scale and physical detail in water allocation tools. The green ellipses show the key strength of some well-known models. Source: Droogers and Bouma, 2014.



A conceptual tool is needed to match water supplies and competing demands, and to assess the upstream–downstream links for different management options in terms of their resulting water sufficiency or un-met demands, costs, and benefits. The Water Evaluation and Planning tool (WEAP) has been developed to meet this need. It uses the basic principle of water balance accounting: total inflows equal total outflows, net of any change in storage (in reservoirs, aquifers and soil). WEAP represents a particular water system, with its main supply and demand nodes and the links between them, both numerically and graphically. Delphi Studio® programming language and MapObjects® software are employed to spatially reference catchment attributes such as river and groundwater systems, demand sites, wastewater treatment plants, catchment and administrative political boundaries (Yates *et al.* 2005).

Users specify allocation rules by assigning priorities and supply preferences for each node; these preferences are mutable, both in space and time. WEAP then employs a priority-based optimisation algorithm and the concept of "equity groups" to allocate water in times of shortage.

This way of making the representation means that different scenarios can be quickly set up and compared, and it can be operated after a brief training period. WEAP has been developed as a standard tool in strategic planning and scenario assessment for multiple applications across the globe.

In order to undertake these assessments the following operational steps can be distinguished:

- The study definition sets up the time frame, spatial boundary, system components and configuration. The model can be run over any time span where routing is not a consideration; a monthly period is used quite commonly.

- System management is represented in terms of supply sources (surface water, groundwater, inter-basin transfer, and water re-use elements); withdrawal, transmission and wastewater treatment facilities; water demands; and pollution generated by these activities. The baseline dataset summarises actual water demand, pollution loads, resources and supplies for the system during the current year, or for another baseline year.
- Projections are developed, based on assumptions about climate change, demography, development policies, costs and other factors that affect demand, supply and hydrology. The drivers may change at varying rates over the planning horizon. The time horizon for these scenarios can be set by the user.
- Scenarios are then evaluated in respect of desired outcomes such as water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

Water supply: Using the hydrological function within WEAP, the water supply from rainfall is depleted according to the water demands of the vegetation, or transmitted as runoff and infiltration to soil water reserves, the river network and aquifers, following a semi-distributed, parsimonious hydrologic model. These elements are linked by the user-defined water allocation components inserted into the model through the WEAP interface.

Water allocation: The challenge is to distribute the supply remaining after satisfaction of catchment demand with the objective of maximizing water delivered to various demand elements, and in-stream flow requirements - according to their ranked priority. This is accomplished using an iterative, linear programming algorithm. The demands of the same priority are referred to as "equity groups". These equity groups are indicated in the interface by a number in parentheses (from 1, having the highest priority, to 99, the lowest). WEAP is formulated to allocate equal percentages of water to the members of the same equity group when the system is supply-limited.

WEAP setup

For the entire country a conceptual approach has been followed to develop a model in WEAP, emphasizing supply and demand issues. The entire country is divided into eight watersheds, according to normal practice as presented in the various documents of the Ministry of Water and Environment, Directorate of Water Resources Management. These eight watersheds and their main characteristics are shown in Table 21and Figure 15**Error! Reference source not found.**.

In each of these eight watersheds the following Nodes has been defined:

- Demand Nodes: These nodes represent the water demand for the entire watershed. A distinction is made between water demands for the following sectors:
    - Urban Domestic
    - Rural Domestic
    - Industrial
    - Livestock
    - Irrigation
- Catchment Nodes: These nodes represent the generation of runoff using the actual amount of precipitation and a runoff factor. These Catchments Nodes includes also groundwater resources.
- River Nodes: These nodes represent the main rivers in the country. Smaller streams are not included as it is assumed that a certain percentage of the runoff from the catchment is available to the Demand Nodes
- Reservoir Nodes

- Runoff Nodes
- Transmission Nodes

An overview of the schematic view in WEAP is shown in Figure 14.

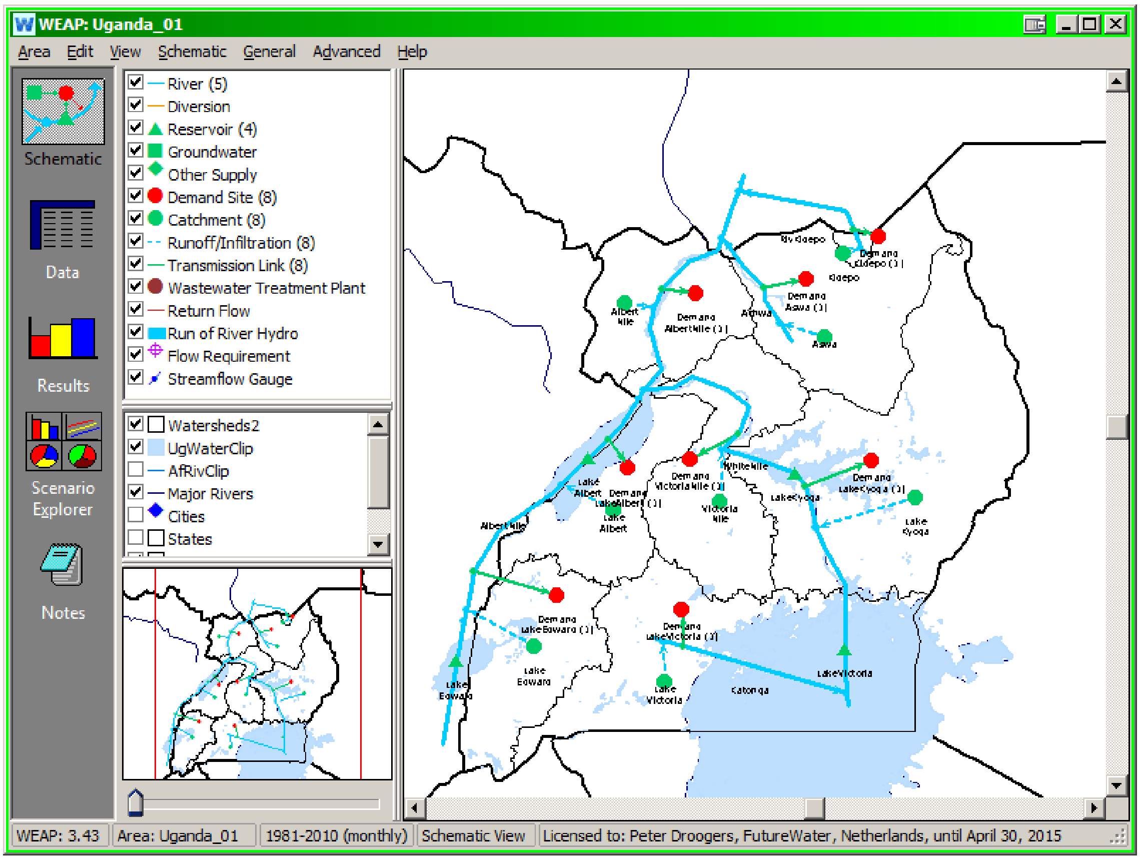
Data to feed the model has come from various sources. The most relevant data sources are:

- Water demand: originating from data documented by the Ministry of Water and Environment, Directorate of Water Resources Management (MWE, 2013).
- Precipitation is obtained from the Climate Research Unit (CRU) data set over the period 1980-2010.
- Runoff coefficients were used as presented by MWE, 2013.

Table 21. Area of the eight watersheds used in the study.

Watershed	Area (km2)
Lake Victoria	59,858
Lake Kyoga	57,669
Victoria Nile	26,796
Lake Edward	18,624
Lake Albert	18,223
Aswa	26,868
Albert Nile	20,004
Kidepo	3,129

Figure 14. Schematic overview of the WEAP model applied to Uganda.



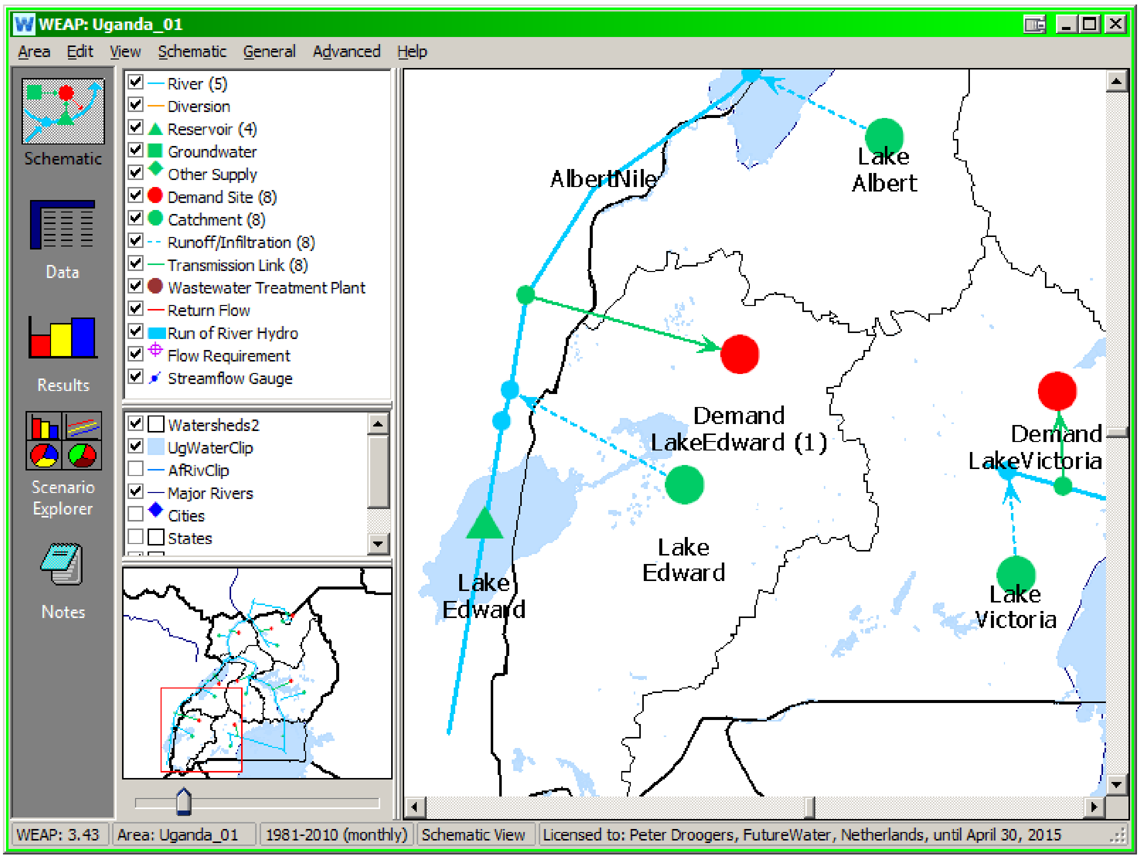
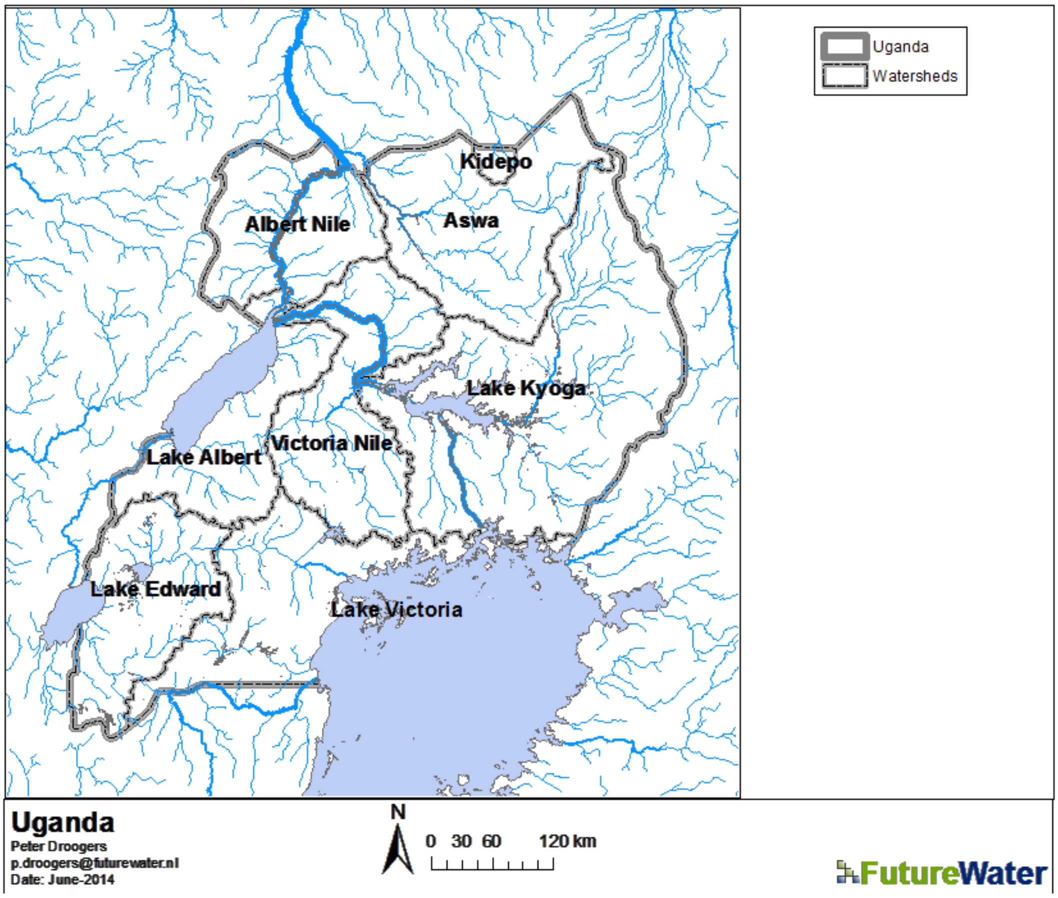


Figure 15. The eight watersheds as used in the current study.



Model performance

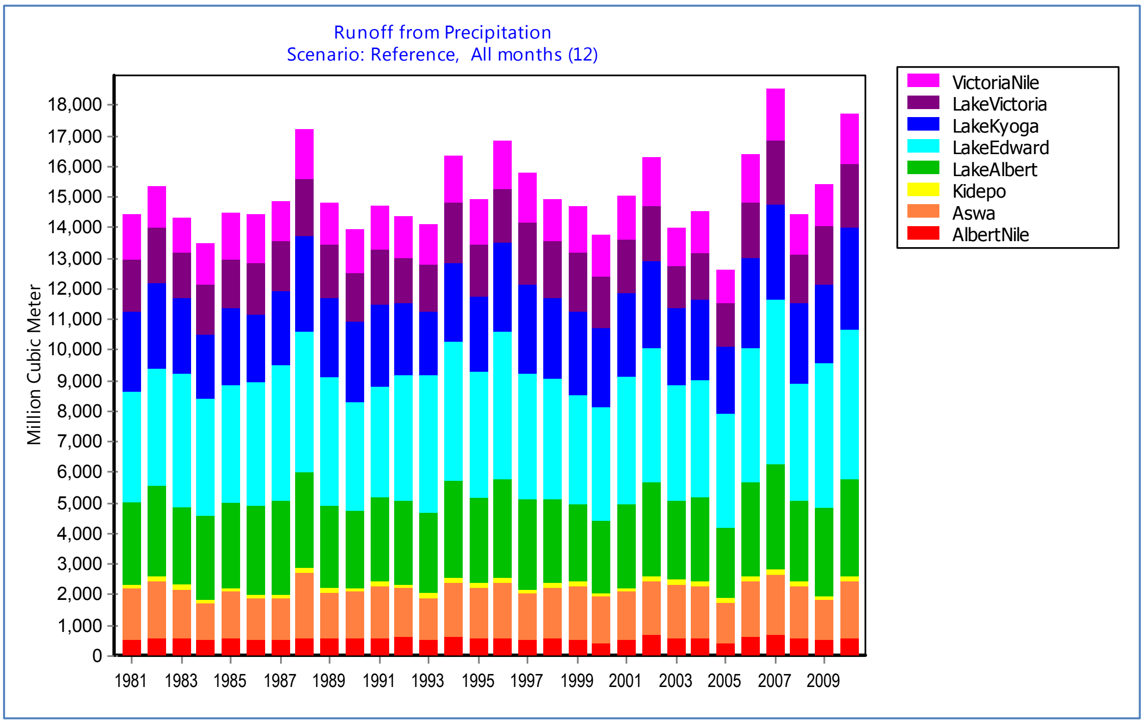
A summarized model performance analysis has been undertaken to ensure that the model can be used for scenario analysis. A complete validation and calibration of the WEAP model developed is beyond the scope of the current study. An important well-known point to bear in mind is that in general relative model accuracy (=comparing scenarios) is higher than actual model accuracy (= comparing observed data to simulated ones). Since the objective of the current study is scenario analysis, accurate representation of observed data is somewhat less relevant and we consider the model results to be reasonably accurate and should provide a basis for evaluating different policies and measures. Nevertheless it is important to note that the model outputs have a considerable margin of uncertainty and this should be taken into account when using them.

The most relevant model performance indicator for the current model is the runoff from the watersheds. Based on monthly precipitation records as compiled in the CRU dataset, combined with runoff factors the total runoff is calculated by WEAP. In the following table andfigures this comparison is presented. In summary the following conclusions can be drawn:

The total simulated runoff of all watersheds in WEAP is the same as the observed one.

- The simulated runoff by WEAP from the individual watersheds is very close to the observed ones.
- The observed runoff is only available as an annual total. The simulated runoff is available over a period of 30 years (1981-2010) on a monthly base.

Figure 16. Runoff from the eight catchment areas as simulated using WEAP as annual totals and monthly averages (1981-2010).



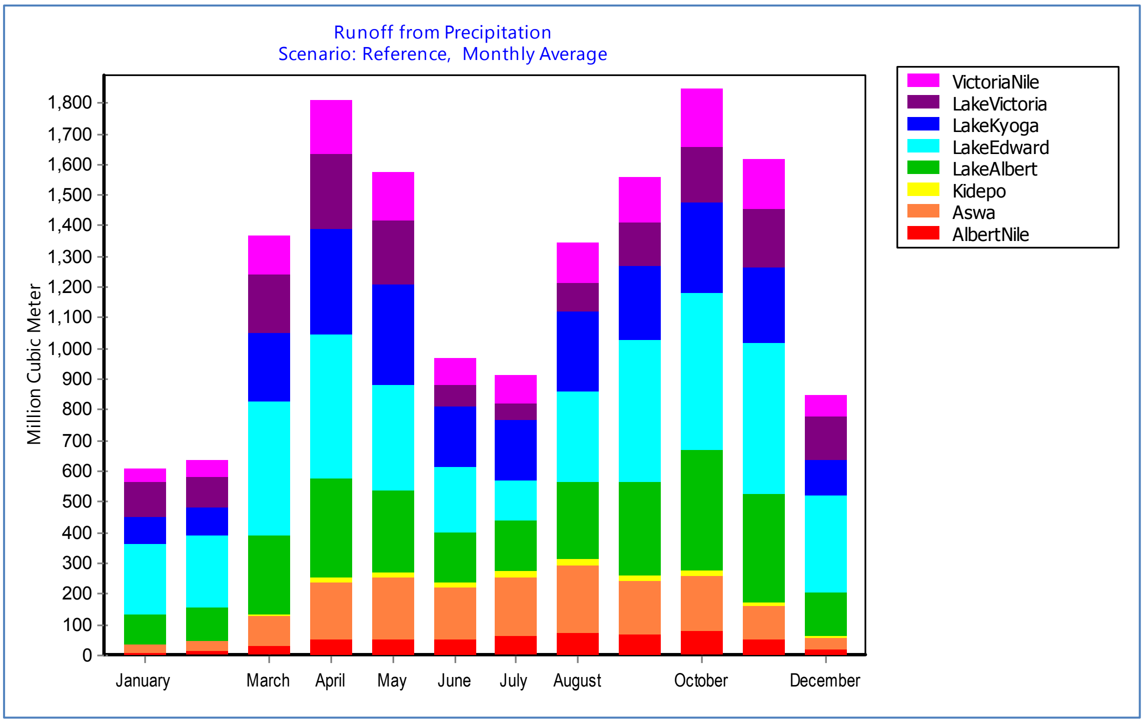
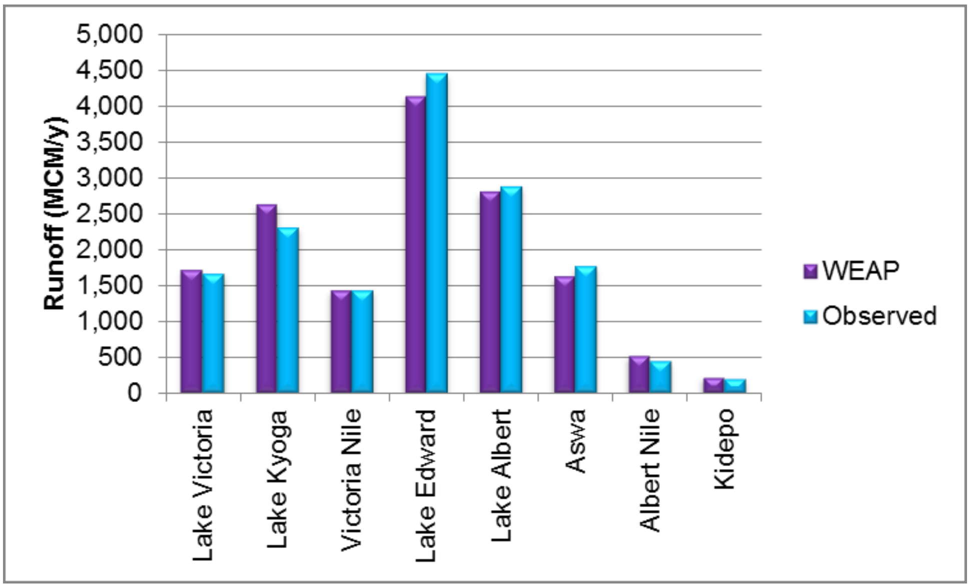


Table 22. Simulated (WEAP) and observed runoff. Simulated runoff average over the period 1981-2010; observed based on report WRE 2013/Table 8-1.

	MCM/y WEAP Mean	MCM/y WEAP Min	MCM/y WEAP Max	MCM/y Observed
Lake Victoria	1,728	1,382	2,057	1680
Lake Kyoga	2,629	2,082	3,340	2320
Victoria Nile	1,438	1,113	1,689	1440
Lake Edward	4,147	3,579	5,331	4470
Lake Albert	2,811	2,312	3,444	2890
Aswa	1,630	1,226	2,107	1770
Albert Nile	528	404	648	450
Kidepo	228	172	295	210
Total	15,140			15,230

Figure 17. Simulated and observed runoff. Simulated runoff over the period 1981-2010, while observed is over an undocumented period.



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