

Water availability at Masaka /
Nabajuzi: a hydrological study
including climate and demographic
scenarios



Deliverable: D7.4
Version 1
Date 15/01/2012

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Document Information

Title	Water availability at Masaka/Nabajuzi: a hydrological study including climate and demographic scenarios
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Deliverable number	D7.4
Deliverable description	The report describes a hydrological study conducted for the Nabajuzi wetland at Masaka town, Uganda. The development of water availability for drinking water consumption is predicted up to the year 2050, considering climate and demographic scenarios.
Report number	D7.4_R4
Version number	V1
Due deliverable date	14 February 2012
Actual delivery date	-
Work Package	WP7
Dissemination level	Public
Reference to be used for citation	Winkler, P. (2012): Water availability at Masaka/Nabajuzi: a hydrological study including climate and demographic scenarios. WETwin Deliverable 7.4

Prepared under contract from the European Commission



Grant Agreement no 212300 (7th Framework Programme)
 Collaborative Project (Small or medium-scale focused research project)
 Specific International Cooperation Action (SICA)

Start of the project: 01/11/2008
 Duration: 3 years

Acronym: WETwin
 Full project title: Enhancing the role of wetlands in integrated water resources management for twinned river basins in EU, Africa and South-America in support of EU Water Initiatives

Introduction

Nabajjuzi is listed as “wetland of international importance” according to the Ramsar convention (Ramsar). Its most important ecosystem service is the provisioning of safe drinking water to the population living in Masaka and the surrounding region. Moreover, the wetland serves as habitat for rare mammal species such as the Sitatunga (*Tragelaphus spekii*) and a rich variety of bird species (management plan, 2004). For the latter, the presence of papyrus is crucial.

The main pressure on the wetland is related to the high population growth of approximately 3% per year (management plan, 2004), causing increasing pollution, land use change due to increased agricultural activities and increasing need of drinking water. Another pressure is related to climate change: As different climate models for the investigated region show partly contradictory tendencies (Fournet, 2010), the role of climate change is more complex compared to the clear effects of population growth. However, it is obvious that climate variability may have a profound effect on water availability in the wetland and on its ecosystem.

For a detailed listing of wetland services, pressures acting on the wetland and the resulting problems see the WetWin document presenting the DSIR analysis (Zsuffa, 2012).

Objectives

In this study the following research questions have been investigated:

- Which amount of water is available per day for drinking water consumption in Masaka at present?
- Which amount of water is available per day for the papyrus ecosystem close to and downstream of Masaka at present?
- How will this water availability develop up to the year 2050, considering climate and demographic scenarios?
- How long are periods of water shortage? This parameter may be used as indicator in the MCDA.

Study site

The study site investigated here is the water body bordering the town of Masaka in the southwest. In figure 1 this site is referred to as “pool 1”, whereas the water body immediately downstream is called “pool2”. Each of the two inflows as well as the outflow of pool 1 is blocked by a dam, where the water is diverted into several culverts below the dam. The roads leading over the dams are called “Kyotera road”, “Kajansembe road” (inflows) and “Mbarrara road” (outflow). Pool 2 receives the outflow of pool1. The size of pool 1 is approximately 1.2 km².

Pool 1 and pool 2, like most other larger water bodies in this region, are almost entirely covered by papyrus. This papyrus cover not only hosts a rich variety of bird species, it also prevents algal growth which has a positive, stabilizing effect on water quality. The drinking water for the town of Masaka is taken directly from this pool. At its east side, there is a pumping station including a water treatment site where mainly iron and organic material is

removed from the water. At present the average daily water intake is approximately 4000 m³ (NWSC, 2010).

The following datasets have been used in this study:

- Water levels and flow velocities have been measured at each culvert on a daily basis from 7th April 2010 to 26th May 2010 by members of the NWSC (NWSC, 2010). This time period belongs to one of the two yearly rainy seasons.
- A digital elevation model (DEM) with a resolution of 30*30 m is available from the SRTM database in the internet (SRTM). It should be mentioned that this DEM is clearly more reliable for the dry land (relying on satellite data) than for water bodies (determined by interpolation between dry land regions).
- The coordinates and exact height levels of each culvert with respect to validated points on the permanently dry land has been measured in August 2010 by the authors. This made it possible to connect the measured water levels (which are originally relative to each culvert) to the DEM and to obtain absolute water levels.
- Climate projections up to the year 2050, i.e. projected inflow at Kyotera and Kajansembe road, on a daily basis, have been performed by members of the PIK in cooperation with NWSC (Fournet, 2010). The projection is based on rainfall data from different stations in and around the area of Nabajjuzi from 1960 to 2000. Thereby the climate models “remo” and “cclm” have been used (Fournet, 2010). The runoff, and consequently the inflow into pool 1, has been calculated using the software SWIM developed by the Potsdam Institute for Climate Impact Research (PIK).
- The projection of water consumption due to population growth and urbanisation has been taken from a study by the Stockholm environmental institute (Aslam, et al., 2010). Details can be found in this report.
- The evapo-transpiration by papyrus has been estimated based on the investigations of Saunders et al. (2007).

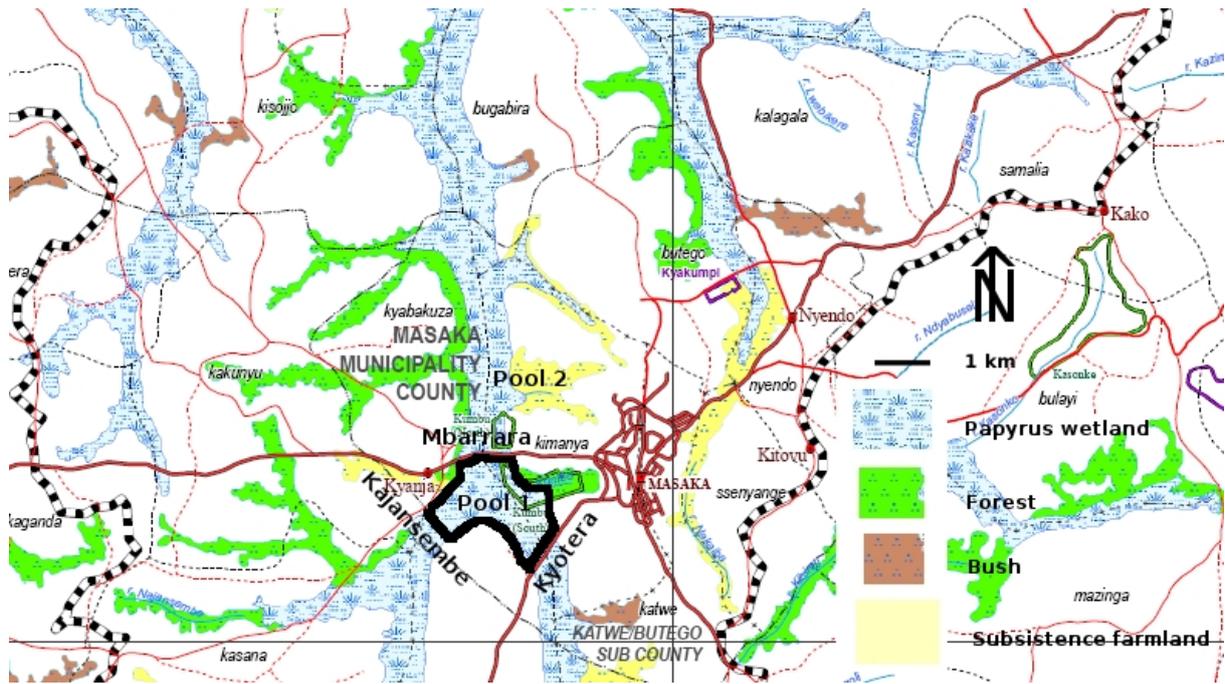


Figure 1: Map of the study site. The pool modelled by the hydrological model is delineated by black lines

Methods

In order to calculate the outflow $Q_{out}(t)$ and the time-dependent water volume $V(t)$ in pool 1, a linear storage model has been applied. The basic assumption of this model is that the outflow is proportional to the water level i.e.

$$Q_{out}(t) = k * h(t)$$

where k is a constant to be determined by calibration. Due to the form of this equation, the water level $h(t)$ is relative to the bottom of the culvert at lowest position (see figure 4 in the results part). Consequently, the outflow is 0 whenever $h(t)$ is 0. Obviously, the pool may contain also a certain water volume, if the water level is below the lowest elevation of any culvert ($h(t) < 0$). In this case the outflow is always 0 and the water balance is governed by inflow, intake and evapo-transpiration only. In the other case, for $h(t) > 0$ the total water balance of pool 1 is

$$\frac{\partial V}{\partial t} = Q_{in}(t) - Q_{out}(t)$$

where $Q_{in}(t)$ is the net inflow into the pool, i.e. the total inflow less intake and evapo-transpiration. For the relation between volume and water level we use the approximation $V(t) = A * h(t)$, where A is the water surface area. This approximation is applicable for $h(t) > 0$, because the change of A with varying water level is rather low due to rather steep slopes of the pool, so it can be assumed constant. Combining these expressions, the differential equation becomes

$$\frac{\partial h}{\partial t} = -\frac{k}{A} * h + \frac{Q_{in}}{A}$$

This is an inhomogeneous linear differential equation of first order which can be solved by the method of “variation of the constant”. The solution is

$$Q_{out}(t) = k * h(t) = k * e^{-\frac{k}{A} * t} * \int dt e^{\frac{k}{A} * t} * \frac{Q_{in}}{A}$$

As the total inflow is known from the climate scenarios and the temporally increasing intake is known from the demographic scenario, outflow, volume and water level can be calculated using this equation. Only a simple numerical integration is necessary for evaluation. This equation is valid for $h > 0$. In dry situations, when the water level is lower than the culvert at lowest position, i.e. $h < 0$ and $Q_{out} = 0$, water level and volume at day i are governed by the simple balance equation $V_i = V_{i-1} + Q_{in\ i} - Q_{ev\ i} - Q_{use\ i}$, where the last two terms are the daily evapo-transpiration and intake, respectively. In this case, the water surface area cannot be assumed to be constant: A is a function of h which can be derived from the DEM.

The unknown system parameter k is determined by calibration to the April/May 2010 dataset: Minimising the mean quadratic deviation

$$\chi^2 = \frac{\sum_{i=1}^N (Q_{out} - k * h)^2}{N}$$

with respect to k (i.e. $d\chi^2/dk = 0$) yields

$$k = \frac{\sum_{i=1}^N Q_{out\ i} * h_i}{\sum_{i=1}^N h_i^2}$$

where N is the number of data points, $\{h_i\}$ is the set of measured water levels and $\{Q_{out\ i}\}$ is the set of measured discharges at the outflow.

Results

The pattern of evapo-transpiration from papyrus found by Saunders et al. (2007) is shown in figure 2. The daily variation (high values around noon, very low values at night) is obvious. It is, however, striking that the seasonal variation does not clearly correlate with rainy and dry seasons. (Compare, for example, the rather low values in August to the rather high ones in September. Both are similarly dry months.) Therefore, we decided to choose the average value of 4.75 kg H₂O per m² and day. This value is approximately 1.3 times higher than the evaporation from open water.

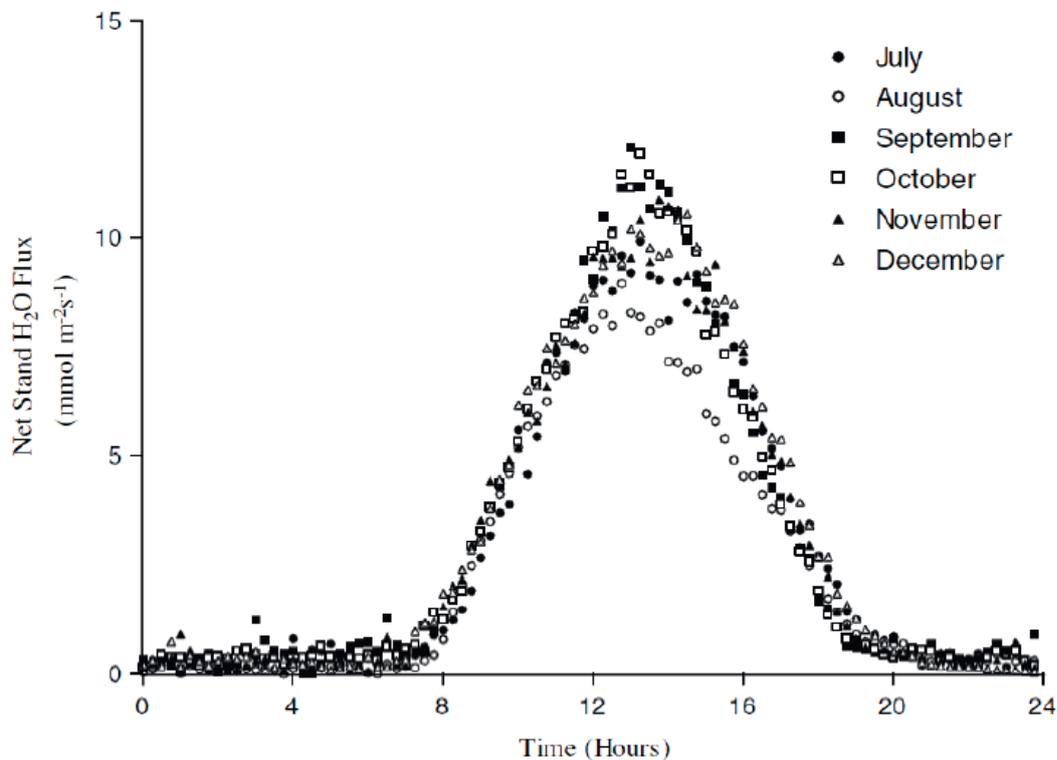


Figure 2: Evapo-transpiration from papyrus found by Saunders et al. (2007).

The projected water consumption up to the year 2050 by Aslam et al. (2010) is shown in figure 3. A dramatic increase by a factor of 5 within 40 years can be observed. For this study the water consumption has been approximated by two linear functions shown in the figure.

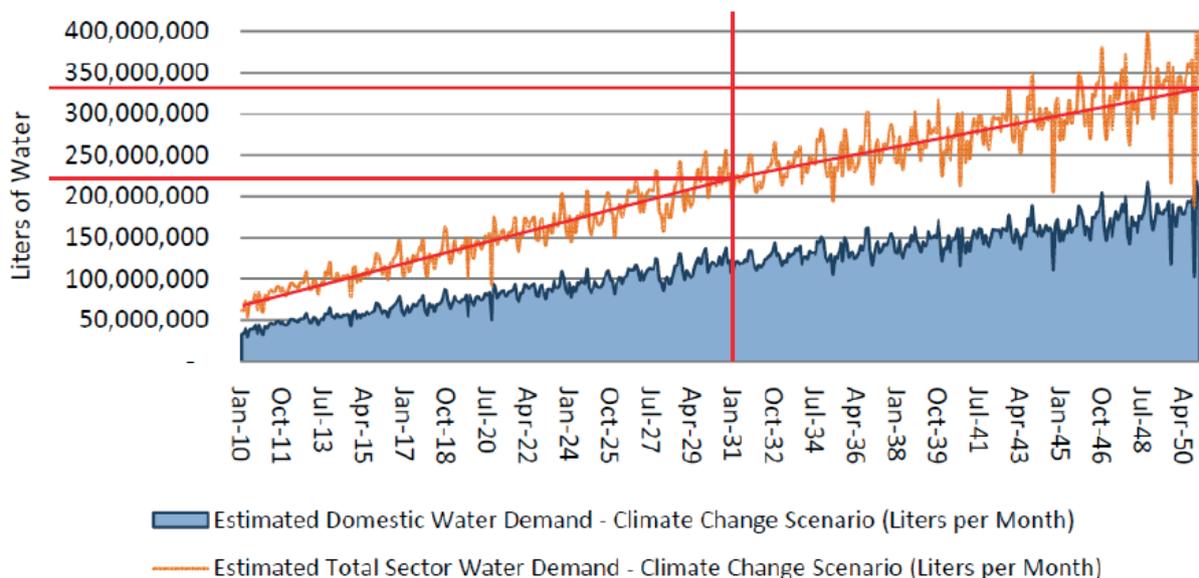


Figure 3: Projected water demand in Masaka region by Aslam et al. 2010. For details see their report.

Figures 4a, 4b and 4c show the locations and diameters of the culverts (measured in August 2010 by the authors) and the depth profiles (measured in Summer 2009 by N Lukooya Bateganya) along the dams at Kyotera road, Kajansembe road (inflows) and Mbarrara road (outflow).

Kyotera road (S4)

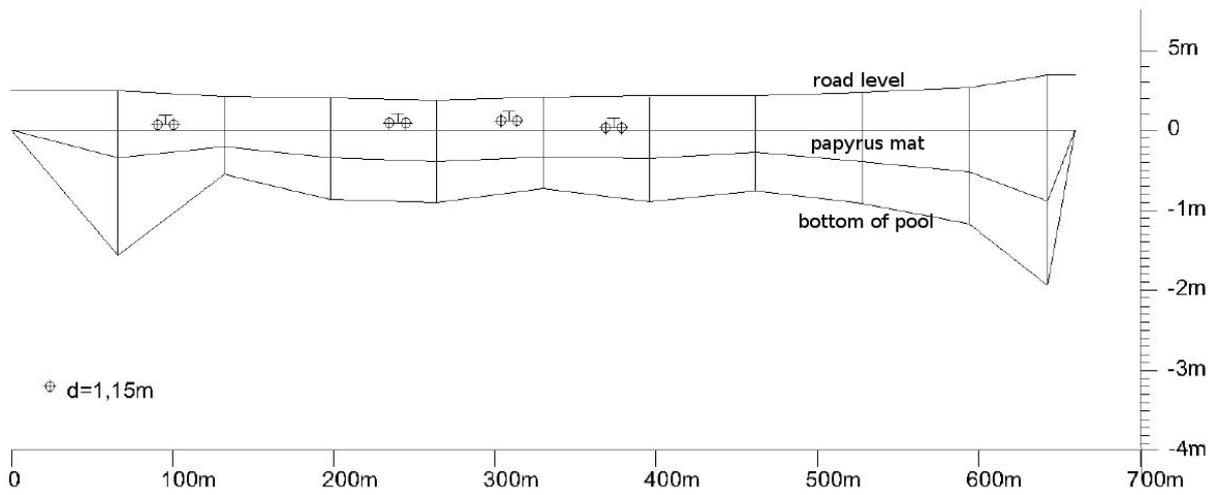


Figure 4a: Kyotera road dam: Culvert locations, diameters and depth profiles.

Kajansembe road (S5)

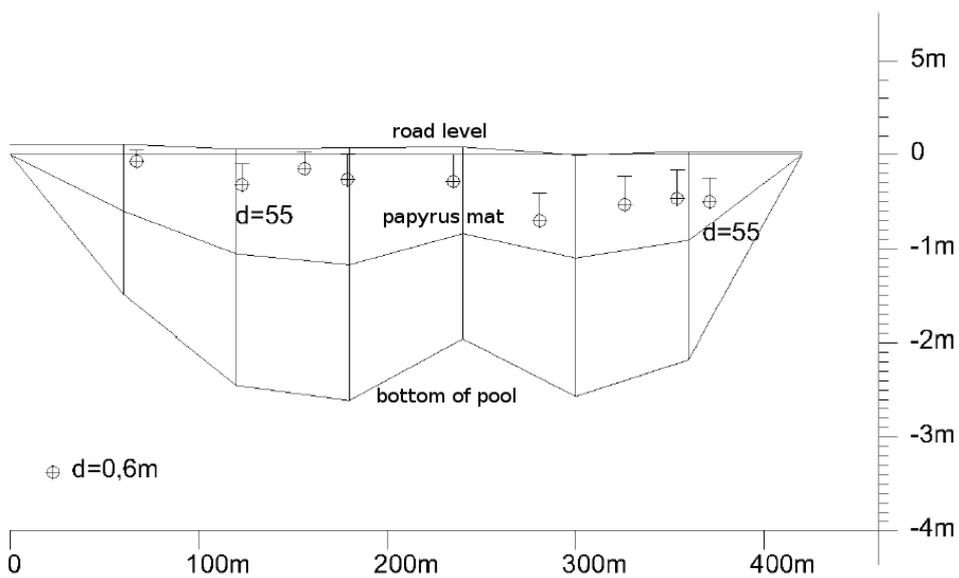


Figure 4b: Kajansembe road dam: Culvert locations, diameters and depth profiles.

Mbarara road (S6)

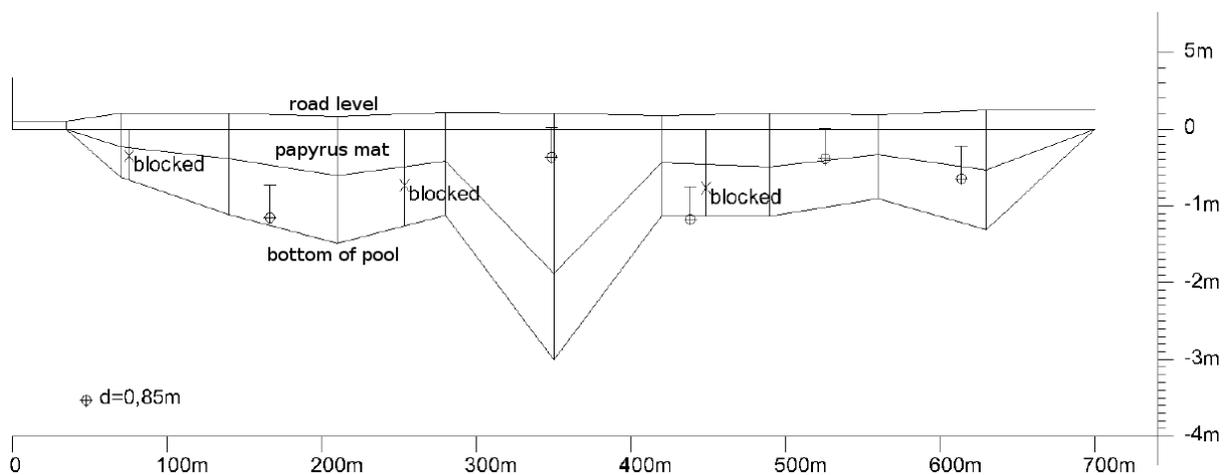


Figure 4c: Mbarara road dam: Culvert locations, diameters and depth profiles.

In these figures, the lowest line denotes the bottom of the pool immediately beside the dam, the middle line shows the lower edge of the papyrus mat and the up most line shows the road level. Note that the scale for positive values on the ordinate is different from the scale for negative ones. The centre of each tube is denoted by a circle and their diameter is indicated by an error bar. (This kind of graphical representation is necessary because of the big difference between the scales of abscissa and ordinate.)

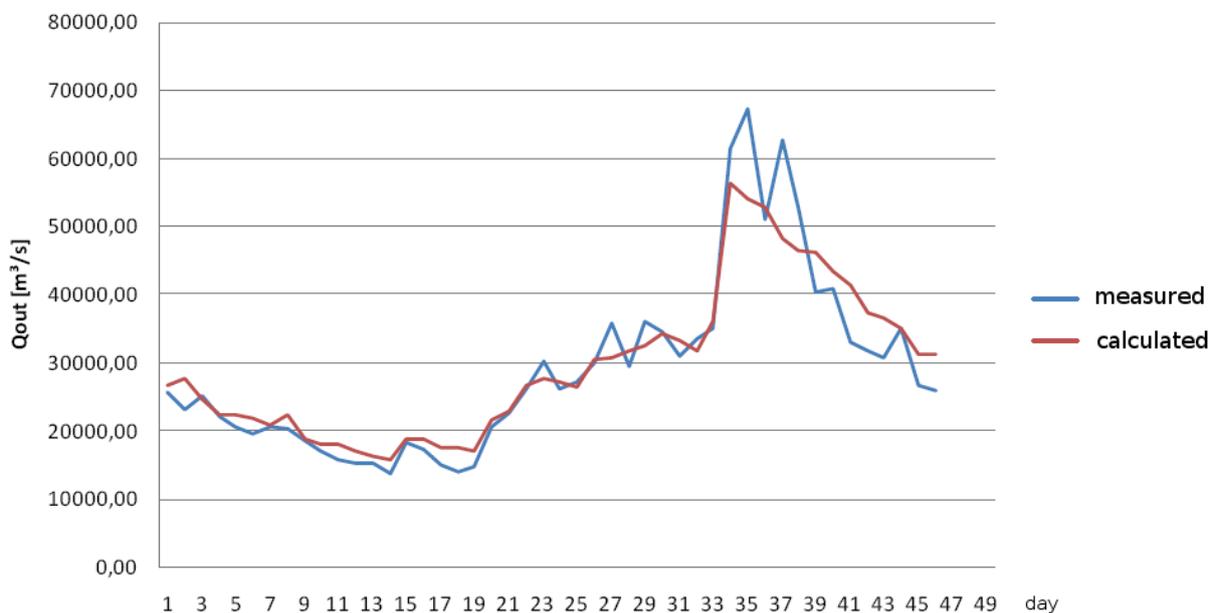


Figure 5: Calibration of the model and comparison with measured values.

The calibration of the model is shown in figure 5. Here, the blue line shows the discharge time series measured in April/May 2010 and the red line shows the modelling result, i.e. the evaluation of the solution of the differential equation presented in the methods section. The parameter k has been determined such, that the mean quadratic deviation between the measured and the calculated curves becomes minimal. The value $k = 87814.3 \text{ day}^{-1}$ leads to a satisfying accordance between measured and calculated outflows. The discrepancy at peak flow is due to the restrained flexibility of a model with only one calibration parameter.

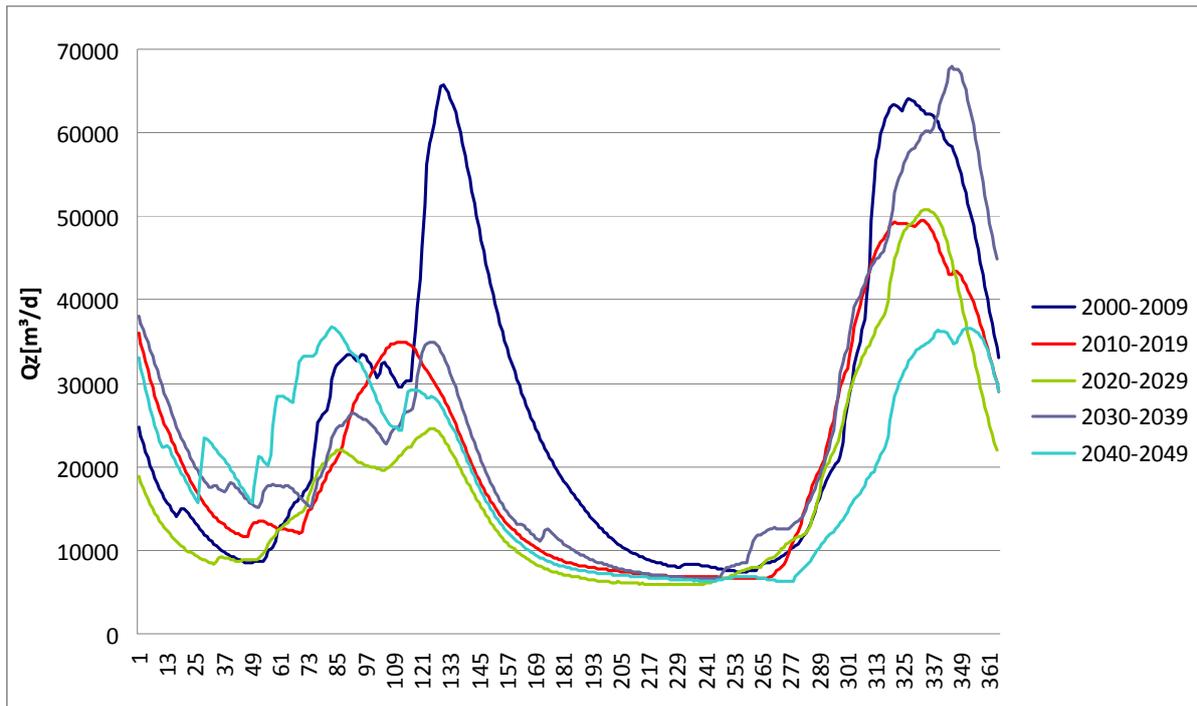


Figure 6: Projection of inflow at Kyotera and Kajansembe roads using the cclm model: Averages over 10 years for each day of the year.

The result of the climate projection using the cclm model (Fournet et al., 2010) is shown in figure 6: The original data consist of a series of daily inflow discharge values up to the year 2100. For the presented model we used the period up to 2050, because water consumption data are available only up to this year. Averaging over blocks of 10 years for each day of the year yields a reasonable and well-understandable representation of such a long data series.

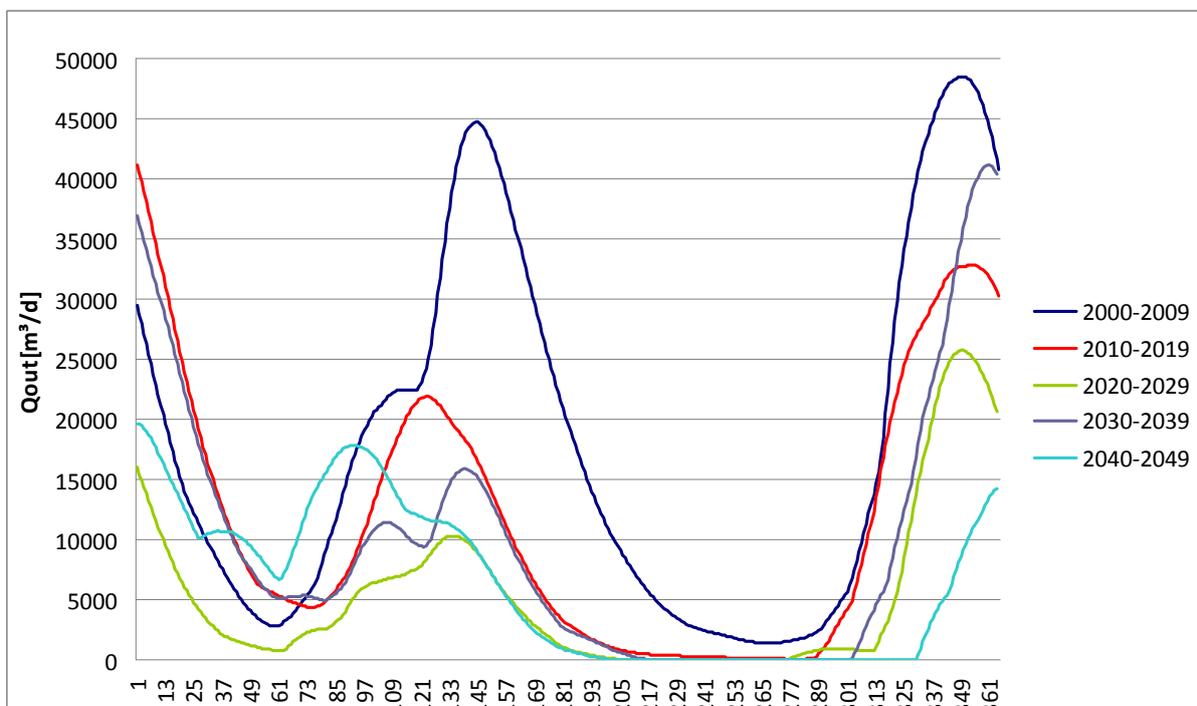


Figure 7: Outflow from pool 1 (at Mbarrara road), averages over 10 years using the cclm projection.

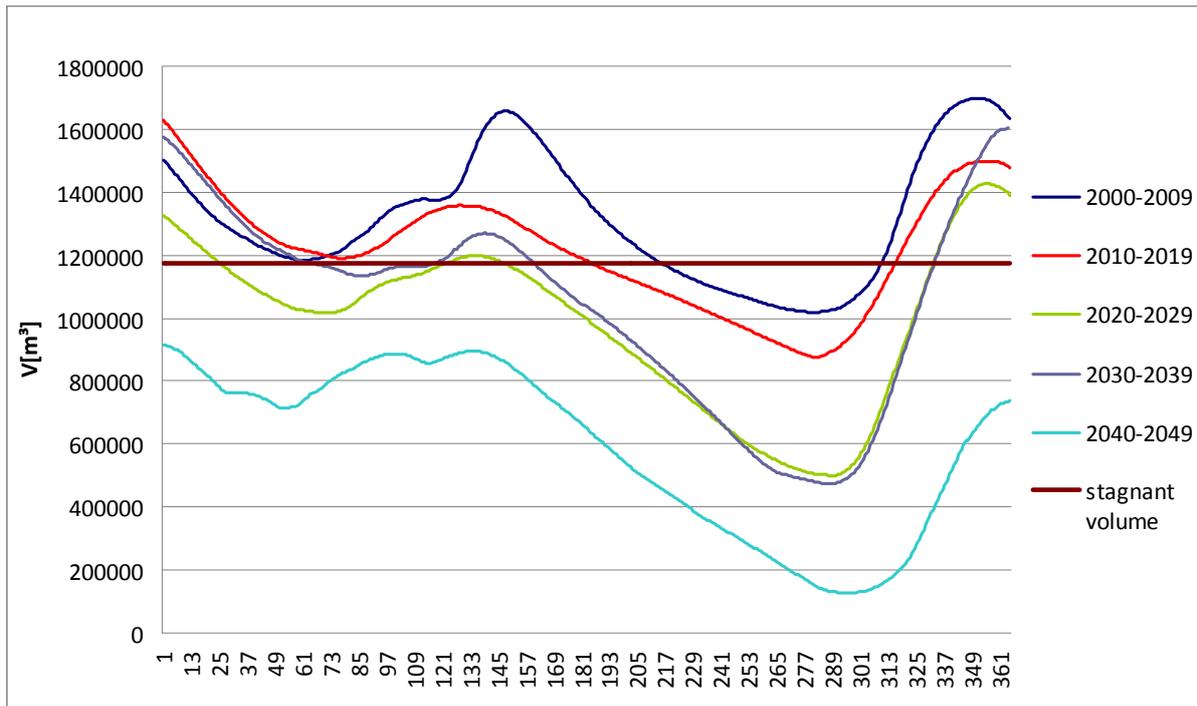


Figure 8: Water volume in pool 1, averages over 10 years using the cclm projection.

The simulation results are shown in figures 7 and 8: The outflow from pool 1 at Mbarrara road is represented as 10-year-averages (Fig. 7). Here, it is striking that except for the years 2000-2009, there are always periods where the outflow becomes 0. The implications will be presented in the discussion section. The total water volume in pool 1 (again as 10-year-averages) is shown in figure 8.

Figures 9, 10 and 11 show the same curves using the remo projection: Inflow to pool 1 in figure 9, outflow from pool 1 in figure 10 and water volume in figure 11.

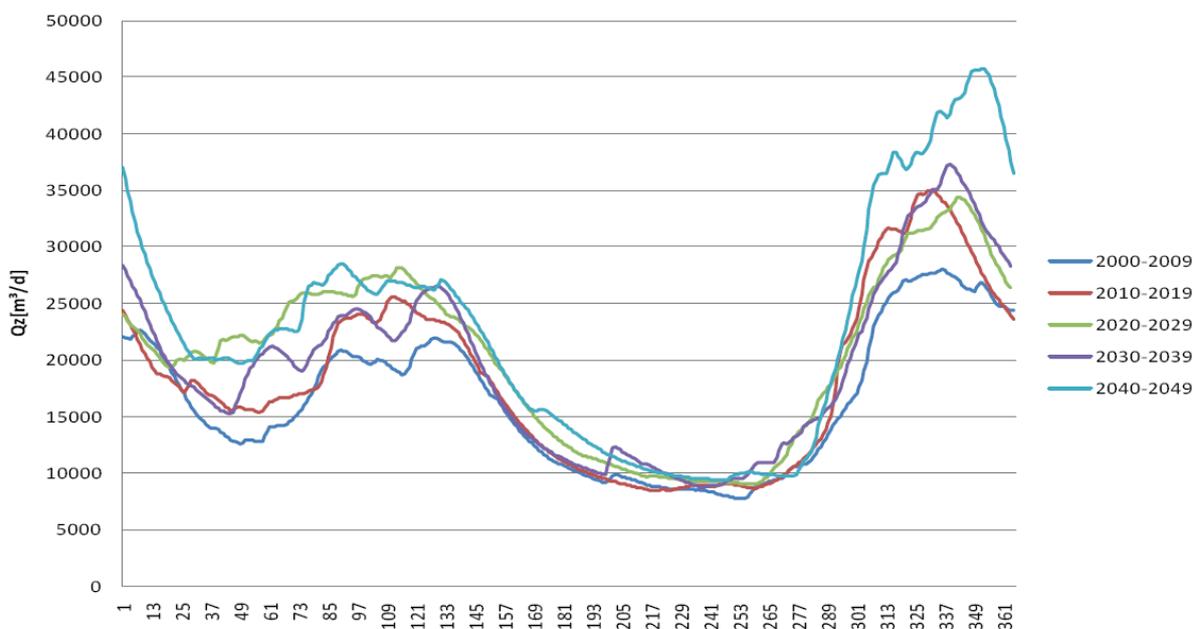


Figure 9: Projection of inflow at Kyotera and Kajansembe roads using the remo model: Averages over 10 years for each day of the year.

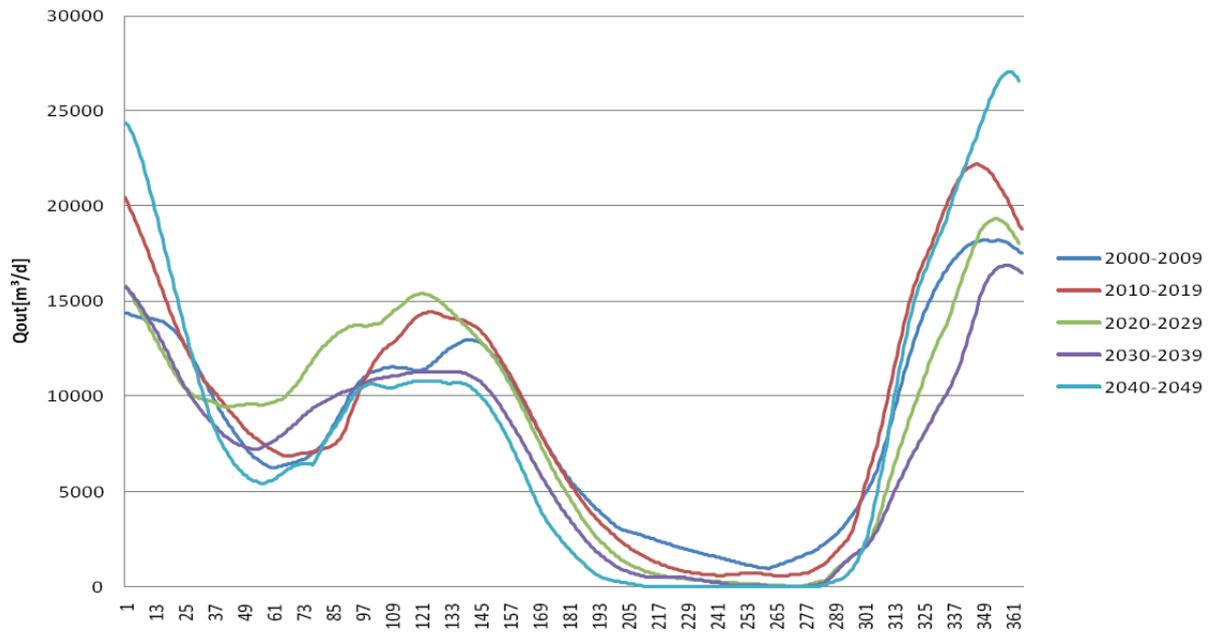


Figure 10: Outflow from pool 1 (at Mbarara road), averages over 10 years using the remo projection.

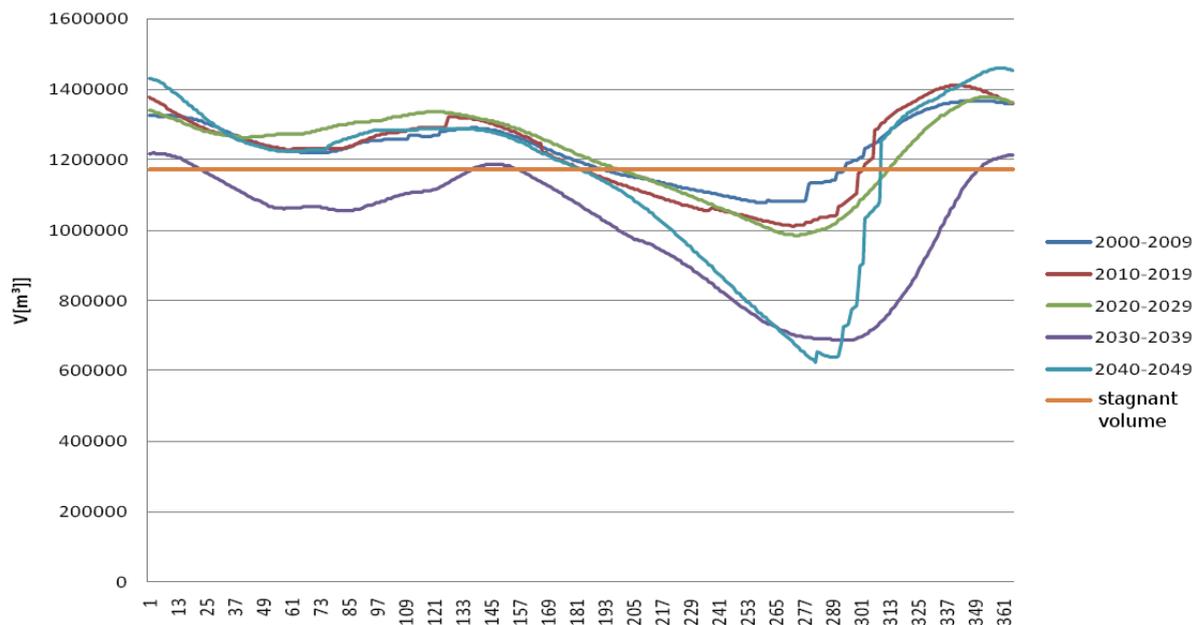


Figure 11: Water volume in pool 1, averages over 10 years using the remo projection.

Discussion and Conclusions

It is striking that the two climate models remo and cclm show very different trends (see figures 6 and 9): remo shows a moderate increase of inflow at Kyotera and Kajansembe road up to the year 2050, except in the second dry period of the year (July-October) where the mean discharge stays roughly constant over the whole time span. In contrast, cclm rather shows a decrease of discharge for the same time period. However, especially in the cclm projection there are significant irregularities: the decade 2020-2029 is exceptionally dry whereas the following decade 2030-2039 is rather wet. Therefore, with some precaution it may be concluded that the climatic situation in Uganda does not show obvious and clearly observable trends, as it is the case in other parts of the world.

Nevertheless, the outflow from pool 1 into pool 2 through the culverts under Mbarrara road does show similar trends in both cases (figures 7 and 10). This is due to the fact that the influence of the increased water consumption is much stronger than the influence of the varying inflow. It can be clearly stated that population growth and urbanisation associated with an increased water consumption has a profound effect on water availability at Masaka: Except for the first two decades (2000-2019) in the cclm projection all 10 year averages show periods in the second dry season where the outflow from pool 1 becomes zero. In the following we will call these periods “periods of water shortage”. This is motivated by the fact, that at zero outflow, there is firstly no water transferred into pool 2 which obviously harms the papyrus ecosystem. Secondly there are stagnant conditions with long retention times in pool 1, which leads to increased water temperatures and may lead to a deterioration of water quality due to decreasing oxygen saturation in the water column and at the sediment surface.

In the cclm projection the length of these periods of water shortage showed an increase with ongoing time periods: From 2020-2029 its average length is 70 days, from 2030-2039 it is 85 days and from 2040-2049 it is on average 130 days. Such dry periods of more than four month length, where there is stagnant water in pool 1 and no outflow to pool 2, could have clear impacts on the population of Masaka as well as can negatively alter the papyrus ecosystem. The remo projection shows a similar trend. However, the periods of water shortage are generally shorter in this projection: From 2020-2029 its average length is 9 days, from 2030-2039 it is 16 days and from 2040 to 2049 it is 75 days.

We suggest using the average length of periods of water shortage as an indicator for (i) the potential extent of drinking water shortage at Masaka, (ii) the danger of the deterioration of water quality in pool 1 and (iii) water shortage for the papyrus ecosystem in pool 2.

The projection of total water volume in pool 1 (see figures 8 and 11 for cclm and remo, respectively) shows in general a similar picture: The depth and width of the water minimum during the second dry season strongly increases with time. Although the extremely low values from 2040-2049 in the cclm projection (figure 8) may seem rather unrealistic, the overall trend is clearly visible and congruent with the remo projection (figure 9).

References

Aslam O., Dale L., Mehta V. and Miller N. L., « Assessing climate vulnerabilities and infrastructure of three small scale water utilities in the lake Victoria basin”, Stockholm Environment institute (2010)

Fournet S., Liersch S. and Hatterman F., “Projection of precipitation and runoff in Nabajjuzi wetland 2010-2100, based on long term observations (1960-2000) using the software SWIM”, to be published within the WetWin project (2010)

Management plan, “Nabajjuzi community based wetland management plan (2004-2008)”, Wetlands inspection division, Ministry of water lands and environment, Kampala, Uganda (2004)

NWSC, personal communication with R. Kaggwa and other members of the National Water and Sewerage Corporation, Uganda (2010)

PIK, Potsdam Institute for Climate Impact Research, Telegrafenberg A 31, 14473 Potsdam, Germany, <http://www.pik-potsdam.de/>

Ramsar, the Ramsar convention on wetlands, <http://www.ramsar.org>

Saunders M. J., Jones M. B. and Kansiime F., “Carbon and water cycles in tropical papyrus wetlands”, *Wetlands Ecol Manage* **15**, 489-498 (2007)

SRTM, shuttle radar topography mission, NASA, <http://www2.jpl.nasa.gov/srtm>

Zsuffa, I. 2012. Driving forces – States – Impacts – Responses: DSIR analyses at the study sites. WETwin Deliverable 3.2.