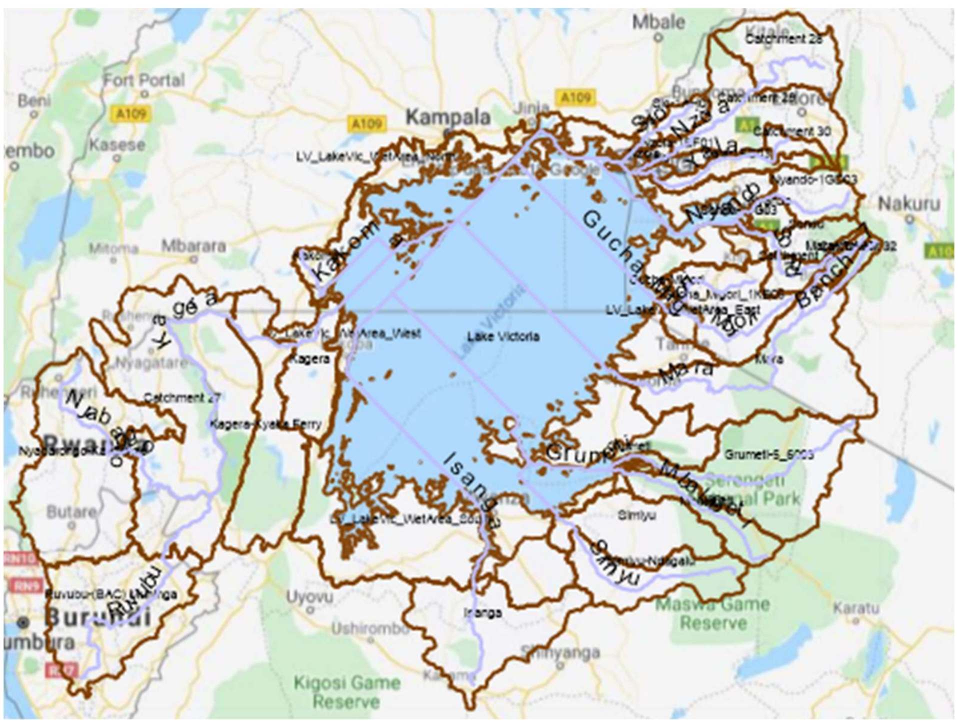
IGAD CLIMATE PREDICTION AND APPLICATION CENTER (ICPAC)

The African Networks of Centres of Excellence on Water Sciences PHASE II (ACE WATER 2)

WAter and COoperation within the NIle River Basin (WACONI)

Hydrology and Water Balance for Lake Victoria sub basin



Draft Final Report

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2019

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1 INTRODUCTION

1.1 Background

The project "*The African Networks of Centres of Excellence on Water Sciences PHASE II (ACE WATER 2)*" aims at fostering sustainable capacity development at scientific, technical and institutional level in the water sector. The project supports twenty (20) AU-NEPAD African Network of Centres of Excellence in Water Sciences and Technology (CoEs) organized in three regional networks, in conducting high-end scientific research on water and related sectors, in order to provide effective scientific and educational support to governments. The project is implemented in partnership between UNESCO, in charge of the human capacity development component, and the JRC that coordinates the scientific component and leads the project.

In the framework of the project scientific component, the CEANWATCE (Central-Eastern Africa Network of WATer Centers of Excellence) identified, by means of collective sharing, the Blue Nile Basin (BNB) and the Lake Victoria Basin (LVB), as sub-catchments of the Nile being very relevant for the development of common research undertakings. These basins pose many challenges from a perspective of Water-Energy-Food-Ecosystem (WEFE) nexus, including, among others, hydropower, reservoir multipurpose optimization and release management (in particular the BNB), rain-fed and irrigated agriculture development, impact of land use and agricultural practices (including livestock and fisheries), role of ecosystem services (natural parks, wetlands), pressures on resources due to population increase and climate variability/change and extreme events risks (drought and flooding).

This project addresses WEFE nexus interdependences and evaluates sustainable bridging-gap solutions, based on state-of-the-art reviews and scientific analysis. Building on the discussions with CEANWATCE and the Inter-Governmental Authority on Development (IGAD), specific actions are to be implemented, taking into account scientific competencies of both CoE and JRC, and in view of an effective cooperation with other key regional stakeholders, towards the development of a dynamic web African Atlas on Water Cooperation, supporting decision making processes through scenarios-based-analysis.

Based on IGAD strategies and priorities and supported by AMCOW (declaration GA/10/2016/Dar/14) in the frame of the ACEWATER2 project, the following areas of scientific investigation relevant to WEFE nexus analysis have been identified:

1. Climate variability and extreme events
2. Hydrology, water balance and hydropower
3. Water and livelihood: agricultural water, health, quality, access, resilience

This report in on the scientific investigation of hydrology and water balances for the Lake Victoria Basin.

The **specific objectives** to be addressed by the IGAD Climate Prediction and Applications Centre (ICPAC) on hydrology, water balance and Hydropower is; to perform hydrological and water balance assessments, including water uses within a scenario based analysis under different climate pressures and management practices focusing on the LVB of the Nile Basin

1.2 Study Area

Lake Victoria basin (LVB) is transboundary river basin which is Africa's largest freshwater lake at its exit. The riparian countries are Burundi, Kenya, Rwanda, Tanzania and Uganda which is the most downstream country. The LVB covers 180,950 square kilometres, with Tanzania occupying 44 %, Kenya 22 %, Uganda 16 %, Rwanda 11 %, and Burundi 7 % of the land area (LVBC, 2018). The lake surface area is approximately 68,870km^2. The average population density in the entire basin is about 165 persons/km^2 making it one of the highest in the region. This is due to its favourable conditions for agriculture, fishing and other economic activities. The growing population, with an average annual growth rate of 3%, exerts increasingly greater pressures on its natural resources (UNEP, 2006). Thus the use of the water related resources supports the livelihood needs of the inhabitants of the basin.

2 METHODOLOGY

2.1 Conceptual framework

The study can be grouped in to three inter-related activities as shown in figure. The data requirement for this research work was identified in the inception stage and there after sourcing for the data commenced, some pre-processing of basic data such DEM and hydrometeorology was carried out at this stage. This was followed by rainfall runoff modelling which was preceded by catchment delineation, and included calibration and validation. The rainfall-runoff model formed the base for water resource modelling on the water use analysis for current and future demands and infrastructure development.

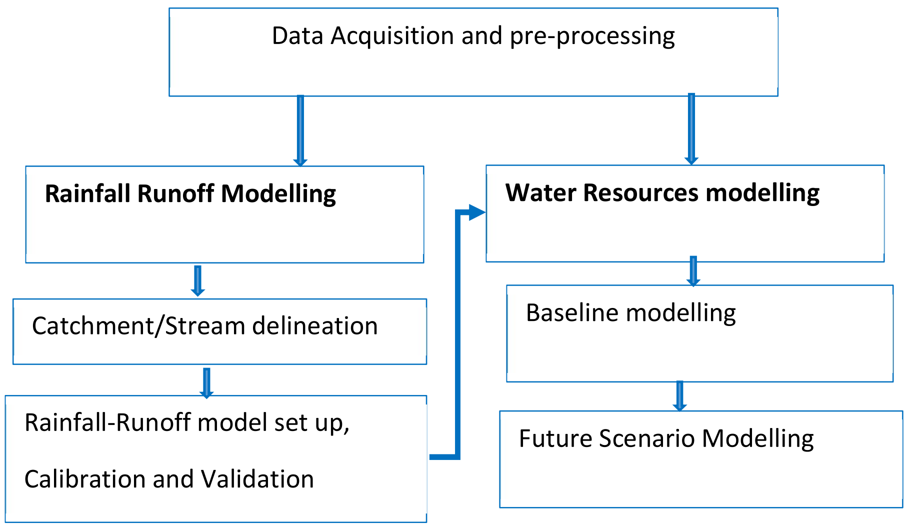

Figure 1: Conceptual Modelling Framework

In this study, water balance components was calculated from calibrated and validated hydrological/rainfall runoff model for the Lake Victoria basins. The impact of current and future water resources availability due to climate variability, uses and infrastructure was evaluated through water resources modelling. The water resources model included current and planned future water use/infrastructure development and Lake Victoria and associated operation rules.

The model was simulated on 30 year (1981-2010) period datasets and calibrated and validated at river gauging and water level points where data existed. Mass balance error and Nash-Sutcliffe Coefficient was used to guide the calibration process.

MIKE HYDRO Basin software was used in this study for delineation, Rainfall Runoff and Water Resources Modelling. MIKE HYDRO Basin is a commercially-available, multipurpose, map-based decision support tool developed by the Danish Hydraulics Institute (DHI) for integrated river basin analysis, planning and management (DHI, 2019). It is designed for analysing water sharing issues at international, national and local river basin level and includes the lumped and conceptual NAM rainfall-runoff model.

The water balance modelling study tasks for the Lake Victoria involved the sequential steps listed below, each of which is discussed in more detail in the following sections and sub chapters:

1. Model sub-catchment delineation
2. Preparation and assignment of hydro-meteorological time series data to model sub-catchments
3. Model calibration and validation

2.2 Model Sub-Catchment Delineation

River network generation and catchment delineation of model sub-catchment areas within the Lake Victoria South Basin were based on the HydroSHED hydrologically conditioned 90 m SRTM DEM (NASA, 2009), processed within MIKE HYDRO Basin's catchment delineation tool. Sub-catchment were delineated upstream of points of interest such as

- River gauging station (where observed River discharge data is available)
- Location of current major infrastructure (e.g. dams)
- Location of future major infrastructure that have been selected to be included in the model
- Outflow of a catchment into the Lake

Due to the difficulty of modelling numerous small catchments and islands that drain directly in to the Lake Victoria, these areas were lumped and grouped as Lake Victoria East, West, North and South. There areas and shapefiles were obtained from literature. In total 35 sub catchments were delineated as shown in the Figure 2.

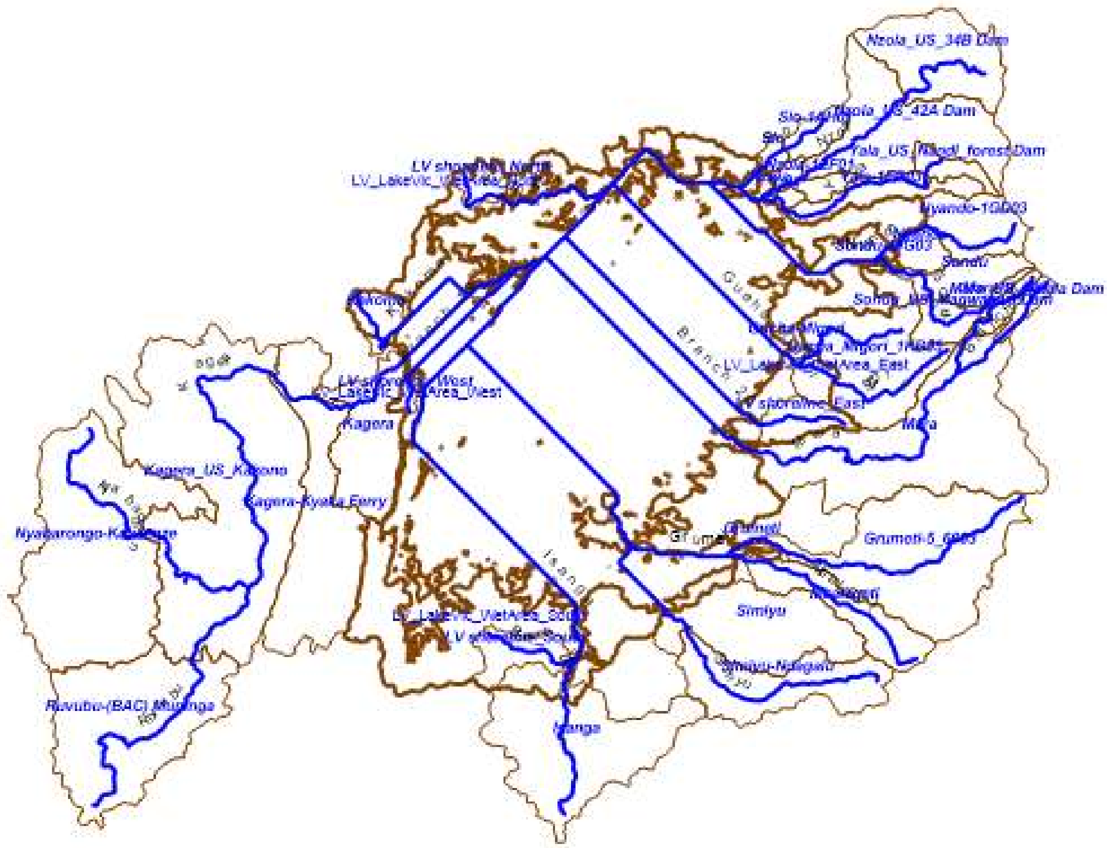

Figure 2: Delineated Sub Catchments-Lake Victoria Basin

3 HYDRO METEOROLOGICAL, INFRASTRUCTURE AND RELATED DATA AVAILABILITY AND ANALYSIS

3.1 Precipitation

Precipitation data is necessary input for running rainfall-runoff models and observed data is best for carrying out the modelling activity. There was a lack of observed rainfall data for this study and thus public domain datasets was the best option. The CHIRPS datasets is available from January 1981 and was the suitable for the simulation period 1981-2010.

CHIRPS daily precipitation data produced by the Climate Hazard Group of the University of Santa Barbara, California (Funk *et al, 2014*), was downloaded for the period Jan 1981 - December 2010, extracted and rendered as times series for each grid over the LVB.

The Daily areal average sub catchment rainfall data was calculated for all the 35 sub catchments. The mean annual precipitation is shown in Figure 3.

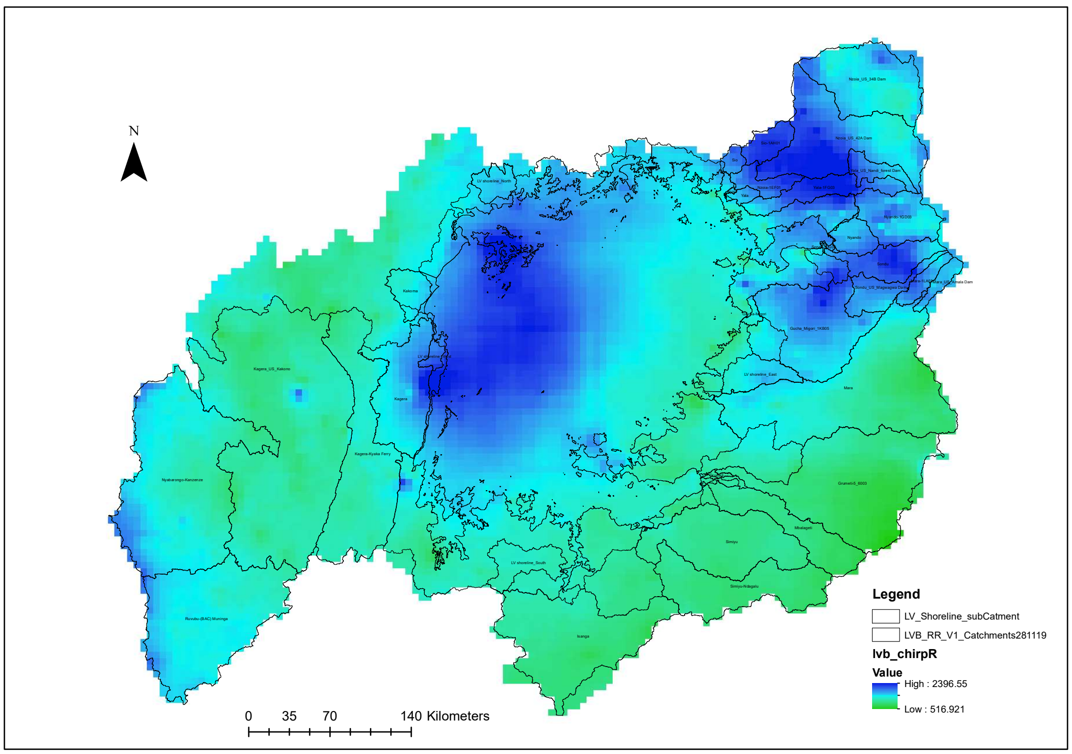

Figure 3: Mean Annual Precipitation (mm/yr) of modelled Sub catchments

3.2 Streamflow data

River discharge data were required for this study in order to calibrate rainfall-ruonff models. The Lake Victoria Basin is a transboundary river basin with five riparian countries thus each country has its own network hydromet stations. Efforts were made to try and get data from these countries and also from research collaborator, Makerere University and only 8 river gauging stations data were obtained. Two more stations data were obtained from anonymous sources on condition that it cannot be shared with the stakeholders. As can be seen from the details of the streamflow datasets shown in Table 1, most of the stations have less than 50% data availability over the simulation period. Quality assessment was done for the river discharge data and all were found to be of good quality for use in calibration and validation.

Table 1: Details of Rivers Discharge Data

No	Name/ Code	River	Country	Temporal Resolution	% data availability (1981-2010)
1	1AH01	Sio	Kenya	Daily	57.1
2	1EH01	Nzoia	Kenya	Daily	60.9
3	1FG03	Yala	Kenya	Daily	44.6
4	1GD03	Nyando	Kenya	Daily	39.1
5	1JG03	Sondu	Kenya	Daily	31.5
6	1KB05	Gucha Migori	Kenya	Daily	37.9
7	1LA03	Mara	Kenya	Daily	52.8
8	Simiyu	Simiyu	Tanzania	Daily	44.2
9	Kagera	Kagera	Tanzania	Monthly	33.3
10	Rusumo	Kagera	Burundi/Rwanda /Tanzania	Monthly	33.3

3.3 Evaporation data

Potential ET (PET) together with precipitation are the two basic inputs required to run rainfall-runoff models. Due to the limited number of evaporation station available in the region and lack of access to it, indirect simple methods for estimation of potential ET was considered. One such method is the temperature based Blaney-Criddle Method (Allen et all, 1986). Using gridded monthly temperature data from the Terrestrial Hydrology Research Group at Princeton University as inputs to this method, monthly PET was calculated for each 0.25 deg grid size over the LVB. This data was then rendered as time series and areal sub catchment monthly average PET (mm/d) calculated for each of the modelled sub catchments. Daily PET for three subctachments is shown in Figure 4.

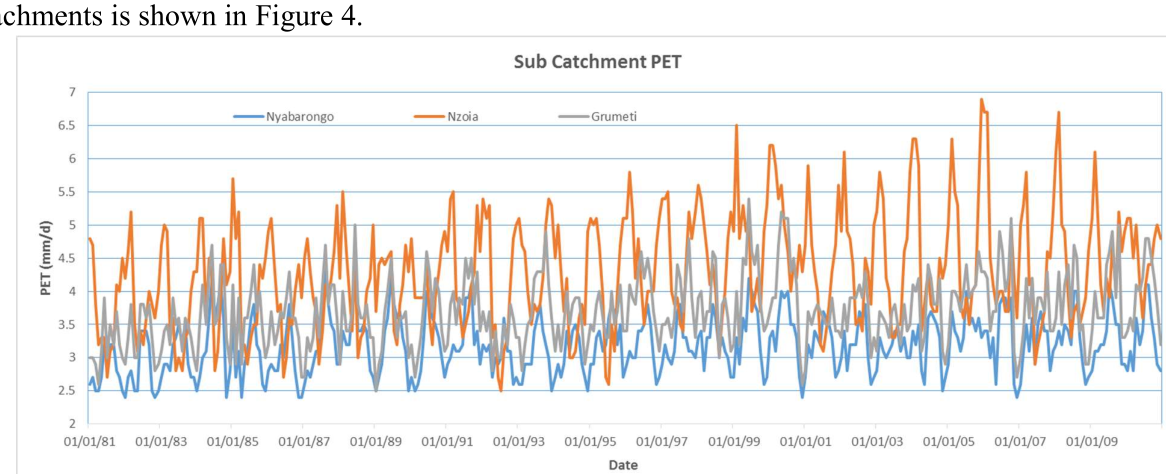

Figure 4: Calculated PET for Three sample sub catchments

3.4 Water Level data

Lake water level data was obtained from the Theia-CNES center as well as from Makerere University. The former is based on satellite altimetry data using Jason, Envisat, Saral and Sentinel Satellites, while the latter is observed data at the Jinja town, Uganda. Since the two data are at different datum, it was necessary to convert the observed data from absolute to relative water level data. A value of 1123.5m datum adjustment was found to give the best fit. The satellite data is available from 1992 while the observed is available for the entire simulation period. The comparison of the raw water level data, adjusted observed datum adjusted and satellite water level is shown in Figure 5, the datum shifted observed and satellite altimetry data use the secondary y-axis.

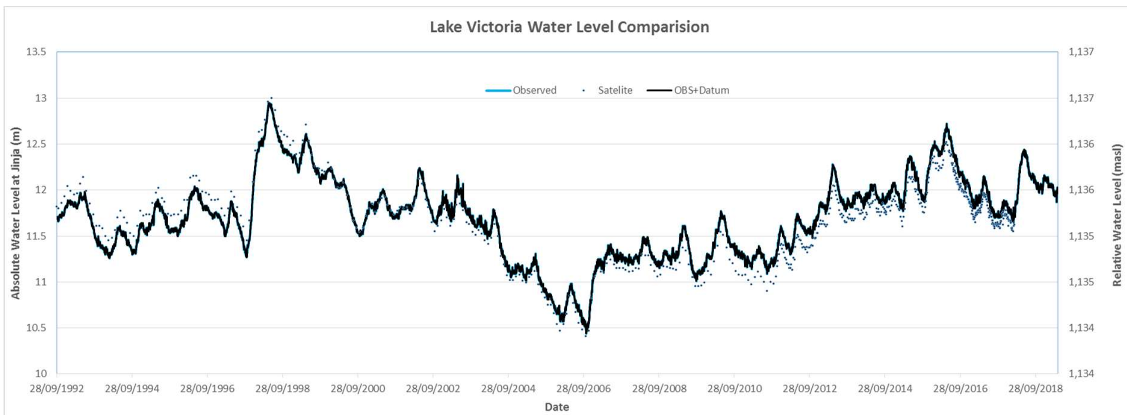

Figure 5: Lake Victoria Water Level Comparison between Observed and Satellite-based Water Levels

3.5 Water Demand data

3.5.1 Domestic/Municipal water demand data

Domestic and municipal water demands depend largely on population and level sanitation. In the Lake Victoria sub basin estimated population data for sub catchment in the year 2000 was available and this data was projected for the years 2030 and 2050 using the World Bank population growth estimates (World Bank, 2019). The demands were thus estimated using 50liters per capita per day which is the lower value of WHO recommendation of 50-100 litres per capita per day (WHO, 2014). The lower value was assumed due to the fact that most of the population are rural with no modern sanitation facilities. The resultant Water demand data for each sub catchment for the three period is given in Table 2 while a more detailed datasheet is available in the Appendix.

Table 2: Estimated Domestic/Municipal Water Demand (m^3/s)

Sub Catchment\ Year	2010	2030	2050
Sio	0.24	0.40	0.65
Nzoia	2.43	3.99	6.53
Yala	0.79	1.30	2.13
Nyando	0.45	0.74	1.22
Sondu	0.58	0.96	1.57
Gucha Migori	1.10	1.80	2.95
Upper Mara	0.25	0.42	0.68
Lowe Mara	0.23	0.43	0.79
Kagera	4.98	9.17	16.89
Grumeti	0.20	0.37	0.69
Isanga	0.34	0.62	1.15
Simiyu	0.38	0.70	1.29
Mbalageti	0.17	0.31	0.56
Muame	0.35	0.65	1.20
Nyabarongo	3.20	5.15	8.27
Ruvubu	1.43	2.69	5.05
Katonga	2.17	3.99	7.35
Bukora	1.19	2.20	4.05

3.5.2 Irrigation Water Demand

Irrigation water demand data was collated mainly from a study done by the Food for Thought (F4T) project (FAO, 2011), which had a baseline for 2005 and projections for year 2030 and 2050. The F4T report had irrigation demands for administrative units or districts rather than sub catchments so the proportion of each unit in a catchment was used which assumes uniform distribution of irrigated area within each administrative unit. The data was cross checked with available Irrigation as well as water resources master plans (GoR, 2010; JICA, 2013; FAO, 2014; JICA, 2018). The cross check was performed at the sub basin level (e.g Lake Victoria basin in Tanzania or Lake Victoria North Catchment Area in Kenya) since the Master plans have current and projected irrigation demand at that level. There was good agreement for all countries except for Tanzania where F4T report had much lower figures compared to the master plan. In this case the Tanzania irrigation master plan figures was adopted and the figure equally divided among the 7 catchments that form the Lake Victoria basin. It is important to note that the reports reviewed did not show any irrigation water use in the two sub catchments in Uganda. The 2010 and project irrigation demand are shown in Table 3.

Table 3: Estimated Irrigation Water Demand (m3/s)

Sub Catchment \ Year	**2010**	**2030**	**2050**
Sio	0.34	0.48	0.59
Nzoia	7.84	10.00	12.32
Yala	3.68	4.65	5.72
Nyando	5.79	7.53	9.28
Sondu	3.20	4.10	5.05
Gucha Migori	14.05	18.12	22.33
Upper Mara	1.15	1.48	1.82
Lowe Mara	0.01	3.21	6.42
Kagera (TZ)	0.01	3.21	6.42
Grumeti	0.01	3.21	6.42
Isanga	0.01	3.21	6.42
Simiyu	0.01	3.21	6.42
Mbalageti	0.01	3.21	6.42
Nyabarongo	10.04	12.06	14.15
Ruvubu	1.52	2.69	4.15

3.6 Lake Victoria and Major Wetlands Data

In order to model the water balance in a lake, one needs data on the bottom and crest level of the lake, the level, surface area and stored volume relationship, release rules on top of the hydromet data rainfall, evaporation as well as infiltration. The release rule or what is what is known as agreed curve was obtained from the literature but mainly the Master plan study for the Uganda Hydropower Development (JICA, 2011) while the other information sourced from existing literature including Wikipedia. The Observed water level data has been explained in section 3.4.

There exists several wetlands such as Ihema and Rushwa in the Kagera catchment of the LVB which attenuate flow in a similar way as lakes and reservoirs do. However there is lack of critical modelling data such bathymetry and this study used a conical shaped reservoir to try and capture the effect such large wetlands has on river flow.

3.7 Current and Planned Reservoir data

The only existing reservoir in the Lake Victoria Basin is the Sondu-Miriu which has day storage facility, however there are several planned reservoirs in the basin as shown in Table 4. The minimum data required for modelling are the Target power, water demand, bottom, top of dead storage, crest levels and level area volume relationship were sources from literature (JICA 1992, AfDB 2018) and where lacking estimated.

Table 4: Planned Reservoirs in the Lake Victoria Basin

Reservoir Name	River	Country	Purpose
Rusomo	Rusumo (confluence of Nyabarongo and Ruvubu)	Burundi, Rwanda & Tanzania	Hydropower
Kakono	Kagera	Tanzania	Hydropower
Nandi	Yala	Kenya	Multi Purpose
Magwagwa	Sondu	Kenya	Hydropower
Amala	Mara	Kenya	Multi Purpose

4 RAINFALL-RUNOFF MODELLING

4.1 Input Data Preparation and model Setup

Model input timeseries data for daily precipitation and PET was prepared for the 35 delineated sub catchment and this was followed by calibration and validation suing the 10 river gauging stations mentioned in section 3.2.

The NAM stands for Nedbør Afløbs Model (in Danish) and means a rainfall-runoff model, it is a lumped conceptual hydrological model and is one of the available modules in the Mike-Hydro model. It simulates the rainfall-runoff processes that occur in the catchment as shown in Figure 6 and its outputs can be directly used in the Water Resources or hydrodynamic module of the Mike-Hydro. Structurally the model represented by four storages: at the top is snow storage followed by upper storage then lower storage and then groundwater storage. The model simulates the rainfall-runoff process by accounting for the water content in each of the four storages which are mutually inter-related. NAM also allows river withdrawals for irrigation or municipal water.

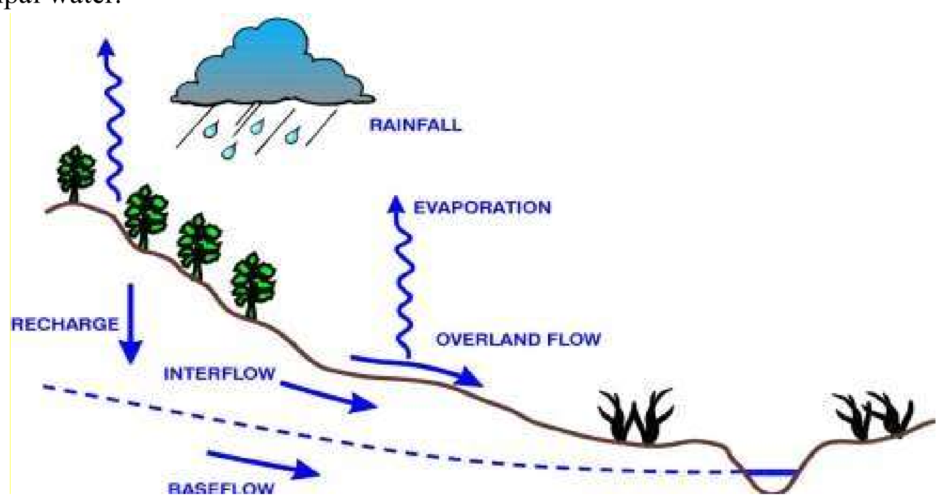

Figure 6: NAM / MIKE Hydro modelled processes (DHI, 2019)

4.2 Model Calibration and Validation

Model calibration involves adjustment of model catchment parameters until a good fit between the model catchment runoff and observed river flow is achieved. In the case of NAM model the parameters that are adjusted are shown in Table 5.

Table 5: NAM Adjusted Parameters (DHI, 2019)

Parameter	Description	Effects
Umax	Maximum water content in surface storage	Overland flow, infiltration, evapotranspiration, interflow
Lmax	Maximum water content in lower zone/root storage	Overland flow, infiltration, evapotranspiration, base flow
CQOF	Overland flow coefficient	Volume of overland flow and infiltration
C_{KIF}	Interflow drainage constant	Drainage of surface storage as interflow
TOF	Overland flow threshold	Soil moisture demand that must be satisfied for overland flow to occur
TIF	Interflow threshold	Soil moisture demand that must be satisfied for interflow to occur
TG	Groundwater recharge threshold	Soil moisture demand that must be satisfied for groundwater recharge to occur
CK1	Timing constant for overland flow	Routing overland flow along catchment slopes and channels
CK2	Timing constant for interflow	Routing interflow along catchment slopes
CK_{BF}	Timing constant for base flow	Routing recharge through linear groundwater recharge

The model was calibrated using observed daily streamflow for the baseline period of 1981-2010. In order to measure the performance of calibration two performance criteria were used:

Water Balance error (WBE) or deviation of runoff volumes: The WBE is calculated as in equation (1). The second visual criteria was the **Nash-Sutcliffe coefficient of Efficiency** (**NSE**), equation (2).

$$\boldsymbol{WBE} = \left(\frac{\boldsymbol{Qo-Q}}{\boldsymbol{Qo}}\right) \times \mathbf{100}\% \quad \text{(eq. 1)}$$

Where Qo is accumulated observed discharge, Qs is accumulated simulated discharge

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(OBS_i - SIM_i\right)^2}{\sum_{i=1}^{n}\left(OBS_i - \overline{OBS}\right)^2} \quad \text{(eq. 2)}$$

Where OBS is observed discharge and SIM is the simulated discharge.

A split approach was used to apportion observed data for calibration and validation based on the length and period of data availability. The calibration and validation period for each gauging station is shown in Table 6. Parameter adjustment (one at a time) was done until the criteria mentioned above was achieved during calibration. In the validation period, no parameter changed. In ungauged catchments or ones where no observed data was available mainly in Tanzania and border Mara and Kagera catchments, average parameter values were used between Mara and Kagera catchments.

Table 6: Calibration and Validation Periods

No	Station Name/ Code	Calibration Period	Calibration Period
1	1AH01	1982-1991	1994-2002
2	1EF01	1982-1991	1995-2002
3	1FG03	1982-1987	1988-1996
4	1GD03	1983-1987	1988-1994
5	1JG03	1983-1988	1989-1995
6	1KB05	1982-1986	1987-1990
7	1LA03	1982-1991	1992-2001
8	Simiyu	1998-2005	2007-2010
9	Kagera (mean monthly data)	1982-1985	1986-1990
10	Rusumo (mean monthly data)	1982-1985	1986-1990

4.3 Calibration and Validation Results

Summarised calibration and validation results are given in Table 7 subsequent Figures while a more detailed graphical results is shown in the Appendix. Good calibration results were achieved in some catchments while in others it was difficult to improve the results beyond the tabulated figure. The length and quality of observed data is particularly critical in achieving good calibration and validation results.

In the Lake Victoria Water Level simulation (Figure 11), the model was able to capture the water level variation well with the exception of the high rainfall period (1998-1999) which was associated with the El Niño phenomena. This may be due to underestimation of the convectional rainfall over the Lake by CHIRPS rainfall product which is also seen in the water balance results in the next section.

Table 7 Calibration and Validation Results

No	**River Gauging Station**	**MBE (%)**		**NSE (-)**	
		Calibration	Validation	Calibration	Validation
1	1AH01	36.2	8.5	0.248	0.456
2	1EF01	15.3	-35.8	0.723	0.078
3	1FG03	20.4	-31.8	0.450	0.277
4	1GD03	141.0	11.0	-0.351	0.348
5	1JG03	-19.0	22.0	0.143	0.614
6	1KB05	47.2	0.70	0.095	0.657
7	1LA03	8.9	-10.2	0.399	0.315
8	Simiyu	33.0	-13.0	-0.129	0.577
9	Kagera	3.3	2.1	-2.12	-0.909
10	Rusumo	18.8	14.9	-0.975	0.477

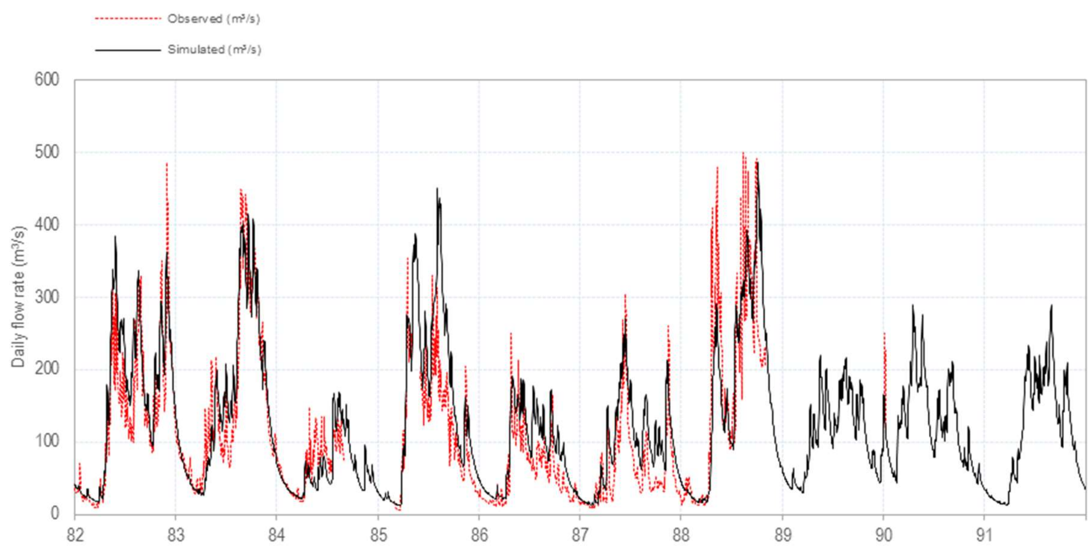

Figure 7: River Nzoia (1EF01) hydrograph for the Calibration Period

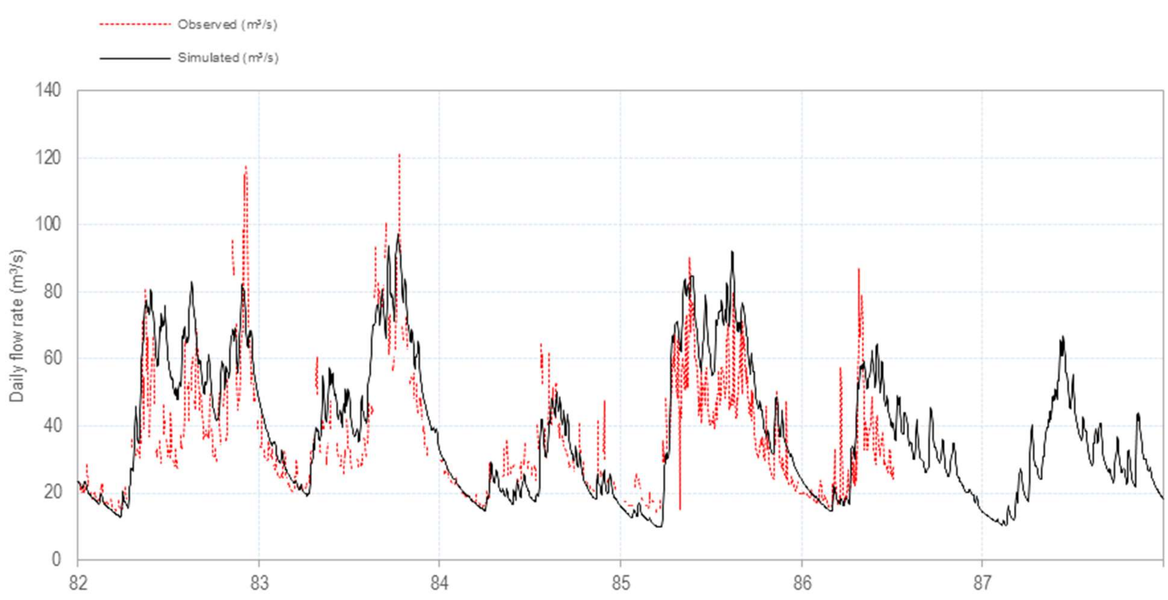

Figure 8: River Yala (1FG03) hydrograph for the Calibration Period

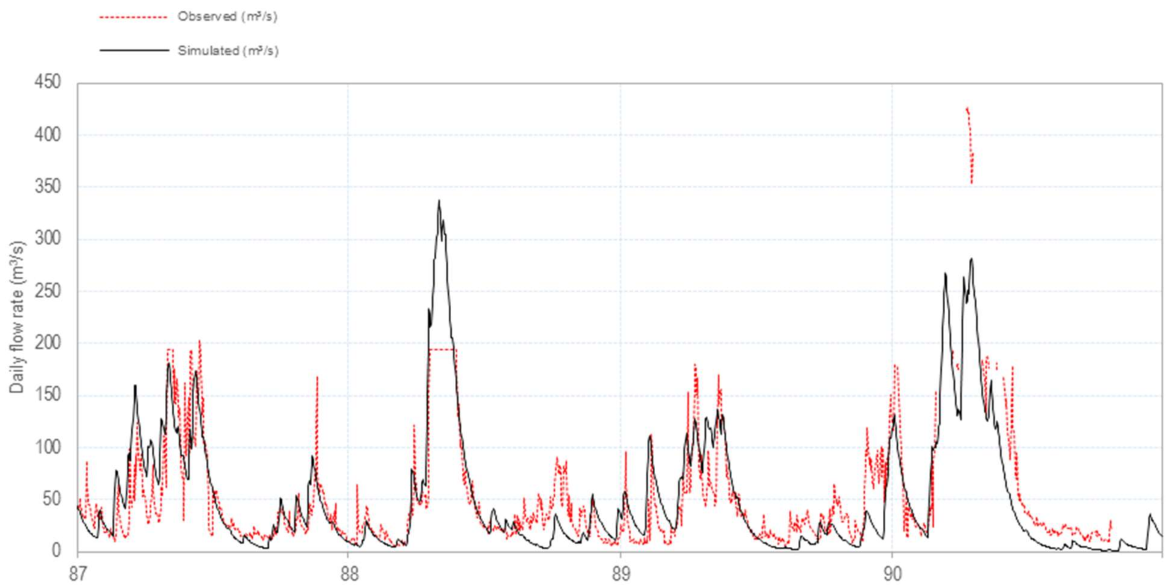

Figure 9: River Gucha-Migori (1KB05) hydrograph for the Validation Period

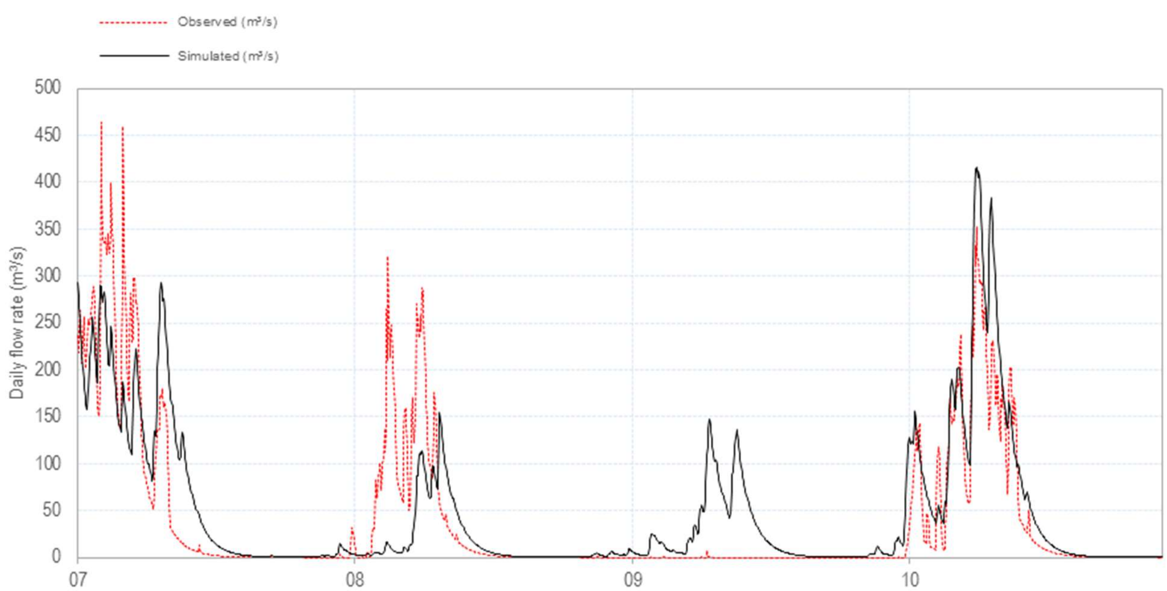

Figure 10: River Simiyu hydrograph for the Validation Period

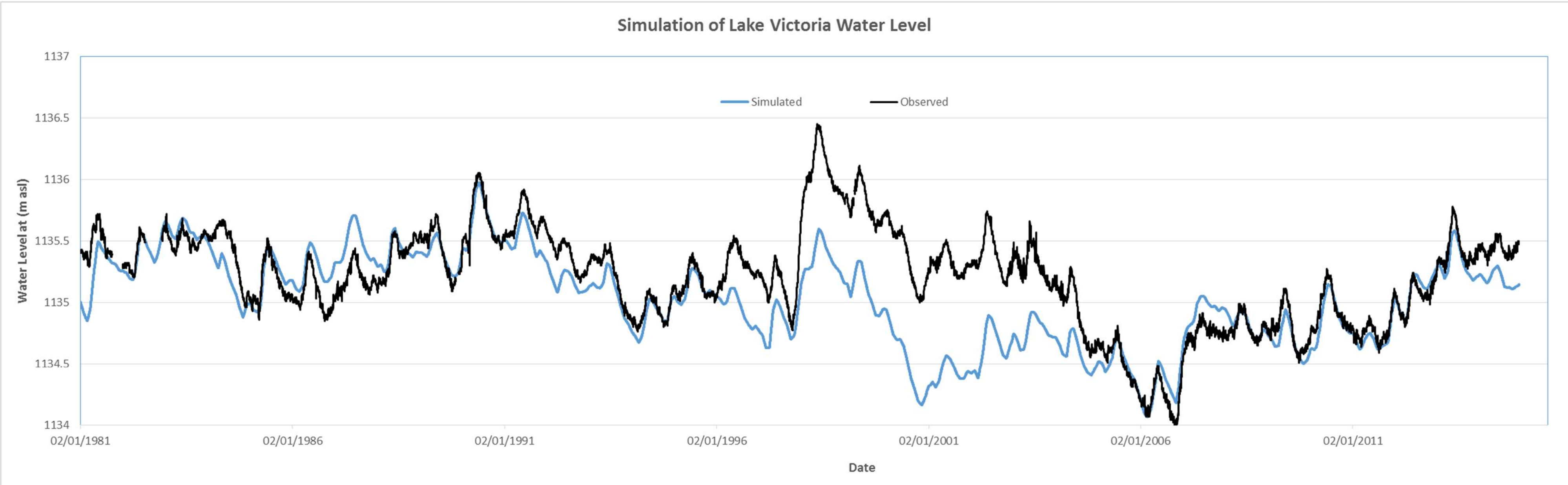

Figure 11 comparison of Simulated and Observed Lake Victoria Water Level

4.4 Lake Victoria Sub Basin Water Balance

Based on the simulation model output over the entire simulation period of 1981-2014, mean outflow from the LVB catchments as well as an estimate of the Lake Victoria water balance were calculated. Although the catchment outflows represent the natural flows from the catchment not all of flows into Lake Victoria as there are consumptive water uses such as irrigation and municipal supply that reduce the flow in the Lake which is what the observed flows indicate. The Lake Victoria water balance however includes net flows to the lake as well as estimated over the Lake Precipitation and Actual Evaporation.

The LVB catchments compare well with the observed LTM, differences do exist and can be attributed to different mean period and in particular the observed data includes the high precipitation observed in the early 1960 which is outside the range of the modelling period. Model inaccuracies include accuracy of input precipitation data also account for the difference.

Table 8: Simulated Long Term Mean Discharge for Lake Victoria Catchments

Sub Catchment	**Simulated LTM discharge (m^3/s) (1982-2014)**	**Observed LTM discharge (m^3/s) (1950-2004)[1]**
Sio	16.8	11.3
Nzoia	132	116.1
Yala	39.1	38.4
Nyando	33.7	20.3
Sondu	48.1	42.4
Gucha Migori	51	56.6
Mara	38.0	36.5
Grumeti	18.7	11.0
Isanga	32.9	29.0
Simiyu	31.92	37.0
Mbalageti	7.6	4.2
Kagera (inflow to LV)	297.4	260.5
Katonga	6.1	4.9

[1]: Regional Lake Victoria Environment Report, Chapter 3 Water Balance (LVEMP, 2005)

Table 9: Lake Victoria Water Balance

Component	**Simulated LTM Volume (km^3/yr)**	**Comparison with Literature (km^3/yr)[2]**
Rainfall	87	125
Inflows from Catchments	32	23
Evaporation	97	110
Outflow (to Victoria Nile)	23	38
Net Water Balance	-1	0

[2]: Data of 1996 from WB quoted in LV Environmental Outlook (2006)

5 WATER RESOURCES MODELLING

5.1 Model Setup and Comparison Indicators

A baseline water resources model was set-up for the Lake Victoria sub basin using the Mike Hydro model, with the outputs from the rainfall-runoff model (stream/natural flow) together with current water use/infrastructure development and Lake Victoria and associated operation rules. Two Scenario models were also built from the baseline and included projected future water use/infrastructure development. Climate variability was implicitly taken in two consideration through the modelled rainfall-runoff output. The details of the scenarios are shown in Table 10. The scenarios take into consideration WEFE issues such water Demand for domestic municipal, irrigated agriculture and hydropower energy.

Table 10: Details of Modelled Scenarios

Scenario	Forcing data	Water Demand	Infrastructure
SC0 - Baseline	1981-2010	2010	2010
SC1 - Near Future	1981-2010	2030 (projected)	Planned Infrastructure
SC2 - Far Future	1981-2010	2050 (projected)	Planned Infrastructure

The water demand and infrastructure associated with each scenario were prepared as indicated in sections 3.5 and 3.7. The reservoirs were operated to meet the demands for the purpose of development (e.g hydropower) as well as downstream demand within the river and no minimum flow requirement was set in this scenario simulations.

In order to compare the performance of the scenarios the following simple indicators were selected.

Long Term Average river discharge at tail end of river reaches: The long term daily simulation results was analysed for each river at the last node feeding in to the Lake to calculate these indicator.

Water demand satisfaction rate: As the model calculates the daily water demand deficit in absolute (volume) as well as percentage form, average values for the entire simulation will be calculated for all river for each scenario.

Sub Basin wide Hydropower Produced: The average hydropower (MW) produced by each of the hydropower station will be summed up for each scenario.

Change in Long term Lake Victoria water Level: The long term change of Lake Victoria compared to the baseline (SC0) will be evaluated as an impact of the upstream water use on the lake. This assumes the outflow from the lake will continue to follow the ‘agreed curve’.

5.2 Scenario Simulation Results

Tables 11 & 12 gives the results of the scenario simulation, as can be seen from the Tables there is a general reduction in mean flow in 2030 and 2050 compared to the baseline 2010 with the reduction in 2050 being higher than 2030. There is an increase in both domestic and irrigation water deficit as well as hydropower produced in 2030 and 2050 compared to the baseline. Municipal water demand deficit is lower than irrigation because it has a higher allocation priority but both will suffer in future due to increased demand even without considering climate change.

It is noteworthy that with new resevoirs and hydropower infrastructure hydropower generation is going to increase in future but the new reservoirs are not able to cope with increased municipal and irrigation water demand hence an increase in demand deficit. The increase in hydropower production in SC2 compared to SC3 is attributed to increase reservoir releases to meet increased downstream demand which benefits the hydropower production. Downstream flows will continue to decrease particularly in unregulated streams.

Regarding the Long Term Lake mean water level, there will be a reduction of 0.47m and 0.55m for the SC1 and SC2 respectively. There is less impact on the lake water level because as can be seen from the Lake water balance almost 80% of the inflow water to the Lake is from precipitation on the Lake itself.

Table 11: Scenario Results

Indicator\Scenario	**SC0 (baseline)**	**SC1**	**SC2**
Long Term Municipal /Domestic Average Deficit (%)	2.0	2.0	4.0
Long Term Irrigation Average Deficit (%)	5.0	12.0	18.0
Basin Wide Average Hydropower Produced (MW)	52.9	332.5	336.7
Change in Long term Lake Victoria water Level	-	0.47m	0.55m

Table 12: River Discharge Scenario Simulation Results

River \ Scenario	**SC0**	**SC2**		**SC2**	
	m^3/s	**m^3/s**	**% change**	**m^3/s**	**% change**
Sio	16.8	15.9	-5.4	15.5	-7.7
Nzoia	132.1	112.3	-15.0	113.4	-14.2
Yala	39.1	35.1	-10.2	33.2	-15.1
Nyando	33.7	26.1	-22.6	24.3	-27.9
Sondu	48.1	42.7	-11.2	41.1	-14.6
Gucha-Migori	51.0	35.9	-29.6	33.0	-35.3
Mara	38.5	26.0	-32.5	20.0	-48.1
Grumeti	18.7	15.9	-15.0	14.0	-25.1
Mbalageti	7.6	5.7	-25.0	4.6	-39.5
Simiyu	31.9	28.7	-10.0	26.3	-17.6
Isangi	32.9	29.6	-10.0	27.3	-17.0
Kagera	297.4	278.7	-6.3	258.7	-13.0

6 CONCLUSION

In this study hydrological modelling and water balance assessments were performed for the Lake Victoria Basin. This included database preparation, rainfall-runoff modelling and scenario based water resource modelling.

The simulated water balances for both the upstream catchments contributing flow to the Lake Victoria as well as the Lake Victoria were in good agreement with documented observed values in the literature.

Water demands was projected into the future based on available literature on future population and irrigation water use. The water use together with planned infrastructure mainly reservoirs and hydropower's was used in scenario based water resources simulation for the period 1981-2010

From the Scenario simulation results, future water use will increase water demand deficit for both domestic and irrigation uses but more deficit will be faced by the irrigation sector. The flows from the rivers in to the Lake Victoria will be reduced by up to 40% in SC2 for some rivers, however there will be about 0.5m drop in Lake water level compared to the baseline period climate due to large portion of the Lake water inflows being supplied by precipitation on the Lake itself. The simulations show that there will be a significant increase in hydropower production in future if the planned projects are actualized.

As a recommendation it will be useful to investigate various forms of precipitation products over the Lake to get a broader view of the actual precipitation variability since there are no ground based measurements data available. Also sourcing for hydromet data for smaller tributaries to get a more accurate water balance is recommended.

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APPENDIX

Domestic Water Demand Calculation

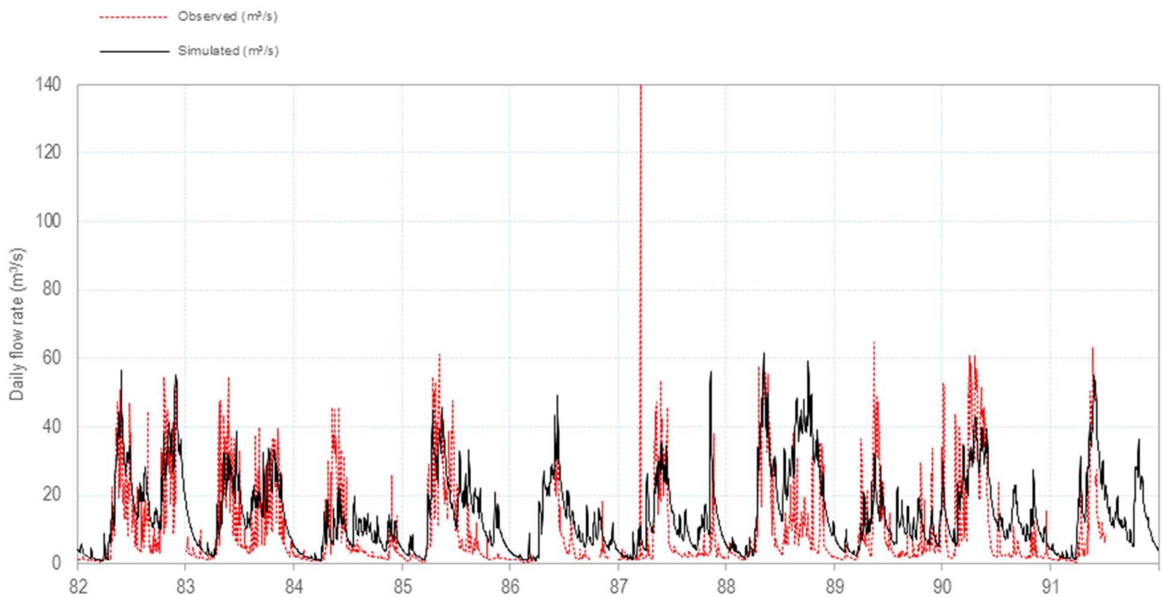
Catchment	Catchment Area (km2)	Density (person/km2)	Population	Growth Rate	Population				Water Demand m3/s (50l/p/d)		
		2000	2000		2010	2030	2050		2010	2030	2050
Sio	1486	221	328,406	2.5	420,387	688,854	1,128,767		0.24	0.40	0.65
Nzoia	14861	221	3,284,281	2.5	4,204,157	6,889,001	11,288,431		2.43	3.99	6.53
Yala	4840	221	1,069,640	2.5	1,369,230	2,243,642	3,676,469		0.79	1.30	2.13
Nyando		174	611,000	2.5	782,132	1,281,614	2,100,073		0.45	0.74	1.22
Sondu		220	788000	2.5	1,008,707	1,652,883	2,708,442		0.58	0.96	1.57
Gucha Migori		224	1481000	2.5	1,895,805	3,106,498	5,090,358		1.10	1.80	2.95
Upper Mara	7472	46	343,712	2.5	439,980	720,959	1,181,376		0.25	0.42	0.68
Lowe Mara	6443	46	296,378	3.1	402,191	740,638	1,363,890		0.23	0.43	0.79
Kagera	35040	181	6,342,240	3.1	8,606,555	15,849,028	29,186,091		4.98	9.17	16.89
Grumeti		21	258000	3.1	350,111	644,733	1,187,280		0.20	0.37	0.69
Isanga		48	430000	3.1	583,519	1,074,554	1,978,799		0.34	0.62	1.15
Simiyu		50	485000	3.1	658,155	1,211,997	2,231,901		0.38	0.70	1.29
Mbalageti		37	211000	3.1	286,331	527,281	970,992		0.17	0.31	0.56
Muame			449000	3.1	609,303	1,122,035	2,066,234		0.35	0.65	1.20
Nyabarongo	24118	181	4,365,358	2.4	5,533,749	8,892,391	14,289,522		3.20	5.15	8.27
Ruvubu	9990	181	1,808,190	3.2	2,477,656	4,651,949	8,734,317		1.43	2.69	5.05
Katonga	15244	181	2,759,164	3.1	3,744,244	6,895,051	12,697,282		2.17	3.99	7.35
Bukora	8392	181	1,518,952	3.1	2,061,250	3,795,806	6,990,002		1.19	2.20	4.05

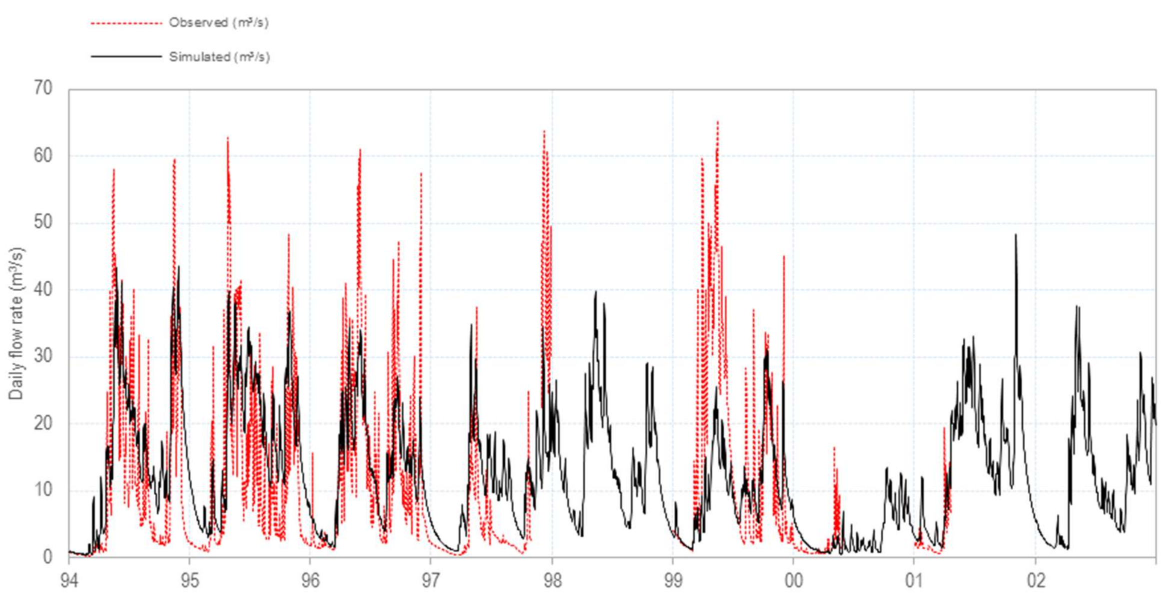
Irrigation Water Demand Calculation

	Water Demand (m^3/s)					
Catchment	2005	2010	2015	2025	2030	2035	2050
Sio	0.3492	0.3370			0.4816		0.5933
Nzoia	7.2490	7.8350			9.9964		12.3156
Yala	3.3685	3.6830			4.6451		5.7228
Nyando	5.4614	5.7870			7.5313		9.2786
Sondu	2.9707	3.2020			4.0966		5.0471
Gucha Migori	13.1434	14.0490			18.1248		22.3297
Upper Mara	1.0718	1.1450			1.4780		1.8209
Lowe Mara	0.0553	0.009	0.86086		3.2078		6.4242
Kagera	0.8102	0.009	0.86086		3.2078		6.4242
Grumeti?	0.0527	0.009	0.86086		3.2078		6.4242
Isanga		0.009	0.86086		3.2078		6.4242
Simiyu		0.009	0.86086		3.2078		6.4242
Mbalageti		0.009	0.86086		3.2078		6.4242

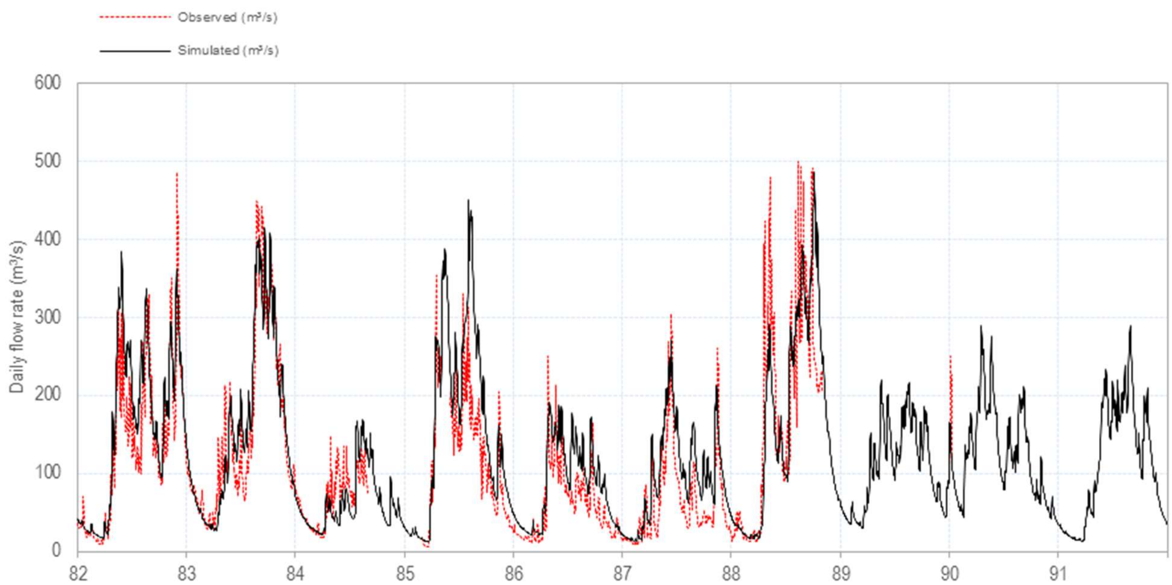
Calibration (first graph) and Validation (second graph) -Simulation Results

Sio River (1AH01)

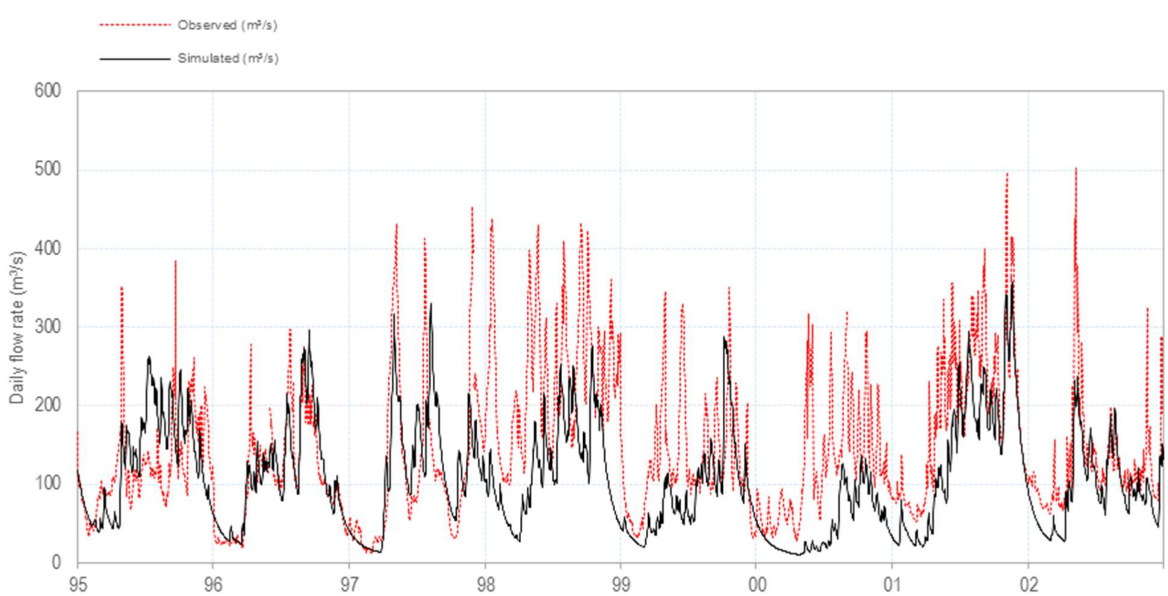




Nzoia (1EF01)

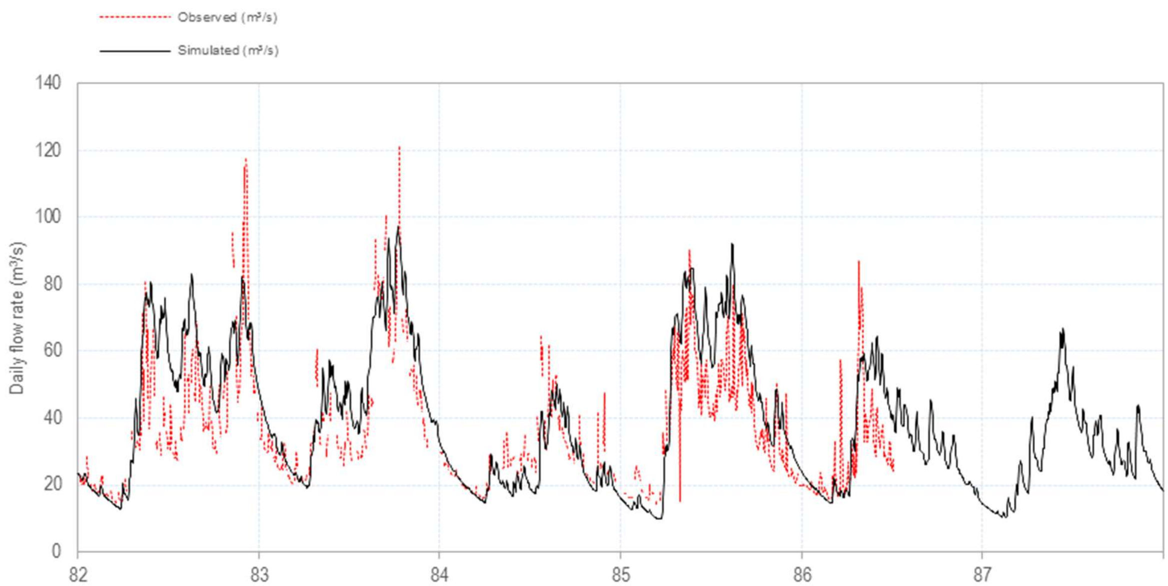


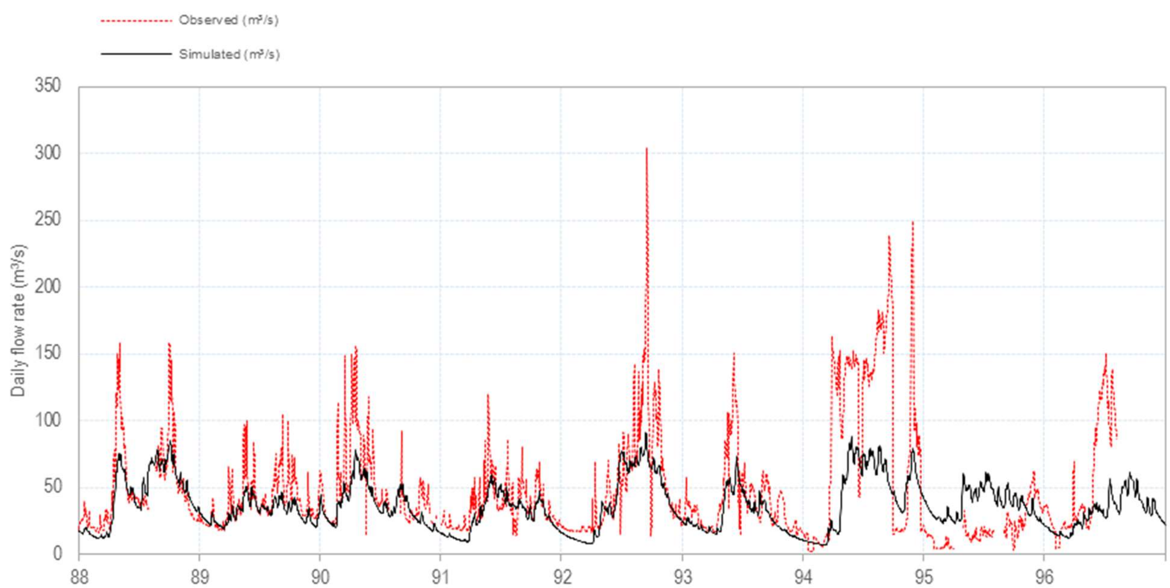
Observed (m³/s)
Simulated (m³/s)
Daily flow rate (m³/s)
600
500
400
300
200
100
0
82
83
84
85
86
87
88
89
90
91



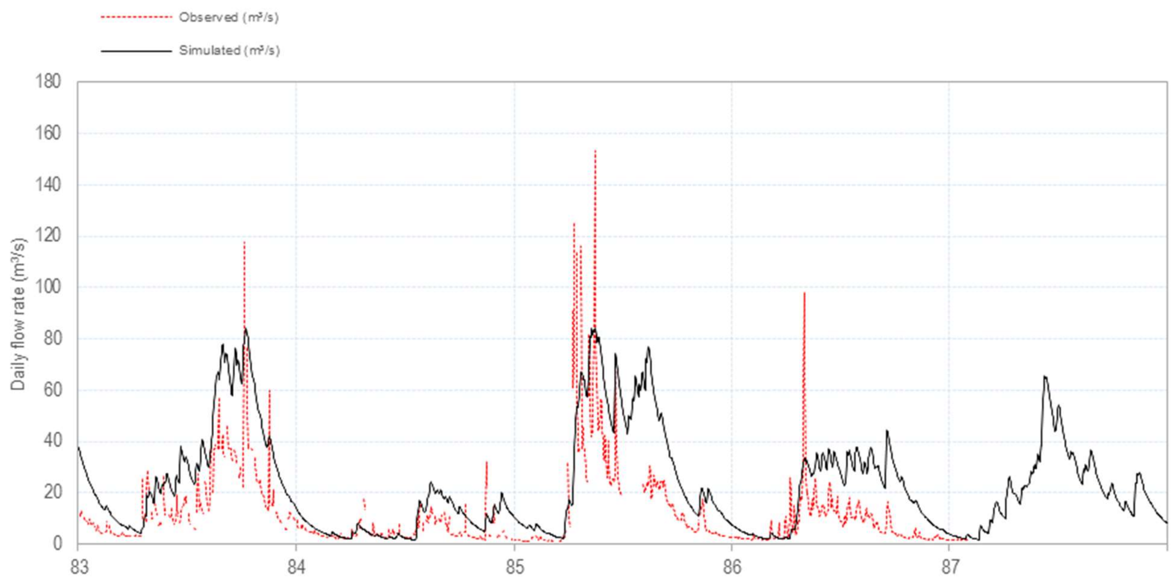
Observed (m³/s)
Simulated (m³/s)
Daily flow rate (m³/s)
600
500
400
300
200
100
0
95
96
97
98
99
00
01
02

Yala River (1FG03)

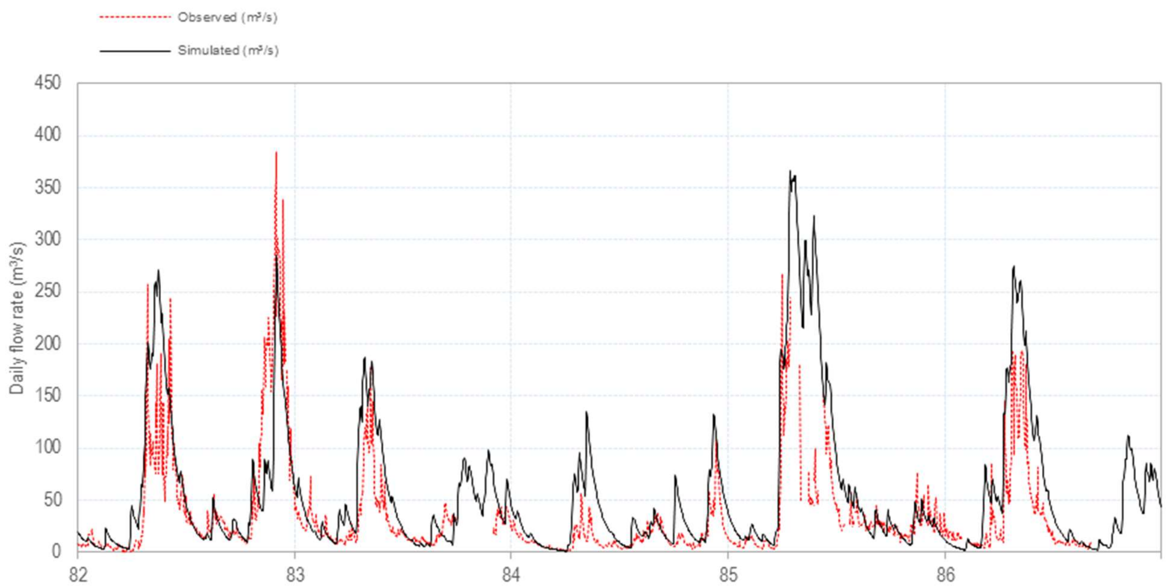


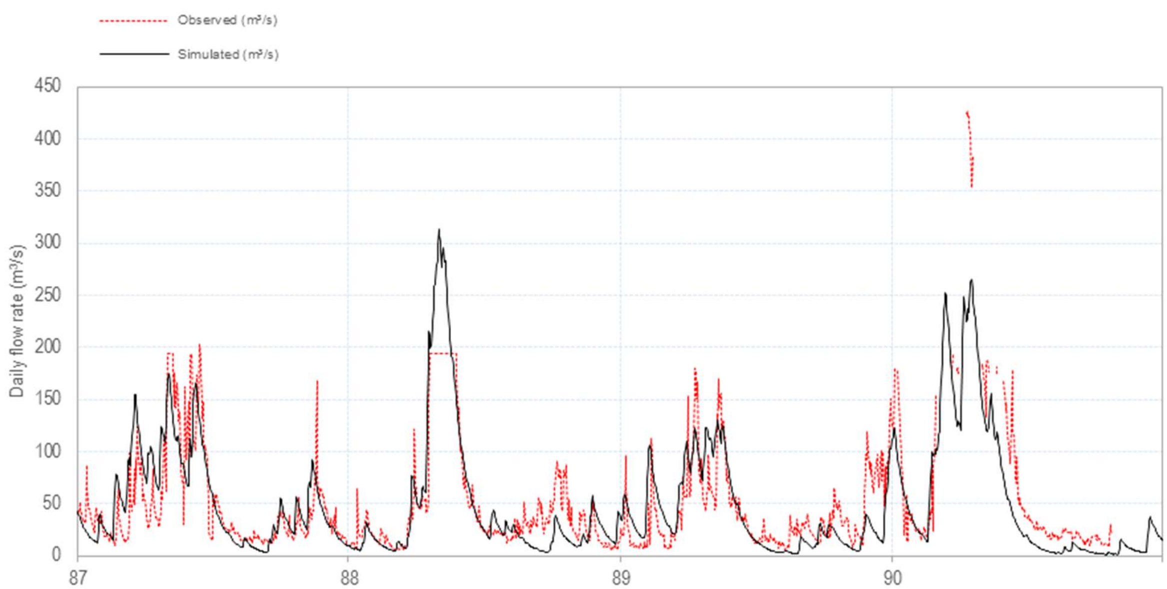


Nyando River (1GD03)

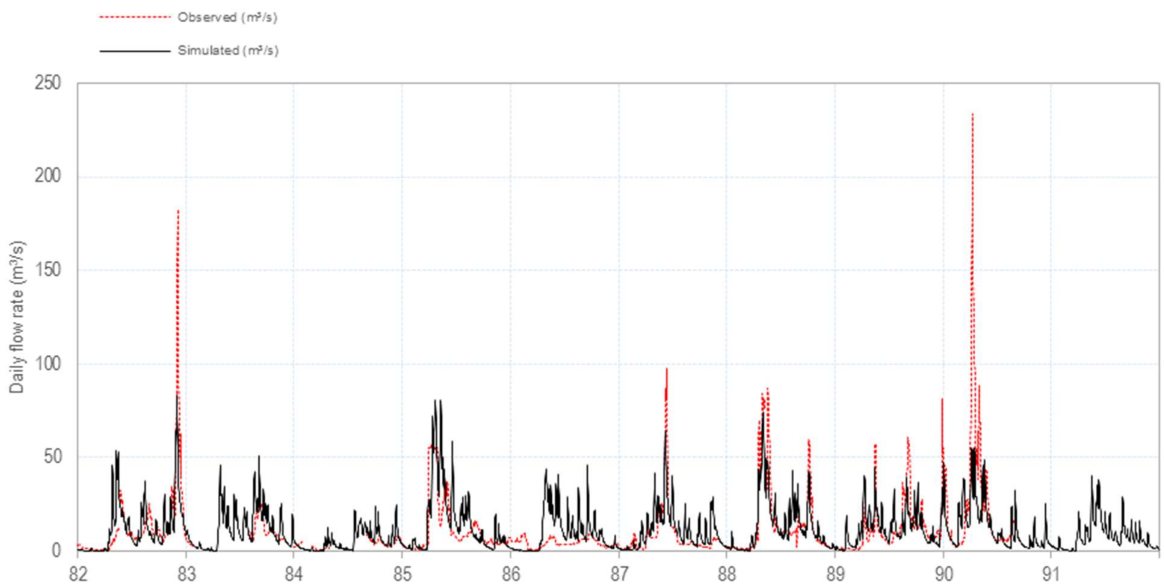


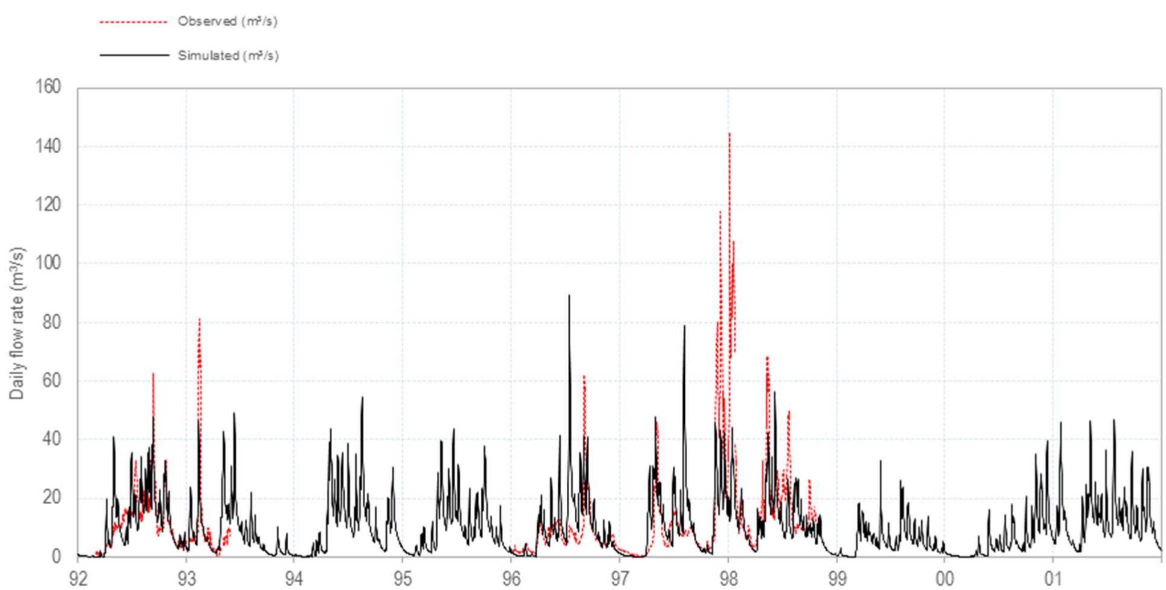
Gucha Migori River (1KB05)



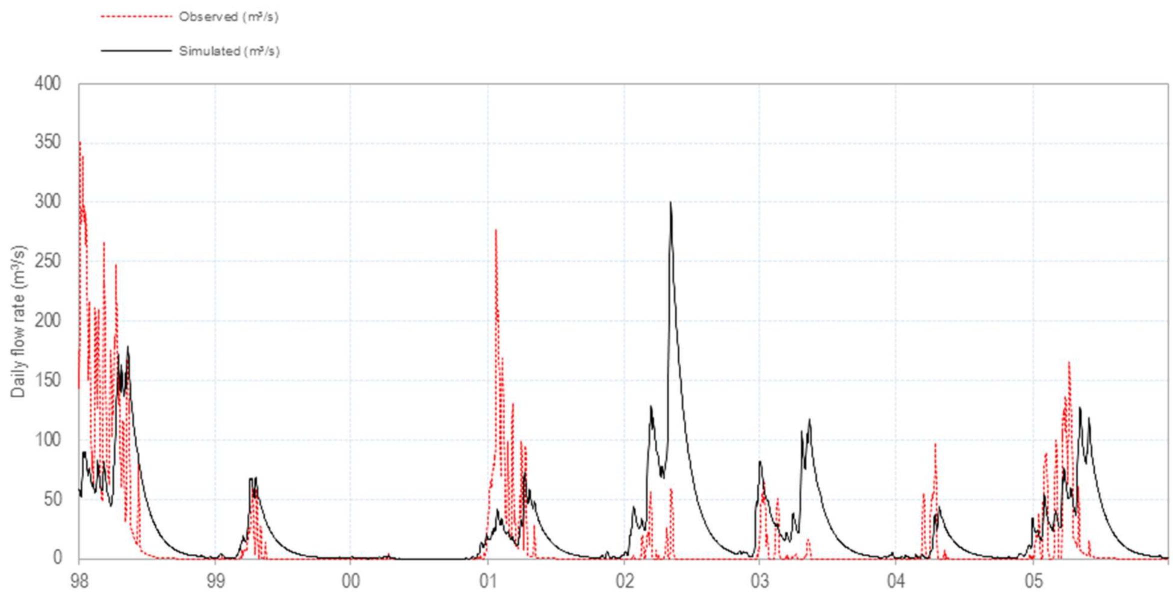


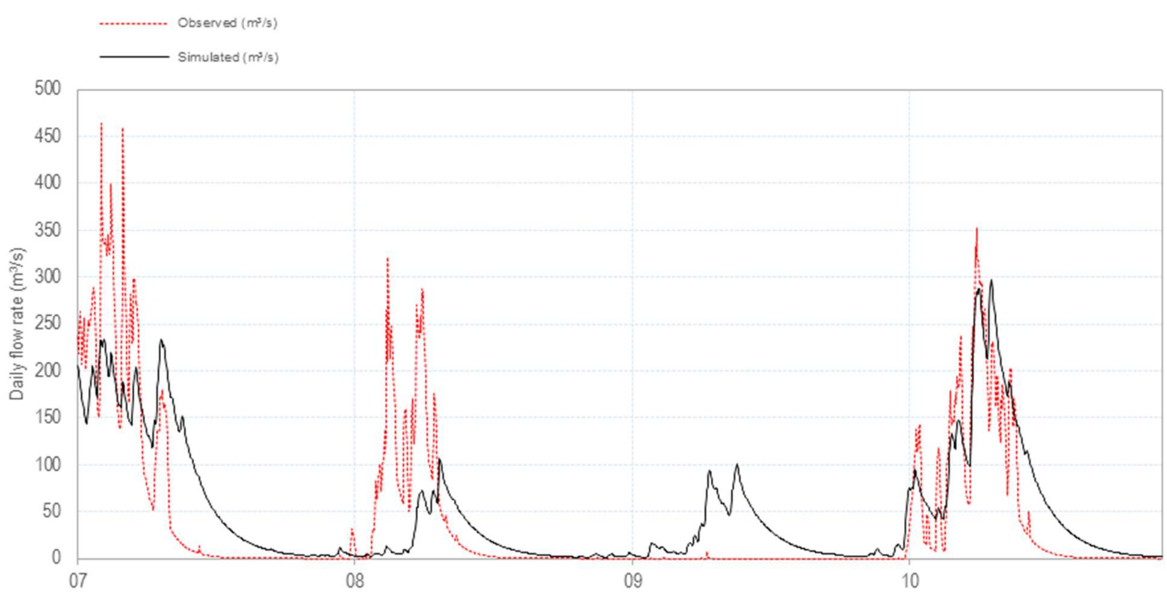
Mara River (1LA03)





Simiyu River





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