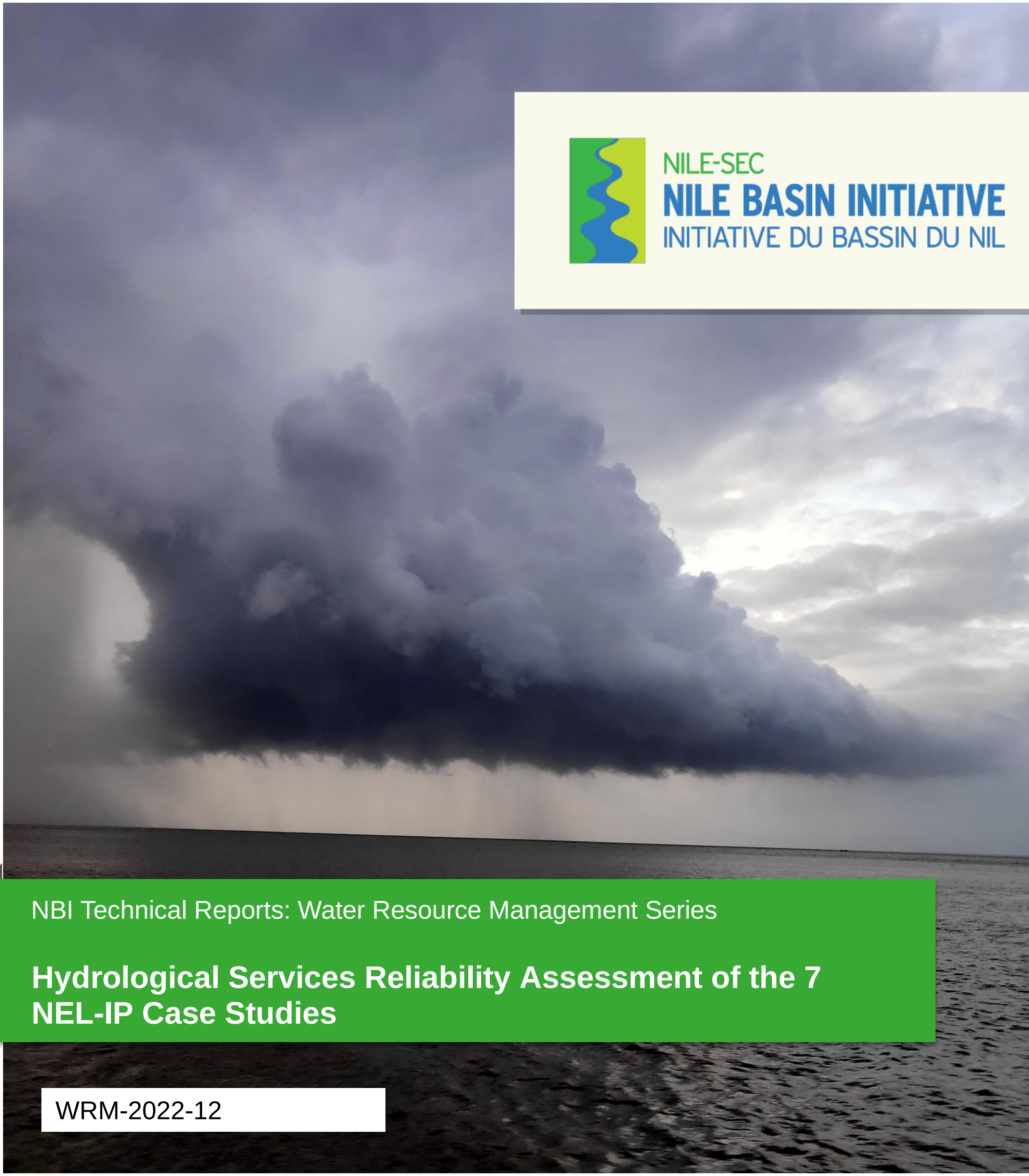

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NBI Technical Reports: Water Resource Management Series

Hydrological Services Reliability Assessment of the 7 NEL-IP Case Studies

WRM-2022-12

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

Document Sheet

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The purpose of the technical report series is to support informed stakeholder dialogue and decision making in order to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the shared Nile Basin water resources.

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Climate Services for Infrastructure

1 INTRODUCTION

It is expected and widely acknowledged that climate change brings an increase in extreme events, be it flood or drought. Concerning flood events, the increase occurs in relation to four aspects: i) higher rainfall intensities, ii) higher frequencies of extreme rainfall, iii) longer duration of extreme rainfall events and iv) increase of areal distribution. All components lead to higher and more severe flood peaks and flood volumes. The risk that existing design guidelines underestimate these flood extremes is given and in particularly true for the future.

As a response, the Nile Basin Initiative Secretariat has launched the project "Enhancing Climate Services for Infrastructure Investments (CSI)" funded by the German Federal Ministry for the Environment and Nuclear Safety (BMU). The aim of the CSI is to provide climate data products and develop human capacity to conduct climate risk assessments and to prioritize measures to adapt to the negative consequences of climate change and extreme weather events on water infrastructures. In essence, the focus is on two climate services:

- Products considering climate change for PMF and IDS for floods based on NBI downscaled climate scenarios
- Assessments in terms of the reliability of services

The Nile Basin Initiative undertook climate change assessments and conducted studies related to climate change scenarios. The results are climate change affected time series for temperature and precipitation. The objective of this assignment is to utilize the work already done in combination with the climate change affected time series in order to:

- develop guidelines on how to incorporate climate change in design flood analysis, operation and safety evaluation of water infrastructures in a changing climate, in particular to develop a Nile Basin Reference Guideline for Flood Frequency assisting planners, policy makers, design experts, dam owners, operators, etc. in design flood analysis for new projects and hydrological safety evaluation of existing water infrastructures.
- apply the Nile Basin Reference Guideline for Flood Frequency for the seven prioritized multi-purpose projects resulting from the Nile Equatorial Lakes Investment Programme (NEL-IP),
- support the NELSAP in strengthening the capacity of the NEL countries to respond and adapt to climate change challenges by providing coaching for participants on the methodologies that will be incorporated in the Nile Basin Reference Guideline for Flood Frequency as part of the Climate Services in planning and climate risk assessment for the seven NELIP prioritized multi-purpose projects.

This report discusses the hydrological service reliability assessment of the 7 case studies and how the NileDSS NEL-IP model was applied for this climate risk assessment.

2 OBJECTIVE AND APPROACH

This project was split into 2 main packages as mentioned in the ToR. This report adderesses Work package 2 of the ToR:

Work package-2 (WP2) – Training and Application:

1- Use the strategic analysis (SWRA) model configuration within the Nile DSS (Mike Basin) to ensure all 7 infrastructures proposed under the study are well represented.
2- Develop indicators / methods that capture aspects required for the climate risk assessment of the infrastructure especially in regards to low flows and that measure performance reliability and aspects of dimensioning. These indicator configurations need to be documented for replicability of approach and scripted into Model/DSS.
3- Conduct analysis using the DSS model and DSS database to calculate the actual indicators for the 7 selected infrastructure sites (usually medium scale multipurpose reservoirs, with power generation, irrigation and flood protection functions).
4- Write up the method in a "manual format / how to" format that can be published as an NBI technical report and enables modellers to replicate the approach – using the 7 cases as earning examples. This shall provide guidance on quantitative assessment of hydrological design parameters using Nile DSS.
5- Develop coaching session on the approach up to 4 for participants of the NBI training course on application of the NBI/CSI Climate Risk Assessment guideline. The course will be organized by NBI and have a lead facilitator – the task of the consultant is to be a resource person/coach and co-trainer on the subject matter of this assignment within the wider training course. For the training and capacity building elements of the assignment, the consultant will coordinate the selection of the case studies and the overall role out of the development of case studies applied to selected cases of NEL-IP Prioritized Multi-Purpose Project, with the relevant officer of NELSAP-CU.

<u>Scope of work</u>

Work package 2 deliverables consist of training materials such as excel tools as well as a manual on how to carry out service reliability assessments for water infrastructures.

3 DATA MANAGEMENT

3.1 Available Datasets

3.1.1 CORDEX Data

CORDEX is the Coordinated Regional Downscaling Experiment developed by the World Climate Research Program (https://www.wcrp-climate.org/). CORDEX datasets are obtained by running Global Climate Models (GCM), which are set-up by different meteorological research institutes all over the world. The model output can then be downscaled using Regional Climate Models (RCM). The 17 CORDEX datasets provided by the NBI have additionally been corrected by applying the quantile mapping bias correction approach using NCEP/NCAR reanalysis (https://rda.ucar.edu/datasets/ds314.0/). The datasets include daily values of precipitation, maximum temperature, and minimum temperature. Table 1 demonstrates an overview of the acquired bias corrected CORDEX datasets received from Nile-SEC as NetCDF files.

Table 1: Overview on the acquired bias corrected CORDEX data acquired from NBI.

Climate variable	Precipitation (mm/sec), maximum temperature (°C), Minimum Temperature (°C)
Spatial resolution	0.44°
Temporal resolution	Daily
Bottom left coordinates	Longitude = 22.44 °, Latitude = -4.84 °
Upper right coordinates	Longitude = 40.04 °, Latitude = 32.56 °
Periods	• 1971-2000 (historical) • 2006-2035 (near projeciton) • 2036-2065 (mid century projection) • 2066-2095 (far projection)
Meteorological Research Institute	BCCR, CLMcom, DMI, KNMI, SMHI, MPI
Global Climate Model (GCM)	CNRM, ICHEC, IPSL, MIROC, MOHC, MPI, NCC, NOAA
Regional Climate Model (RCM)	CCLM4817, HIRHAM5, RACMO22T, RCA4, REMO2009, WRF331
Representative Concentration Pathway (RCP)	RCP 4.5, RCP 8.5

CORDEX datasets was stored in netCDF files. NetCDF is a file format that can be utilized to store the array-oriented scientific data. The files are spatially distributed and require programming scripts to extract the data at a certain longitude and latitude for a climatic variable. Hence, Python scripts were used to extract the required time-series data to TXT files ZRX files prior to being processed or to calculate the IDF and PMP. The CORDEX datasets were also visualized in maps by importing the NetCDF files directly into ArcGIS. Figure *1* shows a precipitation time series sample for a chosen grid cell.

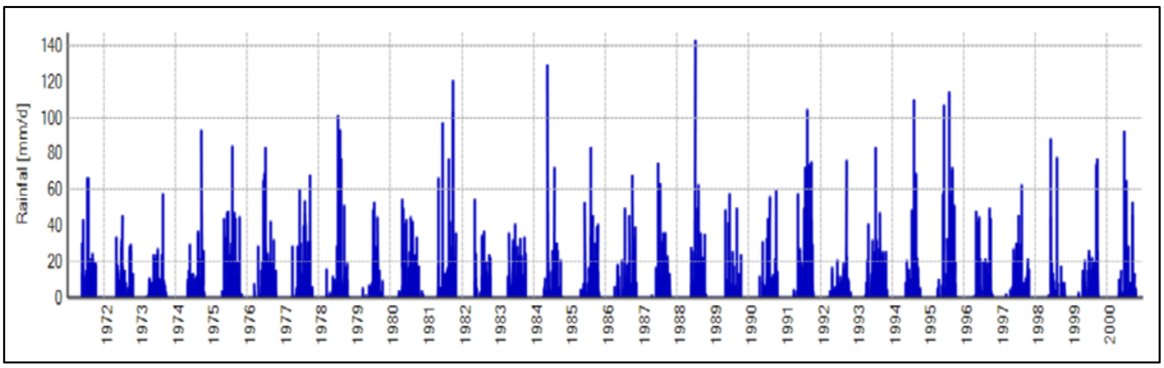

Figure 1: A time series data sample representing the rainfall values for a chosen grid (Cell Number = 739).

Precipitation and minimum and maximum temperature values were aggregated for each subbasin and used as input for the hydrological model. This is explained in chapter 4.3.

3.1.2 Signal change

The signal change [SC] related to temperature and precipitation of each CORDEX dataset can be calculated to detect the deviation from the historical observation dataset using this equation:

$$SC\ [-] = \frac{P - O}{O}$$

With

P : Predicted value (CORDEX model)
O : Observed value (observed rainfall)

Due to lack of temperature and precipitation daily observation datasets covering the whole Nile basin, mean precipitation and temperature can represent the signal change instead of the relative change. Figure *2* shows the mean precipitation and temperature results for all CORDEX datasets including historical, rcp4.5 and rcp8.5.

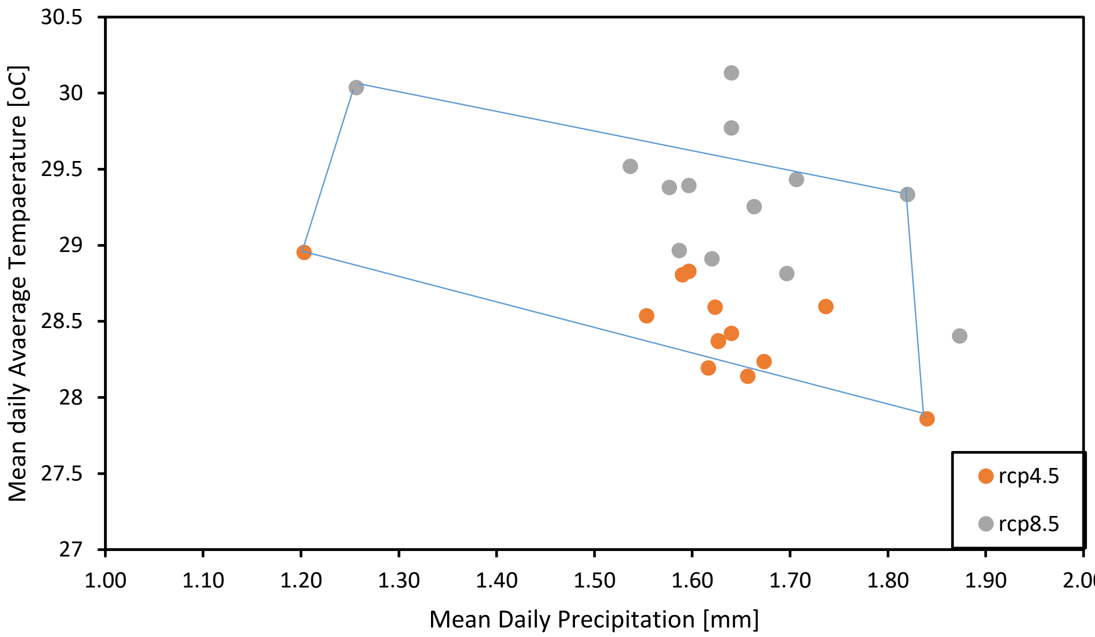

Figure 2: Signal change for selecting CORDEX datasets. Note: the corners of the blue polygon represent the maximum and minimum signal change in terms of precipitation and temperature..

Based on Figure *2*, 4 scenarios were determined which cover the minimum and maximum signal changes of climate in terms of temperature and precipitation:

1. rcp45SMHI_RCA4MOHC_HadGEM2 (represents minimum precipitation and minimum temperature)
2. rcp85SMHI_RCA4MOHC_HadGEM2 (represents minimum precipitation and maximum temperature)

3. rcp45BCCR_WRF331NCC_NorESM1_M (represents maximum precipitation and minimum temperature)
4. rcp85BCCR_WRF331NCC_NorESM1_M (represents maximum precipitation and maximum temperature)

Model 2 was chosen to run the hydrological simulations.

4 CASE STUDIES

The developed methodology and guideline to analyse water infrastructures and assess them with regards to climate change using performance indicators was to be carried out for 7 chosen prioritized multi-purpose projects from the Nile Equatorial Lakes Investment Program (NEL-IP).

Table 1: NEL-IP Prioritized Multi-Purpose Projects

#	Project Title	Country	Status
1	Akanyaru MPP Water Resources Development Project	Burundi/Rwanda	Pre-feasibility studies completed
2	Gogo Falls MPP Water resources development project	Kenya	Feasibility and detailed studies completed
3	Mara valley Irrigation and WM Project	Tanzania	Feasibility and detailed studies completed
4	Ngono MPP Water Resources Development Project	Tanzania	Feasibility and detailed studies completed
5	Parajok MPP Water resources development project	South Sudan	Pre-feasibility studies completed
6	Angololo MPP Water Resources Development Project	Kenya/Uganda	Feasibility and detailed studies ongoing
7	Nyimur/Limur MPP Water Resources Development	South Sudan/Uganda	Feasibility and detailed studies completed

4.1 Existing NELIP Mike Hydro Model

The NELIP Mike Hydro Model was received in the format of a NileDSS database and was then exported from the NileDSS to be edited and updated in MikeHydro. The received MikeHydro model encompasses 80 catchments, 114 water users, 63 reservoirs and 41 hydropower plants. Since not all prioritized projects are relevant for this study, a new version of the model where only the 7 case studies are modelled has been created. Furthermore, changes that have been decided on for the 7 case studies have been incorporated in the model.

4.2 Updates to the Model

After deleting the projects that are not relevant for the study, the new model was left with 27 reservoirs including the 7 chosen case studies and 13 hydropower plants.

The following remarks have been made to the current status of the received model:

- The Tanzanian dams Isanga, Mamwe and Simiyu, as well as Edward are modelled in the SWRA model but not in the NELIP model.
- Sio and Nzoia-Yala Wetlands were added by Sydro to the SWRA model as reservoirs and are still not in the NELIP model.

- BG_GEL Catchment is missing from the NELIP model.
- The Karuma and Isimba projects are now existing projects, so they have not been removed from the model but they have also not been updated.

However, these issues have no influence or direct effect on the 7 case studies as they lie downstream of the 7 projects.

Several changes have been made to the Angololo project such as:

- Dam location
- Dam capacity
- Dam height
- Water supply
- Irrigation
- Power demand time series
- Catchment area

The following data updates have been delivered by NELSAP to be incorporated into the model

Parameter	Representing
Reservoir (NEL_Angololo Dam)	
Chainage	Dam location: V Kapesur (Kenya) / Osimit (Uganda) Axis Coordinates ARC1960/ UTM36N: X = 645713.74 y = 82308.08 1206 Riverbed Elevation (masl) = 1206
Level-Area-Volume table **Flood Control Level** **Characteristic levels**	Dam capacity (31.6 MCM) and dam height (40 m) Min Level = +1222.0

Crest elevation (masl)	Crest length (m)	FSL elevation (masl)	Volume at FSL (MCM)	Dam height (m)	Dead storage volume (MCM)
1246	403	1241.8	31.6	40	2.4

Elevation(m)	Area(m²)	Volume(m³)	CumulativeVolume(m³)
1.241,80	2.761.941,20	2.171.257,73	31.650.114,23
1.241,00	2.634.290,45	2.553.835,91	29.478.856,50
1.240,00	2.473.381,37	2.396.232,81	26.925.020,59
1.239,00	2.319.084,24	2.246.302,01	24.528.787,78
1.238,00	2.173.519,78	2.099.403,12	22.282.485,77

1.237,00	2.025.286,46	1.954.896,72	20.183.082,65
1.236,00	1.884.506,99	1.817.776,72	18.228.185,93
1.235,00	1.751.046,46	1.690.638,20	16.410.409,21
1.234,00	1.630.229,94	1.569.656,03	14.719.771,01
1.233,00	1.509.082,13	1.454.169,33	13.150.114,98
1.232,00	1.399.256,54	1.343.824,88	11.695.945,64
1.231,00	1.288.393,23	1.238.627,54	10.352.120,76
1.230,00	1.188.861,85	1.139.846,44	9.113.493,22
1.229,00	1.090.831,02	1.045.529,00	7.973.646,78
1.228,00	1.000.226,98	958.124,98	6.928.117,78
1.227,00	916.022,98	872.306,79	5.969.992,80
1.226,00	828.590,60	783.780,71	5.097.686,01
1.225,00	738.970,81	694.781,79	4.313.905,30
1.224,00	650.592,77	603.775,25	3.619.123,51
1.223,00	556.957,72	516.210,47	3.015.348,26
1.222,00	475.463,22	442.731,31	2.499.137,79
1.221,00	409.999,40	381.121,34	2.056.406,48
1.220,00	352.243,27	325.250,04	1.675.285,14
1.219,00	298.256,80	272.815,41	1.350.035,10
1,218.00	247,374.01	226,014.47	1,077,219.70
1,217.00	204,654.93	187,208.67	851,205.23
1,216.00	169,762.41	155,625.38	663,996.55
1,215.00	141,488.35	127,189.78	508,371.17
1,214.00	112,891.20	101,509.20	381,181.39
1,213.00	90,127.21	80,158.31	279,672.19
1,212.00	70,189.41	63,598.79	199,513.88
1,211.00	57,008.18	50,852.39	135,915.09
1,210.00	44,696.59	36,756.42	85,062.70
1,209.00	28,816.24	24,084.85	48,306.28

<table>
<tr><td></td><td><table><tr><td>1,208.00</td><td>19,353.45</td><td>16,949.08</td><td>24,221.44</td></tr><tr><td>1,207.00</td><td>14,544.71</td><td>7,272.36</td><td>7,272.36</td></tr><tr><td>1,206.00</td><td>0</td><td>0</td><td>0</td></tr></table></td></tr>
<tr><td colspan="2">Water Users (NEL_Angololo_Irr)</td></tr>
<tr><td>Water use demand time series</td><td>The total net command area is estimated at 3876ha (1911ha for western Ugandan zone and 1965ha for eastern Kenyan zone)
Angololo project water demand for irrigating 4,000ha net area (m³/month):<table><tr><td>JAN</td><td>FEB</td><td>MAR</td><td>APR</td><td>MAY</td><td>JUN</td><td>JUL</td><td>AUG</td><td>SEP</td><td>OCT</td><td>NOV</td><td>DEC</td><td>Total</td></tr><tr><td>3,385</td><td>3,644</td><td>2,919</td><td>752</td><td>661</td><td>2,349</td><td>2,086</td><td>1,622</td><td>2,156</td><td>3,372</td><td>4,170</td><td>4,087</td><td>31,202</td></tr></table></td></tr>
<tr><td colspan="2">Water Users (NEL_Angololo_WS)</td></tr>
<tr><td>Water use demand time series</td><td>Livestock watering and domestic use (over 270,000 people)
The total annual potable water demand for the above population is about 5.2 Mm3 including livestock needs.</td></tr>
<tr><td colspan="2">Hydropower (was not modelled yet)</td></tr>
<tr><td>Chainage</td><td>The proposed hydropower plant is located at the downstream part of the dam</td></tr>
<tr><td>Power demand time series</td><td>The Hydropower generation is estimated at an average power capacity of 1,200KW (energy generation 7.76GWh)</td></tr>
<tr><td colspan="2">Catchment (VN_Upper Malaba)</td></tr>
<tr><td>Area</td><td>Catchment morphological features:<table><tr><td>Area</td><td>Longest Flowpath</td><td>Max. Altitude</td><td>Min. Altitude</td><td>Altitude Difference</td><td>Average Slope</td><td>Average Hillside Slope</td></tr><tr><td>[km²]</td><td>[km]</td><td>[m.a.s.l]</td><td>[m.a.s.l]</td><td>[m]</td><td>[m/m]</td><td>[m/m]</td></tr><tr><td>444.12</td><td>62.56</td><td>4314.0</td><td>1217.8</td><td>3096.2</td><td>0.0495</td><td>0.179</td></tr></table></td></tr>
</table>

The new level-area-volume curve as well as a new characteristics level curve of the Angololo Dam have been implemented in the updated version of the model. The new flood control level has been set to 1240.8 masl.
The new data on water supply and irrigation seems to be much lower than the patterns implemented in the old model, so they have not been updated.

4.3 Climate Data

Daily rainfall and potential evapotranspiration are deposited in the model as time series that cover the entire simulation period. The rainfall time series were created by averaging the precipitation values of all CORDEX Cells which lie within each subbasin defined in the model. They were then linked to the respective subbsains shown in Figure 3.

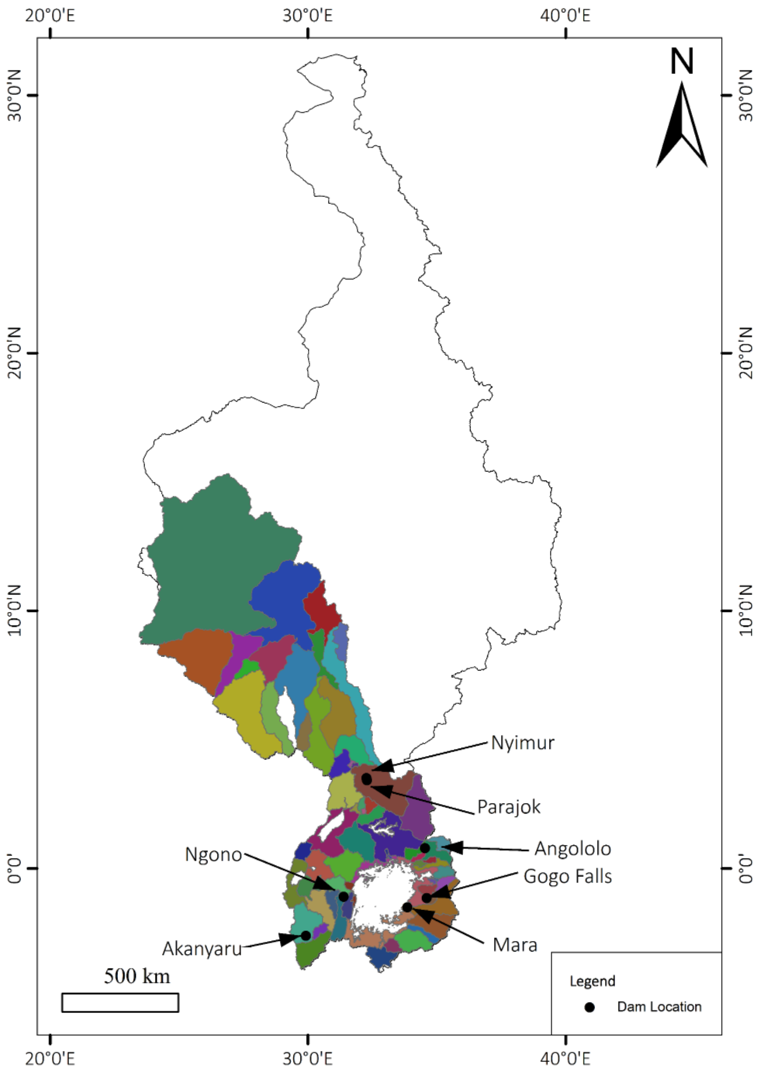

Figure 3: Subbasins of the MikeZero Model

Evapotranspiration was calculated based on the Blaney Criddle approach using the average of the minimum and maximum temperatures of the CORDEX dataset for all the cells that lie within each subbasin defined in the model.

$$ET_{Blaney-criddle} = (8.128 + 0.457 * T) * \frac{S_o * 100}{S_{jahr}}$$

$$ET_p = -1.55 + 0.96 * ET_p$$

Where T is the mean Temperature, S_o, S_jahr are parameters depend on the spatial (location) and temporal characteristics (day number).

The climate data was prepared for the historical period (1971-2000) as well as the RCP 8.5 scenario (2036-2065) of the CORDEX model. The files were saved in the DSF0 format required by MIKE Hydro.

4.4 Simulation Settings

The simulation timestep of the model was changed from a monthly timestep to a daily timestep to simulate in a higher resolution and be able to evaluate the results on a daily basis. The historical scenario was run from 1971-2000 and the RCP 8.5 Scenario from 2036 to 2065.

4.5 Simulation Results

The results of all 7 case studies have been extracted from the model and presented in 7 separate Excel files that can be used for the training. Only the 4 case studies Angololo, Mara, Nyimur and Parajok delivered plausible results that could be discussed in the training workshops. A manual explaining the evaluation carried out in the excel sheets as well as how to use it to evaluate new results has been prepared.

Furthermore, Climate Products were prepared for the catchments of the 4 case studies presented at the workshop. Those included IDF curves, PMP and radar diagrams for the historical and future scenario and can be found in the training materials prepared for the workshop.

5 CLIMATE CHANGE IMPACT ASSESSMENT – SERVICE RELIABILITY

To assess the reliability of hydrological infrastructure services such as hydropower, irrigation, municipal and industrial water demand, flood control and e-flow simulation results from a precipitation runoff model have to be evaluated according to thresholds. The threshold set for each service and the impact score classification can be seen in Table 2.

Table 2: Impact scales of hydrological services

Impact scoring levels		Examples of types of impact scales by objective of assessment						
		Service reliability					Structural integrity	
		Hydropower*	Irrigation***	Municipal/Industrial Water Demand	Flood Control	Low flows	Physical components	Operation and Maintenance
1	Insignificant	<30% reduction** in generated power for up to 30 days/year	<30% reduction in water supply for irrigation for up to 14 consecutive days/year	<30% reduction in water supply for M&I use for up to 1-3 consecutive days/year	Water level within flood buffer and exposure low or medium	<30% reduction of flow below mean minimum flow for up to 7 days/year	Virtually no effect on asset condition, no repairs required	< 0.1% increase in (average) annual cost to sustain service levels
2	Minor	<30% reduction** in generated power for 30-90 days/year **or** 30-70% reduction for up to 30 days/year	<30% reduction in water supply for irrigation for 14-30 consecutive days/year **or** 30-70% reduction for up to 14 consecutive days/year	<30% reduction water supply for M&I use for 3-7 days/year **or** 30-70% reduction in for up to 1-3 consecutive days/year	Water level within flood buffer and exposure high **or** spillway active (frequent flood event 10a) and exposure low	<30% reduction of flow below mean minimum flow for 15-30 days/year **or** 30-70% reduction for up to 7 days/year	Minor damage to asset requiring 0-5% of annual maintenance budget for repairs	0.1-1% increase in (average) annual cost to sustain service levels
3	Moderate	<30% reduction** in generated power for >90 days/year **or** 30-70% reduction for 30-90 days/year **or** >70% reduction for up to 30 days/year	<30% reduction in water supply for irrigation for >30 consecutive days/year **or** 30-70% reduction for 14-30 consecutive days/year **or** >70% reduction for up to 14 consecutive days/year	<30% reduction in water supply for M&I use for >7 consecutive days/year **or** 30-70% reduction for 3-7 consecutive days/year **or** >70% reduction for 1-3 consecutive days/year	Spillway active (frequent flood event 10a) and exposure medium **or** spillway active (rare flood event 50a) and exposure low	<30% reduction of flow below mean minimum flow for >30 days/year **or** 30-70% reduction for 15-30 days/year **or** >70% reduction	Moderate damage to asset requiring 6-25% of annual maintenance budget for repairs	2-10% increase in (average) annual cost to sustain service levels

						for <7 days/year		
4	Major	30-70% reduction** in generated power for >90 days/year **or** >70% reduction for 30-90 days/year	30-70% reduction in water supply for irrigation for >30 consecutive days/year **or** >70% reduction for 14-30 consecutive days/year	30-70% reduction in water supply for M&I use for >7 consecutive days/year **or** >70% reduction for 3-7 consecutive days/year	Spillway active (frequent flood event 10a) and exposure high **or** spillway active (rare flood event 50a) and exposure medium	30-70% reduction of flow below mean minimum flow >30 days/year **or** >70% reduction for 15-30 days/year	Major damage to asset requiring 26-80% of annual maintenance budget for repairs	11-30% increase in (average) annual cost to sustain service levels
5	Extreme	>70% reduction** in generated power for >90 days/year	>70% reduction water supply for irrigation for >90 consecutive days/year	>70% reduction water supply for M&I use for >90 consecutive days/year	Spillway active (rare flood event 50a) and exposure high	>70% reduction of flow below mean minimum flow for >30 days/year	Extreme damage to asset requiring > 80% of annual maintenance budget for repairs	>40% increase in (average) annual cost to sustain service levels

The implementation of the service reliability assessment is explained in detail in the climate proofing manual.

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