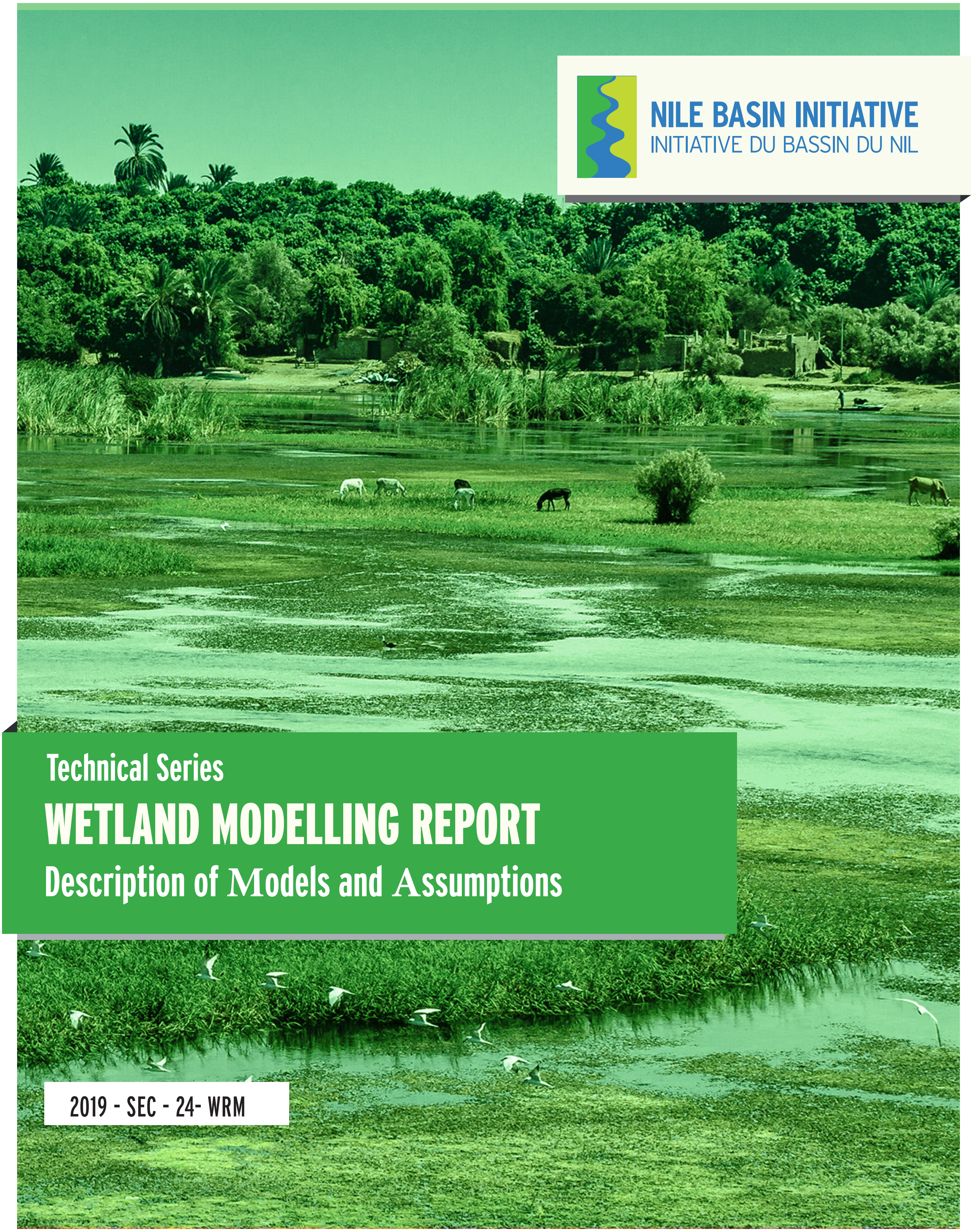

NILE BASIN INITIATIVE
INITIATIVE DU BASSIN DU NIL

Technical Series

WETLAND MODELLING REPORT

Description of Models and Assumptions

2019 - SEC - 24- WRM

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

Document Sheet

This Technical Report series publishes results of work that has been commissioned by the member states through the three NBI Centers (Secretariat based in Entebbe- Uganda, the Eastern Nile Technical Regional Office based in Addis Ababa - Ethiopia and the Nile Equatorial Lakes Subsidiary Action Program Coordination Unit based in Kigali - Rwanda. The content there-in has been reviewed and validated by the Member States through the Technical Advisory Committee and/or regional expert working groups appointed by the respective Technical Advisory Committees.

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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Contents

Abbreviations

ALOS	Advanced Land Observing Satellite
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
ET	Evapotranspiration
HEC-RAS	Hydraulic Engineering Center – River Analysis System
mASL	Meters above sea level
MikeSHE	DHI software Mike Système Hydrologique Européen
NileDSS	Nile Basin Decision Support System
PCP	Precipitation
PET	Potential evapotranspiration
SRTM	Shuttle Radar Topography Mission
MERIT	Multi-Error-Removed Improved-Terrain DEM
WP	Workpackage

1 Background and introduction

This report is part of the GIZ-commissioned project "Nile Basin wetlands of transboundary significance: Inventory, Baseline Study and Framework Management Plan with a nested case study on the Sudd".

WP2, Wetland modelling, has three main objectives:

(1) **Improving NileDSS Hydrology**: The wetland hydrology currently implemented in the NileDSS has to be improved and extended with models where needed.

(2) **Wetland Impact:** Provide a link between inflows (flow or precipitation) and extent of the Wetland Units. This is the basis for assessing wetland changes under future management or climate scenarios.

(3) **Sudd diagnostic study:** Detailed hydrologic and hydraulic modelling is carried out for the Sudd to obtain a detailed and robust model that can be implemented in the NileDSS and that improves the process knowledge and enables impact simulations of the Sudd.

This report contains the methodology and results to fulfil objective (1).

2 Approach to assess and update wetland parameterization in the NileDSS

2.1 Wetland water balance assessment

For each wetland, simulated inflows, outflows, precipitation, evapotranspiration, water level, surface area, stored volume, infiltration, storage change and, if available, observed in- and outflows are extracted and compiled in coherent time series to allow the computation of summary statistics (long term seasonality and annual means). These statistics are used together with the wetland schematic implemented in the NileDSS (Figure 1) which allows an assessment of the wetland implementation as well as to give suggestions for improvement.

For wetlands where inflows do not match well with observations, re-calibration of the NileDSS is suggested. For wetlands where outflows do not match well with observations, improvements in the wetland implementation are suggested. This largely refers to missing precipitation (PCP) and potential evapotranspiration (PET) data. These data are used for the losses- and gains time series for wetlands and it is suggested to fill those with data from the NileDSS from the subbasin in which the wetland is located. This ensures compatibility with the remaining Nile Basin simulations and parameterization of the NileDSS.

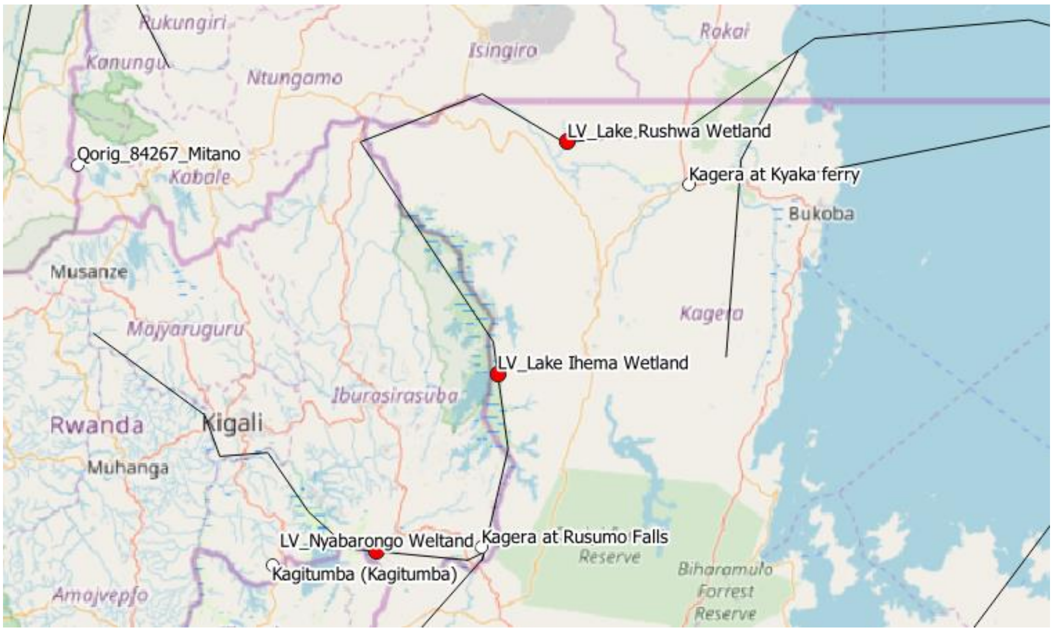

Figure 1. Example of the NileDSS schematic (black lines), location of wetlands (red dots) and flow gauges (white dots) for the Kagera river with the Nyabarongo, Lake Ihema and Lake Rushwa wetlands (Background: Open Street Map)

2.2 Simplified hydraulic modelling

For wetlands were no sufficient data are available that enable an assessment through the Water Balance Approach (chapter 2.1), simplified hydraulic modelling is required. Therefore, a simplified hydraulic modelling approach is used where a 2D hydraulic model routes a range of constant flows through a pre-defined grid domain in order to provide sufficient information for the parametrization of the relevant wetlands. A 2D model is well suited to define the flow path even if this is not pre-defined, which would be required if 1D hydraulic models (e.g. Mike11) would be linked to an overland flood routing model (e.g. MikeSHE). This is important for the current approach, since data and knowledge about detailed flow paths within the wetlands is lacking.

The modelling software chosen for the simplified hydraulic modelling assessment is HEC-RAS 5.0.7. This selection has been undertaken considering the work load and the objectives of the study. Therefore, there are several reasons behind this selection, but the main ones are:

- No full 2D model from DHI is licensed in the NileDSS
- The models do not need to be implemented into the NileDSS – the models are only used to derive the wetland parameterization and can therefore be run in an external model
- HEC-RAS is one of the most widely used and accepted hydraulic modelling software worldwide.
- HEC-RAS has been evaluated by several flood responsible agencies worldwide and it is accepted by relevant organisations such as the Environment Agency of England and Wales or the Federal Emergency Management Agency in the US.
- HEC-RAS capacities and results are comparable to the ones from any other software.
- HEC-RAS 2D flood routing performs as fast of other similar commercial software, and the implementation of the models is simpler.
- HEC-RAS is freely available and would therefore be accessible by anyone wanting to run the models in the future without the need for a licence.

One modelling domain will be defined for each wetland area. The model domain for each area covers the full wetland area, although domains have been extended in the lower area in order to fully represent all the possible flow paths and also in order to extend the downstream boundary conditions as far as possible from the area of interest (in order to minimise the impact that the boundary condition may have on the modelling results). Spacing of the rectangular grid will be selected as a compromise between preserving the main features of the wetland topography under the constraints of run-times to enable sensitivity tests and running multiple discharge scenarios. For this study, rectangular grids with a resolution between 150 and 200m are used (same resolution in x- and y-direction).

2.2.1 Spatial input data

Terrain digital elevation maps have been widely used for many wetland applications throughout the world. However, many Digital Elevation Models (DEMs) based on space-borne measurements still contain height errors that hamper its application for simulating wetland processes. Different DEM resources have been evaluated, such as the SRTM DEM, the MERIT DEM or the ALOS DEM (Figure 2).

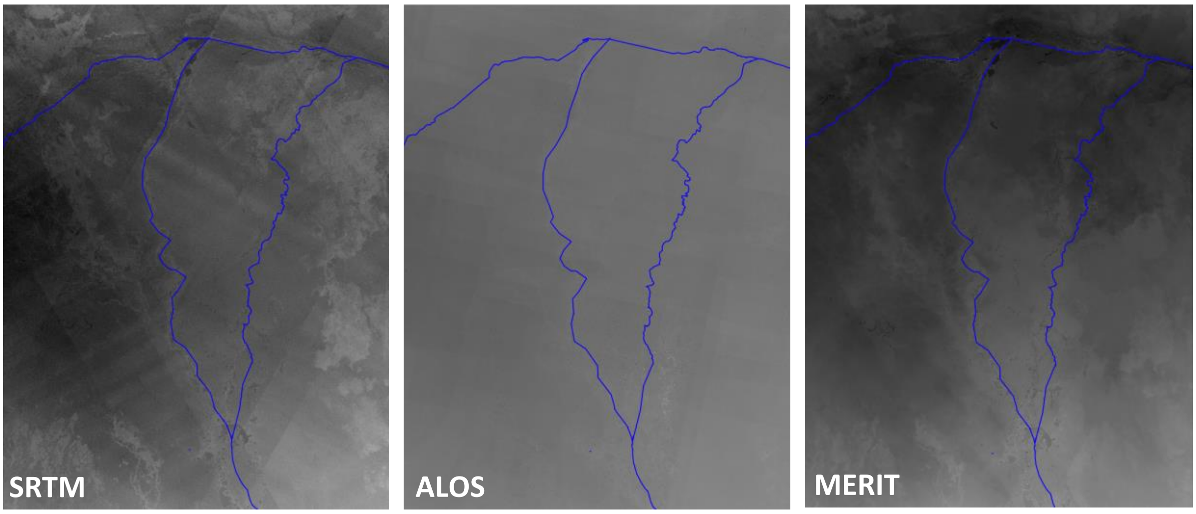

Figure 2. Comparison of SRTM, ALOS and MERIT DEMs in the Sudd (note the patterns in the SRTM and the ALOS, which are >2m along the pattern borders)

In this study, we used the Multi-Error Removed Improved-Terrain DEM (MERIT DEM) at 3 arc resolution (app. 90 m at the equator) that has eliminated error components from existing spaceborne DEMs[1]. Location of the wetlands to be modelled were identified using point shapefiles from the NileDSS and the initial area was determined using Google Earth imagery® in combination with the wetland extent mapped in the 2009 assessment[9]. To avoid not missing the maximum wetland extent, a mask covering a large area for each of the wetlands was prepared and was used to clip the area of interest. The clipped DEM for each wetland was projected to the corresponding UTM N/S – Zone using the WGS 1984 datum.

2.2.2 Boundary Conditions

Two different sets of boundary conditions were defined, namely upstream and downstream boundary conditions. The upstream boundary conditions for the hydraulic modelling implementation were based on data from the Nile DSS with a range of possible inflows to the wetlands derived from daily simulations from 1950 – 1990 at the pre-selected locations of the upstream boundary conditions (see Annex, Table 17). These flows were routed in a constant flow using unsteady flow.

The downstream boundary condition location is placed as far away as possible from the area of interest in order to prevent any impact from the boundary condition on the results in the wetlands. It should be noted that the type of boundary condition used depended on the location of the wetland and are wetland-specific (e.g. open outflow or discharge into a lake).

2.2.3 Resistance

Resistance of the modelling domain was defined as a global Manning's n value over the whole wetland. It should be noted that due to the uncertainty regarding the definition of the resistance in the wetlands, sensitivity tests have been undertaken using values from 0.3[2,3] to 0.04 and the highest flow scenarios in order to assess the impact that this may have on the modelling results. This was carried out since there is not sufficient information regarding resistance values for all the wetlands, and also, the resistance will vary during the year depending on the vegetation. Based on the analysis, a value of 0.06 was chosen as a good compromise to depict velocities and water depths. This value provides a reasonable estimate of the expected lead time in the wetlands, whereas larger values yield lead times that are higher than expected and lower Manning values yield lead times lower than expected. Also, the simulated water depths in the wetland seem more realistic when the 0.06 Manning number is used (see Annex for the Manning's n value sensitivity results in the wetlands). Nonetheless, the information provided by the sensitivity test is valuable, and in case there is further information regarding the resistance in the wetlands (e.g. through calibration) or in order to depict different seasonalities, the different water depths, water discharge and lead times yielded by this test can be used too.

2.2.4 Results extraction

Two different types of results are extracted from the hydraulic model: First, spatial data (water surface elevation, water depth and inundation area) for the whole wetland domain, and second, profile data (flow versus time and flow versus stage) at the outlet point of the wetlands from which the flow time (in this case the time required for a constant flow to be observed in the downstream end) was deduced. These results are further processed to derive the wetland parameterization (chapter 2.3).

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[1] http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/

[2] https://ascelibrary.org/doi/10.1061/%28ASCE%290733-9437%281989%29115%3A2%28203%29

[3] https://gsshawiki.com/Surface_Water_Routing:Overland_Flow_Routing

2.3 Wetland data preparation and processing

The wetlands are simulated in the NileDSS (Mike Basin) as lakes, which are a special implementation of reservoirs. Therefore, the following information is required:

- Level area volume table
- Characteristic levels
- Losses and gains
- Spill capacity

These data need to be derived for new wetlands to be implemented in the NileDSS. As an example, Figure 3 shows the input data for the Machar Marshes that is currently implemented in the NileDSS.

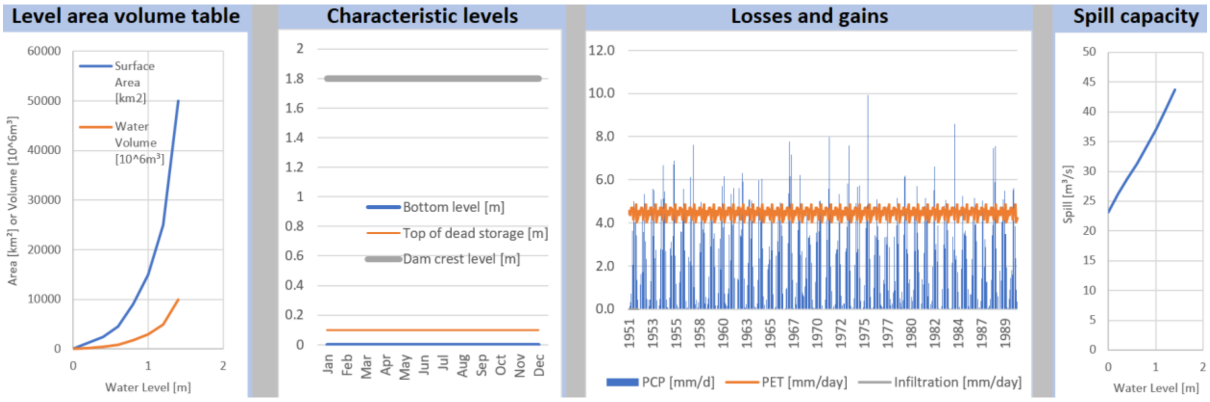

Figure 3. Input data as currently implemented in the NileDSS on the example of the Machar Marshes

2.3.1 Level area volume table

Results from the 2D hydraulic modelling need to be transferred to a relationship that defines the inundated area and according water volume stored in the wetland at a number of water levels. We defined water level of 0m as the bottom elevation of the cross-sectional profile at the wetland outlet. Mike Basin interpolates linearly between the water levels given in the table. A threshold value is included in the process to enable assigning very shallow water levels (e.g. below 0.1m) to dry in order to constrain the maximum area covered by the wetland. As this is an iterative process which requires different threshold values, and different flow values, the process was implemented using the Model Builder Tool. The threshold values applied are 0, 0.1, 0.25 and 0.5 m depths for each flow scenario for each wetland. Each particular flow scenario was iterated for the four threshold values of depths to obtain the area of inundation and the corresponding volume of water stored in the wetland.

In the model Builder (Figure 3), from the raster containing water depths (InRas1) for a particular flow simulated, Band 1 is selected (Band_1) and a threshold value (Threshold Value) is entered as a float value. In the subsequent process, the threshold value is subtracted from the depth grid. The output raster (OutRas1) was reclassified for values <=0 converted to No Data (Convert Grid to 1), whose output (OutRas2) was multiplied with the depth grid from the previous step (OutRas1) to obtain the final depths (OutRas3).
The area for each OutRas3 was obtained as a product of number of cells and grid size, while the volume was obtained as the product of mean depth of the whole grid and the corresponding area of the grid.

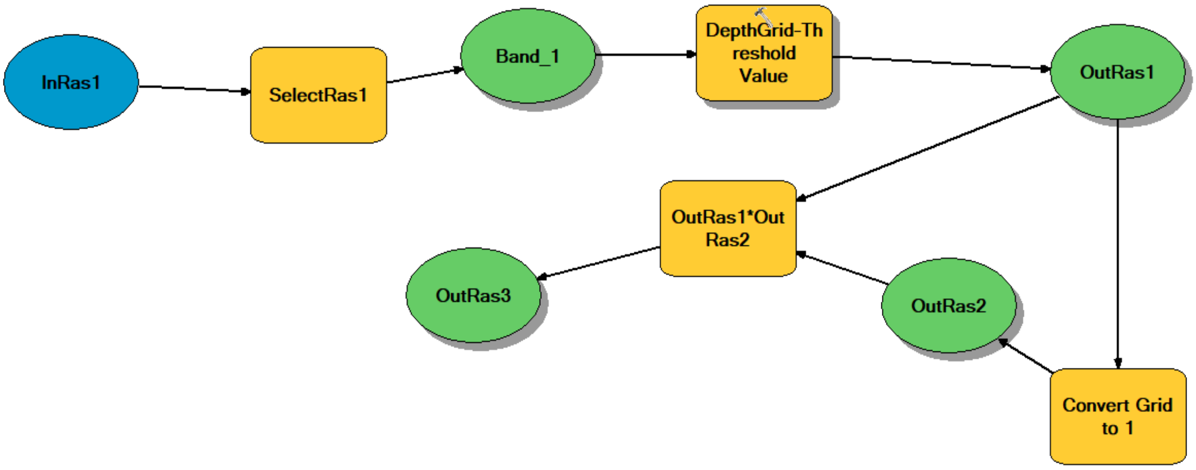

Figure 2. Schematic Implementation of the area and volume calculation in Model Builder Tool

2.3.2 Characteristic levels

Three different characteristic water levels can be included in the model: (1) bottom level, which defines the bottom elevation of the lake (wetland). (2) the dead zone level is the minimum level from which water can be utilised. If the water level is below this zone water can only be lost due to evaporation or bottom infiltration, this can be used in case a permanent wetland has a consistent and minimum water volume. (3) dam crest level is the highest water level in a reservoir before spill occurs, but this level is not used for lakes. We define the bottom level and dead zone level as the minimum elevation of the downstream boundary cross sectional profile.

2.3.3 Losses and gains

Losses from the wetlands are implemented in the model through evapotranspiration and infiltration, while infiltration is assumed to not have a significant influence on the overall watershed water balance in the Nile Basin[6]. Gains to the wetland is direct precipitation on the wetland area. Data can either be entered as long-term seasonal averages or as time series. Lack of losses and gains in the wetland parameterization can cause unrealistic outflow computations and in cases where this was found, suggestions are made for the individual wetlands to obtain PCP and PET from the closest catchment object in the NileDSS.

2.3.4 Spill capacity

The spill capacity governs the outflow delay of the wetlands. Therefore, the hydraulic model is used to derive a discharge rating curve at the downstream boundary of the wetland which relates water level to discharge and which represents the spill capacity curve.

3 Assessment of the status quo of wetland implementation in the NileDSS

The assessment of the status quo is split in two parts: First, assessing the parameterization of the wetlands currently included in the NileDSS to decide which ones need improvement; and second, provide a review of wetlands in the Nile Basin not considered in the NileDSS, but which influence hydrologic and hydraulic processes.

3.1 Wetlands considered in the NileDSS

The simulation of the wetlands in the Nile DSS has been checked against three criteria:

1. Verification of the hydrological processes embedded in the Nile DSS, this includes characteristics of the wetland itself and the interlinkage with the river flow, rainfall, infiltration, evapotranspiration, and runoff processes.
2. Verification of boundary conditions for wetland simulation, i.e., checking hydrometeorological data used in the Nile DSS against observed measurements wherever available.
3. Verifying the water balance at wetlands as an aggregated check for the hydrological simulation in the Nile DSS.
4. Checking the wetland extent and associated level-area-volume curve against literature, satellite images and the 2009 wetlands study[5].

Therefore, verifying the plausibility of wetlands data focuses on the physical characteristics of the wetland area, as well as the boundary conditions of the water balance. On the characteristics, we have specifically checked the level-volume, and level-area relations, as well as the location of inflow and outflow points. Regarding the boundary conditions, we have checked the components of the water balance: inflow, precipitation, evapotranspiration, outflow, as well as infiltration or percolation losses.

Plausibility checks have been made first against observed measurements wherever available, next the checks are based on global datasets, or information available from technical reports or from public sources. The order of magnitude of a given component of the wetland water balance (inflow, precipitation, evapotranspiration, outflow), has been verified against long term mean monthly values (seasonality) and annual time series.

A summary of the data plausibility check is provided in Table 1, with regard to the inflow, outflow, level-area-volume relation, precipitation, evapotranspiration, and overall remarks.
Annex 7.1 gives long term mean values of precipitation, and evapotranspiration over key locations of the wetlands to compare seasonality and the significance of missing process variables (such as precipitation or evapotranspiration), downloaded from IWMI Online Climate Atlas[4]. Wetland extents have been plausibility-checked against the 2009 assessment[5]. Bottom infiltration in the NileDSS wetland parameterization is mostly set to zero, indicating that long-term losses to an unconnected groundwater aquifer do not occur. This assumption is assessed valid[6] and therefore no improvements are required from the Consultant's point of view for the infiltration parameters.
Further information is given below for each wetland, discussing main processes and challenges for a more accurate representation in the Nile DSS.

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[4] http://wcatlas.iwmi.org/Default.asp

[5] NBI, 2009. The Wetlands of the Nile Basin: Baseline Inventory and Mapping.

Swamps of the Baro River: Baro to Adura, BAS-Gilo VR; BAS-Pibor VR1

The river system of Baro, Pibor, and Akobo is very complex, with bifurcation and spills at several locations. One attempt to compute the water balance of the BAS is given by Sutcliffe and Parks (1999)[6] as shown in Figure 4 below.

The schematic given in the Nile DSS covers the main hydrological connections and aggregated wetlands. The simulation as these aggregated wetlands seems to sufficiently account for the impacts on the hydrology and water resources for the whole Nile. Alternatively, the system could be depicted by localized models, with detailed representation of the wetland system. However, this would require significant field data on water level, discharges, and river topography. A summary of the plausibility of the data in the Nile DSS is given in Table 1.

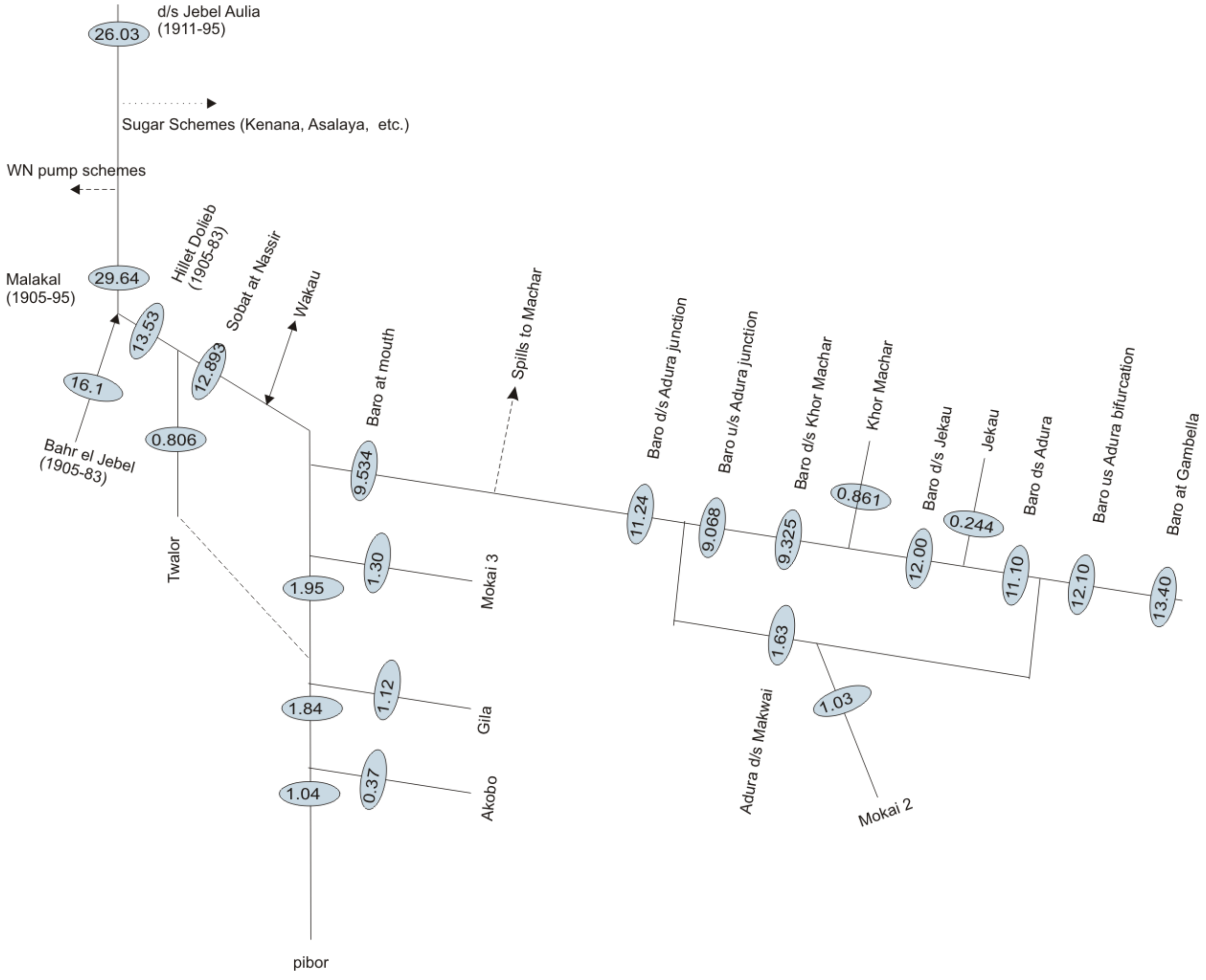

Figure 4. Annual water balance of the Sobat in km^3/year (Source: Sutcliffe and Parks, 1999[6])

Bahr el Ghazal Swamp

The drainage system of the wetlands of Bahr el Ghazal is not well understood. Runoff is generated from the upper catchment in the south-western part of South Sudan (the Nile-Congo divide), and flows through a number of streams before disappearing in large wetland areas including Lake No. Except for

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[6] Sutcliffe JV, Parks YP, 1999. The Hydrology of the Nile, Special Publication No 5. IAHS Press, Institute of Hydrology, Wallingford, Oxfordshire. http://iahs.info/bluebooks/SP005.htm

a few streams (Lol, Pongo, Jur, Tonj, Maridi and Naam), many other smaller streams are not gauged. Other rivers are Lau, Gwir, and Tapari. Depending on the delineation criteria, the wetland may reach between 8,000 to 59,000 km2. Rainfall varies from 1400 mm/yr in the upper catchment to 900 mm/year in the plains. The average annual inflow to Bahr el Ghazal swamps reaches 11 Bm3/year, while outflow from Lake No is around 0.5 Bm3/year. There is spilling from Bahr el Ghazal to the Sudd wetlands, and vice versa. A summary of the plausibility of the data in the Nile DSS is given in Table 1.

The Sudd wetland

The Sudd wetland is a huge swampy area (30,000 to 40,000 km^2), with vegetation composed mainly of papyrus, water hyacinth and grasslands. It is located in South Sudan, and is of vital importance for livelihoods, ecosystem services and water resources. Half of the White Nile flow evaporates when passing through the Sudd (around 16 Bm^3/year). Historically, this phenomenon triggered several water conservation projects in the Nile region (the Jonglei Canal Project). Available information on the hydrology of the Sudd is available and spread over many decades [6, 7, 8].

The average rainfall over the Sudd is about 800 mm/year, average potential evapotranspiration (PET) is 2150 mm/year. The wetland area is very much dependent on the inflow from the White Nile. The wetland area has been tripled after the high river flow of the mid 1960's, when Lake Victoria outflow has been doubled. A summary of the plausibility of the data in the Nile DSS is given in Table 1.

Lake Tana wetlands

These are wetlands along the shore of the lake, consisting of seasonal and permanent swamps. The wetlands support rich biodiversity of both aquatic and terrestrial fauna. Streams flowing into the lake (Gumara, Rib and Megesch), spill over to form swampy areas close to the lake. The wetlands are influenced by the operation of Tissi sat weir, as well as by the newly completed Tana-Belese diversion, for hydropower generation. A summary of the plausibility of the data in the Nile DSS is given in Table 1.

The wetlands of the Equatorial Lakes region: Lake Albert, Lake Ihema, Lake Rushwa, Lake Victoria, Nalubaale_Kiira_Virtual, Nyabarongo Weltand, Lake Kyoga

These neighbouring wetlands, all located in an interconnected region, have a very high density and diversity. They consist of tens of wetlands of different types, and varying sizes. These wetlands support rich flora and faunal systems in the Nile equatorial region, including fish, reptiles, mammals, birds, etc. The hydrology of these wetlands can be very complex interacting with lakes, rivers, and groundwater aquifers. More detailed description of the Equatorial Nile wetlands can be found in "The Wetlands of the Nile Basin: Baseline Inventory and Mapping, 2009"[9]. A summary of the plausibility of the data in the Nile DSS is given in Table 1.

Machar marshes

The Machar marshes are formed because of the spill from the Baro river, and seasonal inflow from torrents originating from the eastern direction (Yabus and Daga). Literature shows different results for the water balance of the Machar marches. It is even not uncommon to see different definitions of these marshes, e.g., seasonal vs. permanent; greenness (NDVI) vs. water evaporation. As such, this results in different wetland delineation, and hence different areas, varying from 2,000 to 20,000 km2,

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[7] Mohamed YA, Bastiaanssen WGM, Savenije HHG. 2004. Spatial variability of evaporation and moisture storage in the swamps of the upper Nile studied by remote sensing techniques. J. Hydrology 289:145–164.

[8] Petersen G. 2008. The Hydrology of the Sudd, Hydrolologic Investigations and Evaluation of Water Balances in the Sudd Swamps of Southern Sudan, Dissertation, Kiel, Germany.

[99] NBI, 2009. The Wetlands of the Nile Basin: Baseline Inventory and Mapping.

and subsequently different water balance results [6, 7, 10, 11]. The key components of the water balance of the Machar marches are: (i) spills from Baro river varies from 1 to 6 Bm3/year, (ii) inflow from the eastern torrents, Yabus and Daga, varies from 1.7 to 5.6 Bm3/year, (iii) Rainfall over the marches is around 900 mm/year which varies appreciably, from around 800 mm/yr on the plains to 1300 mm/yr near Gambela in the south, (iv) evapotranspiration, and (v) outflows through Khor Adar and other streams to the White Nile, or to the lower Sobat. The river system of the Baro-Akoba-Sobat, and down to the Machar marshes is very complex and little is known to determine an accurate water balance. A summary of the plausibility of the data in the Nile DSS is given in Table 1.

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[10] Jonglei Investigation Team 1954. The Equatorial Nile project and its Effects in the Anglo-Egyptian Sudan, Khartoum.

[11] El-Hemry II, Eagleson PS. 1980. Water Balance Estimates of the Machar Marshes. Dept Civ. Engng, Mass. Inst. Tech., Report no. 260.

Table 1. Results of the assessment of wetland simulation in the Nile DSS; “Approach” refers to the method used to update wetland parameterization in the NileDSS (see chapters 2.1 and 2.2)

Wetland	**Inflow**	**Outflow**	**ET rate**	**PCP**	**level-area; level-volume; wetland area**	**Remarks**	**Action**	**Approach**
Baro VR	No observed data	No observed data	Not realistic, even negative values of ET	missing	Level-Area reaches 75,000 km2, seems very large	Seems to significantly buffer inflows	Correct ET and PCP, check max wetland extent	Wetland water balance (chapter 4.1), Comparison to remote sensing*
Baro_to_Adura	app. 130% higher than observed	realistic	Constant and high ET	missing	realistic	None	Correct ET and PCP, correct inflows	Wetland water balance (chapter 4.2)
BAS_Gilo VR	realistic	realistic	realistic	realistic	Level-Area reaches 49,000 km2, seems very large	None	Check max wetland extent	Comparison to remote sensing*
BAS_Pibor VR1	realistic	realistic	Seasonal pattern of ET rate, though less pronounced, see Annex 1	realistic	Level-Area reaches 27,500 km2, seems very large	None	Check max wetland extent	Comparison to remote sensing*
Bahr el Ghazal Swamp	realistic	realistic	realistic, only slight underestimation in Jan/Feb/Mar, see Annex 1	realistic	realistic	None	No action required	None
BJ_Sudd Swamp VR1	Shows no seasonal pattern, too high	Fairly steady, realistic	Constant rate of ET, instead of seasonal pattern, see Annex 1	realistic	Fairly constant wetland extent	High losses (>60%)	Correct inflows and water balance	Detailed Sudd diagnostic study**
2BJ_Sudd Swamp VR2	Inflows seem too high	realistic	Constant rate of ET, must show seasonal pattern, see Annex 1	realistic	Wetland area shows very small seasonal pattern	Very high losses (almost 70%)	Correct inflows and water balance	Detailed Sudd diagnostic study**
2BJ_Sudd Swamp VR3	10% higher as Mongalla inflows	Similar to inflows	missing	missing	Wetland area too large (50,000 km^2), and with no seasonal pattern	Very little losses (<1%)	Correct ET, PCP, wetland extent	Detailed Sudd diagnostic study**

Lake Tana	No complete observed data	realistic	realistic	realistic	Level-volume-area relation of Lake Tana (Wetland impact unclear)	The whole lake assumed as a wetland, while in fact, smaller areas along the shore are the wetland	No action required	None
LA_Lake Albert	Seems under-estimated	Seems underestimated, 20 vs 30 Bm3/year	Slightly overestimated	realistic	Level-volume-area relation of Lake Albert (Wetland impact unclear)	The whole lake assumed as a wetland, while in fact, smaller areas along the shore are the wetland	No action required	Wetland water balance (chapter 4.5)
LV_Lake Ihema Wetland	Seems underestimated, 5.4 vs 7 Bm^3/yr	realistic	missing	missing	realistic	None	Correct ET and PCP, recalibrate DSS inflows	Wetland water balance (chapter 4.5)
LV_Lake Rushwa Wetland	Seems underestimated similar to outflow	realistic	missing	missing	realistic	None	Correct ET and PCP	Wetland water balance (chapter 4.7)
LV_Lake Victoria Owen Falls Dam	Lower than outflow	realistic	Slightly overestimated	realistic	Level-volume-area relation for Lake Victoria	The whole lake assumed as a wetland, while in fact, areas along the shore are the wetland	Check inflows	Wetland water balance (chapter 4.8)
LV_Nalubaale_Kiira_Virtual	Inflow same as outflow	realistic	missing	missing	realistic	None	Correct ET and PCP	Wetland water balance (chapter 4.9)
LV_Nyabarongo Weltand	No observed data	No observed data	missing	missing	Level-Area reaches 27,500 km^2 and simulated area 7000 km^2 - seems very large	None	Correct ET and PCP Check max wetland extent	Wetland water balance, 2D hydraulic modelling (chapter 4.10)
VN_Lake Kyoga	No observed data	Slightly overestimated by about 10%	missing	missing	realistic	None	Correct ET and PCP	Wetland water balance (chapter 4.11)

WN Machar Marshes	realistic	realistic	Constant ET rate, instead of seasonal pattern, see Annex 1	realistic	depends on definition of wetland, the literature shows very wide range of wetland area from 2,000 to 20,000 km2	Seasonal pattern of wetland area seems realistic. inflow from torrents must be smaller than spill from Baro River	Correct ET	Wetland water balance (chapter 4.12)

* requires comparison with results from WP1 – wetland extent from Remote Sensing
** will be dealt with in the separate Sudd diagnostic study

3.2 Wetlands in the Nile Basin not currently considered in the NileDSS

The list of wetlands within the Nile basin includes more than 70 major wetlands in *The Wetlands of the Nile Basin* NBI report[9]. These wetlands vary in size from small wetlands of a few square kilometres, to as big as 50,000 km^2 or even more. Although almost all wetlands are of vital importance to the local ecosystem, and they provide valuable services, only few are of significant importance with regards to hydrology and hydraulics of the river flow. As such, the list of wetlands included in the NileDSS is largely exhaustive. The analysis of the wetlands not currently included in the NileDSS yielded the result, that the following wetlands should be included due to their size and hence, the possible impact on the Nile's hydrology:

- the Dinder Wetlands (chapter 5.1)
- Mara wetlands (chapter 5.2) and
- the Sio Nzoia Yala Nyando wetlands (chapter 5.3)

Additional wetlands have negligible impacts on the Nile hydrology and water resources. These wetlands can be crucial for the local ecosystem, and they are directly dependent on the Nile water for the ecosystem services provided, but they may have little impact on the Nile hydrology and water resources. Therefore, to preserve the simplicity of the Nile DSS to support water resources planning and management, it is advisable to limit the hydrological simulation of wetlands to the ones that impact hydrology and water resources.

But on the other hand, the remaining wetlands are very much dependent on Nile hydrology which means that if the flood regime is changed, the functioning, or even existence of this or similar wetlands are at risk. These wetlands will be considered through the second objective of the work package (Wetland Impact) through a remote sensing-based approach that links wetland extent and wetland units to the hydrological conditions.

4 Updating wetland parameterization of already existing wetlands in the NileDSS

The following summary gives suggestions for each wetland how to improve the parameterization in the NileDSS. Where possible, the data to update the parametrization is taken from the NileDSS database to ensure compatibility, data availability and -access. In these cases, the names of the respective files where the data are available are given below.

4.1 Baro VR - Correct ET and PCP

In the current NileDSS setup, PCP is constantly set to 0mm/day and PET shows seasonal variations from 7.9mm/d to -2.5mm/d for this wetland. Negative values of PET may be explained from combining PET and PCP, but for clarity, it is suggested to separate the two processes. This should be corrected by updating the file "*Baro VR LossesGains.dfs0*", where PCP and PET can be taken from the catchment "*BAS_Lower Baro DS Machar*".

The reasons for the implementation of this wetland in the NileDSS are unclear. Flows from the Baro are diverted into the wetland based on a bifurcation table, where a maximum of 300m^3/s flow remain in the Baro and the remainder is routed into the wetland. The wetland's size in the DSS can reach up to 73.500km^2 and as such is able to buffer significant flows. However, such a wetland at the outlet of the Baro does not exist. It is hence possible that the wetland was implemented to account for implausibilities in the upstream data- and model situation.

Maximum wetland extent will be compared to results obtained from the remote sensing analysis (Workpackage 1).

4.2 Baro_to_Adura - Correct ET and PCP

In the current NileDSS setup, PCP is constantly set to 0mm/day and PET is constantly set to 10mm/day for this wetland. This should be corrected by updating the file "*Losses and gains time series_R511.dfs0*", where PCP and PET can be taken from the catchment "*BAS_Lower Alwero*".

Inflows to the wetland originate from the Baro-Adura bifurcation and outflows from Alwero dam. Observed data from 1950 for the Baro-Adura bifurcation and simulated outflows from Alwero dam are 130% lower than inflows simulated in the DSS for the 1950s.

4.3 BAS_Gilo VR - Assess wetland extent

Maximum wetland extent will be compared to results obtained from the remote sensing analysis (Workpackage 1).

4.4 BAS_Pibor VR1 - Assess wetland extent

Maximum wetland extent will be compared to results obtained from the remote sensing analysis (Workpackage 1).

4.5 LA_LakeAlbert Wetland – outflow discrepancy

Compared to observed outflows at *“Lake Albert at its Exit”*, simulated outflows from the wetland are underestimated (20 vs 30 Bm^3/yr) which is probably due to underestimated inflows. However, not for all streams to Lake Albert, observed data is available. It is suggested to re-calibrate upstream regions to achieve a better match to observations.

4.6 LV_Lake Ihema Wetland - Correct ET and PCP

In the current NileDSS setup, PCP and PET is constantly set to 0mm/day for this wetland. This should be corrected by including a file “*Lake Ihema LossesGains.dfs0*”, where PCP and PET can be taken from the catchment “*LV_Kagera_Kagera*”.
Compared to observed inflows at *“Kagera at Rusumu falls”*, simulated inflows to the wetland are underestimated and upstream regions should be re-calibrated to achieve a better match to observations.

4.7 LV_Lake Rushwa Wetland - Correct ET and PCP

In the current NileDSS setup, PCP and PET is constantly set to 0mm/day for this wetland. This should be corrected by including a file “*Lake Rushwa LossesGains.dfs0*”, where PCP and PET can be taken from the catchment “*LV_Kagera_Kishanda*”. This lack of losses also causes outflows to be similar to the inflows. Similar to Lake Ihema Wetland (chapter 4.5), inflows are underestimated which would be improved if Lake Ihema Wetland is corrected.

4.8 LV_Lake Victoria Owen Falls Dam – outflow discrepancy

Inflows to the implemented Lake Victoria are 30% lower than outflows, but according to the water balance analysis, PCP on Lake Victoria is higher than ET which causes these increased outflows. Therefore, no action is required.

4.9 LV_Nalubaale_Kiira_Virtual - Correct ET and PCP

In the current NileDSS setup, PCP and PET is constantly set to 0mm/day. However, PCP and PET on the maximum surface area of 0.2km^2 of the wetland will have only a negligible impact on the water balance and can therefore be ignored. Having equal in- and outflows, and no significant wetland area in the region, the wetland’s purpose in the NileDSS schematization is unclear.

4.10 LV_Nyabarongo Wetland - Correct ET and PCP and 2d hydraulic modelling

In the current NileDSS setup, PCP and PET is constantly set to 0mm/day for this wetland. This should be corrected by including a file “*LV Nyabarongo LossesGains.dfs0*”, where PCP and PET can be taken from the catchment “*LV_Kagera_Rwagitugusa*”.

In addition, the wetland parameterization regarding the level-area-volume curve was assessed as implausible. Therefore, simplified 2D hydraulic modelling on the grid shown in Figure 5 was applied to derive the level area volume table and the spill capacities.

Therefore, HEC-RAS was run with the following conditions:

- a normal depth type downstream boundary condition
- grid resolution of 150m (302,695 cells) with a roughness value of 0.06
- five inflow scenarios ranging from 50 to 600m³/s flow input each at the southern and northern end of the model domain Table 17, Annex)
- simulation length was required to be more than three months until a constant flow at the outlet was reached
- the threshold depth during post-processing to set the grid to dry conditions was 0m

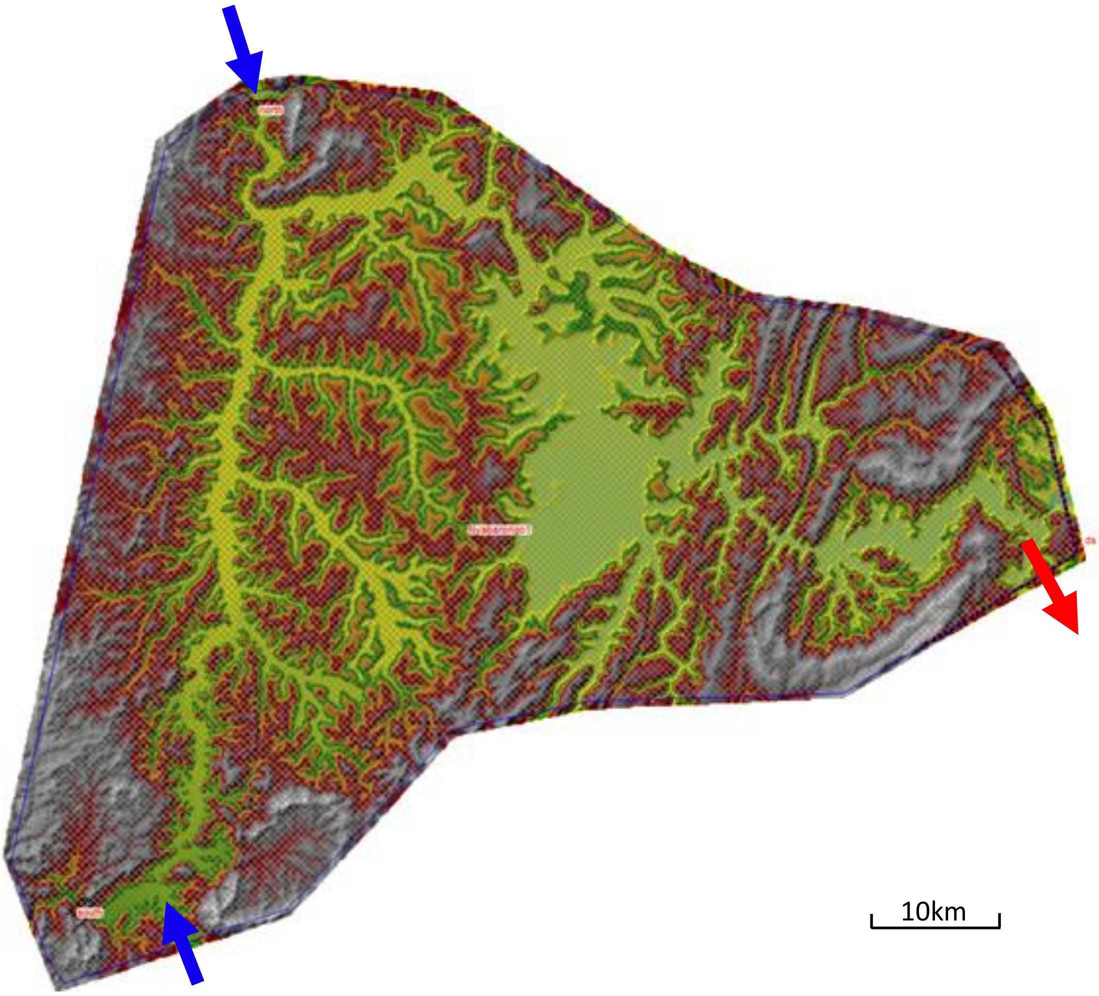


Figure 5. Nyabarongo wetland model domain; blue arrows show the inflow locations, red arrow the outflow location

4.10.1 Spatial Results and level area volume table

Water depth, the water surface elevation and the inundation area were extracted for the five flow scenarios simulated. An example depth grid is shown in Figure 6. The level area volume table deduced from the results is given in Table 2.

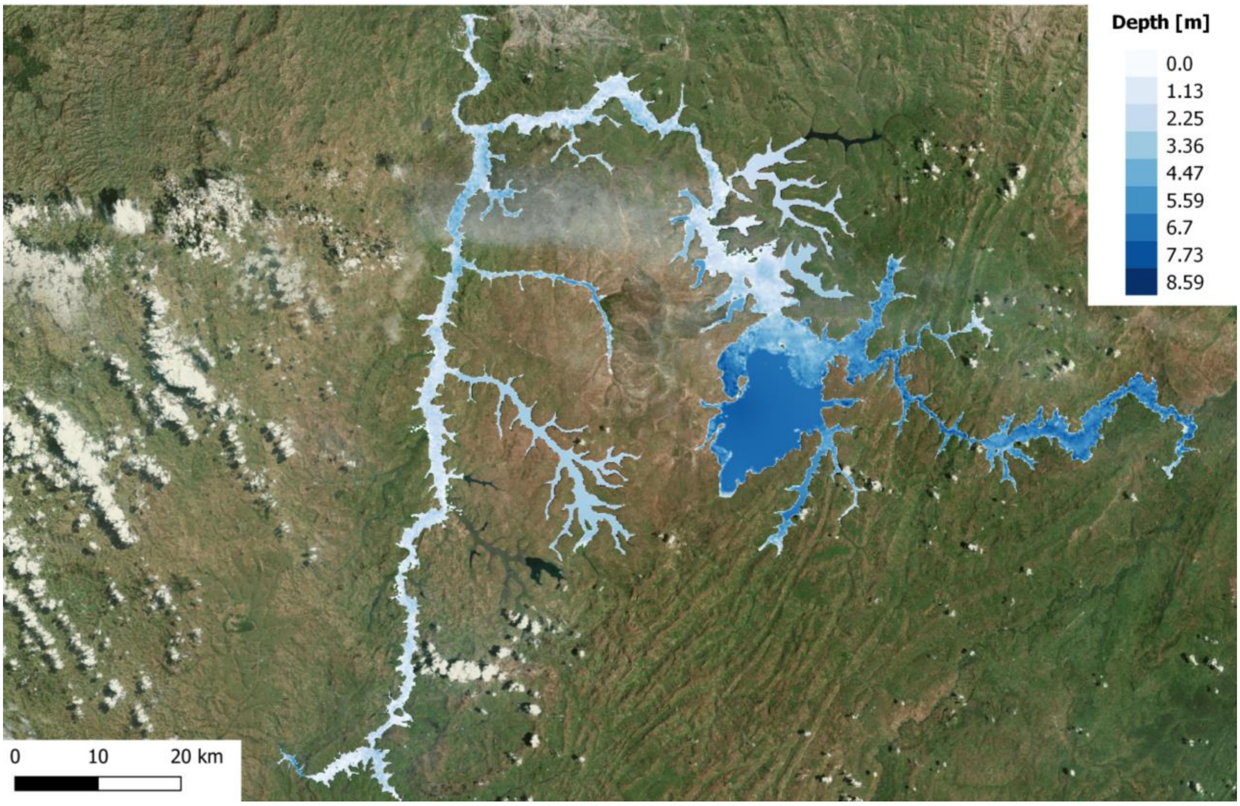
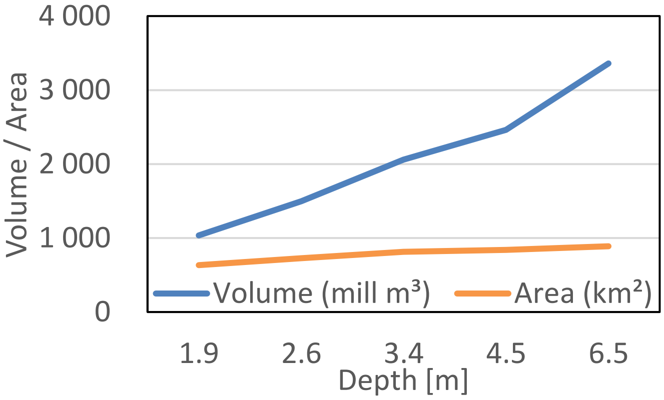


Figure 6. Nyabarongo water depth (m) for flow scenario 1 (600m³/s from both southern and northern inflow) Background: Bing Maps

Table 2. Level Area Volume table and diagram for the Nyabarongo wetland

Depth (m)	Volume (mill m³)	Area (km²)
1.9	1035.5	633.5
2.6	1498.9	726.5
3.4	2060.1	811.8
4.5	2461.7	841.4
6.5	3359.8	888.9

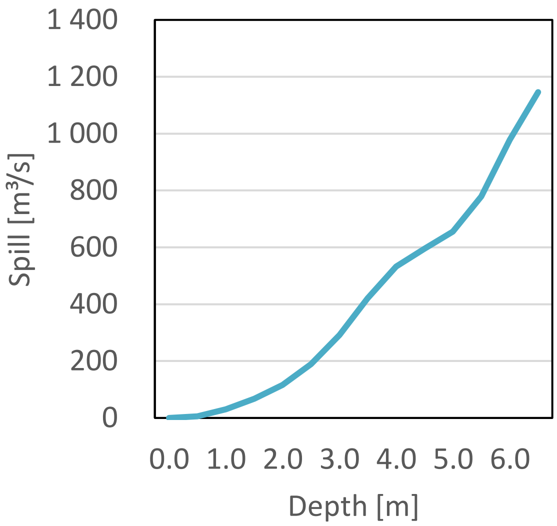


4.10.2 Profile Results and spill capacities

The spill capacities derived from the cross-section profile located in the outlet of the wetland is shown in Table 3.

Table 3. Spill capacity (rating curve of stage versus flow) at the outlet profile of the Nyabarongo wetland

Depth [m]	Spill [m³/s]
0.0	0.0
0.5	5.5
1.0	30.5
1.5	68.0
2.0	116.0
2.5	189.5
3.0	292.0
3.5	421.0
4.0	532.5
4.5	596.0
5.0	655.5
5.5	779.0
6.0	978.0
6.5	1146.0



Results from the hydraulic modelling are significantly different to the wetland implementation in the NileDSS, where spill capacities are much lower (by a factor of 10) and storage areas and volume much higher (by a factor of 30). This indicates, that the Nyabarongo Wetland is a strong buffer in the NileDSS, which was not found in the simulations. The wetland is located in a comparably steep region with few areas where water can flood vast plains, indicating that the hydraulic simulation is plausible.

4.11 VN_Lake Kyoga - Correct ET and PCP

In the current NileDSS setup, PCP and PET is constantly set to 0mm/day. This should be corrected by including a file "*VN Lake Kyoga LossesGains.dfs0*", where PCP and PET can be taken from the catchment "*VN_LakeKyoga*".

4.12 WN_Machar Marshes - Correct ET

In the current NileDSS setup, PCP and PET is kept in the range of 4.0-4.8mm/day which does not resemble the actual seasonality for this wetland. Therefore, PET in the file "*Machar Marshes PrecEvap.dfs0"* should be taken from the catchment "*VN_Machar_Marshes*".

5 Implementing new wetland parameterization in the NileDSS

5.1 Dinder wetland

For the implementation of the wetland in the NileDSS, precipitation and potential evapotranspiration (losses and gains table) can be taken from the catchment “BN_Dinder” (Identifier C102).

Simplified 2D hydraulic modelling on the grid shown in Figure 7 was applied to derive the level area volume table and the spill capacities.

Therefore, HEC-RAS was run with the following conditions:

- a normal depth type downstream boundary condition
- grid resolution of 150m (202,840 cells) with a roughness value of 0.06
- six inflow scenarios ranging from 500 to 3000m³/s flow at the inflow location of the model domain (Table 17, Annex)
- simulation length was required to be about 20 days until a constant flow at the outlet was reached
- several sensitivity tests were undertaken regarding the roughness values in order to ascertain the stability of the model and also the impact that this parameter may have on the modelling results
- the threshold depth during post-processing to set the grid to dry conditions was 0.1m

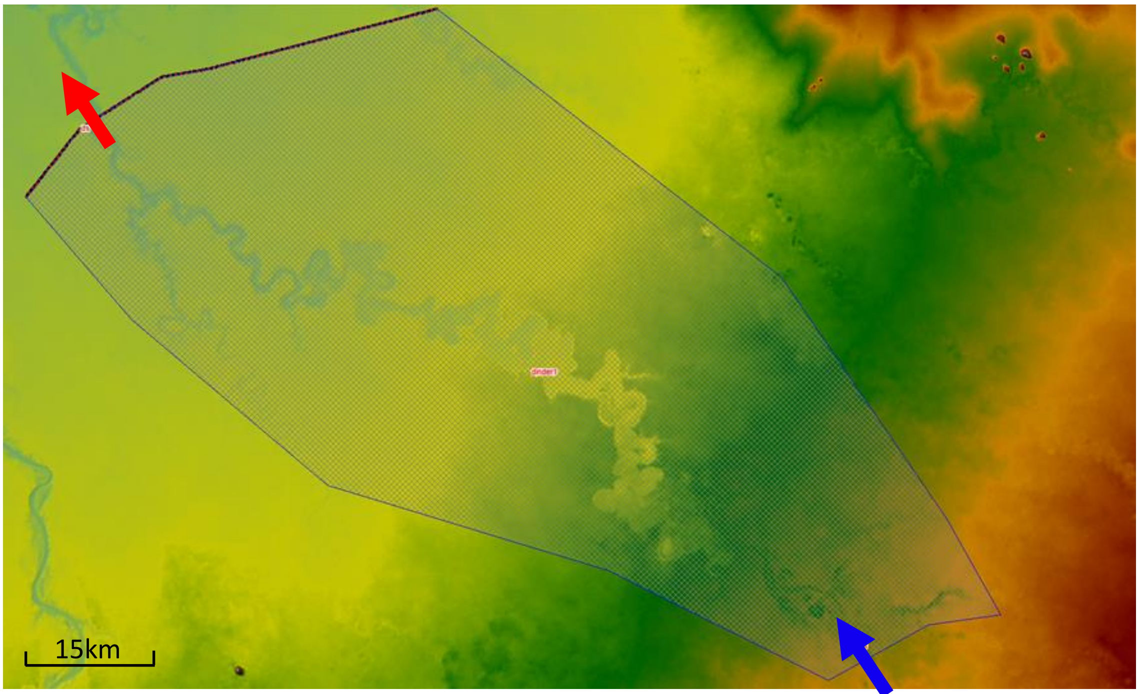


Figure 7. Dinder wetland domain; blue arrow shows the inflow location, red arrow the outflow location

5.1.1 Spatial Results and level area volume table

Water depth, the water surface elevation and the inundation area were extracted for the five flow scenarios simulated. An example depth grid is shown in Figure 8. The level area volume table deduced from the results is given in Table 4.

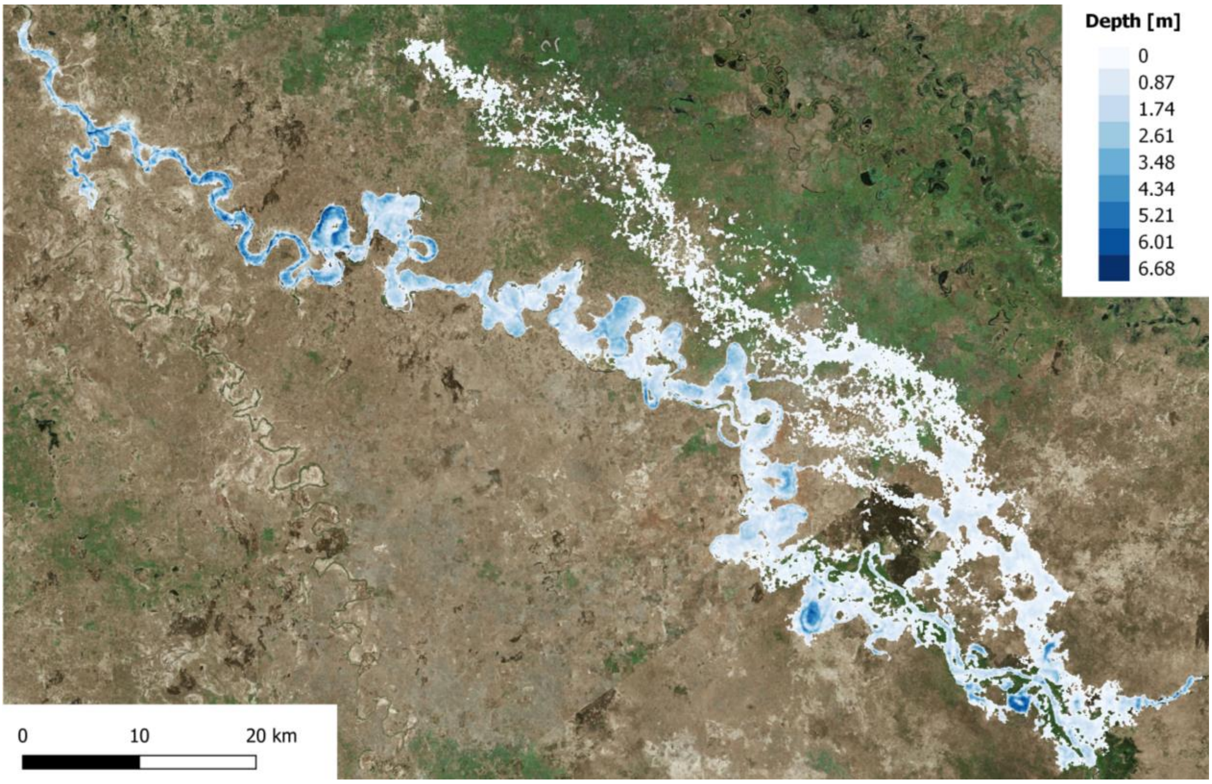
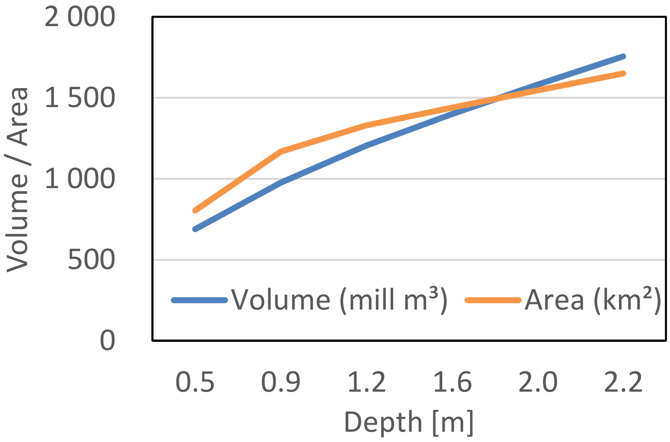


Figure 8. Dinder water depth (m) for flow scenario 6 (500m³/s at the inflow). Background: Bing Maps

Table 4. Level Area Volume table and diagram for the Dinder wetland

Depth (m)	Volume (mill m³)	Area (km²)
0.5	688.7	804.0
0.9	976.3	1168.7
1.2	1204.8	1329.6
1.6	1400.2	1438.0
2.0	1582.0	1545.6
2.2	1755.5	1650.3



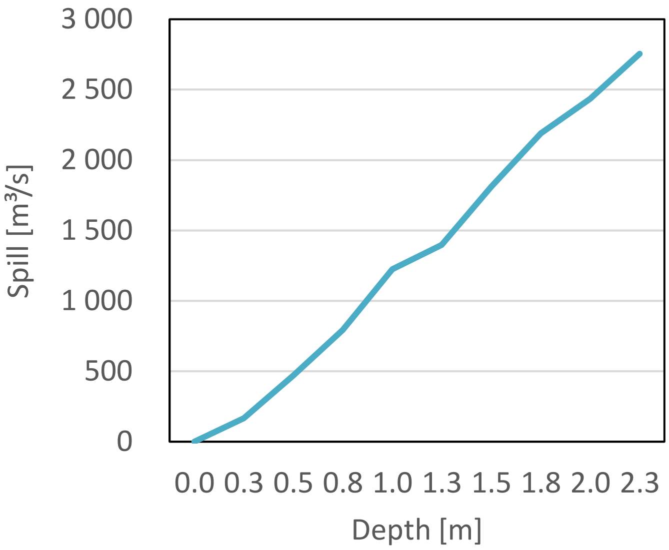
Characteristic levels of the wetland can be set to a bottom level and top of dead storage of 432 mASL.

5.1.2 Profile Results and spill capacities

The spill capacities derived from the cross-section profile located in the outlet of the wetland is shown in Table 5.

Table 5. Spill capacity (rating curve of stage versus flow) at the outlet profile of the Dinder wetland

Depth [m]	**Spill [m³/s]**
0.0	0.0
0.3	167.3
0.5	471.8
0.8	792.8
1.0	1225.1
1.3	1398.4
1.5	1809.9
1.8	2190.8
2.0	2434.5
2.3	2754.9



5.2 Mara wetland

For the implementation of the wetland in the NileDSS, precipitation and potential evapotranspiration (losses and gains table) can be taken from the catchment “LV_Mara” (identifier C18).

Simplified 2D hydraulic modelling on the grid shown in Figure 9 was applied to derive the level area volume table and the spill capacities.

Therefore, HEC-RAS was run with the following conditions:

- a constant water level type boundary condition was used to account for the outflow of the Mara wetland into Lake Victoria
- grid resolution of 150m (98,600 cells) with a roughness value of 0.06
- six inflow scenarios ranging from 100 to 1000m³/s flow input each at the inflow location of the model domain (Table 17, Annex)
- simulation length was required to be up to 15 days until a constant flow at the outlet was reached
- several sensitivity tests were carried out in order to ascertain the stability of the model and also the impact that this parameter may have on the modelling results (Annex 7.4).

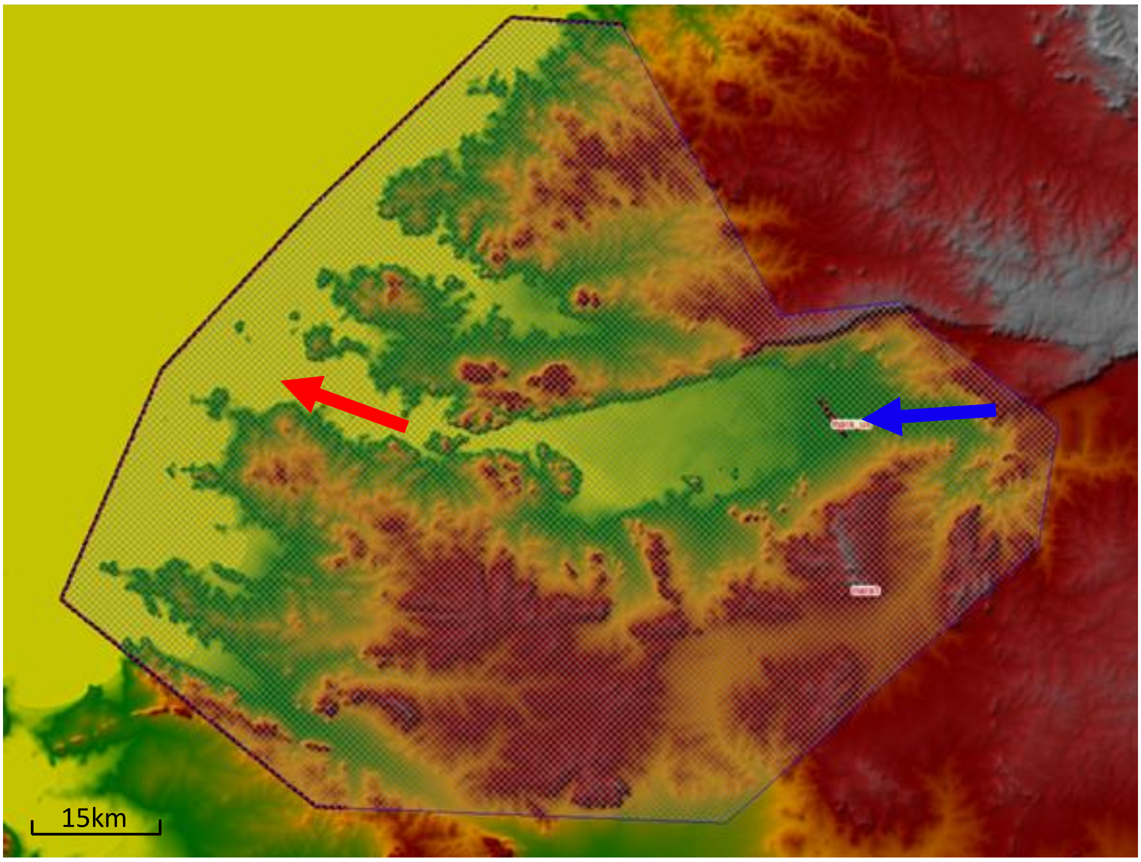


Figure 9. Mara wetland domain; blue arrow shows the inflow location, red arrow the outflow location

5.2.1 Spatial Results and level area volume table

Water depth, the water surface elevation and the inundation area were extracted for the five flow scenarios simulated. An example depth grid is shown in Figure 10. The level area volume table deduced from the results is given in Table 6.

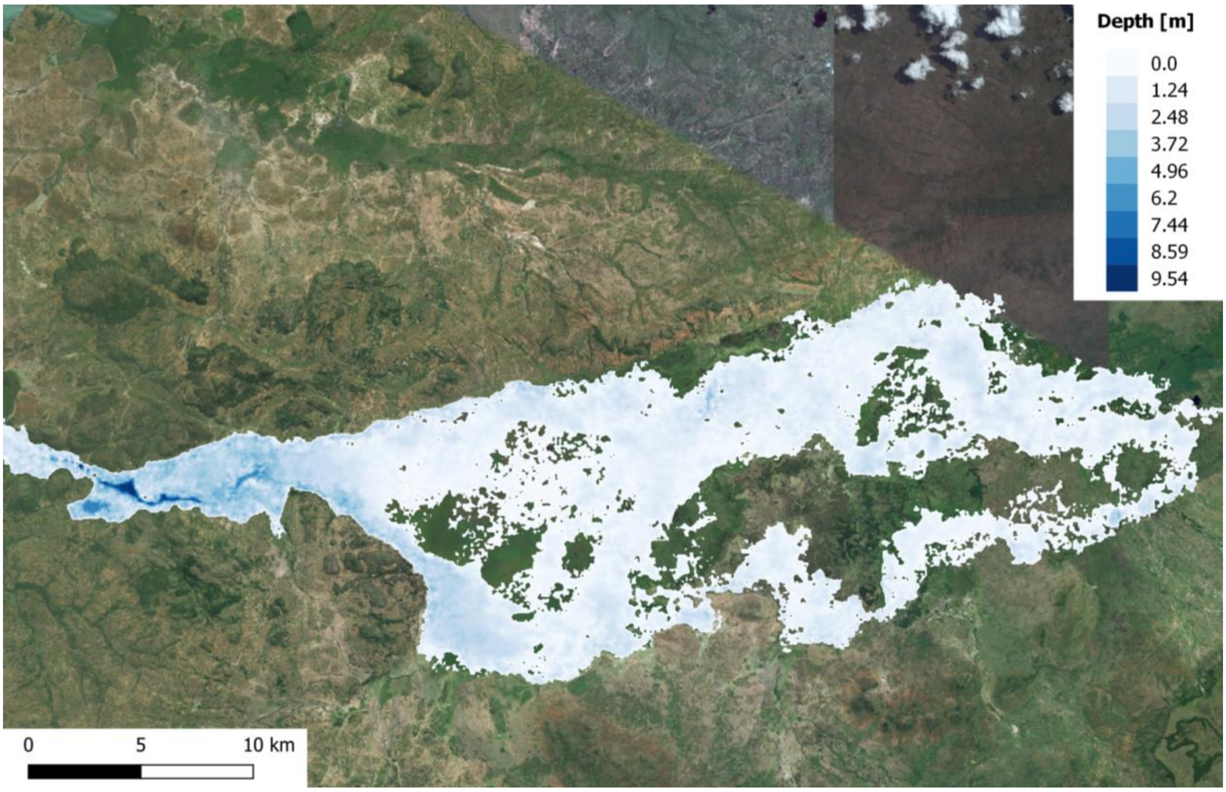
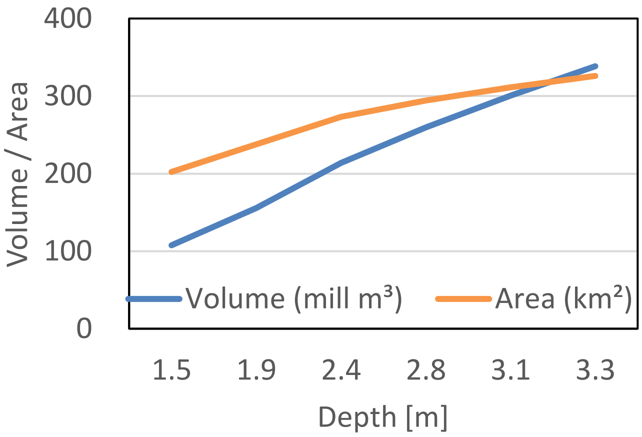


Figure 10. Mara wetland water depth (m) for flow scenario 1 (1000m³/s inflow). Background: Bing Maps

Table 6. Level Area Volume table and diagram for the Mara wetland

Depth (m)	Volume (mill m³)	Area (km²)
1.5	107.6	202.2
1.9	155.5	237.8
2.4	213.7	273.1
2.8	259.7	294.3
3.1	300.4	311.2
3.3	338.5	326.0



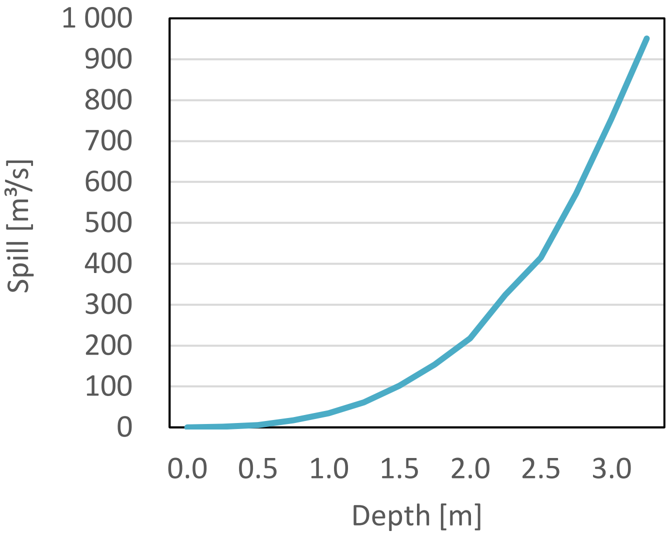
Characteristic levels of the wetland can be set to a bottom level and top of dead storage of 1135 mASL.

5.2.2 Profile Results and spill capacities

The spill capacities derived from the cross-section profile located in the outlet of the wetland is shown in Table 7.

Table 7. Spill capacity (rating curve of stage versus flow) at the outlet profile of the Mara wetland

Depth [m]	Spill [m³/s]
0.0	0.0
0.3	1.5
0.5	6.0
0.8	17.0
1.0	34.6
1.3	60.9
1.5	101.8
1.8	153.3
2.0	217.6
2.3	324.4
2.5	414.6
2.8	571.0
3.0	753.4
3.3	950.7



5.3 Sio-, Nzoia-, Yala-, Nyando wetland

The wetland complex of the Sio, Nzoia, Yala, Nyando are close to each other and therefore depicted in one 2D hydraulic model domain. Therefore, the grid shown in Figure 11 was applied to derive the level area volume table and the spill capacities.

HEC-RAS was run with the following conditions:

- a constant water level type boundary condition was used to account for the outflow of the Mara wetland into Lake Victoria
- grid resolution of 150m (380,243 cells) with a roughness value of 0.06
- five inflow scenarios ranging from 20 to 1900m³/s flow input each at the three rivers (Table 17, Annex)
- the area inundated by the Sio was for all cases disconnected from the southern wetlands, so that outflows were computed for two profiles (red arrows in Figure 11).
- simulation length was required to be up to 12 days until a constant flow at the outlets was reached

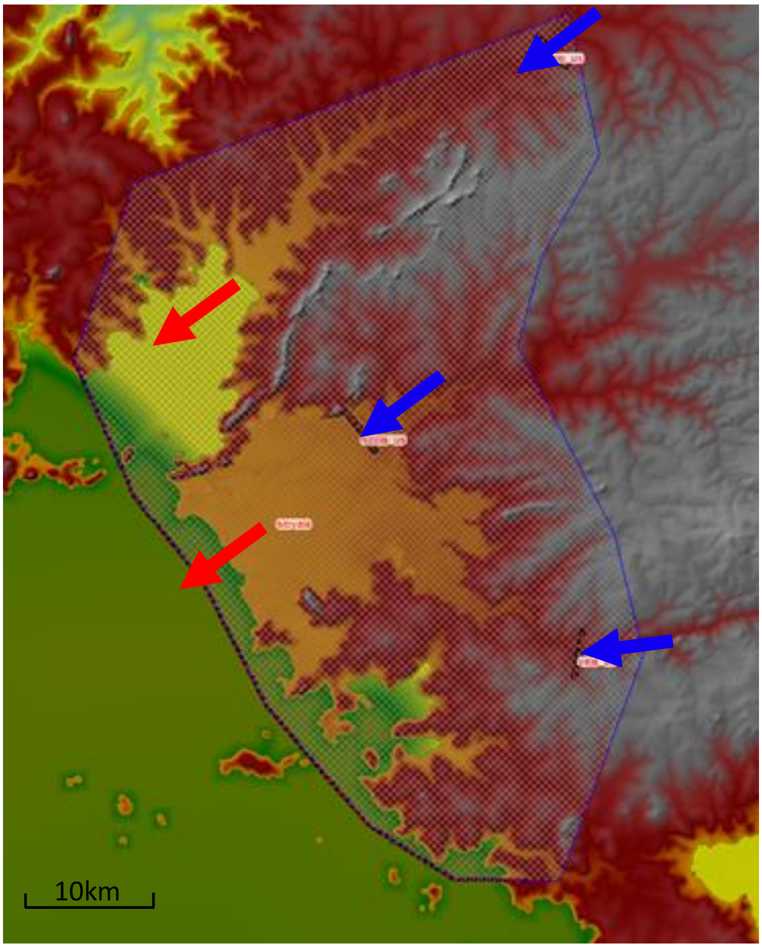


Figure 11. Sio, Nzoia, Yala and Nyando wetland domain

5.3.1 Spatial Results and level area volume table

Water depth, the water surface elevation and the inundation area were extracted for the five flow scenarios simulated. An example depth grid is shown in Figure 12. The level area volume table deduced from the results is given in Table 8 and Table 9.

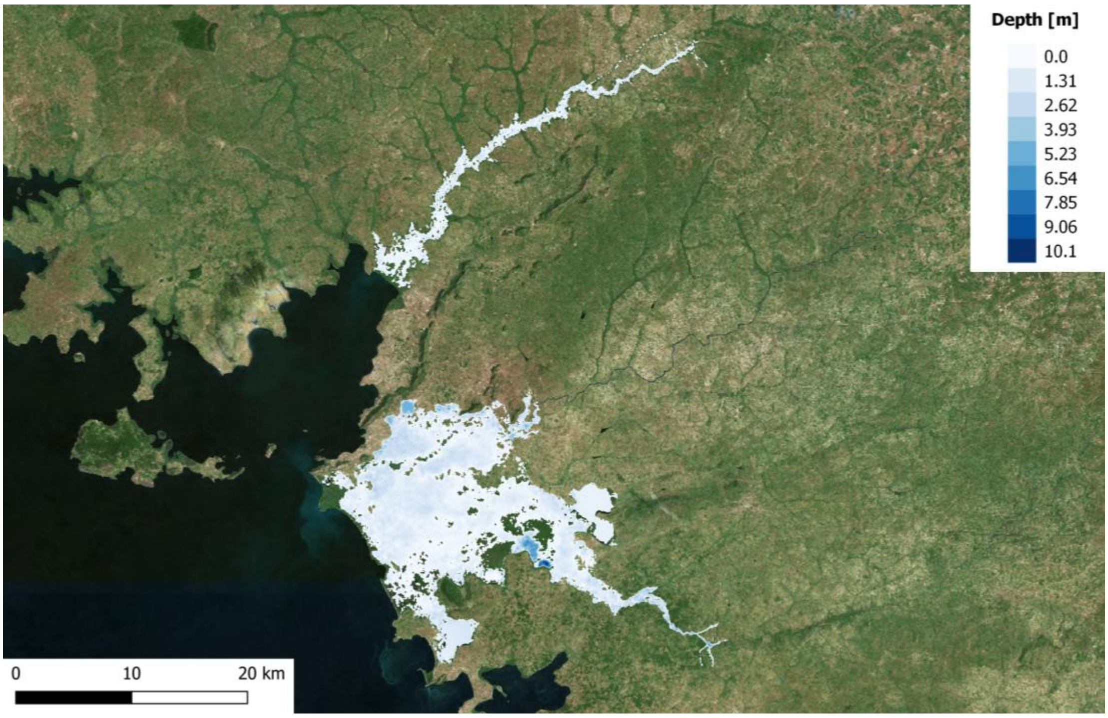


Figure 12. Sio, Nzoia, Yala, Nyando water depth (m) for flow scenario 1. Background: Bing Maps

Table 8. Level Area Volume table and diagram for the Sio wetland

Depth (m)	Volume (mill m³)	Area (km²)
0.2	5.2	11.3
0.3	11.2	22.2
0.3	18.6	29.5
0.4	22.2	32.3
0.4	25.4	34.3
0.5	28.3	35.8

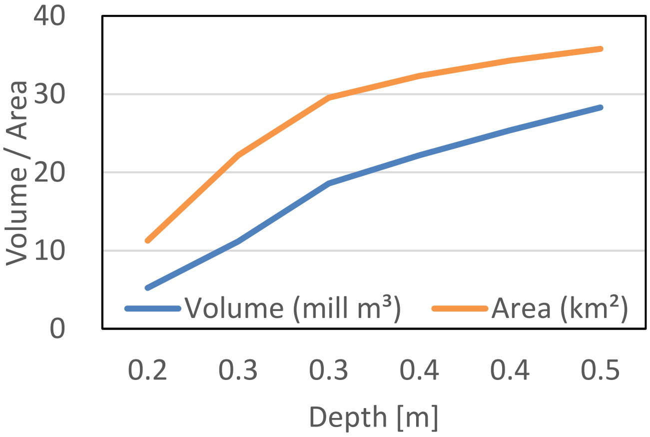
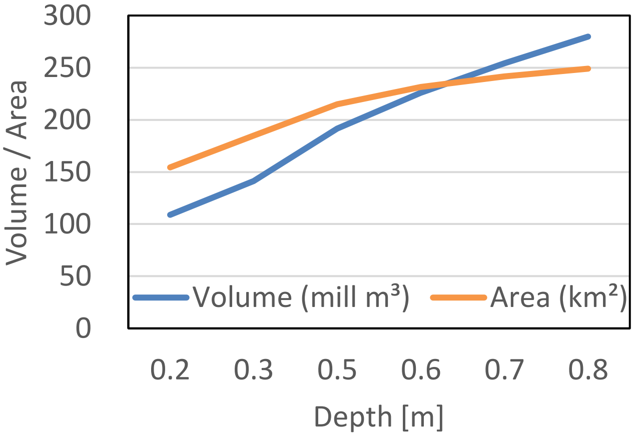


Table 9. Level Area Volume table for the Nzoia, Yala and Nyando wetlands

Depth (m)	Volume (mill m³)	Area (km²)
0.2	108.9	154.4
0.3	141.2	184.8
0.5	191.5	214.8
0.6	225.8	231.4
0.7	254.3	241.5
0.8	279.8	249.0



Characteristic levels of the Sio wetland can be set to a bottom level and top of dead storage of 1137 mASL, for the Nzoia, Yala, Nyando wetland to a bottom level and top of dead storage of 1137 mASL.

5.3.2 Profile Results and spill capacities

The results in the cross-section profile located in the outlet of the Sio wetland is shown in Table 10. The results in the cross-section profile located in the outlet of the Nzoia, Yala and Nyando wetland is shown in Table 11.

Table 10. Spill capacity (rating curve of stage versus flow) at the outlet profile of the Sio wetland

Depth [m]	**Spill [m³/s]**
0.0	0.0
0.1	5.0
0.2	25.7
0.3	71.6
0.4	132.1
0.5	194.9

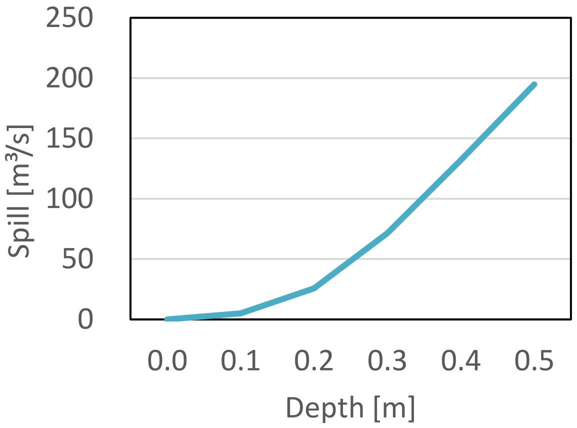
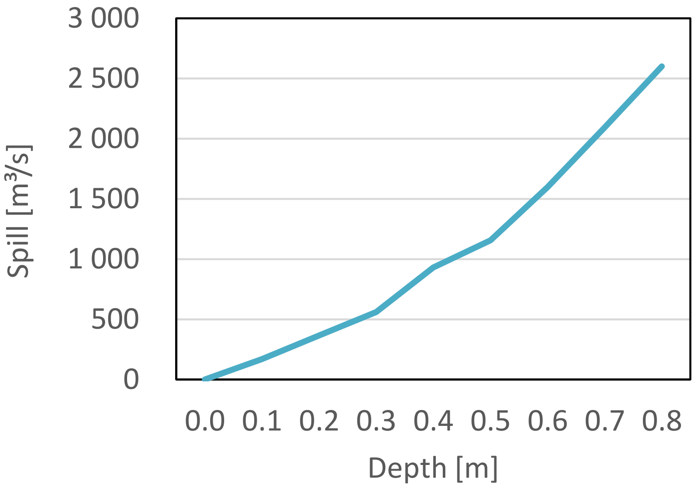


Table 11. Spill capacity (rating curve of stage versus flow) at the outlet profile of the Nzoia, Yala, Nyando wetland

Depth [m]	**Spill [m³/s]**
0.0	0
0.1	169
0.2	366
0.3	559
0.4	930
0.5	1156
0.6	1599
0.7	2094
0.8	2601



6 Conclusions and outlook

The hydrologic depiction of the 17 wetlands implemented in the NileDSS have been assessed. In the following, the main findings are summarized and links are provided to the chapters where more detailed information is available.

2 are considered plausible with no lack of data and with realistic simulation of the processes:

- Bahr el Ghazal
- Lake Tana
- LV_Lake Victoria Owen Falls Dam

11 wetlands are assessed as needing improvement in the water balance with a correction of evapotranspiration and precipitation:

- Baro VR (Chapter 4.1)
- Baro_to_Adura (Chapter 4.2)
- BJ_Sudd Swamp VR1
- 2BJ_Sudd Swamp VR2
- 2BJ_Sudd Swamp VR3
- LV_Lake Ihema Wetland (Chapter 4.6)
- LV_Lake Rushwa Wetland (Chapter 4.7)
- LV_Nalubaale_Kiira_Virtual (Chapter 4.9)
- LV_Nyabarongo Wetland (Chapter 4.10)
- VN_Lake Kyoga (Chapter 4.11)
- WN_Machar Marshes (Chapter 4.12)

7 wetlands show either under- or overestimation of inflows simulated through the NileDSS:

- Baro_to_Adura (Chapter 4.2)
- BJ_Sudd Swamp VR1
- 2BJ_Sudd Swamp VR2
- 2BJ_Sudd Swamp VR3
- Lake Albert (Chapter 4.5)
- LV_Lake Ihema Wetland (Chapter 4.6)
- LV_Lake Rushwa Wetland (Chapter 4.7)

The purpose/existence of the following wetlands in the NileDSS is unclear:

- Baro VR (Chapter 4.1)
- LV_Nalubaale_Kiira_Virtual (Chapter 4.9)

3 wetlands require a comparison of their extents with remote sensing data (Workpackage 1) since a complete simulation of the BAS in the 2D hydraulic model was not feasible within the scope of this project:

- Baro VR (Chapter 4.1)
- BAS_Gilo VR (Chapter 4.3)
- BAS_Pibor VR1 (Chapter 4.4)

For the implementation of the three Sudd wetlands, the following issues have been found which will be dealt with in the separate Sudd diagnostic study:

- Strong difference in water losses between the three wetland implementations
- Lack of seasonal pattern for ET or missing losses/gains
- Lack of seasonal pattern of wetland extent

- Too high inflows

Due to their size, three wetlands are considered possible candidates to be included in the NileDSS. For those, simplified 2D hydraulic modelling was carried out and input data for to the NileDSS has been derived:

- Dinder wetland (Chapter 5.1)
- Mara wetland (Chapter 5.2)
- Sio-, Nzoia-, Yala-, Nyando Wetland complex (Chapter 5.3)

Estimated impact on the overall Nile hydrology of adding these additional wetlands is considered low. All wetlands are however more significant than for instance the implemented wetland of "Baro_to_Adura".

Missing wetlands in the NileDSS or wetlands that are currently not sufficiently parameterized may nevertheless be implicitly included in the hydrological parameterization of the NileDSS. In other words, the catchment parameters of the current NileDSS parameterization may account for the real-world wetland processes based on the auto-calibration performed by DHI to parameterize the NileDSS. For instance, the Nyabarongo wetland was simulated in HEC-RAS due to implausibilities with the observed wetland extent and water balance. The results from the modelling are significantly different to the currently implemented wetland parameterization (Chapter 4.10), where the wetland represents a significant flow buffer. This means that parameters may require re-calibration if the wetland parameters derived within this project are updated or included in the NileDSS. It is envisioned that those parameters will include catchment parameters:

- Storages (Umax, Lmax)
- Runoff parameters (CQOF, CKIF, CK1,2, CK2, TOF, TIF)
- Groundwater parameters (TG, CKBF, Carea, Sy, GWLBF0, GWLBF1)

Next steps within the workpackage include the link between wetland extent and wetland units (papyrus, reed, grass) to hydrological flows as well as the detailed implementation of the Sudd hydraulic model.

7 Annexes

7.1 Mean Climate Data

Table 12 to Table 16 show mean climate data for wetlands obtained from IWMI climate Atlas[4]:

Table 12. Baro at Gambela (Lat 8 º 14 ' 0 " N Long 34 º 35 ' 0 " E)

Month	P50 (Mm/month)	Temp (deg. C)	(DTR) (deg. C)	Ref Humid (%)	Sunshine (% of Hrs)	Wind Run (m/s)	Penman Eto (mm/day)
Jan	2.55	26.6	15.6	36	82	3.3	7.2
Feb	6.37	27.8	15.5	33	81	3.1	7.6
Mar	25.96	29.1	14.7	37	72	3	7.6
Apr	57.45	28.9	13.5	47	68	2.8	6.8
May	139	27.6	11.8	60	63	3	5.9
Jun	147.62	26.2	10.4	66	54	3	5.0
Jul	212.79	25.3	9.1	73	47	2.9	4.3
Aug	211.49	25.4	9.3	74	52	2.6	4.4
Sep	147.56	25.9	10.4	71	59	2.6	4.8
Oct	100.73	26.6	11.9	68	66	2.4	5.0
Nov	41.24	26.3	13.5	52	77	2.4	5.6
Dec	7.51	26.1	15	42	83	2.9	6.4

Table 13. Sudd wetlands (Lat 8 º 32 ' 0 " N Long 30 º 13 ' 0 " E)

Month	P50 (Mm/month)	Temp (deg. C)	(DTR) (deg. C)	Ref Humid (%)	Sunshine (% of Hrs)	Wind Run (m/s)	Penman Eto (mm/day)
Jan	0	27.3	16.7	30	79	3.1	7.5
Feb	0	29.1	16.8	26	80	2.9	8.1
Mar	1.32	31.2	15.4	32	66	2.7	7.8
Apr	22.69	31.2	14.1	44	64	2.4	6.9
May	81.93	29.8	12.3	60	61	2.4	5.8
Jun	112.77	27.8	11.1	69	52	2.4	4.8
Jul	143.01	26.7	9.9	76	45	2.1	4.1
Aug	162.42	26.6	10	78	48	2	4.2
Sep	127.48	27.2	10.9	76	52	2	4.4
Oct	68.01	28	12.5	69	62	2	4.9
Nov	0.74	27.9	15.1	49	76	2.2	5.8
Dec	0	27.2	16.6	36	83	2.8	6.8

Table 14. Bahir Dar (Lat 11 º 35 ' 0 " N Long 37 º 23 ' 0 " E)

Month	P50 (Mm/month)	Temp (deg. C)	(DTR) (deg. C)	Ref Humid (%)	Sunshine (% of Hrs)	Wind Run (m/s)	Penman Eto (mm/day)
Jan	0.82	17.3	19.3	43	84	3.3	5.3
Feb	0.22	18.8	19	39	82	3.3	5.9
Mar	4.31	21.1	17.6	39	75	3.2	6.4
Apr	16.68	21.7	16.8	43	71	3.2	6.3
May	69.46	21.7	14.7	53	65	3.3	5.7
Jun	168.82	20.4	12.5	59	58	3.4	5.0
Jul	431.43	19	10.4	71	47	3.5	4.0
Aug	377.95	19	10.6	75	49	3.2	3.8
Sep	193.75	19.1	12.5	68	60	2.9	4.3
Oct	77.33	19.5	14.2	64	70	2.9	4.5
Nov	11.37	18.6	16.3	53	79	2.8	4.7
Dec	0.58	17.2	18.6	48	84	3	4.7

Table 15. Lake Albert (Lat 1 º 54 ' 0 " N Long 30 º 36 ' 0 " E)

Month	P50 (Mm/month)	Temp (deg. C)	(DTR) (deg. C)	Ref Humid (%)	Sunshine (% of Hrs)	Wind Run (m/s)	Penman Eto (mm/day)
Jan	28.49	17.6	13	64	52	2	3.8
Feb	49.12	17.8	12.9	63	54	2	4.0
Mar	110.38	17.8	12	67	41	2.1	3.7
Apr	162.37	17.5	10.5	74	42	2.2	3.4
May	126.2	17.2	10	78	43	2.1	3.1
Jun	88.62	16.6	10.2	78	51	1.9	3.1
Jul	92.57	16.2	10.1	78	43	1.8	2.9
Aug	162.94	16.2	10.1	78	42	1.9	3.1
Sep	181.79	16.4	11	77	50	1.9	3.4
Oct	194.76	16.8	11	76	48	2	3.4
Nov	150.29	16.9	11.2	75	49	2	3.3
Dec	38.45	17	12.1	69	54	1.9	3.5

Table 16. Machar Marshes, South Sudan (Lat 9 º 30 ' 0 " N Long 33 º 10 ' 0 " E)

Month	P50 (Mm/month)	Temp (deg. C)	(DTR) (deg. C)	Ref Humid (%)	Sunshine (% of Hrs)	Wind Run (m/s)	Penman Eto (mm/day)
Jan	0	26.9	16.2	33	82	3.5	7.6
Feb	0.01	28.4	16.7	28	81	3.2	8.2
Mar	1.77	30.5	15.7	31	72	2.9	8.1
Apr	22.57	31	14.6	39	71	2.7	7.6
May	83.32	29.6	12.3	56	61	2.9	6.3
Jun	113.39	27.6	10.7	66	48	2.9	5.1
Jul	160.42	26.3	9.3	75	42	2.7	4.2
Aug	178.65	26.3	9.2	77	47	2.3	4.2
Sep	132.34	26.8	10.3	75	53	2.3	4.5
Oct	84.25	27.8	12.1	69	64	2.2	4.9
Nov	7.03	27.6	14.7	48	79	2.3	5.9
Dec	0.01	26.8	15.9	37	83	3.2	7.0

7.2 Hydraulic model inflow scenarios

Table 17. Upstream Boundary Condition Inflows for the hydraulic model (m^3/s)

Scenario	Mara	Sio, Nzoia and Yala			Dinder	Machar					Nyabarongo	
		Sio	Nzoia	Yala		Baro 1	Baro 2	Eastern torrents 1	Eastern torrents 2	Eastern torrents 3	North	South
1	1000	200	1900	850	3000	750	375	200	200	200	600	600
2	800	160	1520	680	2500	600	300	150	150	150	300	300
3	600	120	1140	510	2000	480	240	100	100	100	200	200
4	400	80	760	340	1500	384	192	70	70	70	100	100
5	200	40	380	170	1000	300	150	30	30	30	50	50
6	100	20	190	85	500	240	120	10	10	10		

7.3 Development of flow over time in the simulated wetland hydraulics

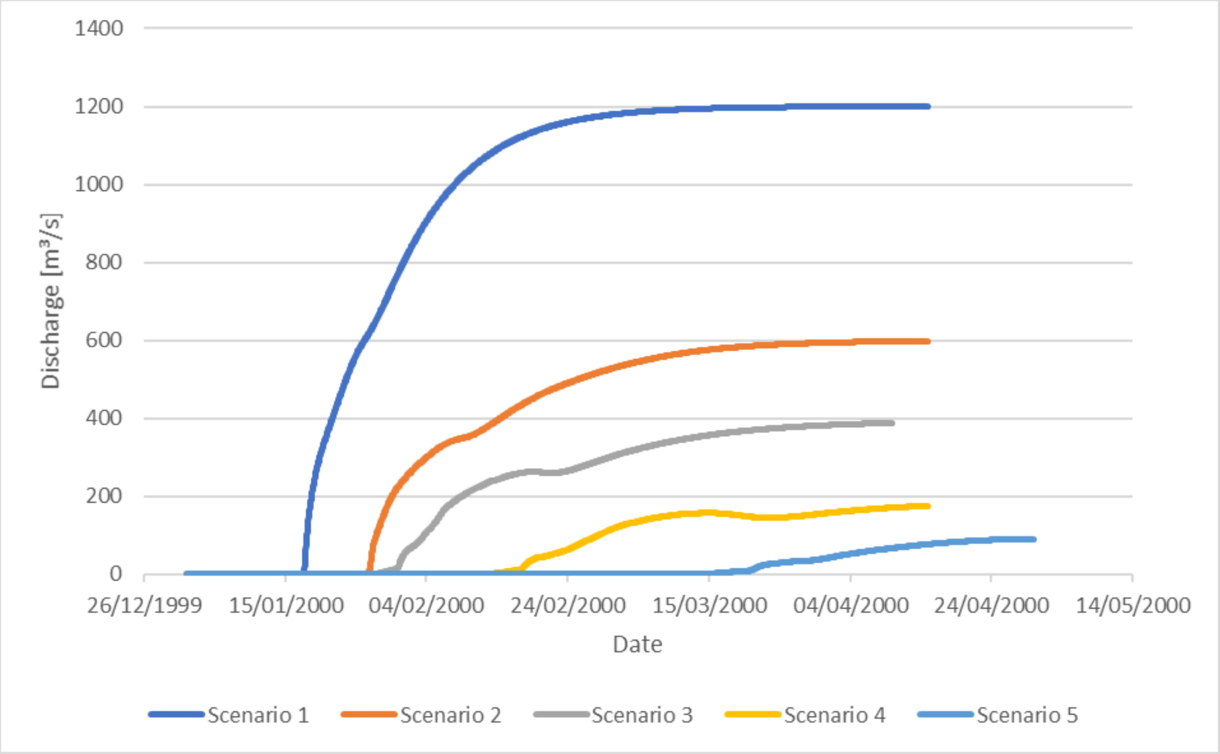


Figure 13. Development of flow (m^3/s) over time at the outlet profile of the Nyabarongo wetland

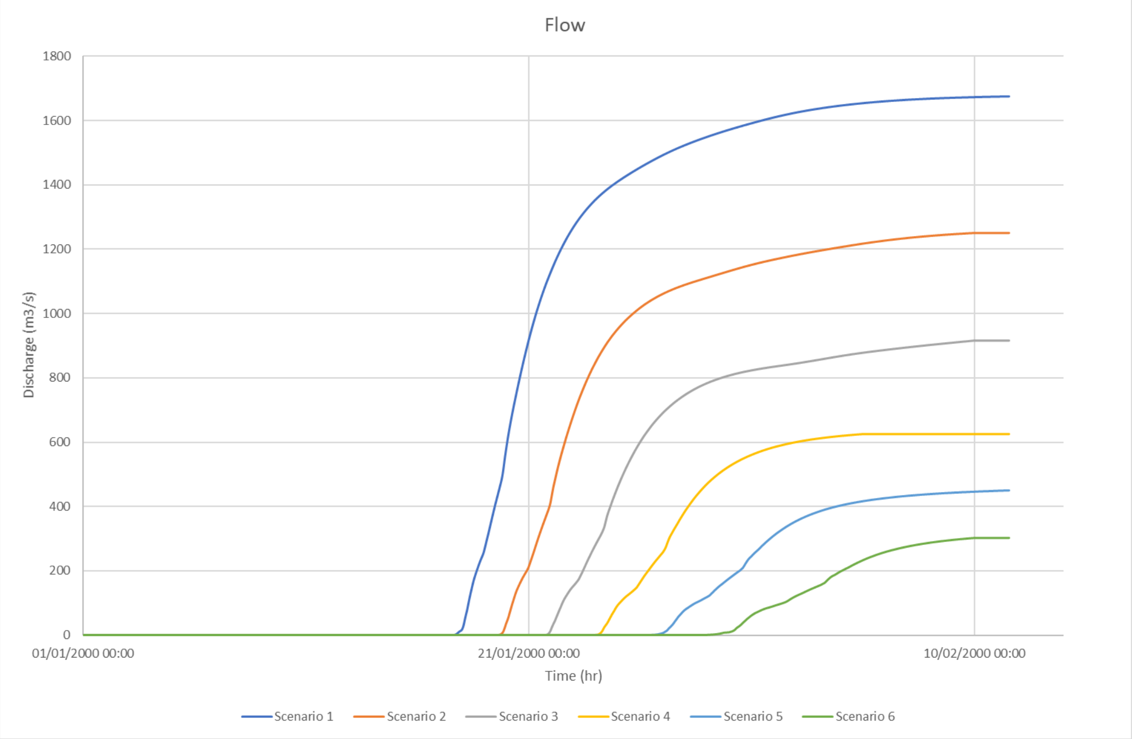


Figure 14. Development of flow (m^3/s) over time at the outlet profile of the Machar Marshes

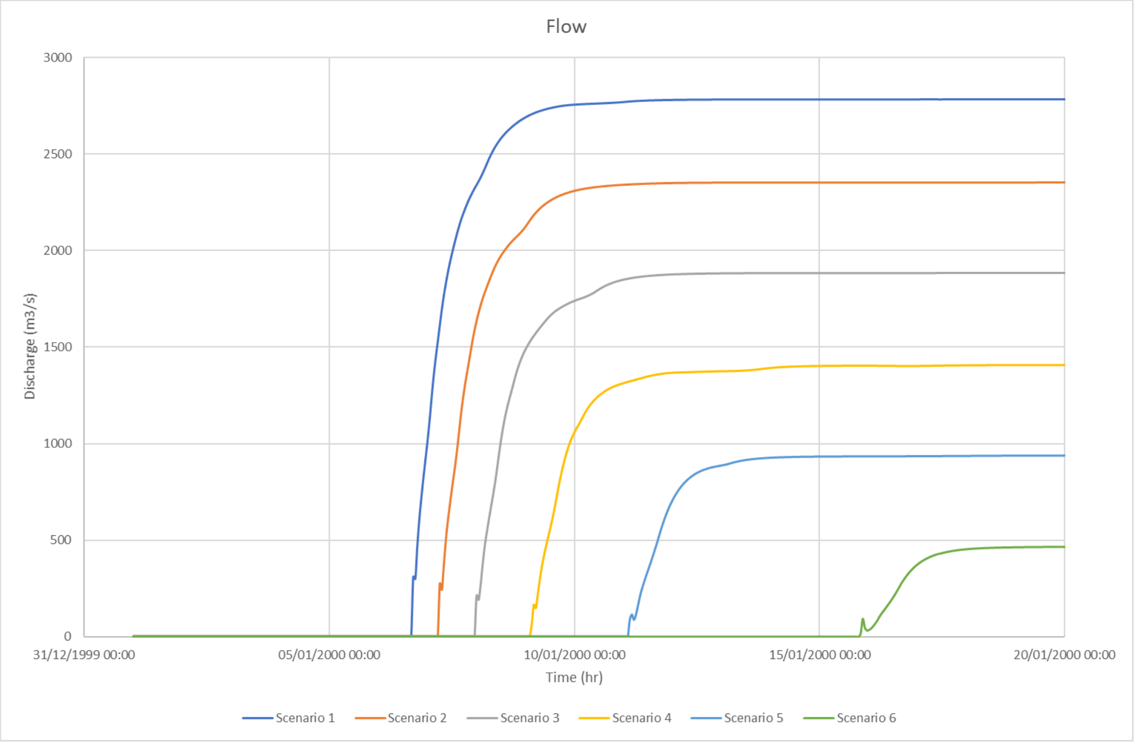


Figure 15. Development of flow (m^3/s) over time at the outlet profile of the Dinder wetland

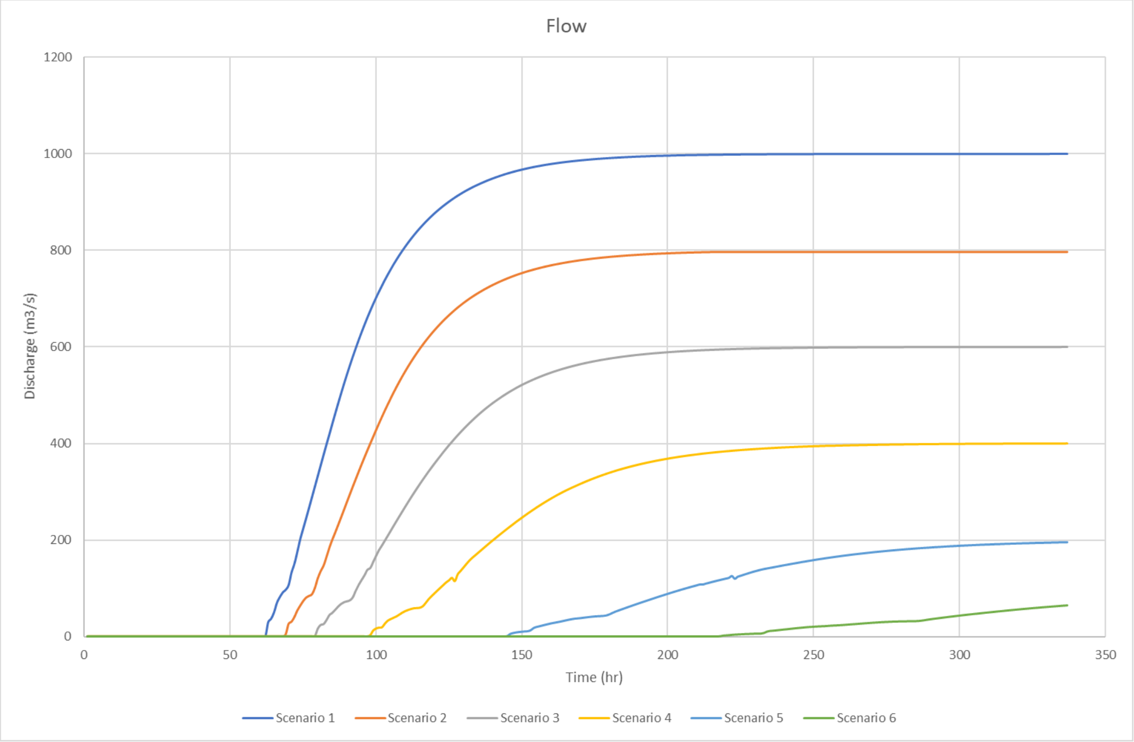


Figure 16. Development of flow (m^3/s) over time at the outlet profile of the Mara wetland

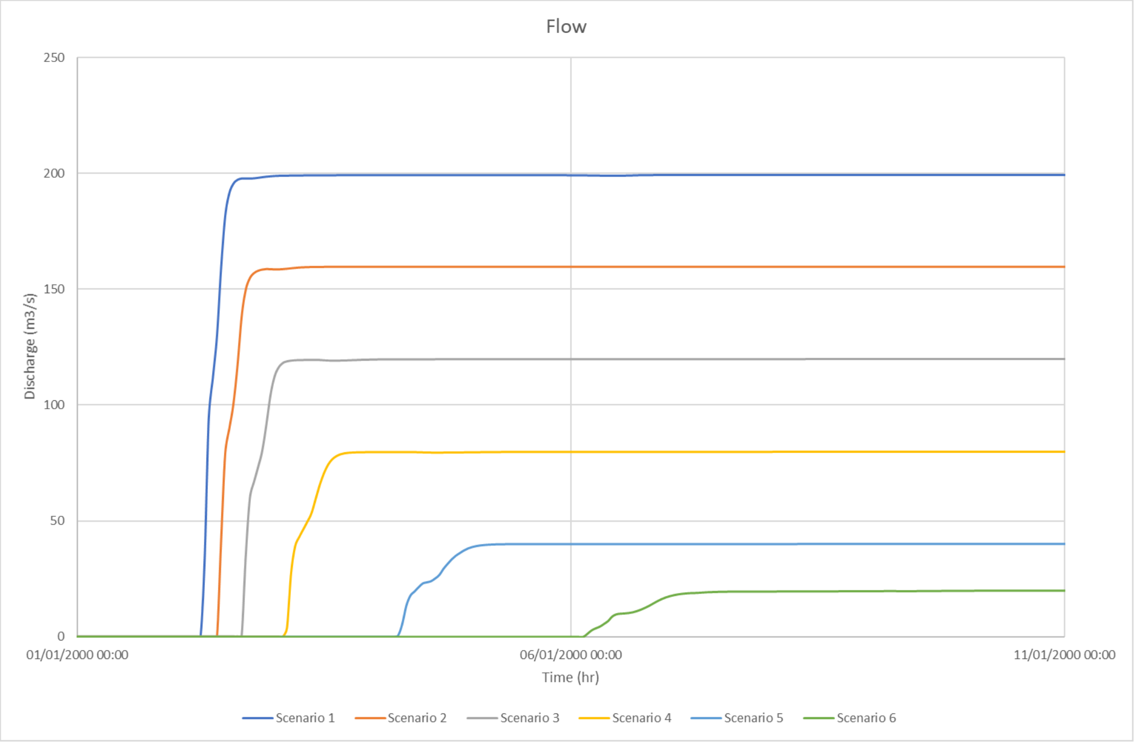


Figure 17. Development of flow (m^3/s) over time at the outlet profile of the Sio wetland

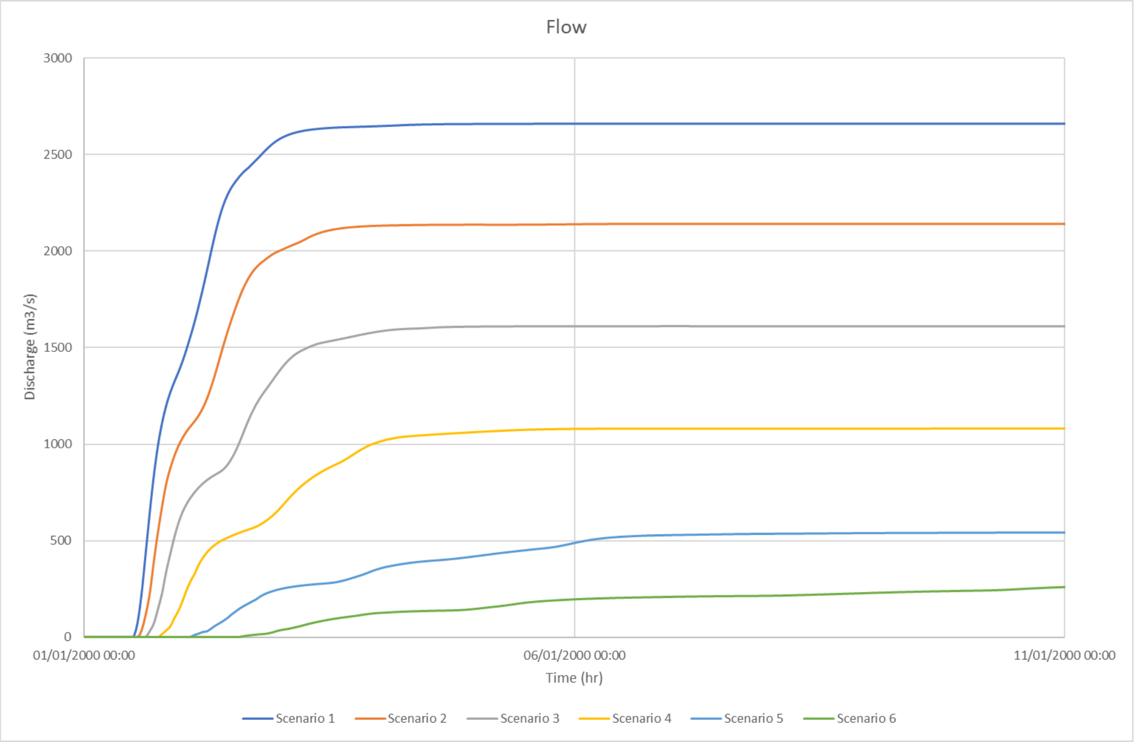


Figure 18. Development of flow (m^3/s) over time at the outlet profile of the Nzoia, Yala, Nyando wetland

7.4 Manning's n sensitivity tests

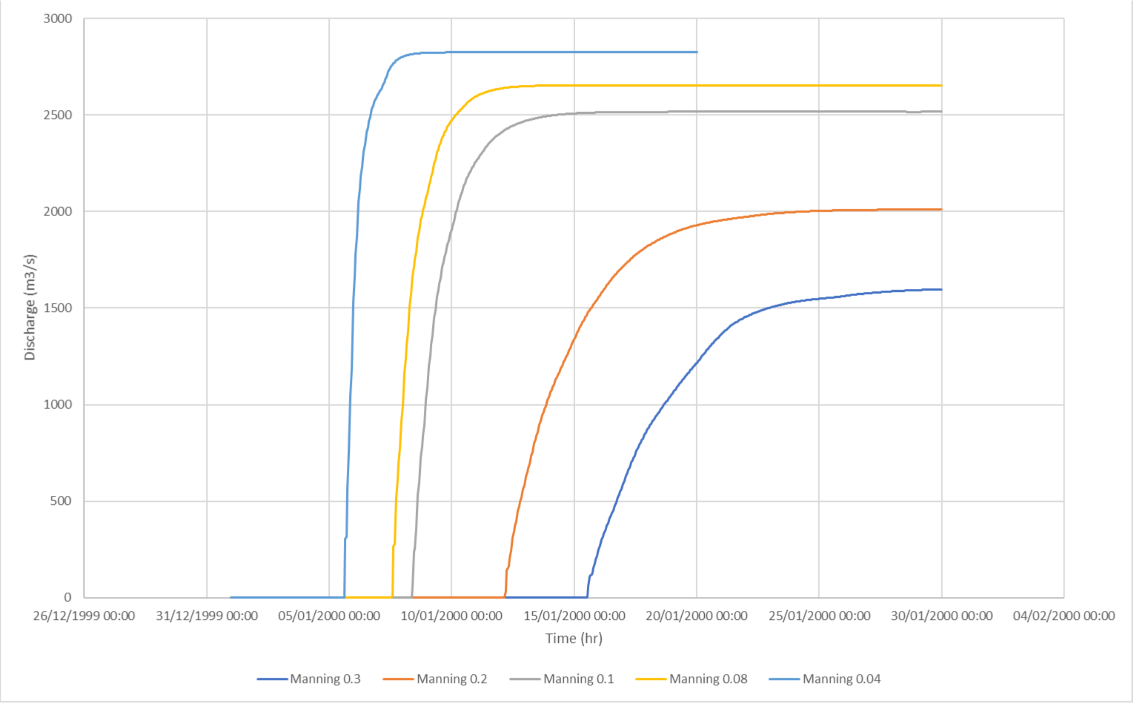


Figure 19. Development of flow (m^3/s) over time at the outlet profile of the Dinder wetland for the range of Manning's n values (please note that for Manning's n values higher 0.1 significant flows are diverted and do not leave the model domain via the outflow profile)

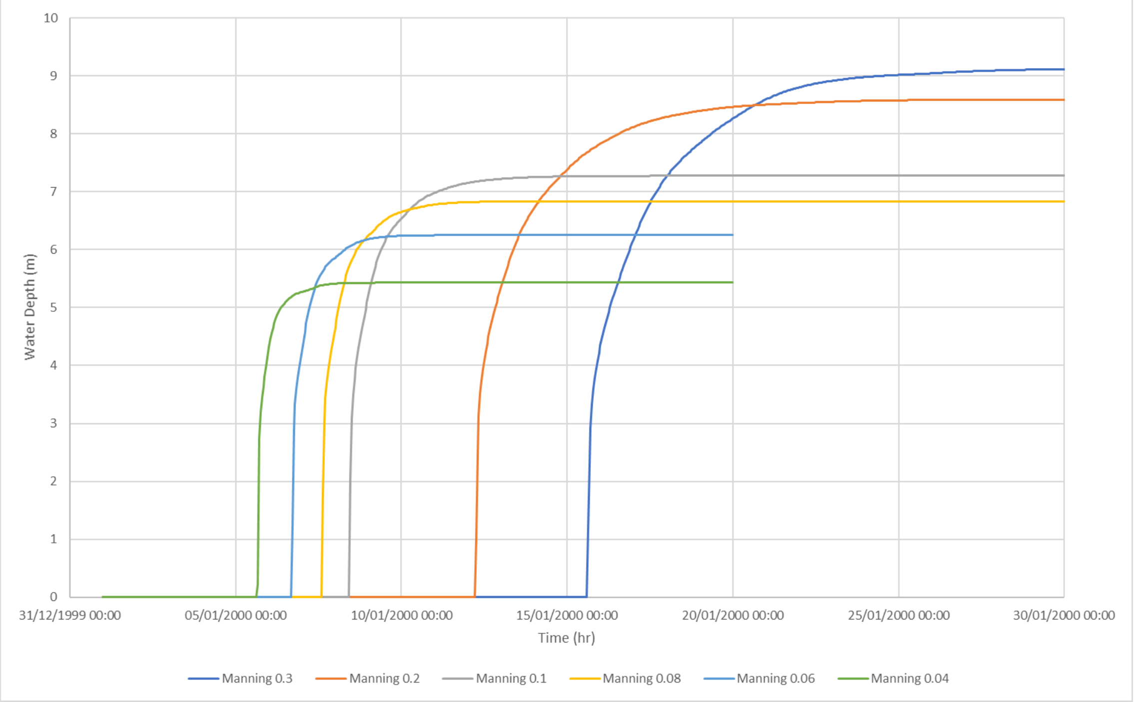


Figure 20. Development of water depth (m) over time at the outlet profile of the Dinder wetland for the range of Manning's n values

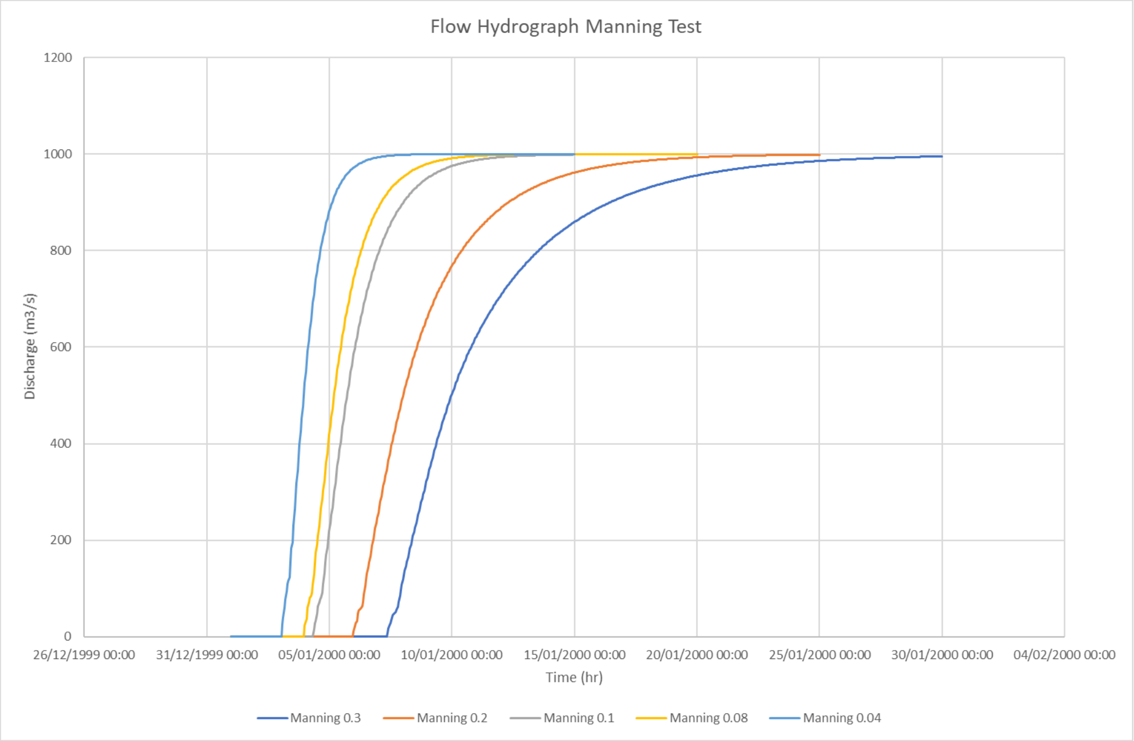


Figure 21. Development of water depth (m) over time at the outlet profile of the Mara wetland for the range of Manning's n values

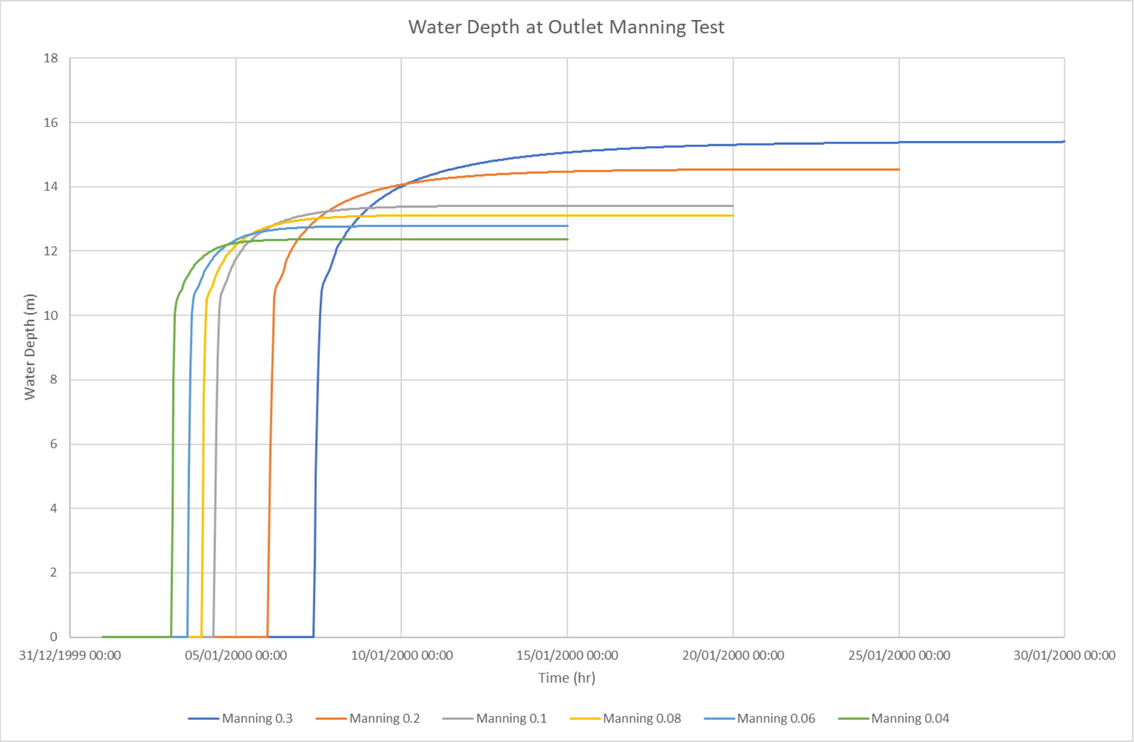


Figure 22. Development of water depth (m) over time at the outlet profile of the Mara wetland for the range of Manning's n values

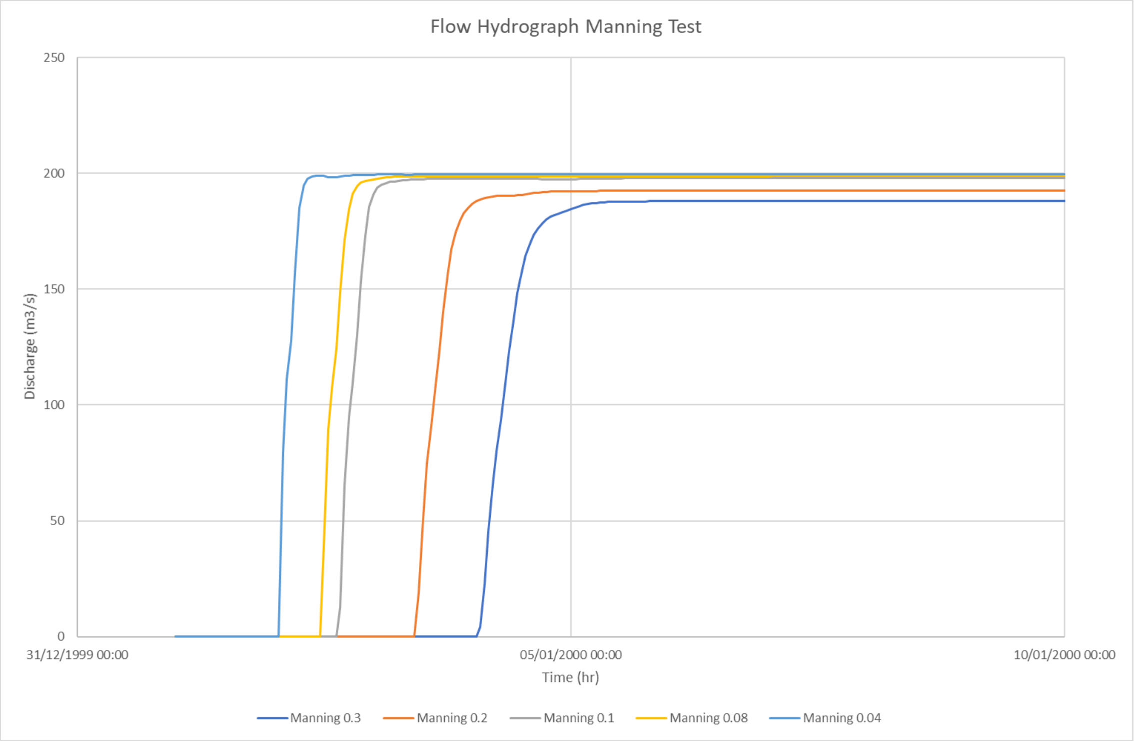


Figure 23. Development of flow (m^3/s) over time at the outlet profile of the Sio wetland for the range of Manning’s n values

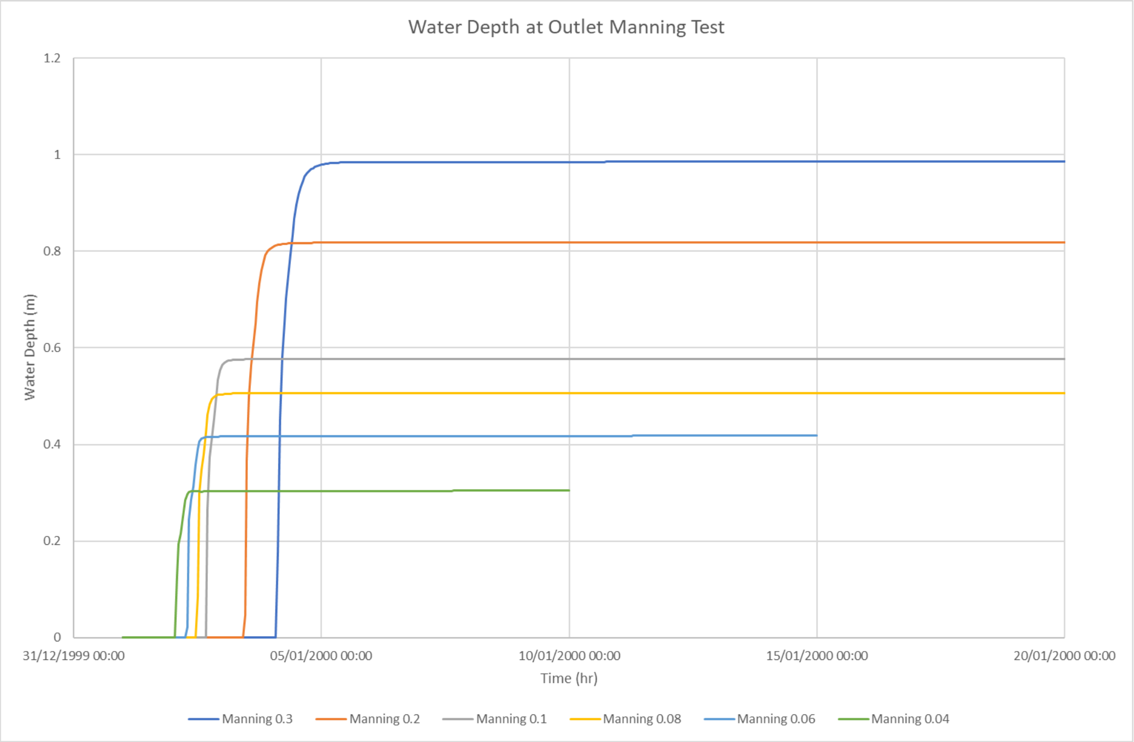


Figure 24. Development of water depth (m) over time at the outlet profile of the Sio wetland for the range of Manning’s n values

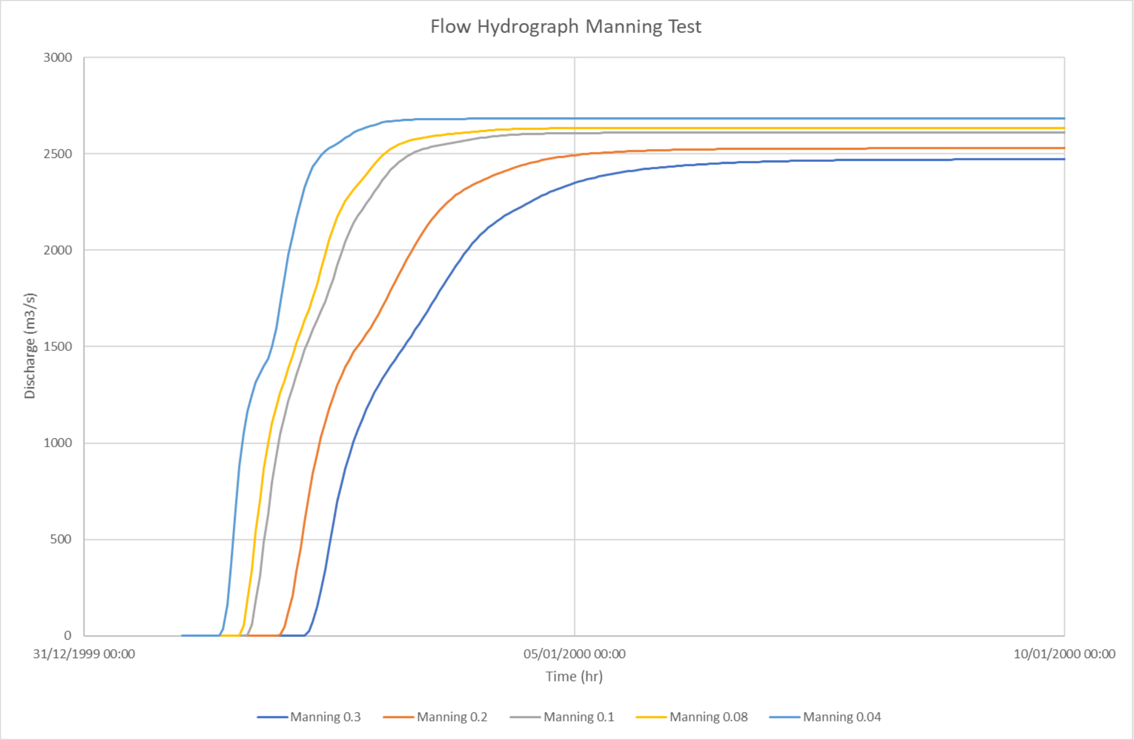


Figure 25. Development of flow (m^3/s) over time at the outlet profile of the Nzoia-Yala-Nyando wetland for the range of Manning's n values

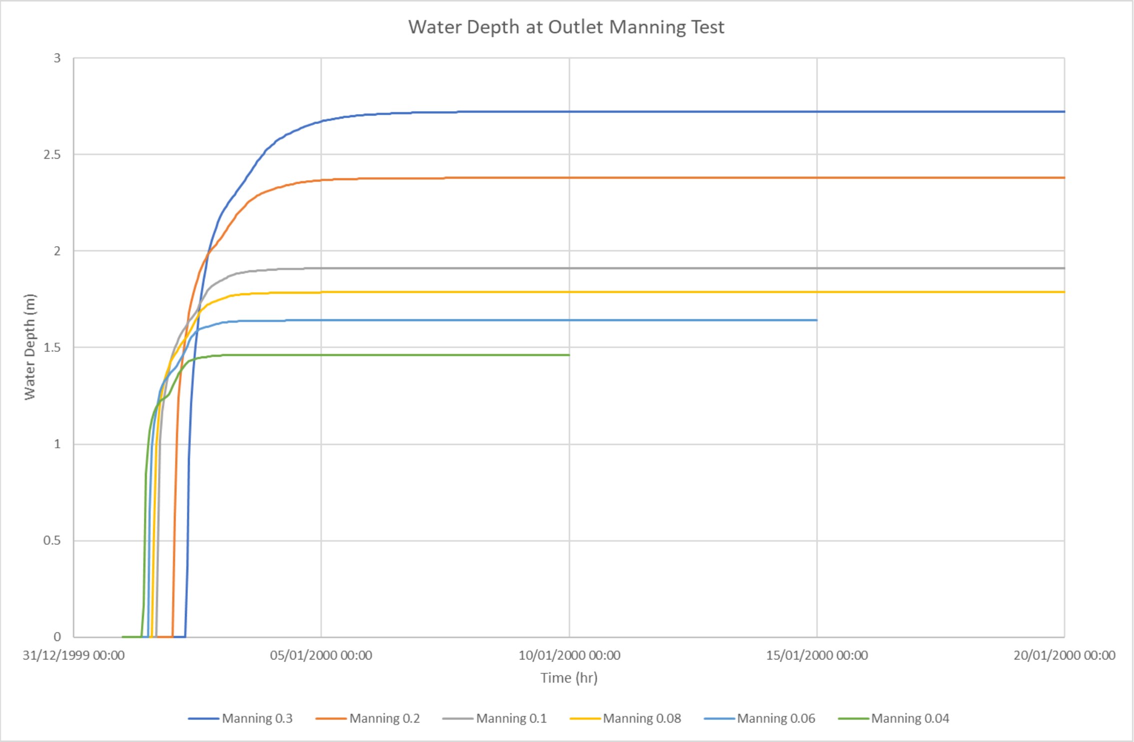


Figure 26. Development of water depth (m) over time at the outlet profile of the Nzoia-Yala-Nyando wetland for the range of Manning's n values

ONE RIVER ONE PEOPLE ONE VISION

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