Assessment of reservoir response to flood conditions to optimize hydropower operations – Isimba HPP Uganda

Évaluation de la réponse des réservoirs aux conditions d'inondation pour optimiser les opérations hydroélectriques - Isimba HPP Ouganda

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Abstract. Lake Victoria is the largest tropical lake in the world and the source of river Nile, the longest river in the world. Due to prolonged precipitation above the average over the past two years, the lake water levels have increased surpassing the highest ever recorded of 13.41m in 1964. To mitigate the negative impacts on the people, navigation and developments in the flood zones, lake outflows were gradually increased from 1000cumecs to 2400cumecs. Isimba Hydropower Plant (HPP) with a reservoir capacity of 170 million cubic meters is the fourth hydropower plant along the upper Nile cascade with a design flood level of 1055m above sea level. Reservoir operation is constrained by the bridge construction and ferry operation works downstream which are affected by the increased discharges. There is also uncertainty of the incoming discharge magnitude and travel time due to lack of an upstream gauging station. This paper seeks to assess the reservoir response to the increasing flood conditions using Hydrologic Engineering software for flood routing and to model an operation water level (OWL) that optimizes power production and flood control whilst ensuring public safety of the downstream activities through real-time forecasts in the short term.

Résumé. Le lac Victoria est le plus grand lac tropical du monde et la source du Nil, le plus long fleuve du monde. En raison des précipitations prolongées au-dessus de la moyenne au cours des deux dernières années, les niveaux d'eau du lac ont augmenté dépassant le plus haut jamais enregistré de 13,41

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m en 1946. Pour atténuer les impacts négatifs sur les populations, la navigation et les développements dans les zones inondables, les débits des lacs ont été progressivement augmenté de 1000cumecs à 2400cumecs. La centrale hydroélectrique d'Isimba avec une capacité de réservoir de 170 millions de mètres cubes est la quatrième centrale hydroélectrique le long de la cascade supérieure du Nil avec un niveau d'inondation de conception de 1055 m au-dessus du niveau de la mer. L'exploitation du réservoir est limitée par la construction du pont et les travaux d'exploitation des bacs en aval qui sont affectés par l'augmentation des rejets. Il existe également une incertitude quant à l'amplitude des rejets entrants et au temps de parcours en raison de l'absence d'une station de jaugeage en amont. Cet article cherche à évaluer la réponse du réservoir aux conditions de crues croissantes à l'aide d'un logiciel d'ingénierie hydrologique pour le routage des crues et à un niveau d'eau modal (OWL) qui optimise la production d'énergie et le contrôle des crues tout en assurant la sécurité publique des activités en aval grâce à des prévisions en temps réel dans le court terme.

1 Introduction

1.1 Background

As the largest lake in Africa and also the second largest freshwater lake in the world, Lake Victoria has a surface area of 68,800km2 and serves as the major reservoir of River Nile. The prolonged intensive precipitation received in the Lake Victoria basin over the past two years has led to an increase in the lake water levels which have surpassed the highest ever recorded of 13.41m in 1964. This came as a result of climate change and also the human settlement activities along the flood plains of the lake banks. To mitigate the negative impacts on the people, navigation and other economic developments in these flood zones, the permitted lake outflows were gradually increased form 1000cumecs to 2400cumecs in order to reduce on the lake water level. The Victoria Nile (south section of River Nile) is the main outfall of the lake and owing to regulation of lakes, its annual discharge is around 854m3/s which is controlled through a hydropower plant complex built at the outfall section. Isimba (HPP) is the fourth Dam on the Victoria Nile cascade (see Figure 1) whose inflows are mainly from the discharges of the upstream dams and no major tributaries along the river reach.

Figure 1 Showing the layout of Isimba Hydropower plant

A flood is a temporary rise in water surface elevation resulting in inundation of areas not normally covered by water. The gradual increase of permitted discharges increases the risk of overtopping which is the most common cause of Dam failures in the world and therefore the operation of the reservoir is further strained in order to safely accommodate the incoming flood.

1.2 Study Area

1.2.1 Location

Isimba HPP is a runoff river station located on the White Nile approximately 50km downstream of Lake Victoria in Southern Uganda. The plant was commissioned on 21st March 2019 and is currently operated by Uganda Electricity Generation Company Limited (UEGCL) under the defects liability period. The plant undertakes part of the function of peak-regulation of the power grid. It is equipped with four vertical Kaplan turbine – generator units with a unit capacity of 45.8MW, thereby giving a total installed capacity of 183.2MW. This study is limited to the assessment of response of the Isimba reservoir to flood conditions as a single reservoir system whose inflows mainly come from the upstream Bujagali Hydropower Plant (BHPP) outflows see figure 2

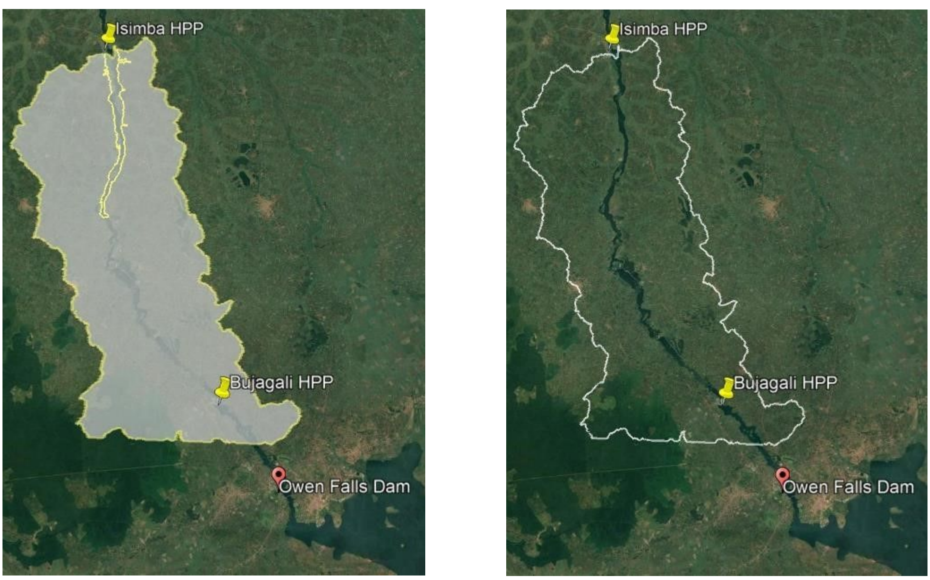


Figure 2 Showing the location of the Isimba Hydropower plant reservoir along the Upper Victoria Nile cascade (Google Earth)

1.2.2 Description of Structures

The main civil structures of the plant include; The Left and Right earth-rock fill embankment dams with a total length of 1424m and maximum dam height of 26.5m, concrete gravity dams 1&2 with a length of 140m (including wing walls) and a maximum height of 26.5m, overflow ogee spillway (SP1 & SP2), powerhouse and a 132kV switchyard. The main powerhouse is laid in a riverbed and designed to accommodate four generating units and an erection bay. See Figure 1 for a project overview.

The computed design inflow discharge from hydraulics is 1344m3/s which translates into 336m3/s for a single generating unit. Isimba HEPP has a reservoir capacity of 170,680,000m3 and a rated head of 15.4m. The normal reservoir water level of the plant is 1054.5m.asl under which the reservoir capacity is 160,800,000m3. The probable maximum flood (PMF) water level and minimum operating water levels are 1055m.asl and 1052.5m.asl respectively. The spillway is designed for a 1,000year standard flood of 3500m/s and checked with a 10,000year flood of 4500m3/s. [1]

2 HEC ResSim reservoir model

Hydrologic Engineering Center's Reservoir System Simulation (HEC-ResSim) is a computer program comprised of a graphical user interface (GUI) and a computational program to simulate reservoir operations. HEC ResSim represents a system of reservoirs as network composed of four types of elements: junctions, routing reaches, diversion, and reservoirs [2]. Junctions represent stream confluences or points where external flows enter the system. Routing reaches represent the natural streams in the system, and the lag and attenuation of a reach is computed by one of a variety of hydrologic routing methods. A reservoir is composed of a pool and a dam

2.1 Watershed

A watershed is a collection of data associated with a particular reservoir or study [3]. In this study, the Isimba HPP watershed is modelled as a single reservoir system with its inflows coming straight from the upstream dam, BHPP see figure 3 below. Georeferenced shape files are imported into HEC ResSim for stream alignment and watershed setup. The elevation 1055 contour from the DEM is used for the reservoir demarcation since it corresponds to the highest reservoir storage level.

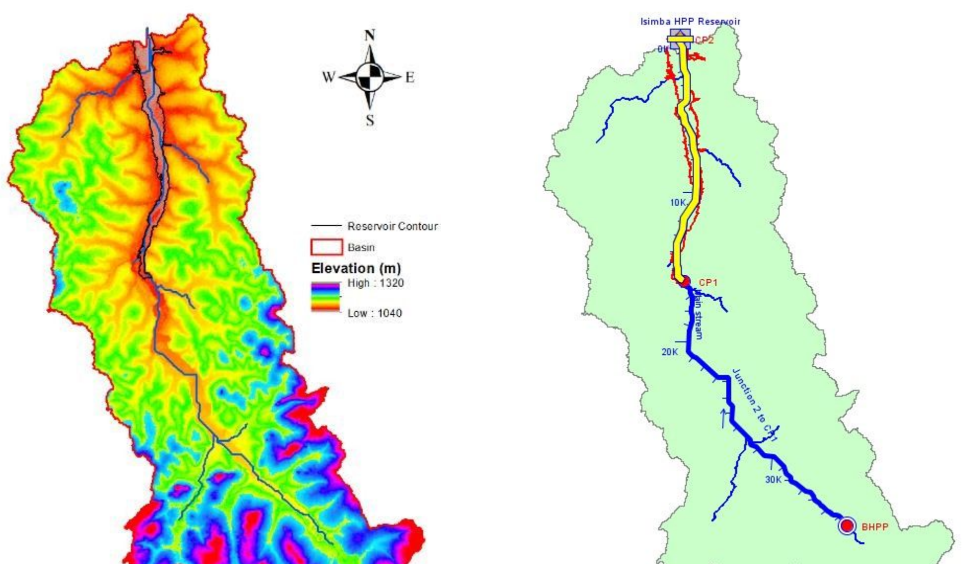


Figure 3 Showing the DEM of the watershed and HEC ResSim reservoir model setup

2.1.1 Reservoir Physical components

The Isimba HPP reservoir physical characteristics are defined in the Physical characteristics tab of the reservoir editor see figure 4. The tailwater curve is defined under the Dam in the reservoir tree in order to the computation of the downstream rule requirements in the operations tab. A group outlet is introduced to represent the spillway system of the Dam with controlled outlet SP2 being the surface radial gates (for reservoir stage regulation and flood control) whereas controlled outlet SP1 being the submerged radial gates (mainly used for sediment flushing and occasionally flood control when the inflows are excessively high.) A power plant is added and calibrated using the Isimba power generation design data and curves.

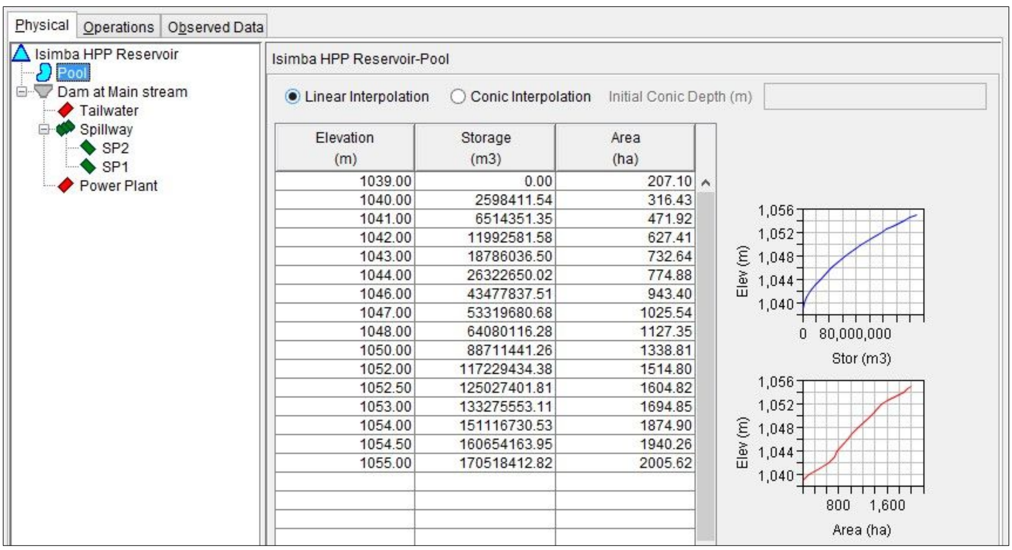


Figure 4 Showing a screenshot of the reservoir physical characteristics defined in the HEC ResSim model

3 Reservoir Operations

3.1 Isimba Reservoir System Operations

For the reservoir, the maximum flood level is 1055.00m.asl and the normal water level 1054.5m.asl, minimum reservoir level is 1052.50m.asl [3]. The reservoir operates to maximize the reservoir stage whist minimizing the tailwater level in order to have a high net head which would therefore translate into higher power generation. The operation water level ranges from 1052.5 to 1055.0m and the power generation regulation storage is 35.63x106 m3, the installed capacity is 183.2MW, and the rated head is 15.10m. The project is located in the river reach with less sediment.

3.1.1 Normal Operation

The reservoir operates using a daily operation mode with water level ranging from 1052.50m.asl to 1054.5m.asl. The power generation is as required by the national power grid system. According to the water supply requirement of power generation operation, it can undertake partial peaking task. During wet season it will conduct base-load operation.

3.1.2 Flood Season

The reservoir operates in compliance with the flood dispatching requirement to ensure the safety of the reservoir during flood season [1]. The flood release system is open to ensure flood release. When the quantity of the flood inflow is less than the flood discharge capacity, the reservoir will control the discharge to maintain the reservoir level lower than 1055.00m.asl and when the quantity of inflow is larger than flood discharge capacity, it will discharge at full capacity. Timely alarm will be given to Isimba according to the discharge from Bujagali HPP at the upper reach to ensure safe flood release. Figure 5 shows the observed reservoir discharges during the high flow period.

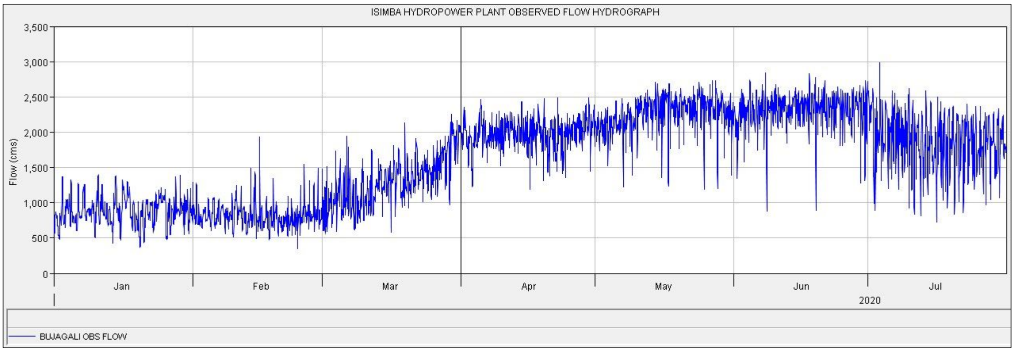


Figure 5 Showing the observed reservoir discharges as plotted in HEC-DSSVue

Dams built for hydropower production have a potential for conflict with flood control since hydropower developments aim to keep water level as high as possible during the period to ensure greater hydropower generation with a consequently smaller empty volume. Under these circumstances, the dam may worsen flooding conditions both upstream and downstream form the dam. The Dam was designed for a 1,000year standard flood of 3500m/s and checked with a 10,000year flood of 4500m3/s [2]. Figure 6 shows the gradual increase of the permitted cascade discharges with a discharge of 2000cumecs at the start of April which then rises to 2200cumecs (equivalent to the Isimba 20-year flood) and then finally to 2400cumecs from May through to June. This thereafter drops back to 2000cumecs in August. The outflows from Bujagali Hydropower plant serve as inflows into the Isimba HPP reservoir due to lack of major tributaries or river diversion along the river reach.

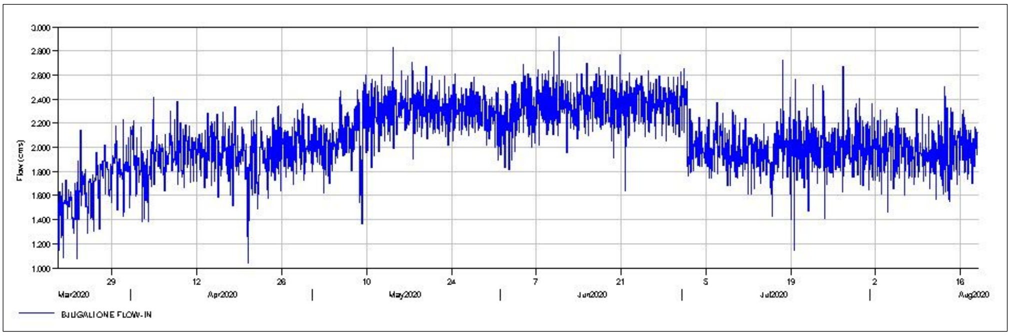


Figure 6 Showing the Bujagali outflow hydrograph as plotted using HEC-DSSVue.

3.1.3 Downstream constraints

Isimba Hydropower plant is required to maintain an environmental flow of 400cumecs throughout the year for the downstream users and also the aquatic environment [2]. The reservoir operations are further constrained by the ferry operation works downstream which require the tailwater elevation to be greater than 1038.7m.asl at all times (downstream minimum stage rule) in order to allow for ferry docking. During the 4 months' period of the high flows, bridge construction works were also being undertaken downstream of the Dam and a maximum tailwater level of 1040.5 was required during the off work hours (Downstream maximum stage rule) and a tail water level of 1039.5 during the working hours for safety of the workers. See figure 7 for a cross-section through the power plant showing the upstream and downstream design and flood water levels.

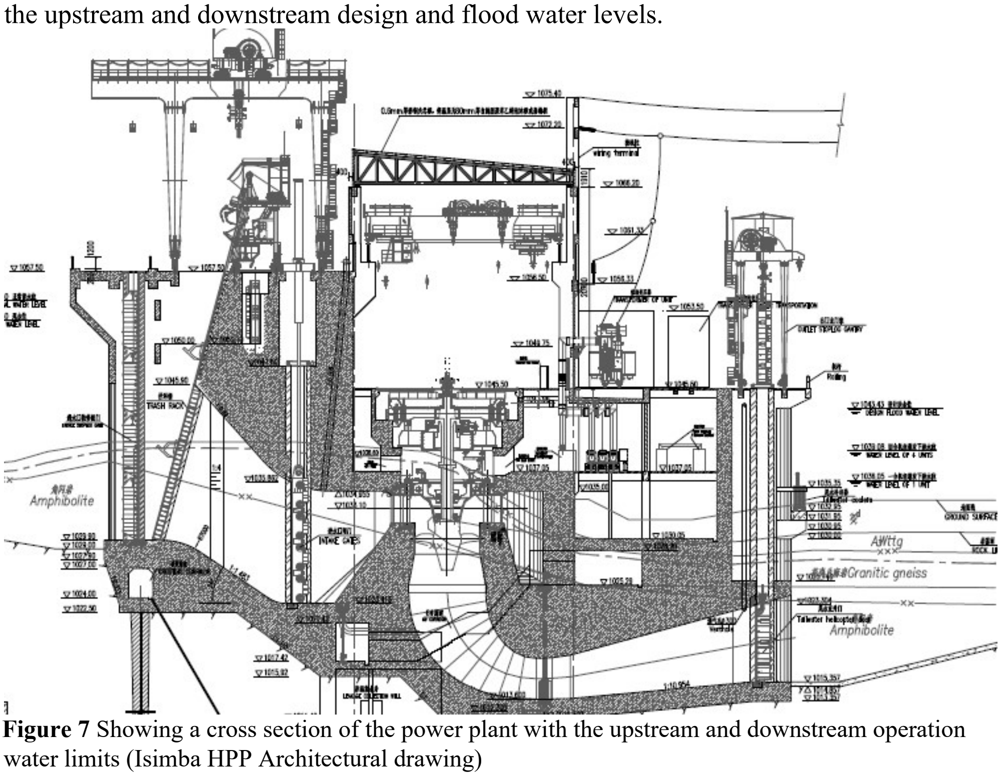


Figure 7 Showing a cross section of the power plant with the upstream and downstream operation water limits (Isimba HPP Architectural drawing)

3.2 Reservoir Operations Data

The regulation plan of the reservoir is described by varying the target pool elevation commonly called the guide curve. The storage of the reservoir above this target curve is referred to as the Flood control pool whereas the storage below this pool elevation is defined as the conservation pool.
The reservoir zones are defined with elevation 1055m.asl being the Q4500 (corresponding to the Probable Maximum Flood PMF of 10,000cumecs, elevation 1054.5 as the Flood control level, and elevation 1052.5 as the inactive zone [4]. See figure 8 below.
The rules are then applied to different zones in order to archive optimal operation of the reservoir during the high discharge period without compromising the power generation capability requirement of the hydropower plant.

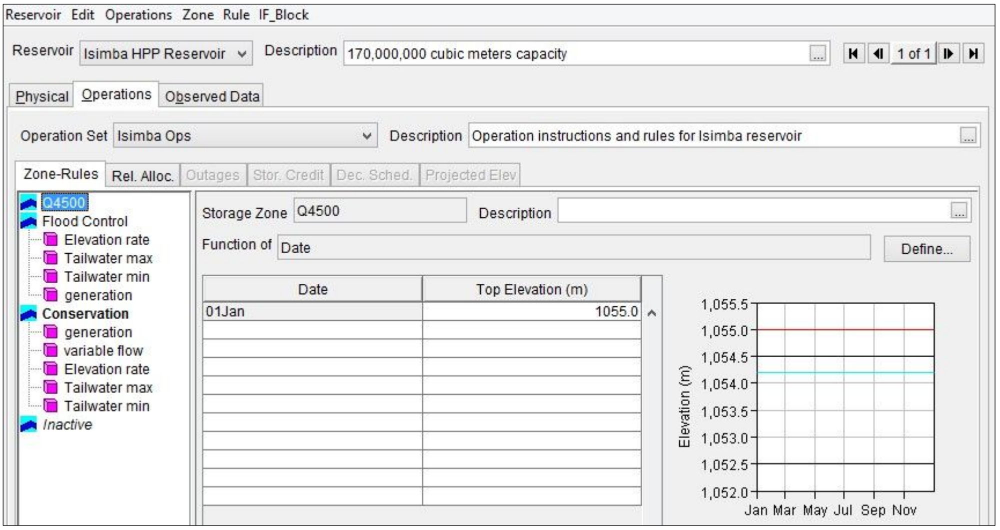


Figure 8 Showing the different zones used in defining the reservoir operations data

Release allocations are then assigned to the different components of the reservoir so that priority is given to the most critical areas depending on the defined situation. The power plant is ranked first since the ultimate goal is to maximize power production during the peak hours and thereafter any excess discharge is the spilled via the spillway which is modelled as a controlled flow. SP2 (surface radial gates) are also ranked above the lower radial gates (SP1) under the controlled group outlet with a sequential allocation type. This means that water will only be spilled through the lower radial gates only if the capacity of the upper radial gates is used up and if the condition is defined otherwise. See figure 9 below.

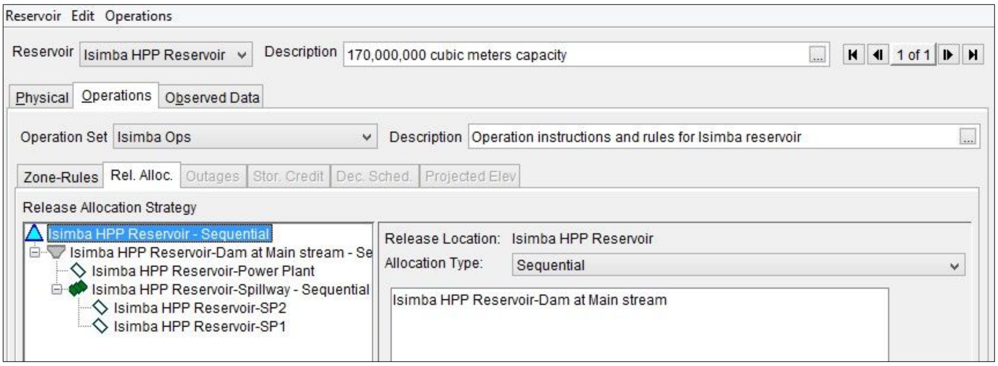


Figure 9 showing the release allocation of the reservoir components

3.2.1 Alternatives and simulation module

An alternative consists of a reservoir network, run control specifications, an operation set for each reservoir in the network, definition of the initial condition (lookback) and a mapping of all the time series record to identified inflows.

The time series data used for the alternative is developed in HEC-DSSVue which is then used to define the lookback, and observed data parameters in the alternatives editor. The data sets include elevation and flow data used the running the simulations. The data was also collected from the Dam SCADA system.

4 Simulation

Simulations were run for different alternatives so as to choose which operation water level (OWL) or guide curve best suits the predefined condition and constraints of the site. Considering the aforementioned downstream constraints, figure 10 shows the most suitable guide curve where the reservoir stage is maintained between El.1054.2 and El.1054.5. From the graph, there are many fluctuations in the head water level which are then attenuated to smoothen out the curve. This provides a high working net head by maximizing the reservoir head water level and thus leaving a buffer of 0.5meters for flood control. Figure 11 shows the corresponding power produced and the flow allocation between the power plant and the spillway as earlier defined in the release allocation of the reservoir components.

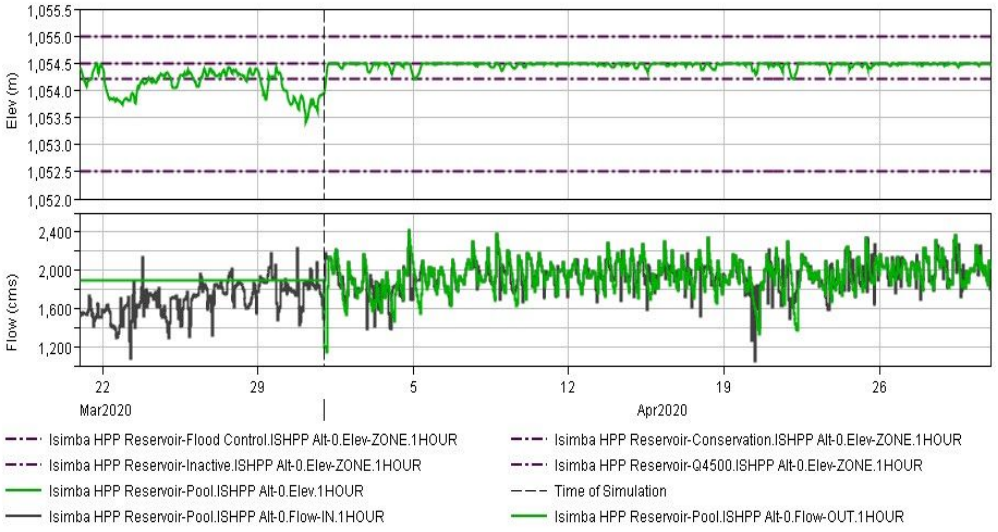


Figure 10 showing the most suitable desired Operation water level (OWL)

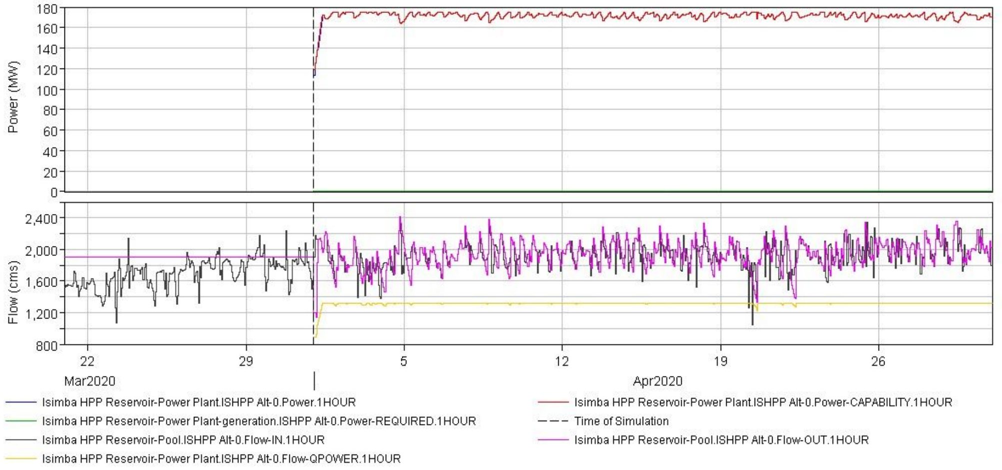
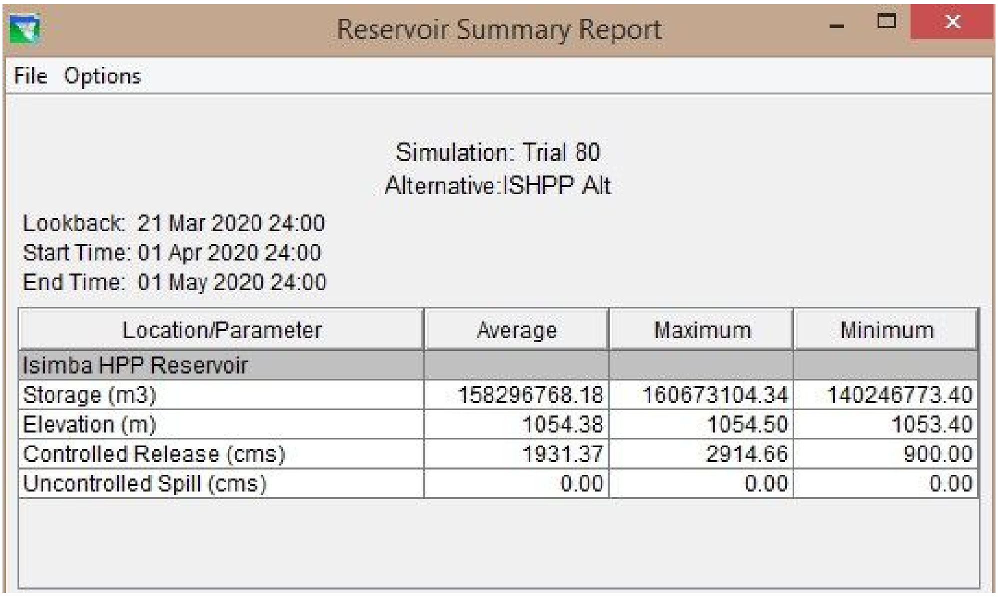


Figure 11 Showing the corresponding power produced and release allocations

See figure 12 for a summary of the simulate reservoir operations.



Location/Parameter	Average	Maximum	Minimum
Isimba HPP Reservoir			
Storage (m3)	158296768.18	160673104.34	140246773.40
Elevation (m)	1054.38	1054.50	1053.40
Controlled Release (cms)	1931.37	2914.66	900.00
Uncontrolled Spill (cms)	0.00	0.00	0.00

Figure 12 showing a summary report of the simulated reservoir operations

5 Summary and Conclusions

The main aim of this study is to model the Isimba HPP reservoir operations in order to assess its response to flood conditions. The study is undertaken to satisfactorily simulate reservoir operation for optimal water use for hydropower generation and flood control upstream and downstream. It contributes for solving the challenge of water management problem through improving reservoir operation system. Specifically intended to inform water resource managers and other stakeholders to make viable plans for sustainable operations. The operator must simultaneously meet water demands that rise from all stakeholders and other activities. Each of these demands imposes constraints on the storage and release of water from the reservoir and needs and constraints often conflict with one another. HEC ResSim was applied for Isimba HPP for hydropower production, flood control and downstream hazard mitigation and safety and integrity of the dam itself. Alternatives were configured for different scenarios to model the reservoir operations so that the best reservoir operation rule that optimizes water release was selected for modelling. The criterion for selection of the best reservoir operation is based on the simulation results of averages energy generation per daily time step considering its effect on the availability of water at the downstream flows. According to the simulation results obtained, the aforementioned guide curve best suits operation of the reservoir. This study has provided general operation strategies for reservoir releases according to the current reservoir level, hydrological conditions and the time of year and develops a unique guide curve (Operation water level) for the Isimba HPP reservoir operations. UEGCL should consider installation of a gauging station for more precise and accurate determination of the incoming discharges into the reservoir.

References

1. Feasibility study of Isimba Hydropower plant final report Isimba Hydropower Plant Operation and maintenance manual
2. USACE, Hydrologic Engineering Center (JDK & MBH), HEC-ResSim 3.1 User's Manual, Version 3.1, 2013
3. AF - consult, Dam safety management system for Isimba HPP and Karuma Hydro Power Projects - Operation and Maintenance manual - Isimba HPP, 2019.