Lessons learnt from dealing with climatic extreme events - A case of L. Victoria and the White Nile Cascade

Leçons tirées de la gestion des événements climatiques extrêmes - Le cas de L. Victoria et de la cascade du Nil Blanc

Wilberforce Manirakiza*[1], *Emmanuel* Tumwesigye[2], *Kevin* Otim[3], *Mary* Akurut[4], and *Harrison* E. Mutikanga[5]

[1]Dam Safety Engineer, Uganda Electricity Generation Co. Ltd (UEGCL), 75831 Kampala, Uganda
[2]Lecturer, Makerere University, 75831 Kampala, Uganda
[3]Civil/Structural Engineer, Eskom Uganda Ltd, 942 Jinja, Uganda
[4]Manager, Dam Safety & Water Resources, UEGCL, 75831 Kampala, Uganda
[5]Chief Executive Officer, UEGCL, 75831 Kampala, Uganda

Abstract. Lake Victoria storage and water levels are affected by changes in precipitation, evapotranspiration, tributary inflows and outflow in the single Nile River outlet at Owen Falls Dam. In May 1964, the lake reached its first highest recorded level of 13.46 m at the Jinja Pier that resulted into the Nile River outflow of 1910 m^3/s. Consequently, the decision to construct Owen falls extension later in year 2000 was motivated by the risk assessment to mitigate the potential of regional hydrology reverting to the 1960s conditions. However, the catchment has consistently had above-normal precipitation coupled with accelerating land use changes that have resulted into higher inflows from the lake tributaries. In May 2020, the lake level surpassed the 1964 record, peaking at 13.47 m towards the end of May. These two occurrences (1964 and 2020) greatly affected hydropower generation, disrupted socio-economic activities around the lake and along the river and posed a threat on the safety of Nile Cascade dams. This paper therefore, presents the integrated multi-sectoral framework that was adopted to assess and mitigate the risks involved. The paper also identifies challenges, opportunities, interventions and lessons learnt from such risks and uncertainties.

Résumé. Le stockage et les niveaux d'eau du lac Victoria sont perturbés par les variations de précipitation, d'évapotranspiration, des débits

* Corresponding author: irakizawilber@gmail.com

d'affluents et de sortie dans l'unique exutoire du Nil au barrage d'Owen Falls. En mai 1964, le lac a atteint son premier niveau le plus élevé enregistré à 13, 46m à la Jinja Pier, ce qui a entraîné un débit sortant du Nil de 1910 m^3/s. Par conséquent, la décision de construire l'extension des chutes Owen en 2000 a été motivée par l'évaluation des risques visant à atténuer le potentiel de retour de l'hydrologie régionale aux conditions des années 1960. Cependant, le bassin versant a toujours eu des précipitations supérieures à la normale couplées à des changements accélérés d'utilisation des terres qui ont entraîné des apports plus élevés en provenance des affluents du lac. En mai 2020, le niveau du lac a dépassé le record de 1964, culminant à 13, 47 m vers la fin de mai. Ces deux événements (1964 et 2020) ont grandement affecté la production hydroélectrique, perturbé les activités socio-économiques autour du lac et le long de la rivière, et ont constitué une menace pour la sécurité des barrages de la Cascade du Nil. Ce document présente donc le cadre multisectoriel intégré qui a été adopté pour évaluer et atténuer les risques encourus. Le document identifie également les défis et opportunités, les interventions effectuées et les leçons tirées de ces risques et incertitudes.

1 Introduction

Lake Victoria covers a surface area of about 68,800 km2 shared across three East African countries; Uganda (45%), Kenya (6%), and Tanzania (49%) and a total catchment area of about 258,000 km^2 (see Figure 1 & Figure 3). Lake Victoria has 17 tributaries with a regional basin consisting of five countries namely Uganda, Kenya, Tanzania, Rwanda and Burundi. The Lake offers several diverse uses to the people of East Africa including water supply, agriculture, navigation, fishing, recreation, hydropower generation, etc. The outflows of Lake Victoria, the third largest freshwater lake by area are controlled by Nalubaale and Kira dams (Owen Falls Complex) built across the River Nile. The Nile River has a segment commonly known as the White Nile, which has over the time been developed with a cascade of dams. There are currently five (5) dams among which include: Nalubaale, Kira, Bujagali, Isimba and Karuma Dams. The details on the background of development and salient features of the dams are discussed in sections 1.1 and 1.2 respectively.

1.1 Background

Before 1954, the lake was naturally regulated by the terrain of the natural rock weir known as "Rippon Falls", at the source of River Nile. After recommendation to the Colonial Government of Uganda in 1947, Owen Falls Dam (currently named as Nalubaale Power Station) was constructed and commissioned in 1954 by Queen Elizabeth II. Having been built just downstream of Rippon Falls, the dam submerged the Rippon falls and the natural rock weir lake control properties were found to interfere with power generation. This motivated the decision to blast and remove part of the rock thus transferring what was considered natural regulation of the lake to artificial control by the dam operators. Therefore, Nalubaale Dam was considered to retain and control the natural discharges of Lake Victoria through the River Nile. It is against this background a water discharge policy popularly known as the "Agreed Curve" was set with a primary objective of addressing the vulnerable concerns and interests of the downstream riparian countries. The Agreed Curve, which emulates the relationship between the Lake levels and the outflows, was provided for the Nile Basin countries in the colonial period after 1954 when the Owen falls dam was constructed. According to the authors of the policy, compliance to the Agreed Curve was to ensure that water releases through the power station and its sluice gates would neither unduly drain the waters of the lake nor cause the undue rise in the lake water levels that would result into flooding.

In spite of the conformity to the Agreed Curve by the Power Station operators, there was an unexpected 2.5m rise in the lake levels between 1961 and 1964 that led to a dramatic change in the hydrology of the White Nile. In May 1964, the lake reached its first highest level of 13.46m recorded at the Jinja Pier. In a bid to mitigate the rising water levels, the outflow through the dam was increased up to 1910 m^3/s, which caused a dramatic change in the hydrology of the White Nile from the normal flows. This flood situation and the increasing demand for electricity in Uganda, initiated a study to determine the feasibility of adding another power station adjacent to Owen Falls. The decision to construct Owen Falls Extension currently named as Kiira Power Station was informed by the risk assessment that was done to mitigate the potential of regional hydrology reverting to the pre-1960s condition [1].

Subsequently, the lake again exhibited another anomalous behaviour between 2001 and 2006 but this time the lake levels declined by about 1.1m below the 10-year average level of 1134.7 meters above sea level with reference to Mombasa Datum (MD). This occurred towards the end of 2006 and was attributed to the additional discharge from the second dam at Kiira and long periods drought due to climate change in the same period. Following this event and allegations made in different news articles and publications, the contribution of the non-compliance with the agreed curve to the declining lake levels was established and thereafter the efficacy of the agreed curve to actually uphold the hydrological health of the lake was examined [2]. A new equation that links percentage contributions of the River Nile outflow in the depletion of the lake waters to daily rate of net drop in the lake water level and the daily rate of water releases from the power plants was derived. Upon quantification, this equation confirmed that there was less contribution (15%) of depletion of the lake caused by the plant operations, and the anomalous behaviour was rather attributed to meteorological and hydrological factors.

About 65 years after the first highest level was recorded, the catchment consistently received above-normal precipitation coupled with accelerating land use changes that resulted into higher inflows from the lake tributaries. Towards the end of May 2020, the lake level surpassed the 1964 record peaking at 13.47 m. This led to severe flooding of the communities that had settled around the lake and sustained continuous discharge of up to 2400 m^3/s, for a period of 2 months at Nalubaale-Kiira dam in order to protect the aging dams, reduce lake levels and mitigate flooding upstream. These two occurrences (1964 and 2020) greatly affected hydropower generation, disrupted socio-economic activities around the lake and river Nile, and posed a higher potential threat on the safety of the Nile Cascade dams. This paper presents the integrated multi-sectoral framework that was adopted to assess and mitigate the risks involved, and identifies challenges, opportunities, interventions and lessons learnt from such risks and uncertainties.

1.2 Overview of The White Nile Cascade

The Nile cascade has five existing large dams as shown in Figure 1 with different and comparable features as summarized in Table 1. The detailed features of the dams are discussed in this section.

Table 1. Summary of salient features of the White Nile Cascade Dams.

Description	Unit	Parameters				
		Nalubaale PS	Kira PS	Bujagali HPP	Isimba HPP	Karuma HPP
Dam Type		Concrete	Composite	Composite	Composite	Concrete
PMF (10,000 yr)	m³/s	4,200		4,500	4,500	4,700
Spillway	m³/s	1,272	1,740	4,500	5,230	4,800
Plant Discharge	m³/s	1,150	1,120	1,375	1,375	1,224
Dam height	m	30.0	32.0	30.0	26.5	14.0
Dam crest level	m.a.s.l	1136.15	1137.00	1114.54	1057.50	1032.00
Max. flood level	m.a.s.l	1135.00	1135.00	1112.00	1055.00	1030.00
Length of Dam	m	726	380	850	1,599	314

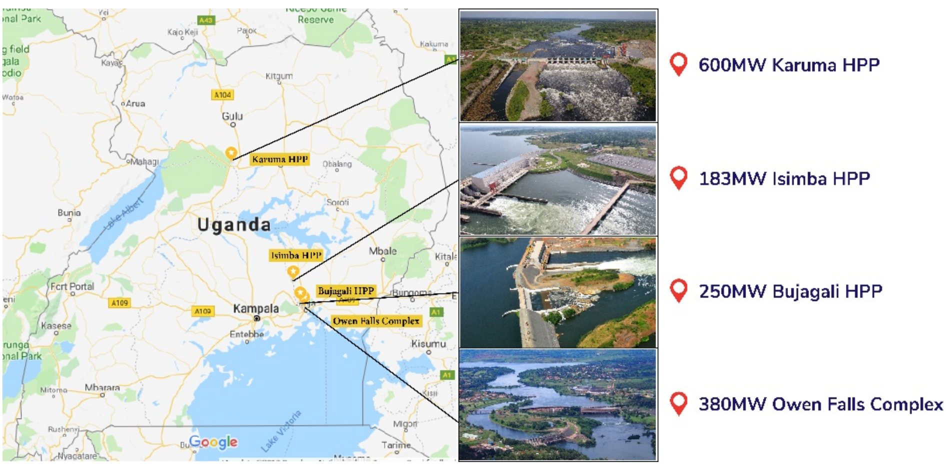


Fig. 1. Layout of the Cascade Power Plants.

1.2.1 Nalubaale Power Station (NPS)

Nalubaale Power Station formerly known as Owen Falls Dam has an installed capacity of 180MW with a 726m long concrete dam of height of 30m and a rated head of 20m. Nalubaale Dam has six low level sluices with a combined capacity of 1,272 m³/s and a combined plant discharge rating of 1,150m³/s. The dam is classified as a high hazard dam given the size of its reservoir which extends into the Lake Victoria. The power station has been affected by Alkali Silica Reaction (ASR), a chemical reaction which in the presence of water causes structural movements and detrimental effects to civil hydro infrastructure including reduction in gate clearances, concrete cracking, failure of support structures and turbine/generator alignment problems.

1.2.2 Kiira Power Station (KPS)

The Kiira Power Station is constructed on the east bank of the Owen Falls, approximately 800 m downstream from the Nalubaale power station. A canal leading from the reservoir of the Nalubaale power station with a length of approximately 1.6 km, 150 m width and 20 m depth was excavated into the left Nile riverbank to feed the power station. There exists a close-coupled intake and powerhouse structure installed with five vertical shaft fixed-blade propeller turbines, each with a rated capacity of 40 MW. The dam has a crest length of 380m and 3-gated spillways with a combined discharge capacity of 1740 m^3/s

For both Kira and Nalubaale, the warning Head Water Level is at EL 1134.5 and flood level is at EL 1135. Kira and Nalubaale have free boards of 2m and 1m respectively. Nalubaale and Kira are in parallel with a combined maximum probable flood (Design flood flow P=0.01%) of 4,200 m^3/s.

1.2.3 Bujagali Hydropower Plant (BHPP)

Bujagali HPP has installed capacity of 250MW with an 850m composite dam of maximum height of 30m and a rated head of 15m. Bujagali has two gated spillways, a flap gate and siphon spillway with a combined capacity of 4,500 m^3/s [3]. Bujagali HPP was commissioned in 2012 and is located 16km downstream of the Owen Falls Complex and approximately 25km upstream of Kalagala falls offset, that was devoted for environmental and social protection.

1.2.4 Isimba Hydropower Plant (IHPP)

Isimba HPP has an installed capacity of 183.2MW on a 1.6km long composite dam of maximum height of 26.5m and a rated head of 15m. Isimba has a combined maximum spillway capacity of 5,250m^3/s. Isimba Dam consist of 2 flap gates, 3 Submerged radial gates and 2 Surface radial gates (SP2). The check 10,000-year flood level is 1055.00m while the flood discharge is no more than 4500m^3/s.

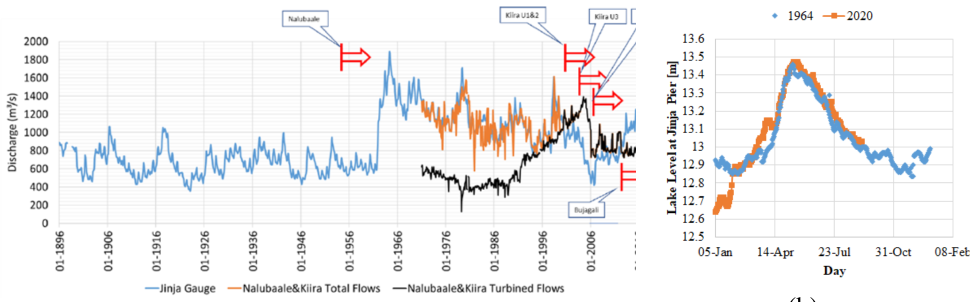
1.2.5 Karuma Hydropower Project (KHPP)

Karuma HPP has an installed capacity of 600MW from a 314m long concrete gravity with a dam of height 14m and gross head height of the dam barrage of 70m. The combined spillway capacity of the nine gate openings is 4700 m^3/s and ecological flow is designed for 100 m^3/s. Karuma HPP has a combined plant discharge of 1,224m^3/s and maximum probable flood (Design flood flow P=0.01%) of 4700 m^3/s.

2 Regional Hydrology

2.1 Hydrological Analysis

Comparison of Lake Victoria and River Nile outflows shows that the outflow from Lake Victoria followed the lake levels until early 2000s as mimicked by the Agreed Curve of 1959 as shown in
Fig. **2**a.



(a) (b)

Fig. 2. (a) Outflow from the lake since 1896 [4] and (b) Lake Level trends for 1964 and 2020.

Prior to 1954, the outflow from Lake Victoria followed a natural function of the lake water levels and the geometry of the Ripon Falls at Victoria Nile. The first highest recorded lake levels were encountered in 1964 following the heavy rainfall experienced in the Lake Victoria region (Fig. 2). However, after 2002, River Nile outflow deviated greatly from the Lake level variations probably attributed to climate change and increased outflow attributed to the construction of the Kiira power station. Consequently, there was a decrease in Lake Levels between 2002 and 2006. The Lake Victoria levels recovered thereafter from the 2005/06 drought low level of 10.5 meters to average of about 11m in 2012 as measured at the Jinja pier. However, in May 2020 the lake level continued to rise even surpassing the 1998 and 1964 levels to 13.47 m. The Lake levels have steadily increased since 2006 surpassing the 1964 record in May 2020 (Fig. 2b). probably attributed to the change in regulation of the Victoria Nile outflow at Jinja and hydrological changes. It should also be noted Lake Victoria levels heavily depend on the rainfall received over the Lake Victoria basin, for example, in 1998, the lake levels rose by almost 1.2m due to the El-Nino heavy rains that were experienced that year and increased tributary inflows. The El Nino phenomena is known to occur every 2-7 years as noticed by the sharp peak in water levels in those years. The increase in lake levels could partly be attributed to the high precipitation and consistent above-normal rainfall in the past two years, coupled with destruction of forests, vegetation and wetlands in the past thus leading to high inflows from the Lake Victoria tributaries as explained by the UNMA – Uganda National Meteorology Authority forecasts (Fig. 3) and/or the change in outflow regulations of the River Nile. Cumulatively, the Lake Victoria tributaries contribute an average of about 815 m^3/s but highly varying total inflows in the range (247 - 8764 m^3/s) depending on the rainfall received over the Lake Victoria basin. The Kagera river is the highest contributor of inflows (33%) with an average flow of 266 m^3/s and maximum of about 1200 m^3/s followed by Nzoia River that contributes about 15% of the total inflows [5]. In the past, the River Nile outflows varied between (480 – 1910 m^3/s) with an average flow 1057 m^3/s. The Lake volume however highly depends on rainfall and evapotranspiration over the lake itself. More specifically, rainfall over the lake contributes 52% of the lake storage/levels; while evapotranspiration from Lake Victoria contributes about 47.9% and the combined contribution of outflow and inflow on the Lake is less than 0.3%, (inflow constitutes 0.012% while outflow contributes 0.015%). This means that more than 92% of the water that falls over Lake Victoria is lost through evapotranspiration, while the rest of the water, inflows and Nile outflows dictate the lake level fluctuation. Researchers have indicated that the high annual variability of inflows and outflow strongly influences the Lake Victoria water balance/water levels.

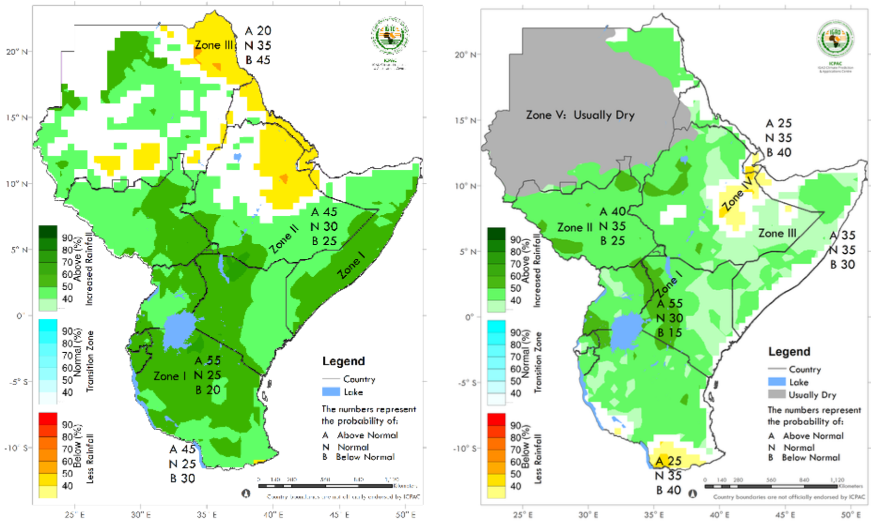


Fig. 3. Rainfall performance of September to December 2019 rainy season and March to May 2020 respectively.

2.2 Discharge Analysis

In the 1960s, the highest outflow of the Nile was recorded on May 30, 1964 at 1910.16 m³/s when the lake water level was 13.46 i.e. 1136.102 m.a.s.l MD. Based on the MD, the Nalubaale crest level is located at 1136.15 m.a.s.l while the dam warning level is 1134.5 m.a.s.l. During the recent flooding, the average Nile flows tripled from about 800 m³/s in January 2020 to over 2400 m³/s in May 2020. By May 2020, the lake level reached a maximum of 13.47 m i.e. 1136.112 m.a.s.l MD necessitating a discharge above 1900 m³/s. This increase was gradual as permitted by the Ministry of Water & Environment, Uganda in incremental steps of 1200, 1300, 1350, 1400, 1450, 1500, 1700, 1850, 2000, 2200, 2400 and back to 2000 cumecs between March 2020 and October 2020 to cater for the next rainy season. This was done to minimise shock to the ecosystem and allow the public time to adjust to the high discharges especially since Lake Victoria is a large reservoir that requires a long time to reduce its levels.

The impact of increased discharges showed that at Nile discharges of 1700 m³/s, Isimba HPP had to impound water for 1-2 hours and release about 1400 m³/s for the ferry downstream to cross at 1039.5m Tail Water Level (TWL) in the morning and evening. At 2000 m³/s, Isimba could not impound anymore for the ferry to cross as the dam approached its flood water level thus threatening its safety. The ferry operations were later suspended not only due to the increased flows but also due to the Covid-19 restrictions. Downstream of the Isimba Hydropower station is a bridge linking Kayunga and Kamuli districts and incidentally, the bridge was under construction during the high discharge period. The Contractor's limit for works was at a discharge of about 1900 m³/s which corresponds to the TWL of 1040.1 m.a.s.l. The optimum TWL is 1040.3 m.a.s.l at a discharge of 2000 m³/s. Therefore, it was important to have close coordination between the Contractor and the Isimba HPP Control room. Overall, the water level downstream of Isimba dam increased by 1.3m since the start of the incremental discharge. This generally affected the construction works, as the Contractor had to raise his jetty to minimise disruption by the Nile flows. Additionally, a siren was sounded to alert the Contractor whenever the TWL was anticipated to hit 1041 m.a.s.l. This lessened the risks of delayed works as well as loss of lives.

The highest impact of increased discharge is the flooding of the low-lying areas closer to the river Nile banks and wetlands. For high discharges of 2000 m^3/s and above, it was expected that the areas within 100 meters of low-lying areas from the river would experience a higher rise in water. It was observed that water was moving outwards to a distance of about one (1) kilometre in low-lying areas around Lake Kyoga and Lake Victoria. Other major impacts of the rising water levels were on water transport and river crossing by ferries downstream of the White Nile.

2.2.1 Nile Cascade Coordination

Until March 2020, there was no streamlined coordination of discharges across the Nile Cascade Plants as all dams were under different management. This made it difficult for operators to determine the necessary releases for both Dam Safety and optimal power production. In the wake of the increasing water levels, a Nile Cascade Committee was formed under Uganda Committee on Large Dams (UCOLD) to allow real time access for discharges via an online platform on google sheets. This was helpful in improving production planning and minimising safety risks associated with high flows. It also gave a platform to conduct various discharge tests. The coordination will be built further into a further Flood Forecasting system that will be accessible across all the Nile Cascade Dams.

2.2.2 Discharge Tests

The need to streamline cascade dam operation during extreme event flows motivated the need to conduct discharge tests for the cascade system of the power plants along the White Nile. The joint exercise was undertaken by the Directorate of Water Resources Management in collaboration with cascade plant operators from May 9-13, 2020. The tests involved varying discharges ranging from 2000m^3/s to 3000m^3/s. During the tests, not only were observations of technical aspects related to the performance of the power plants made but also the impacts to communities downstream of the power plants. The tests sought to improve and streamline cascade operation of dams during high flows, evaluate the consistency and accuracy of discharge from each of the power plants and identify constraints to hydropower production at prevailing extreme high releases from Lake Victoria. These tests allowed studying the behaviour of the power plant reservoir during lowering or build-up of their reservoir levels and monitoring of the variation of tail water elevations

The system used for measurement and data processing included an Acoustic Doppler Current Profiler (ADCP) that was connected to a processing PC installed with a software for data acquisition, processing and dissemination [6].

2.2.3 Dam Break Analysis & Emergency Preparedness

In 2018, UEGCL hired a Dam Safety Consultant to develop a Dam Safety Management System (DSMS), which constituted undertaking a Dam Break Study for all the dams on White Nile Cascade. The study modelled the worst-case scenarios associated with the Nile cascade dam failures. A failure at Nalubaale dam posed no significant danger to Bujagali if spillways were opened in time, although resulted into dam overtopping. Bujagali's resilience is attributed to the flood wave being absorbed by its reservoir and partly discharged through the siphon spillway. However, the breaching of Bujagali did not overtop Isimba as the breach wave was absorbed by the Isimba reservoir. The failure of Isimba dam had no effect on Karuma [7].

Upon the completion of the DSMS, it was a requirement to enrol periodic awareness programs on Emergency Preparedness as per the Emergency Preparedness Plan (EPP). EPP awareness campaigns were undertaken forming part of the operationalization of the EPP. Workshops targeted district and sub-county level stakeholders, which included disaster management committees and influential leaders. These workshops mainly involved presentation of the EPP and simulation of a Tabletop exercises. Eskom Uganda Limited, who are the operators of Nalubaale, also undertook sensitization of communities on the public safety issues associated with increased releases downstream while Bujagali undertook a dam break drill. This was done with participation of all cascade dam operators under the umbrella of the Nile Cascade Committee that was initiated and is supported by UCOLD.

3 Risks and Uncertainties

3.1 Hydropower Related Risks

At the peak of the 2020 flooding, most hydropower plants on the White Nile Cascade had to release higher flows from the emergency gates and generation Units. This created extreme fluctuations in tail water and head water levels, which greatly affected power generation (see Table 2). The high water levels also dislodged floating islands and vegetation, which caused National Blackouts in some incidences. At Isimba HPP, the effects were three-fold; increased availability of water for power generation, loss of generation capacity due to reduced generation head and loss of generation capacity due to increased head losses resulting from clogging of trash racks. Prior to the period of increased flows, the average flows through the Victoria Nile were below 1000 m^3/s. Due to the downstream ferry operations, Isimba HPP was obligated to discharge enough water (about 700 m^3/s minimum) to facilitate ferry crossing even if it meant spilling during off peak hours. This operation compromised the ability of the Isimba HPP to store enough water to be utilised during peak hours. With the increase inflows, this constraint was eliminated, as more water was available for generation at full capacity. For Isimba, increased inflows up to 1500 m^3/s had a positive impact on the plant generation while flows greater than 1500 m^3/s had a negative impact as the excess water lead to a build-up in TWL downstream thereby reducing the available head for generation. This limitation was overcome by adopting a reservoir operation procedure comprising of reservoir draw down during off peak hours and build-up during peak hours when total discharge was reduced so as to lower the TWL and hence provide sufficient head for power generation. Due to the immediate downstream bridge construction works, total discharge during reservoir draw down was limited to 2500 m^3/s which was not enough to draw down the reservoir during the flow regime of 2400 m^3/s. Plant generation capacity was hence limited to 160MW. Generation above 160 MW required closing of all spillways, which could lead to rapid reservoir build up and risk the safety of the dam due to upstream flooding.

Table 2. Summary of Hydropower related risks.

S/N	Risk Description	Ranking	Mitigation Measures
1.	High flows, requiring increased discharges and resulting into extensive fluctuation of HWL & TWL causing head losses and reduced energy output	High	Adopting optimum reservoir operation procedures, Creation of cascade data sharing platform and Cascade discharge tests to configure optimal operations
2.	Accumulation of weed in intake, obstruction of gates operation and affecting power production	High	Installation of the floating boom to intercept and frequent operational removal of the weed from the dam intakes

3.	Large Floating island masses due to disturbance of lake banks from the rising water levels.	High	Regular reservoir inspection; Disintegrate the island when still upstream and removal of debris; Installation of a large boom structure upstream of the Nile.

Rising water levels accelerated heavy influx of floating island masses consisting of debris and various vegetation from the riverbanks, which end up accumulating at the plant's intake and trash racks causing clogging, and increased head losses which compromised power generation and increased the frequency of trash rack cleaning. The debris chocked intake screens and cooling water systems, disrupting electricity generation at the Kiira, Nalubaale and Bujagali Hydro Power Plants leading to a nationwide power outage (See The New Vision of April 16, 2020). This occurred during a period of heightened dam safety risk due to increase in the Lake Victoria water levels and a Covid-19 pandemic lockdown, which generated more challenges towards the timely response and remediation of its impacts. The removal of the Islands was a combined and coordinated multi-sectoral effort involving the usage of excavators, dump trucks, tag boats and wheel loaders to remove all the debris and transport it to a permanent disposal site. The emergency response to remove both islands lasted a period of 10 days and involved a number of governmental ministries, agencies and private agencies.

3.2 Dam Safety Related Risks

The effects on of the hydrological changes resulted into several dam safety issues and risks. Some of the loose soils closer to the power stations which did not have adequate rock cover or where restoration / flood wave protection works were not adequately done experienced some erosion and slope collapses due to a beaching effect from the higher wave action as shown in the Fig. 4.

Fig. 4. Excessive erosion and slope collapses.

High flows along the cascade led to increased reservoir levels creating an extra hydraulic loading against the cascade dams, excessive erosion of the riverbanks & several slope collapses of the reservoir rim. This necessitated modification in monitoring procedures to increase the frequency inspections and data collection (Fig. 5) for purposes of early detection of any dam safety incidents or progressions that could be detrimental to the dams [8].

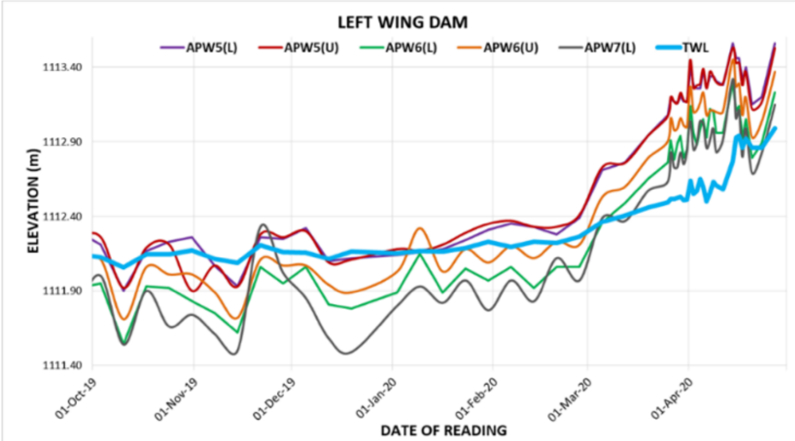


Fig. 5. Graph showing effect of rising tailwater pressures on piezometers at Kiira Dam.

The cascade dam operators and owners facilitated emergency awareness campaigns and dam break drills to enhance preparedness for any eventuality. The dams had already developed local working risk registers and risk informed dam safety management systems as discussed in [9]. Therefore, by the time, the 56-year flood arrived, the cascade dams were adequately prepared using the Risk Based Approach. Additionally, during this high flow period, new dam safety risks were identified, ranked, mitigation measures suggested & risk informed interventions were made. Part of this is summarized in Table 3.

Table 3. Summary of Dam Safety related risks.

S/N	Risk Description	Ranking	Mitigation Measures
1.	Loss of power supply for whatever reason; inability to operate gates; water level raises and overtops the dam	High	Mobile pumping set to be used; also diesel generator; EPP activation
2.	Exceptional flood causing prolonged operation of spillway leading to failure	High	Monitoring & maintenance; coordinated operation of the cascade; routine testing of gates; EPP
3.	Failure of u/s dams increases water level above design capacity	High	Monitoring water levels upstream, Early Warning System coordinated for the whole cascade, EPP and Emergency Drawdown of reservoirs, Communication with upstream plants Emergency Response Plan: Quick response coordinated by Government; Have a cascade coordination team
4	Collapsing slopes of the reservoir rim and excessive erosion of the riverbanks resulting into sedimentation	Moderate	Regular reservoir inspection; Survey the slopes and stabilise the collapsed slopes; Should be captured in the Civil O&M Manual, Cascade cooperation [10]
5	Increased loading and risk of over topping of dams	High	Spilling of water to control water level within acceptable limits Increased monitoring of dam instrumentation

However, these climatic extreme events did not come with only risks and uncertainties, it also came with a few opportunities including increased water for generation, opportunity for design improvements in slope protection and lessons learned for future reference.

3.3 Public Safety Related Risks

Rising lake levels led to flooding of communities that had settled around the lakeshores. Most of population affected were those who had illegally occupied the buffer zone. Relocation of the affected communities came with the prevailing challenges relating to the Covid-19 pandemic lockdown and restrictions. Due to the increased flows through the Nile, many socio-economic activities like bridge construction, water transport, fishing, tourism, recreation and sand mining were affected. Some activities were stopped where as others were regulated as per the flows.

Table 4 shows some of the public safety risks that were identified.

Table 4. Summary of Public Safety related risks.

S/N	Risk Description	Ranking	Mitigation Measures
1	Loss of life and properties resulting from delayed warning of downstream population when the spillway gates are opened	High	EPP; Communication and alarm system in the communities; evacuation routes; training of people likely to be affected
2	Operational failure of the Ferries disrupting transportation because of increased discharges.	Extreme	Coordination between the ferry operators and the Plant operators; Closing monitoring and keeping the tailrace at the appropriate level

The increased discharges resulted into several incidents on the cascade, including a boat accident where a family of four lost control of their vessel and entered through the Kiira Power Station Spillways that were open at the time. Such incidents call for evaluating areas of improvement including fixed barriers across the reservoirs, larger signages and siren systems. More importantly is the need to continuously carry out Emergency Preparedness awareness campaign and public safety education on risks around dams in coordination with local leaders and Disaster Management Committees.

4 Lessons Learnt

Prior to the onset of the flooding events, UCOLD initiated cascade stakeholder meetings to establish the Nile Cascade Committee (NCC) involving plant operators, regulators and other water users along the White Nile. Among the key deliberations made was the opportunity to share discharge data among the plant operators which was very helpful to downstream plant operators. At the onset the floods, the Cabinet Committee on government response to flooding in Uganda decided that the political coordination would be done by the Office of the Prime Minister whereas the technical coordination would be by the Ministry of Water and Environment (MWE). It is upon this background that an inter-ministerial technical team on government response to flooding was formulated. This team was constituted by senior officers from relevant institutions chaired by the Permanent Secretary of MWE. A consolidated report was drafted with an Action Plan highlighting that interventions that needed to be made. This team coordinated and oversaw implementation of the required interventions by relevant stakeholders. Many challenges were faced by affected institutions while dealing with the floods though there were also some opportunities involved. In the past, there are some generic lessons learnt that have been documented and were relevant to Uganda's situation among which include but not limited the following;

1. Dam operators need to address public safety around their dams. A safety boom can go a long way not only to save lives but also trap floating weed. Public safety awareness can also save lives.
2. Floating booms should always be considered most especially in project areas prone to floating debris in order to direct the debris away from the powerhouse to prevent loss of head.
3. For dam safety regulatory programs, it is important to have a reserve source of funding identified for responding to any emergency. "Emergency fund" should be part and parcel of any operator' operation and maintenance budget.
4. Dam operators may operate a gated spillway at release levels less than those specified in the Standard Operating Procedure if there is potential for downstream consequences.
5. Conducting Potential Failure Mode Analyses, Risk Analysis and periodic assessments of high and significant hazard dams are effective methods that can keep the dams safe.
6. Emergency alarm/warning system can be an effective means of providing warning to downstream water users and residents in close proximity to the dam.
7. Regular monitoring, inspections and maintenance is important to the early detection of dam safety related problems, provide an opportunity for intervention and consequently prevent dam failure.
8. Appropriate reservoir operation and inspection is not only important for optimization of power production but also for mitigating dam failure related risks and early detection of public safety related incidents
9. Failure of upstream dams/reservoirs should be considered in design and dam break analysis of closely spaced dams

Other major specific lessons learnt include the following;

1. When confronted with disasters, the Government of Uganda has the capacity to mobilize resources (equipment and manpower) and respond quickly to emergencies.
2. Power system stability associated with frequency and voltage fluctuations is of great concern. In order to ensure energy security and reliability of supply, there is need for an independent panel of experts to evaluate and assess the capability of the power transmission system to withstand system fluctuations and recommend improvement measures to the Government.
3. The hydraulic structures of hydropower plants are exposed to serious dam safety and revenue generation loss without a robust log boom in place to contain not only floating debris, but the emerging threat of floating islands. The need to redesign and install log booms and/or waterway barriers at Jinja dam cannot be overemphasized.
4. There is need for adapt Nalubaale Dam operations to the inter-annual variation of precipitation patterns and lake levels as a result of climate change. These measures must be informed by studies of the future climate change impacts on the Lake Victoria basin and hydropower generation.
5. Future hydrological studies should cover longer historical and future projections for 150 years from 1950 to 2100 to minimize inherent model uncertainties.
6. The Nalubaale-Kiira complex is a strategic asset for the Government not only for hydropower generation, but flood control. Since 1951, the Lake Victoria outflow has been regulated by the Agreed Curve, yet the current extreme hydrological events

and the commissioning of Kiira hydropower station in 2000, warrants deviation from the Agreed Curve by spilling more water.

7. The unprecedented water spilling of 2,400 m^3/s was twice the design capacity of 1,272 m^3/s for the Nalubaale sluice gates and three times the allowable discharge of 800 m^3/s under normal conditions. These high water releases led to erosion of the river banks along the cascade of hydropower plants and increased the tailwater level at Nalubaale raising dam safety concerns. The high flows and reservoir water levels can erode or reduce the stability of natural slopes. These flows can also uplift and reduce stability of floating islands. There is need to investigate whether these conditions are within current dam design criteria and the implications on downstream activities.
8. There is need to regulate the Lake Victoria outflow and efficiently utilize water resources to mitigate against seasonal changes. Reducing water spillage and increasing power generation, requires either the construction of a new dam at Jinja or increasing the water spilling capacity of the existing hydropower dams through the redesigning and renewal of the aging dams. Uganda Electricity Generation Company Limited (UEGCL) initiatives in this regard needs to be fully supported by the Government.
9. Stability analysis of the dam should be undertaken during operation using parameters derived from existing conditions especially during extreme events. An external independent peer review and verification of the analysis is an effective means of providing quality assurance and reducing risks associated with design oversights and deficiencies.
10. There is urgent need to build on UCOLD initiatives and strengthen the nation's dam safety regulatory framework.

5 Conclusion

The climatic extreme events have tested the current principles of flood and dam safety management along the White Nile Cascade, revealing opportunities for further improvements in processes and procedures. To better manage such risks, a risk informed strategy should be adopted cognizant of certain critical factors surrounding such extreme events. At the pinnacle of all this is the need to create dam safety legislation in Uganda to regulate operations of dams of all sizes, with an objective of protecting downstream population, enforcing operational guidelines, ensuring accountability in the event of failure. This along with improved cascade cooperation shall go a long way in averting future risks and impacts of changing climatic conditions.

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