10 Environmental Flow Assessment

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10.1 Introduction

The Environmental Flow Assessment (EFA) assesses the impacts on aquatic ecology and social reliance of flow alteration due to the planned operation of Ruzizi III HEPP and specifically the environmental flow of 10 m^3/s as defined in the Project's Feasibility Study. The EFA provides support towards assessment of flow-related impacts but does yield recommendations for development of mitigation.

The EFA considers both the impacts in the dewatered reach between the dam wall and the powerhouse tailrace and the impacts of hydropeaking downstream of the powerhouse tailrace. The initial scope of the EFA was to assess the impacts upstream of the Burundi order. However, due to concerns that were identified during the assessment, the scope was extended to also assess potential impacts downstream of the Burundi border.

As such, the EFA study area (Figure 10-1) is defined as:

- The main study area is the Ruzizi River from the existing Ruzizi II HEPP at the upstream extent to the confluence of the Ruzizi River with the Ruhwa River at the downstream extent (28 km).
- The extended study area is the Ruzizi River from the existing Ruzizi II HEPP at the upstream extent to Lake Tanganyika at the downstream extent (150 km).

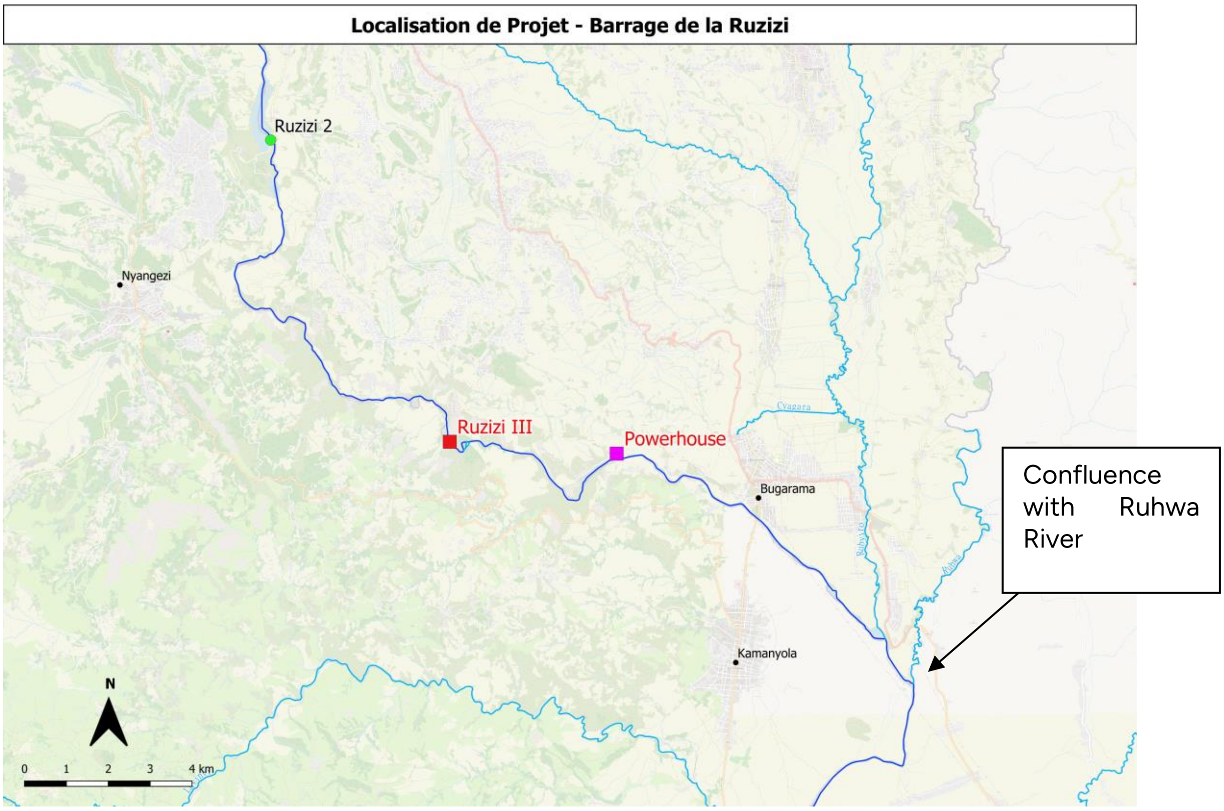

Figure 10-1 Environmental Flow Assessment study area

The EFA as presented is informed by the IFC Good Practice Handbook (The 'Handbook') on Environmental Flows for Hydropower Projects.

Based on the guidance provided in The Handbook (see the accompanying annex for further details), the EFA approach adopted herein aligns with a <u>medium-resolution assessment</u> in that:

- it assesses the hydrological and hydraulic characterisation (state) of both the dewatered reach between the dam wall and tail race and the downstream hydropeaking reach; and

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- it establishes functional relationships between the hydrological and hydraulic characteristics (state) and the ecological and social context (impact) of the two reaches – geomorphology, aquatic ecology, terrestrial ecology, and social reliance are all explicitly considered.

In adopting a medium-resolution assessment, key characteristics of Ruzizi III have been explicitly considered. Although the Project will be in a location that is subject to selected attributes that suggest that a high-resolution assessment is required (potential significant transboundary issues, position in a cascade), it is also located in a reach that is already heavily modified (due to the presence and operation of upstream Ruzizi I and II HEPP), suggesting that a low-resolution assessment is sufficient.

The Critical Habitat Assessment (Chapter 9) indicates that the middle and upper Ruzizi River in which Ruzizi III is located potentially qualifies for Critical Habitat for two non-migratory threatened catlet species: *Chiloglanis ruziziensis* (Critically Endangered) and *C. asymetricaudalis* (Endangered). It appears these species mainly occur in tributaries such as the Ribyiro, Ruhwa and others, where they have been found at the confluence with the Ruzizi River. There are, however, no recent formal records for these species in the main Ruzizi but this may be an artefact of difficult sampling conditions due to high flow and water depth. There are several other restricted range fish species that qualify for Critical Habitat at the basin scale, including three migratory fish species that occur in the Lower to Middle Ruzizi River downstream of the Ruzizi III Project (*Labeobarbus leleupanus; L. caudovittatus* and *Acanopoeta tanganicae*).

The sufficiency of such a medium-resolution assessment has been confirmed by a broad-scale assessment of the hydrological and hydraulic characteristics in the extended study area downstream of the border with Burundi, to identify if any potential significant transboundary impacts may arise including potential impacts on Critical Habitat.

This assessment has shown that the effects of Ruzizi II / III hydropeaking are expected to significantly attenuate with distance from the Ruzizi III Project.

Flow fluctuations 60 km downstream of the Burundi /Rwanda border (some 20 km upstream of the northern limit of the Ruzizi National Park and Ramsar site will only be slightly detectable or measurable. The minimum water level during off peak flows will be in the order of 3 cm lower than the current minimum water level caused by Ruzizi-I/II operation. Maximum water levels will be no higher than those of the current conditions, which are also no higher than the natural conditions (before operation of Ruzizi-I and -II).

A small incremental effect in flow level increase and speed of change of water levels is predicted to occur due to the proposed operation of Ruzizi III. Importantly, the associated community safety related ramp-up rates remain well below threshold values of 5 cm/minute. The water level change amplitude during ramp up and ramp down is 160 cm immediately downstream from the Ruzizi III powerhouse tailrace, and this amplitude decreases with distance downstream. Similarly, the associated fish-stranding related ramp-down rates are well below threshold values of 1 cm/minute. As such, it is concluded that the hydrological and hydraulic hydropeaking effects present no significant transboundary impacts with Burundi nor impact potential Critical Habitat in the Ruzizi River system.

This EFA has adopted a medium-resolution assessment, and this is considered suitable by the ESIA Consultant and REL, it is nevertheless recognised that the suitability will be assessed by the Environment and Social Independent Panel of Experts (IPoE) and if necessary, will be revised to address the panels comments post financial closure.

10.2 Preparatory Activities

Prior to undertaking the assessment of EFlows, a variety of preparatory steps were undertaken to better set the context for the assessment. This included:

- Review and collection of available hydrological and hydraulic data;
- Desk-based geomorphology and sediment assessment; and
- Collection of field data – hydrological; terrestrial ecology; aquatic ecology; socio-economic surveys.

The review and collection of available hydrological and hydraulic data is more fully described in Chapter 7 - Environmental Baseline Situation (Section 7.6 - Hydrology). This includes an assessment of the monthly inflows to Ruzizi II and the study area, an assessment of the study area hydrology including observed water levels and the hydrological and hydraulic characteristics of the study area and water levels near Lake Tanganyika, and a summary of flood risk at the Ruzizi III dam site. Key baseline hydrology characteristics include:

- Potential longer-term variations in hydrological conditions. The EFA is undertaken for the existing hydrological conditions which represent the current baseline situation.
- Short-term / daily variation in river water level due to existing hydropeaking from the operation of Ruzizi II. This is observed at the Manda monitoring site (approximately 2 km downstream of the Ruzizi III dam wall) and at the Kamanyola water level monitoring site (approximately 6 km downstream of the Ruzizi III dam wall), but is not observed at the Ruzizi monitoring site in Burundi (located 125 km downstream of Ruzizi III / 14 km upstream of Lake Tanganyika).

The geomorphology and sediment assessment are more fully described in Chapter 7 – Environmental Baseline Situation (Section 7.4 – Geomorphology). This includes a general geomorphological description of the Ruzizi River from Lake Kivu to Lake Tanganyika and a summary of Ruzizi III sediment load estimates for suspended sediment, bedload, and landslides.

A hydrological field visit was undertaken in January 2022. This included stakeholder meetings with GIZ, the Rwanda Water Resources Board (RWB), and the Ministry of Infrastructure (MININFRA) in Kigali, and ABAKIR in Rubavu. The field visit included a drive through of the Lake Kivu catchment from Rubavu to Kamembe (Figure 10-2), a visit to Ruzizi II reservoir (Figure 10-3), a detailed walk-over of the Ruzizi River from Ruzizi III to the Ruhwa River, and water level observations at Kamanyola monitoring station (Figure 10-4). A photographic and video record of river flow conditions, and laser measure readings of selected channel features along the Ruzizi River, were obtained and used to inform the development of the reach hydraulic model.

Sediment laden inflows to Lake Kivu at Rubavu	Sediment laden Lake Kivu tributary inflow near Rutungura	Lake Kivu outlet

Figure 10-2 Lake Kivu catchment (Rubavu to Kamembe)

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View of Ruzizi II reservoir


Spill over Ruzizi II reservoir


Ruzizi River channel downstream Ruzizi II spill

Figure 10-3 Ruzizi II reservoir


View upstream of unfinished bridge


Braided channels (1.3 km downstream unfinished bridge)


Riffles (2.1 km downstream unfinished bridge)


Natural weir across the river (3.2 km downstream unfinished bridge)


Left-bank still water (0.5 km upstream Bugarama Bridge)


Kamanyola monitoring station (upstream Bugarama bridge)


Natural weir across the river (1.5 km downstream Bugarama bridge)


Natural weir and channel braiding (3.8 km downstream Bugarama Bridge)


Left-bank channel at confluence with Rubyiro River

Figure 10-4 Ruzizi River (selected locations)

A Terrestrial and Aquatic Ecology field visit was undertaken in January 2022, with an additional half day aquatic survey in February 2022 (under low flow/off peaking conditions). These field visits have informed the Terrestrial and Aquatic Ecology sections of the Environmental Baseline chapter. The terrestrial baseline includes an assessment of vegetation and flora, and terrestrial fauna (birds; mammals; and herpetofauna). The aquatic baseline includes an assessment of: i) hydrogeomorphological types; ii) aquatic biotopes; iii) benthic diatoms; iv) aquatic flora; v) aquatic macroinvertebrates, and vi) fish.

A socio-economic field visit was undertaken in January-February 2022. This is more fully described in Chapter 8 – Social Baseline Situation (Section 8.1.3 Primary Data Collection), and has informed the assessment of, *inter alia*: i) land-use along the reach of the Ruzizi River downstream of the Project; ii) river uses (water supply and domestic activities, river crossing, medicinal and spirituality properties, irrigation); iii) economic activities (agriculture, fishing, fish farming); and iv) community infrastructure (water supply).

10.3 Eco-hydraulics

10.3.1 Introduction

The assessment of eco-hydraulics provides a description of the hydrological and hydraulic characteristics in the study area that are (potentially) affected by the Project. This characterisation is undertaken for current baseline conditions and for post-project conditions such that the change in conditions induced by the project can be assessed.

The EFA eco-hydraulics have been developed by SLR based on: i) the hydrological inflows presented in the baseline hydrological assessment; ii) 1D hydraulic modelling of the main and extended study area; and iii) a local 2D hydraulic model for an approximate 1.7 km reach centred around the Ruzizi III dam wall.

10.3.2 Hydrological Inflows

The assessment of hydrological inflows is presented in Chapter 7 – Environmental Baseline Situation, and includes the following components relevant to the EFA:

- An assessment of the monthly inflows to Ruzizi III and study area inflows including: i) intervening catchment inflows between Ruzizi II and Ruzizi III; ii) Rubyiro River inflows; and iii) Ruhwa River inflows.
- An assessment of the study area hydrology including: i) observed water level variations at the Kamanyola (Bugarama Bridge), Manda, and Ruzizi in Burundi (14 km upstream of Lake Tanganyika) water level monitoring stations; and ii) modelled hydrological / hydraulic characteristics for the "Ruzizi III Reach" between the proposed dam wall and powerhouse locations, and the "Ruzizi II – Burundi Border Reach". The "Ruzizi III Reach" represents the proposed future "dewatered reach" and as such an analysis of reach area, depths, velocities, shear stress, and hazard is presented for the current range of observed flows (i.e., from 10 m^3/s to 160 m^3/s). The "Ruzizi II – Burundi Border Reach" represents the current study area (upstream of Burundi) that is subject to hydropeaking effects, and as such an analysis of variation in flow and level, and ramp-up and ramp-down rates, for selected key locations along the reach is presented.

10.3.3 1D Hydraulic Modelling

The "River Channel Hydraulics" report (December 2020), produced as part of the Ruzizi II Feasibility Study, describes the analysis and modelling undertaken to develop high flow level-flow rating curves at selected sites of interest between the Ruzizi III dam wall and powerhouse. A HEC-RAS 1D hydraulic model was developed for the river reach between the dam wall and approximately 1.4 km downstream of the powerhouse based on cross-section survey data (see Figure 10-5) and local LiDAR data.[1] During model development, any discrepancies between cross-section survey data and LiDAR were removed by adjusting the survey data.

[1] The cross-section survey data is more thoroughly described in the "Draft Report of Ruzizi Bathymetric Survey for Ruzizi III HEPP" report (Tiger Engineering Company Limited, January 2021). An ADCP was used to survey cross-sections at 68 out of 80 planned locations – 12 locations were not able to be surveyed due to the high level of turbulence. The ADCP surveyed data was extended onto the riverbanks using Total Station topographic survey.

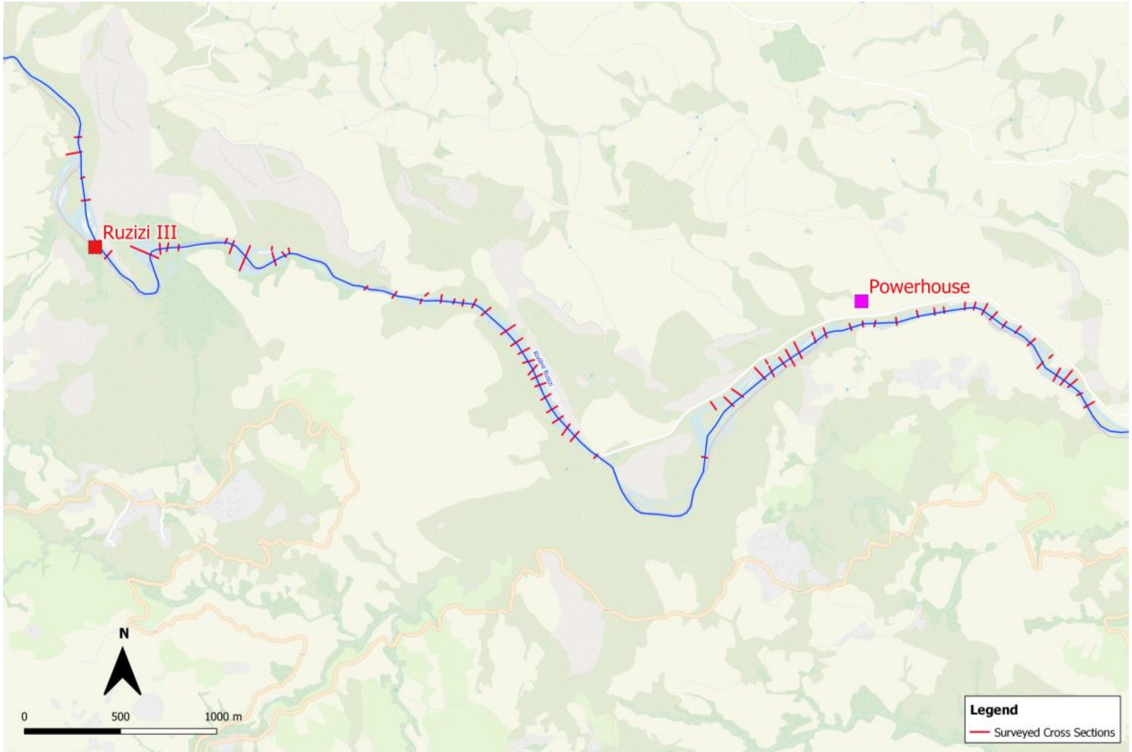

Figure 10-5 Ruzizi III cross-section survey data

The existing HEC-RAS model of the reach between the Ruzizi III dam wall and approximately 1.4 km downstream of the powerhouse includes the 5.5 km-long Ruzizi III dewatered reach. The model has been obtained and re-run for a range of steady state flows to provide a hydraulic characterisation of the reach representing the proposed Ruzizi III dewatered reach. Flows over a range of 10 m^3/s to 160 m^3/s have been modelled as these correspond to the typical flow range currently observed in the reach due to the hydropeaking operation of Ruzizi II, located 12 km upstream of Ruzizi III dam wall.

The existing HEC-RAS model has been used as the basis for constructing a 1D hydraulic model of the extended study area from Ruzizi II dam wall to Lake Tanganyika. The model has been constructed as follows:

- 166 model cross-sections and Ruzizi II outflow and three tributary inflows / Ruzizi III outflow and two tributary inflows providing a detailed representation of 27.2 km of the Ruzizi River in the main study area and the uppermost part of the extended study area downstream of the Burundi border (Figure 10-6), and
- 8 model cross-sections and five additional tributary inflows providing a broad-scale representation of a further 61 km of the Ruzizi River in the remainder of the extended study area down towards Lake Tanganyika (Figure 10-7).

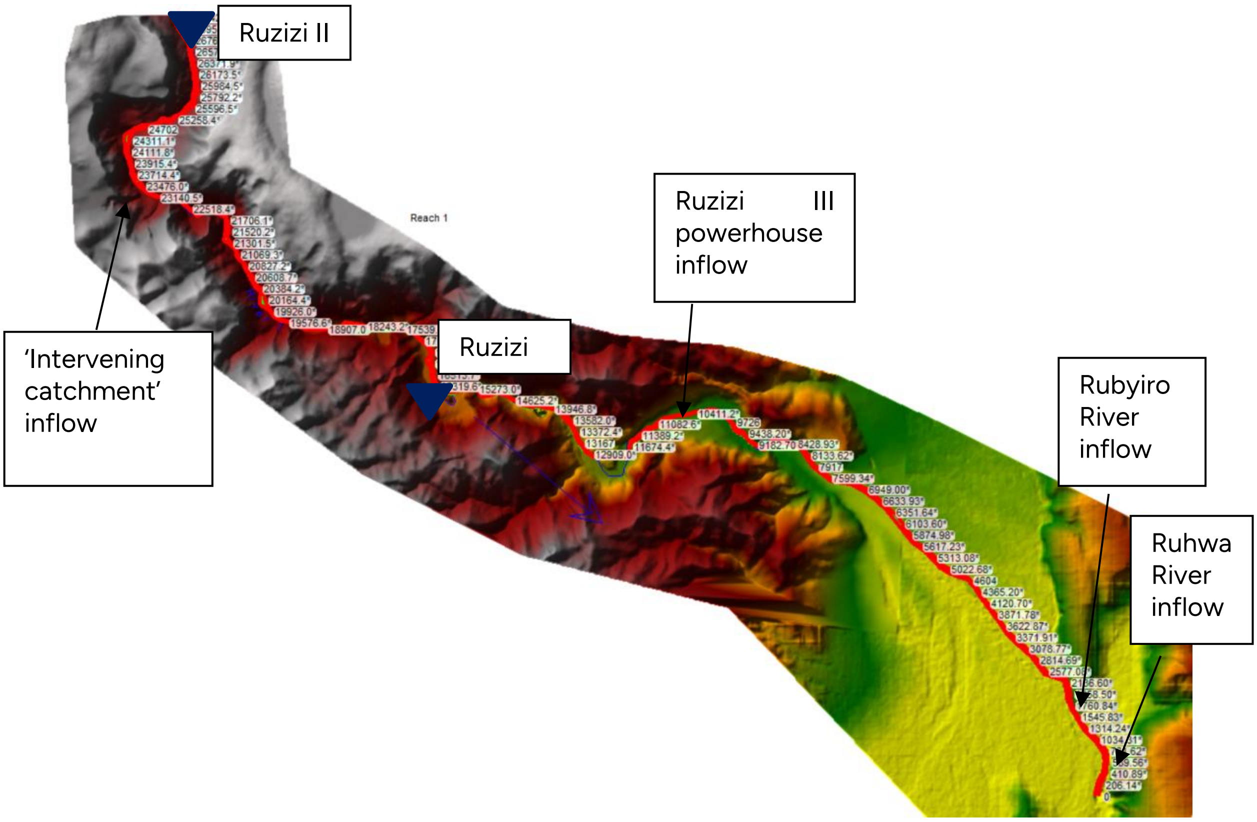

Figure 10-6 Ruzizi 1D hydraulic model of the main study area

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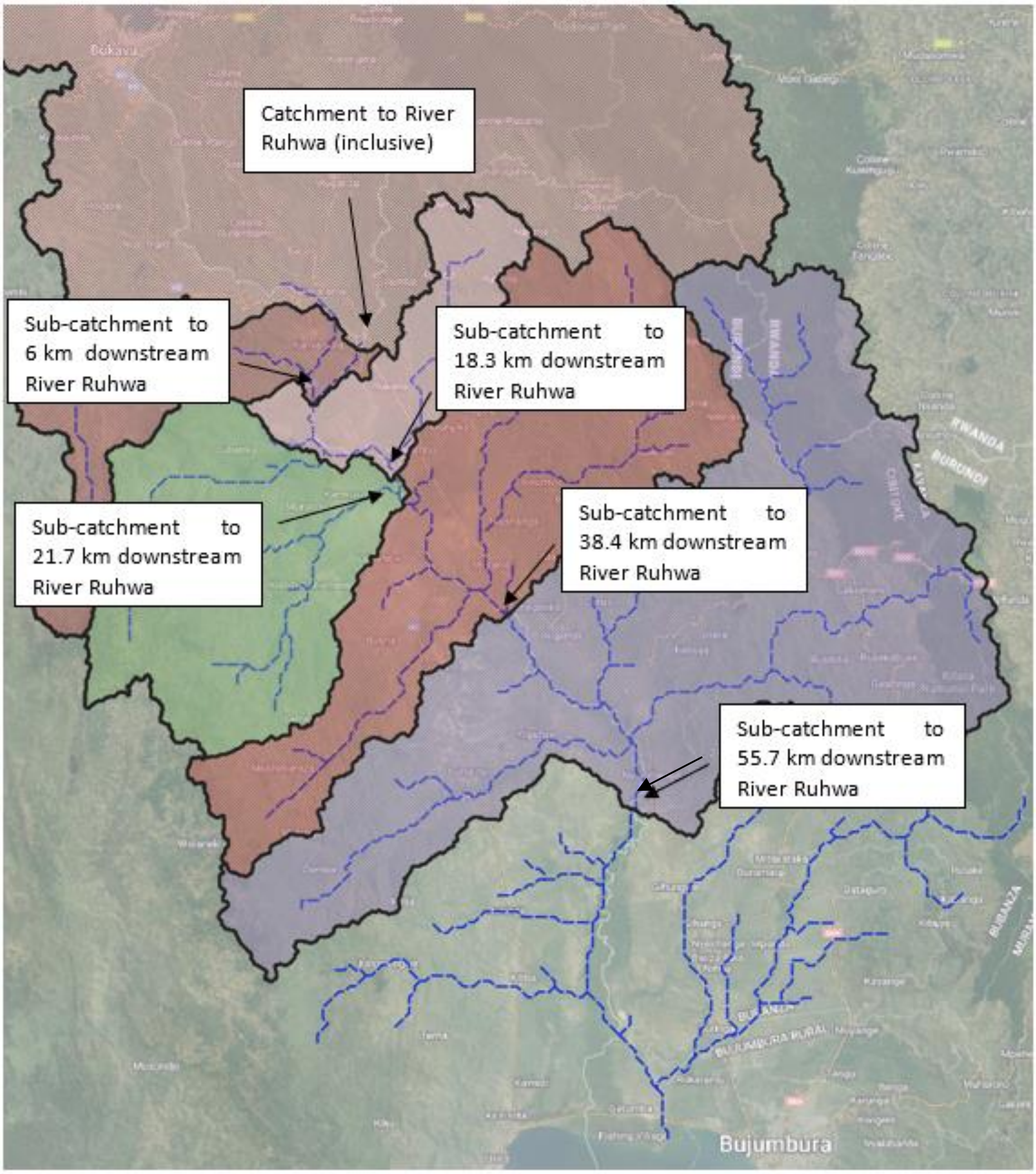

Figure 10-7 Ruzizi extended study area tributary inflows (downstream River Ruhwa)

Surveyed cross-section data has been reviewed and cross-sections generated for the non-surveyed reaches. The cross-sections explicitly take into account both the general pattern of in-bank river geomorphology and local variation. Cross-section width has been estimated from satellite imagery. Bank-full levels have been defined with reference to available DTM data, ALOS 30 m data in the reach downstream of Bugarama Bridge and 2m photogrammetry data (Fichtner, 2009) in the remainder of the (non-surveyed) reach upstream of Bugarama Bridge. The DTM data bank-full long profile was reviewed – and included use of field observations (January 2022) of the river profile – to smooth out local discrepancies. Field observations were also used in assigning roughness values to the synthetic cross-sections. As with the existing HEC-RAS model, the main channel was assigned a Manning's n value of 0.07, while out-of-bank was assigned a value of 0.1.

A summary of the model inflows from (i) the upstream location at Ruzizi II for current conditions and (ii) the upstream location at Ruzizi III for post-project conditions, and including tributary inflows from the River Rubyiro and River Ruhwa, is provided in Table 10-1 and Table 10-2. Model inflows vary according to general hydrological conditions and are related to optimised reservoir operation schedule scenarios as defined in the Feasibility Report. Five flow conditions are presented:[2]

- "Very dry" conditions (95% exceedance probability);
- "Dry" conditions (90% exceedance probability);
- "Normal" conditions (50% exceedance probability);
- "Wet" conditions (10% exceedance probability); and
- "Very wet" conditions (5% exceedance probability).

Table 10-1 Summary of hydraulic model inflows (current conditions)

Location	Very Dry	Dry	Normal	Wet	Very Wet
Ruzizi II Environmental Flow (m^3/s)	10.8	10.8	10.8	10.8	10.8
Ruzizi II powerhouse release (m^3/s)	Between 0 m^3/s and 150 m^3/s depending on powerhouse release schedule and upstream flow conditions				
Intervening Catchment Flow (m^3/s)	1.3	1.6	2.4	3.7	4.9
Total Flow to Ruzizi III (m^3/s)	78.3	84.3	108.4	131.1	139.2
River Rubyiro Flow (m^3/s)	4.0	4.9	7.0	11.3	14.9
River Ruhwa Flow (m^3/s)	8.6	10.6	15.2	24.5	33.4

Table 10-2 Summary of hydraulic model inflows (post-project conditions)

Location	Very Dry	Dry	Normal	Wet	Very Wet
Ruzizi III Environmental Flow (m^3/s)	10.0	10.0	10.0	10.0	10.0
Ruzizi III powerhouse release (m^3/s)	Between 0 m^3/s and 150 m^3/s depending on powerhouse release schedule and upstream flow conditions				
Intervening Catchment Flow (m^3/s)	N/A	N/A	N/A	N/A	N/A
Total Flow from Ruzizi III (m^3/s)	78.5	84.5	108.6	131.3	139.4
River Rubyiro Flow (m^3/s)	4.0	4.9	7.0	11.3	14.9
River Ruhwa Flow (m^3/s)	8.6	10.6	15.2	24.5	33.4

Hydrological conditions in the extended study area are derived from the 'Baseline Study for the Basin of Lake Kivu and the Ruzizi River' (Sher Consult, 2020) and represent annual average flow conditions. These are given as:

- Additional tributary inflows, 6 km downstream Burundi border – 6.5 m^3/s;
- Additional tributary inflows, 18.3 km downstream Burundi border – 10 m^3/s;
- Additional tributary inflows, 21.7 km downstream Burundi border – 7.1 m^3/s;
- Additional tributary inflows, 38.4 km downstream Burundi border – 17.4 m^3/s; and
- Additional tributary inflows, 55.7 km downstream Burundi border – 16.1 m^3/s;

The two-scale 1D model representation of the Ruzizi River provides the required hydrological and hydraulic characterisation of the river reach affected by hydropeaking. It enables an assessment to be made of the predicted effects of hydropeaking and its attenuation in the extended study area and supports the selection of a medium-resolution assessment method.

The 1D hydraulic model has been used to provide preliminary assessment of the hydraulic characteristics in the extended study area downstream of the River Ruhwa / Burundi border to help determine the study area over which it is necessary to relate project-induced change in

[2] Flow conditions are specified with reference to % exceedance probability, i.e., the percentage of time for which flow conditions are exceeded. For example, "very dry" conditions are exceeded 95% of the time such that they would only occur, on average, for approximately 7 days in any given year.

hydrological and hydraulic conditions to ecological and social reliance impacts. Further details are provided in 10.4.4.

10.3.4 2D Hydraulic Modelling

A 2D hydraulic model of the 1 km reach downstream of the Ruzizi III dam wall has been constructed in TUFLOW based on the available LiDAR data and surveyed cross-section data in this reach. This first kilometre reach is typically representative of the whole dewatered reach. It comprises both steep sections with low depths and high velocities and a flatter, slower flowing section with deeper water. The LiDAR representation of the main channel was compared with the cross-section data to best inform the representation of the river channel. As the LiDAR data does not fully represent the conveyance capacity of the river channel adequately, the surveyed cross-sections were used to incorporate into the model representation of an appropriately scaled river channel.

The 2D hydraulic model has been developed to illustrate the variety of flow conditions experienced in the dewatered reach under current hydropeaking conditions. Water depths in this reach vary between less than 0.5 m to greater than 4 m and velocities vary between less than 0.5 m/s to greater than 2.5 m/s based on channel morphology and slope. Further details are provided in the accompanying annex.

The 2D hydraulic model has also been used during the assessment of EFlows in the 5.5 km dewatered reach to provide additional hydrological and hydraulic characterisation of the 1 km reach downstream of the Ruzizi III dam wall, providing further evidence to support the assessment of the functional relationship / impact on aquatic ecology of the 10 m^3/s EFlow proposed by the Project for this reach. Further details are provided in section 10.4.2.

10.4 Assessment of EFlows

10.4.1 Introduction

The assessment of EFlows presented herein explicitly considers **3 distinct reaches**:

- the 5.5 km long **dewatered reach** between Ruzizi III dam wall and the powerhouse release;
- the 10 km long **hydropeaking reach** downstream of the Ruzizi III powerhouse release to (just downstream of) the Burundi border; and
- the 123-km-long **extended hydropeaking reach** downstream of the Burundi border to Lake Tanganyika.

Importantly, the assessment is presented with reference to the current baseline hydrological conditions, under which river flow upstream of Ruzizi II is determined by Lake Kivu water levels (and its associated natural variation) and the operation of Ruzizi I and, more directly, Ruzizi II hydropower plants.

Lake Kivu water levels and its associated natural variability govern the monthly intra-annual and inter-annual variability of inflows to Ruzizi III. Similar natural variability is also apparent in tributary inflows downstream of Lake Kivu, both in the ‘intervening catchment’ between Ruzizi II and Ruzizi III and further downstream near the Burundi border (the Rubyiro and Ruhwa tributaries, 13 km and 15 km downstream for the Ruzizi III HPP, respectively).

The operation of Ruzizi I and Ruzizi II hydropower plants varies according to this broader hydrological context. However, under all broad hydrological conditions, both plants operate under hydropeaking conditions such that a wide variation in sub-daily flows occurs in the Ruzizi River.

The hydrology baseline summarises recent operation of Ruzizi II HEPP illustrating the impact on water levels observed at Kamanyola at, Bugarama Bridge, 4 km downstream of the Ruzizi III powerhouse tailrace (see Figure 10-8). This shows: i) the regular occurrence of variation in sub-daily water levels of between 1 m and 1.5 m; and ii) such variation is not predictable – it can occur at different times of the day. These variations are within the threshold ramp up and ramp down rates for human safety and fish of 5 cm/min and 1 cm/min, respectively.

As the current baseline hydrological conditions in the Ruzizi River are not predictable, the EFA is based on the Ruzizi Cascade Model presented in the Feasibility Study (Tractebel, 2020). This explicitly takes into account the hydrological conditions in the Lake Kivu catchment as well as the optimised operational rules of Ruzizi I, Ruzizi II, and Ruzizi III. These operating conditions are based on a system-wide energy demand curve (see Figure 10-9) that divides the day into three periods: Peak Period 1; Peak Period 2; and Off-peak. Operational release curves have been defined for Ruzizi I, Ruzizi II and Ruzizi III, as shown in Figure 10-10:

- For Ruzizi I, it is optimal to release at the maximum installed capacity during the morning and afternoon peak periods. Outflow during the late-morning / early-afternoon secondary peak period and during the off-peak period vary according to hydrological condition – outflows are maximised when the reservoir level is greater than 1462.3 masl.
- For Ruzizi II, releases are constrained during the morning and afternoon peak periods due to limited storage and lag between Ruzizi I and Ruzizi II. Releases during the secondary peak period and during the off-peak period are conditioned by the Ruzizi I releases and the limited storage.

For Ruzizi III, it is optimal to release at the maximum installed capacity during the morning and afternoon peak periods. Outflow during the late-morning / early-afternoon secondary peak period and during the off-peak period vary according to hydrological condition. The high storage at Ruzizi III helps to mitigate against occurrences of “non-optimal” operation at Ruzizi II.

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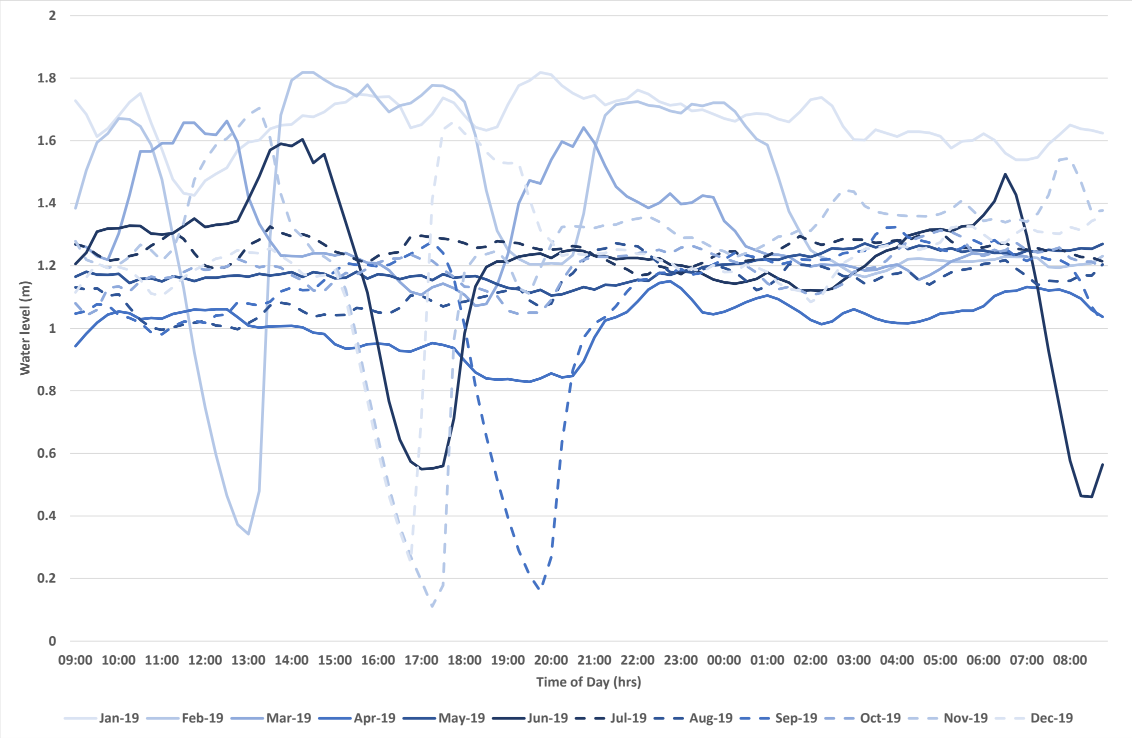

Figure 10-8 Selected Daily Water Levels at Kamanyola (2019)

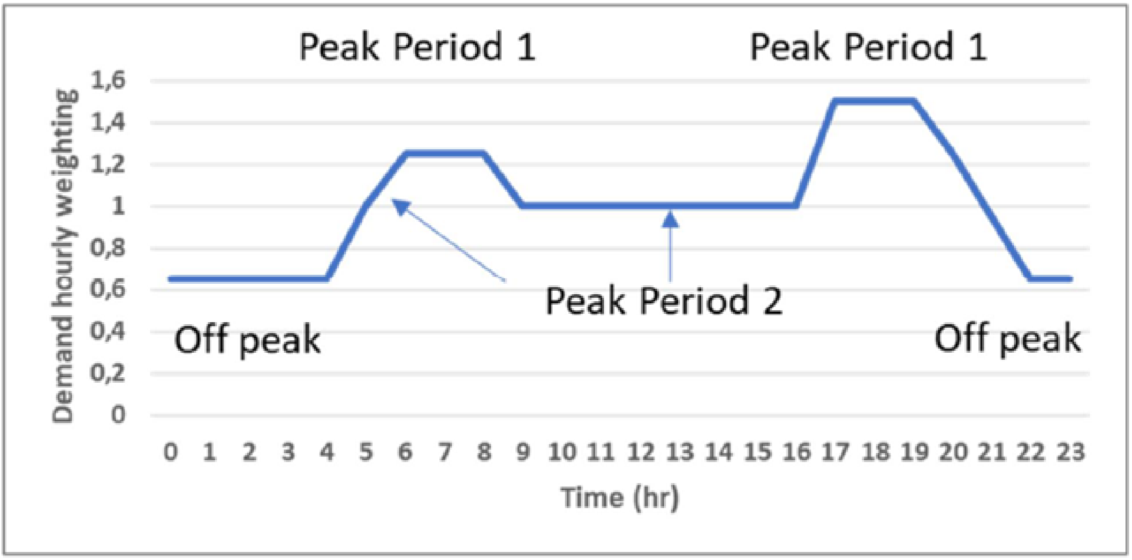

Figure 10-9 Ruzizi System Energy Demand Profile (after Tractebel, 2020)

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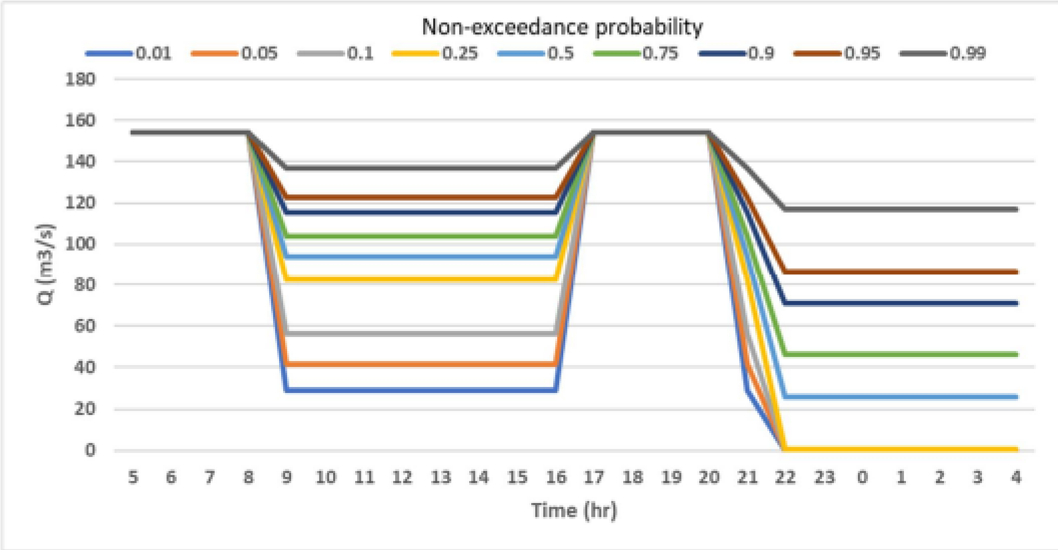
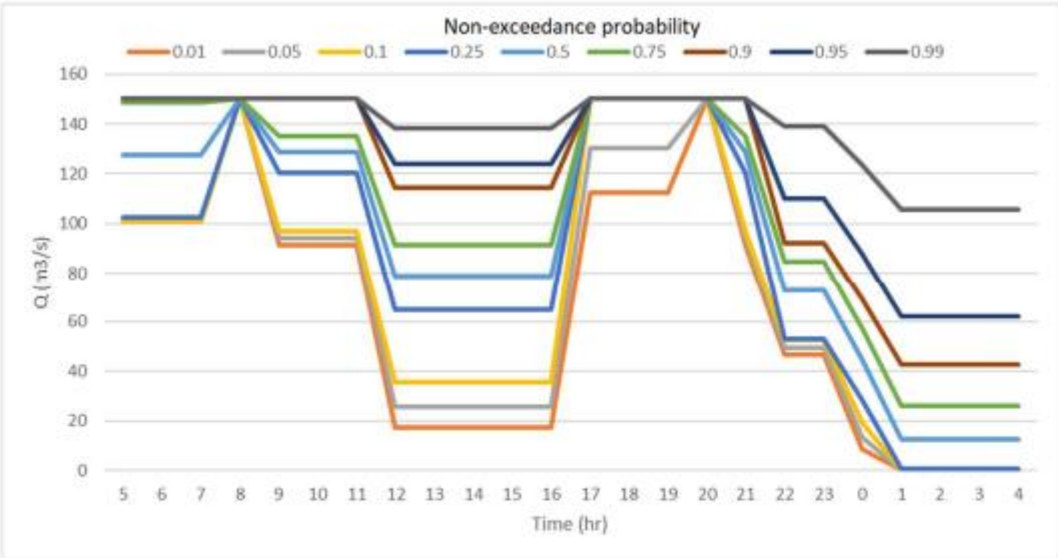
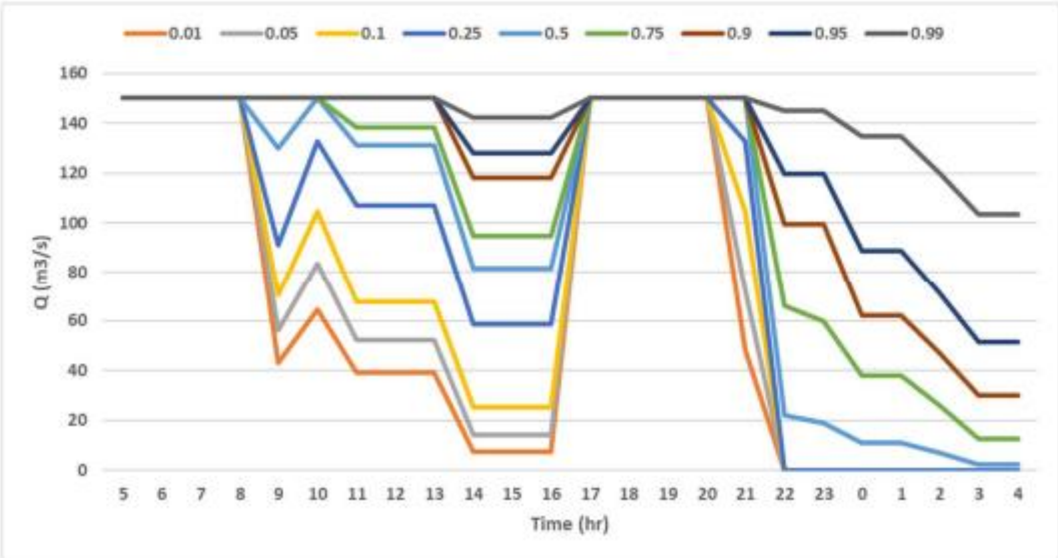


Ruzizi I



Ruzizi II



Ruzizi III

Figure 10-10 Ruzizi I, Ruzizi II, and Ruzizi III Operational Release Curves (after Tractebel, 2020)

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An important feature of hydropower operation is the ramp-up and ramp-down rates at the powerhouse, i.e., the time taken to change from one flow rate to another. Based on the hydrological analysis of existing water level data and discussions with REL, it has been assessed that the Ruzizi III powerhouse ramp-up and ramp-down rates are expected to be faster than the existing Ruzizi II ramp-up and ramp-down rates. Changes in turbined flow at Ruzizi II have been assessed to occur over a 30-minute duration whereas changes in turbined flow at Ruzizi III have been taken to occur over a 15-minute duration. However, the expected rate of water level variations from ramp up and ramp down rates are expected to be within thresholds for human safety and fish of 5 cm/min and 1 cm/min, respectively. During the start-up the Project will monitor rates of water level variations as strategic points and adapt ramp-up and ramp-down rates accordingly (see Vol. IV ESMP).

The full reach from Lake Kivu to downstream the Ruhwa River, showing the location of Ruzizi I, Ruzizi II, and Ruzizi III, is shown in Figure 10-11.

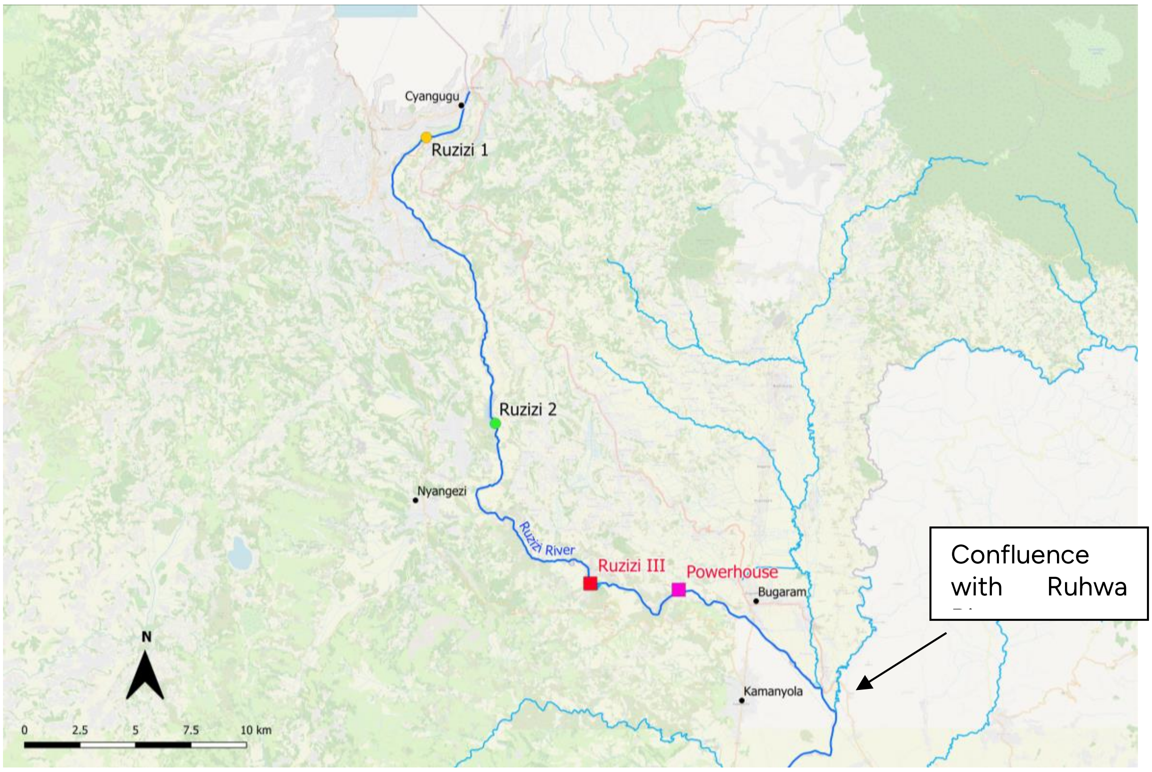

Figure 10-11 Ruzizi River from Lake Kivu to downstream the Ruhwa River

10.4.2 The Dewatered Reach – Ruzizi III Dam Wall to Powerhouse Tailrace

The dewatered reach is approximately 5.5 km long and is located between the planned Ruzizi III dam wall and the powerhouse release of turbined water back into the Ruzizi River.

The hydrological and hydraulic characteristics associated with the dewatered reach can be readily differentiated between the current baseline in which the reach is subject to hydropeaking effects associated with the operation of the Ruzizi II powerhouse release and the future post-project conditions in which an environmental flow release is to be made from the Ruzizi III dam wall. To date, the project has envisaged a simple, single value of 10 m^3/s for flow releases (9% Mean Annual Flow (MAF)) (Tractebel, 2020).

An assessment the of hydrological and hydraulic conditions of the dewatered reach has been made over a range of different flow rates, varying from 10 m^3/s (current environmental flow release from Ruzizi II to 160 m^3/s (the combined current environmental flow release and

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maximum hydropeaking release from Ruzizi II). Hydrological and hydraulic conditions associated with 10 m³/s and 160 m³/s are highlighted as these represent the current conditions experienced in the reach due to the hydropeaking operation of Ruzizi II.

Due to the irregular and unpredictable nature of historic releases from Ruzizi II, the proposed optimised Ruzizi II powerhouse release schedule (Tractebel, 2020) has been taken to represent "typical" current conditions. Such conditions each day include those associated with a minimum flow of approximately 10 m³/s and a maximum flow of approximately 160 m³/s. Selected hydraulic characteristics are highlighted for different modified environmental flows (10, 16.5 and 22 m³/s) to assist in contextualising the expected ecological and social impacts in the dewatered reach at different flow thresholds.

Figure 10-12 and Figure 10-13 show the extent of the 5.5-km reach between Ruzizi III dam wall and the powerhouse. The reach is heterogeneous in nature with a steeper, more turbulent, section in the middle-upper reach and a relatively shallower, less turbulent, section in the lower section near the powerhouse.

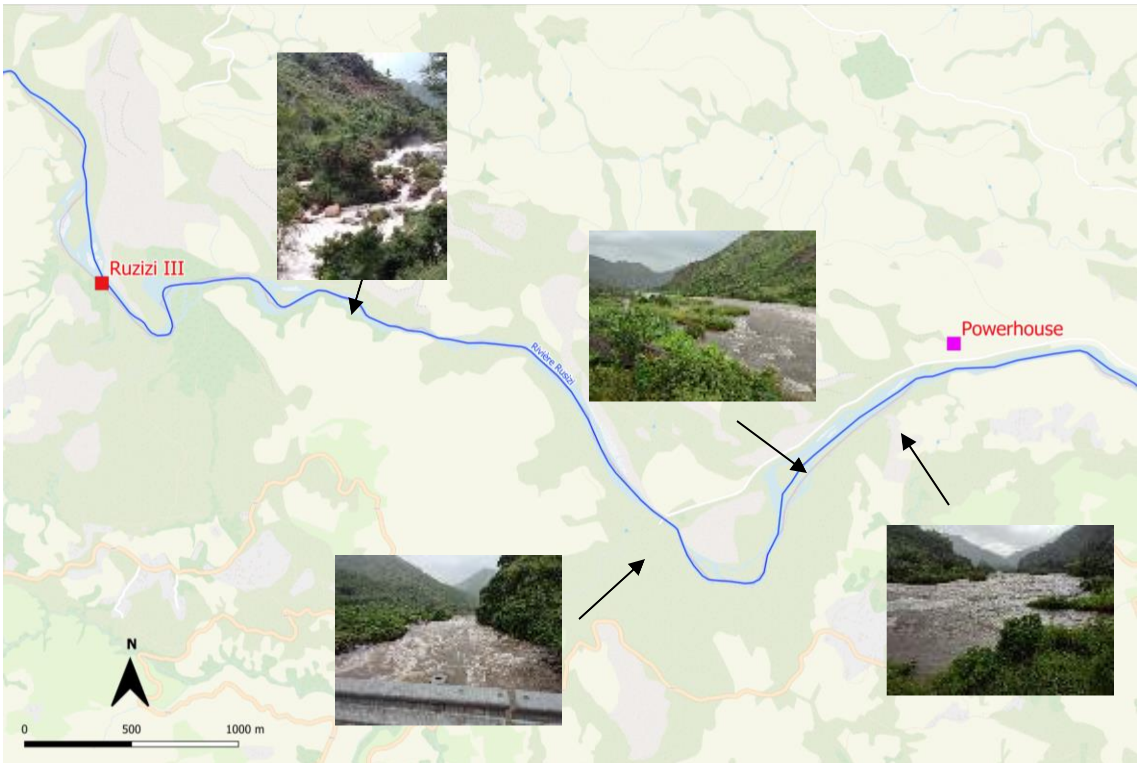

Figure 10-12 Ruzizi Reach between Ruzizi III Dam Wall and Powerhouse

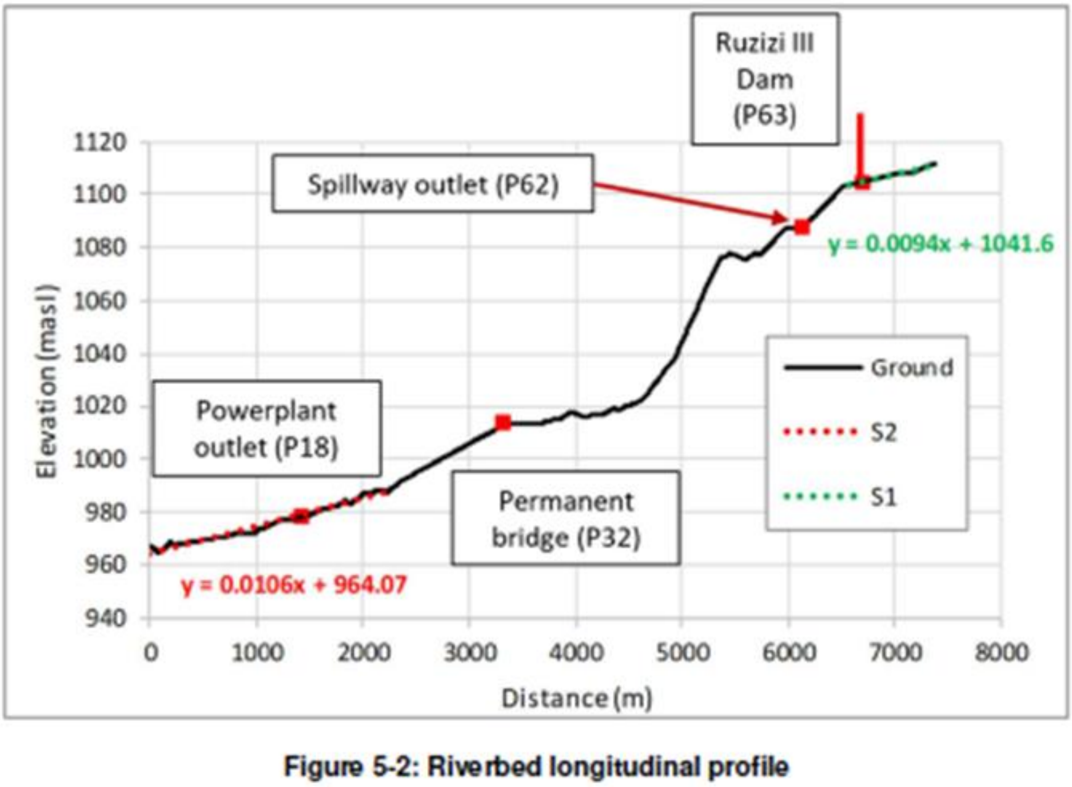

Figure 10-13 Longitudinal Profile of the Ruzizi Reach from Ruzizi II Dam wall to the Powerhouse (after Tractebel, 2020)

A Hydrological and Hydraulic Characteristics

The hydrological and hydraulic characteristics in the 5.5-km dewatered reach is currently subject to a high level of sub-daily variation in river flow. The total wetted area typically varies between 157,000 m^2 and 354,000 m^2. Compared with average flow conditions, it both shrinks to half of its usual size and expands by approximately one-sixth of its usual size on a daily basis. Average depth changes on a typical day between 0.55 m and 1.60 m. Average velocity changes on a typical day between 0.55 m/s and 1.15 m/s.

The transition to a future post-project environmental flow release for the dewatered reach will necessarily remove the variation in sub-daily river flow and provide more stable hydrological and hydraulic characteristics.

Figure 10-14 and Figure 10-15 summarise the variation of total wetted area for different flow conditions between 10 m^3/s (current minimum flow) and 160 m^3/s (current peak flow):

- At a flow of 10 m^3/s, the total wetted area is 157,000 m^2 (44% and 48% of peak and natural Average Annual Flow (AAF), respectively);
- At a flow of 16.5 m^3/s, the total wetted area is 183,000 m^2 (52% of peak flow);
- At a flow of 22 m^3/s the total wetted area is 204,000 m^2 (58% of peak flow);
- At a flow of 160 m^3/s, the total wetted area is 354,000 m^2 (100%, 109% peak/natural AAF);
- Under normal conditions, the total wetted area is at least 86% (also 86 m^3/s) for 75% of the time – and even under dry conditions it is at least 74% (48 m^3/s) for 75% of the time;
- During daylight hours, the total wetted area varies between 87% and 100% under normal conditions (and drops to 74% under dry conditions). During night-time hours, the total wetted area drops to 61% under normal conditions (and drops to 46% under dry conditions); and

- The largest change in total wetted area (and indeed all hydrological and hydraulic characteristics) is expected to occur during the transition between end of night-time operation to start of daylight operation as a switch is made between reservoir refill operations to energy production operations.

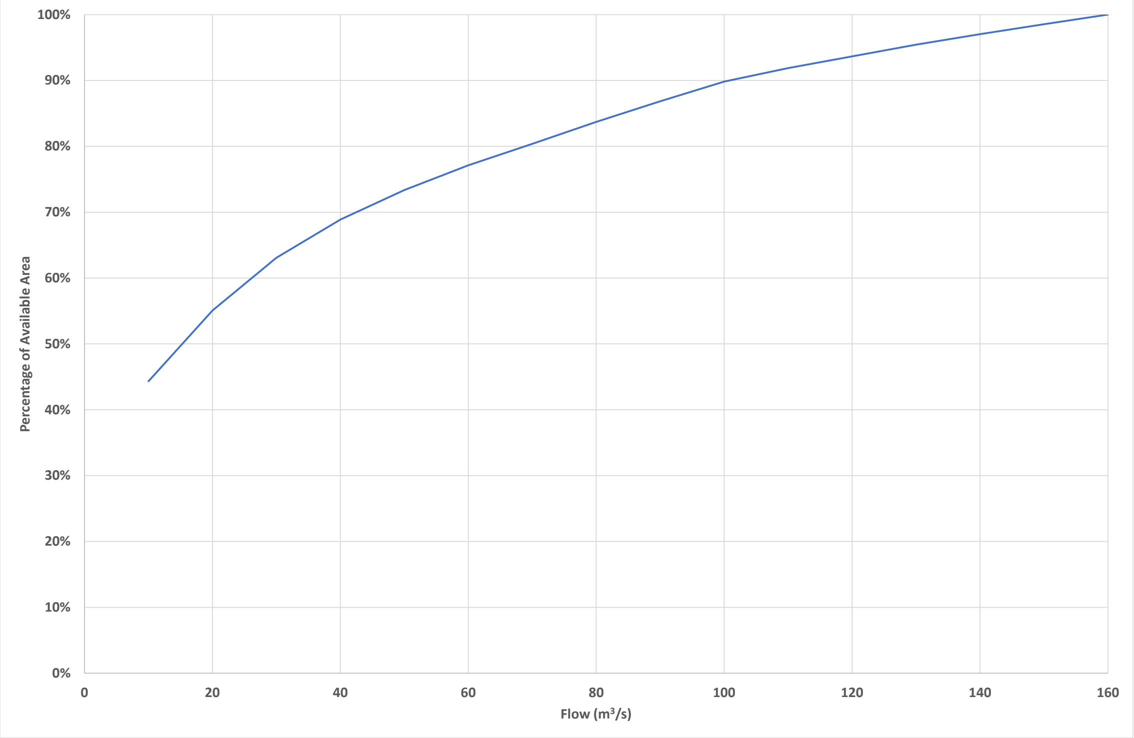

Figure 10-14 Variation of dewatered reach total wetted area under different flow conditions

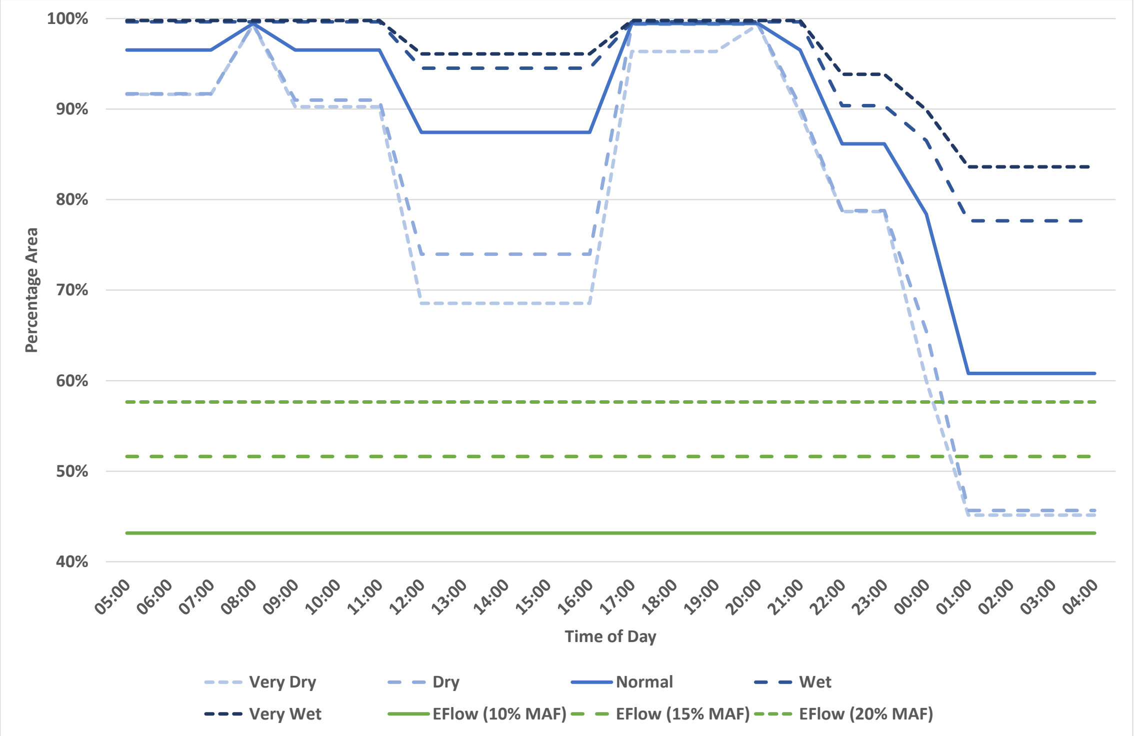

Figure 10-15 Sub-daily Variation of Dewatered Reach Total Wetted Area

Figure 10-16 summarises the monthly average intra-annual and inter-annual variation of dewatered reach total wetted area:

- Under normal wet period conditions, the dewatered reach total wetted area varies between 88% and 94% throughout the year. The wetted area reduces to up to 83% in dry conditions and increases by up to 98% in wet conditions.
- Under normal dry period conditions, the dewatered reach total wetted area varies between 87% and 84% throughout the year. The wetted area reduces to up to 80% in dry conditions and increases by up to 91% in wet conditions.
- The total wetted area under different levels of environmental flow is also presented, showing clearly that the total wetted area is significantly lower than the current (monthly average) total wetted area.

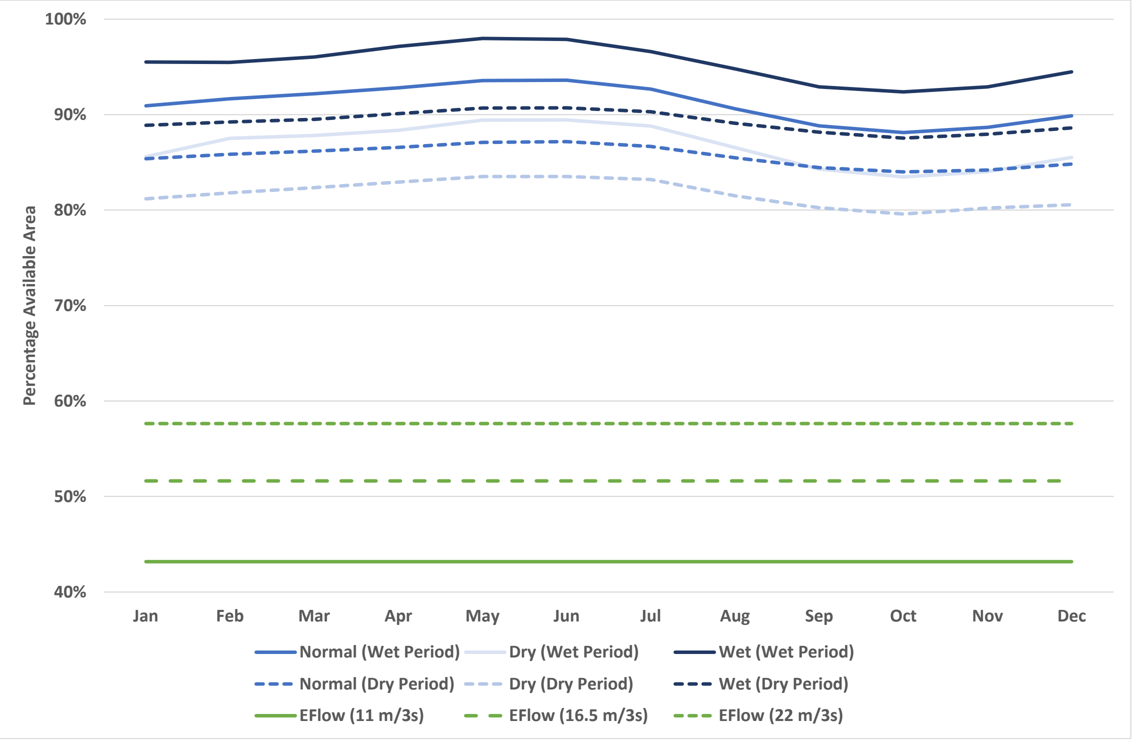

Figure 10-16 Intra-annual and Inter-annual Variation of Dewatered Reach Total Wetted Area

Figure 10-17 summarises the variation of average depth (and total wetted area) in the dewatered reach for different flow conditions between 10 m^3/s (current minimum flow) and 160 m^3/s (current peak flow):

- At a flow of 10 m^3/s, the average depth is 0.55 m (over a wetted area of 44%, 48% peak/natural AAF); and
- At a flow of 160 m^3/s, the average depth is 1.60 m (over a wetted area of 100%, 109% peak/natural AAF).

Significant variability of water depths within the reach can also be identified, for example:

- At a flow rate of 10 m^3/s, 91,000 m^2 (26%, 28% peak/natural AAF) is at least 0.5 m deep, 40,000 m^2 (11%) is at least 1 m deep, and 6,000 m^2 (2%) is at least 2 m deep; and
- At a flow rate of 160 m^3/s, 335,000 m^2 (95%, 103% peak/natural AAF) is at least 0.5 m deep, 287,000 m^2 (81%) is at least 1 m deep, and 131,000 m^2 (37%) is at least 2 m deep.

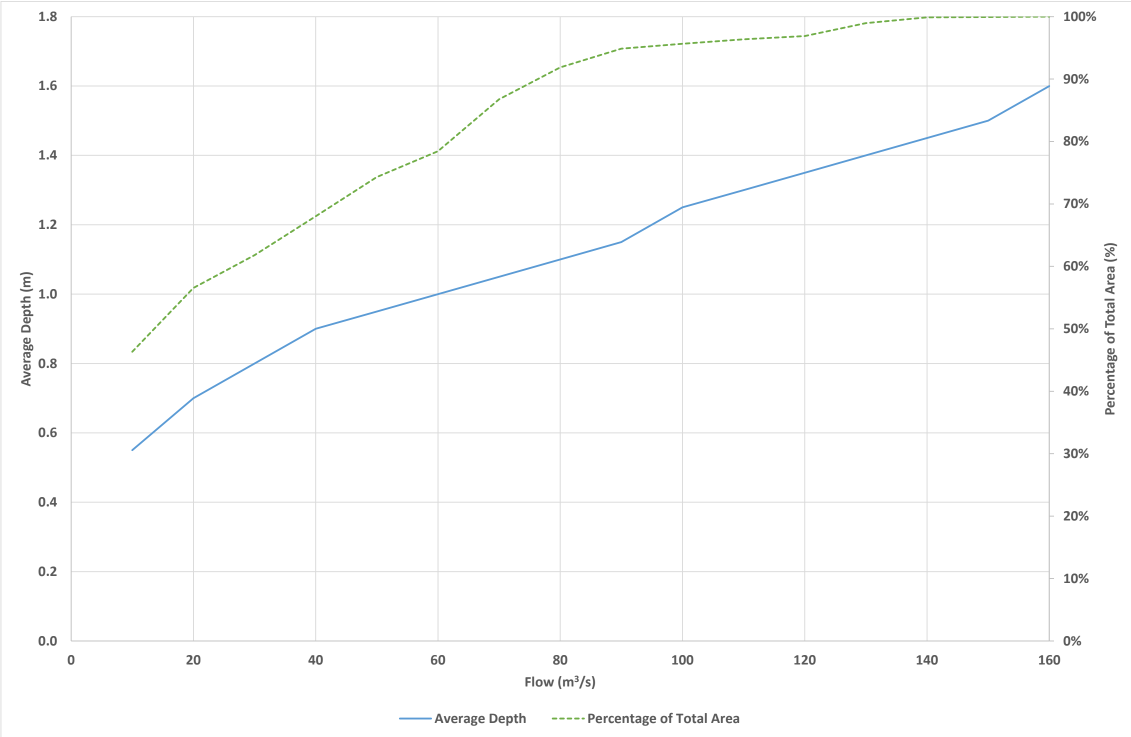

Figure 10-17 Variation of Dewatered Reach Average Depth Under Different Flow Conditions

Figure 10-18 summarises the variation of average velocity (and total wetted area) in the dewatered reach for different flow conditions between 10 m^3/s (current minimum flow) and 160 m^3/s (current peak flow):

- At a flow of 10 m^3/s, the average velocity is 0.55 m/s (over a wetted area of 44%, 48% peak/natural AAF); and
- At a flow of 160 m^3/s, the average velocity is 1.15 m/s (over a wetted area of 100%,109% peak/natural AAF).

Significant variability of within reach velocities can also be identified, for example:

- At a flow rate of 10 m^3/s, 82,000 m^2 (23%, 28% peak/ natural AAF) is at least 0.5 m/s fast, 37,000 m^2 (10%) is at least 1 m/s fast, and 3,000 m^2 (1%) is at least 2 m/s fast.
- At a flow rate of 160 m^3/s, 339,000 m^2 (96%, 103 peak/natural AAF) is at least 0.5 m/s fast, 185,000 m^2 (52%) is at least 1 m/s fast, and 98,000 m^2 (28%) is at least 2 m/s fast.

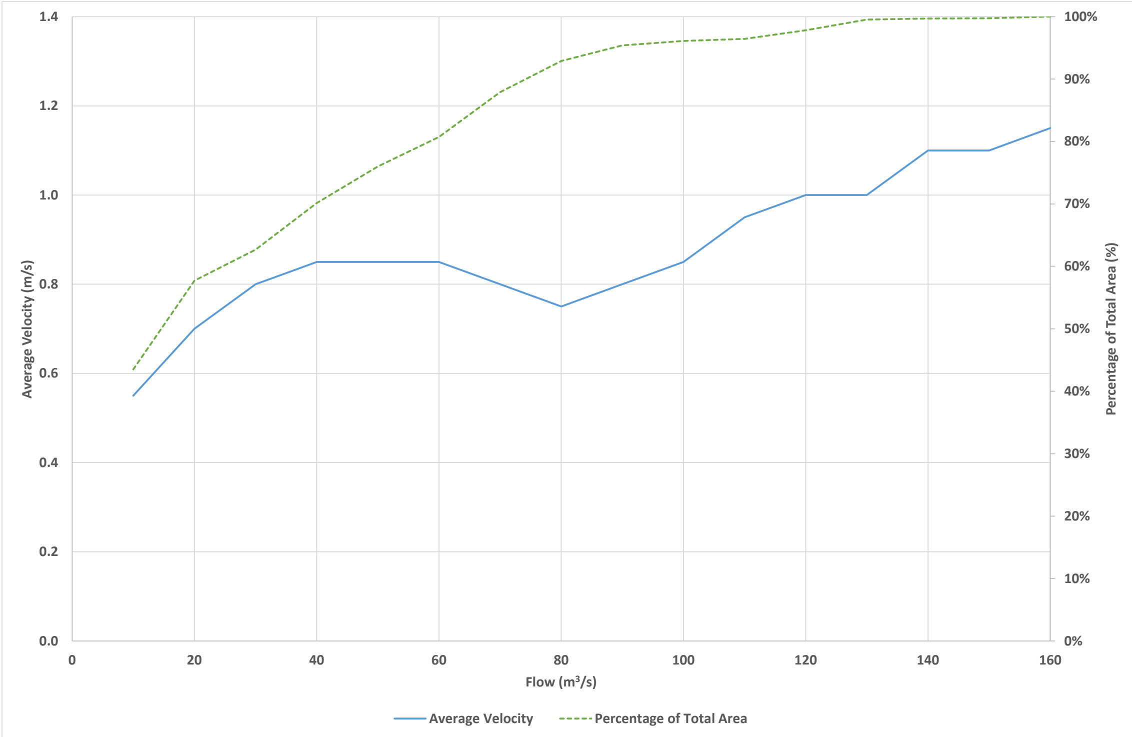

Figure 10-18 Variation of Dewatered Reach Average Velocity Under Different Flow Conditions

A summary of the combined effects of depth and velocity (hazard) is presented in the accompanying annex. Hazard status is particularly relevant to considering community safety. Hazard is significantly lower at low flows (approximately 10 m^3/s) than it is at high flows (approximately 160 m^3/s), illustrating the potential danger that may be faced during ramp-up from off-peaking to peaking conditions in the river.

The hydraulic conditions in the 1 km reach below the Ruzizi III dam wall with an EFlow of 10 m^3/s are further illustrated by the 2D hydraulic modelling as illustrated in Figure 10-19, Figure 10-20, and Figure 10-21.

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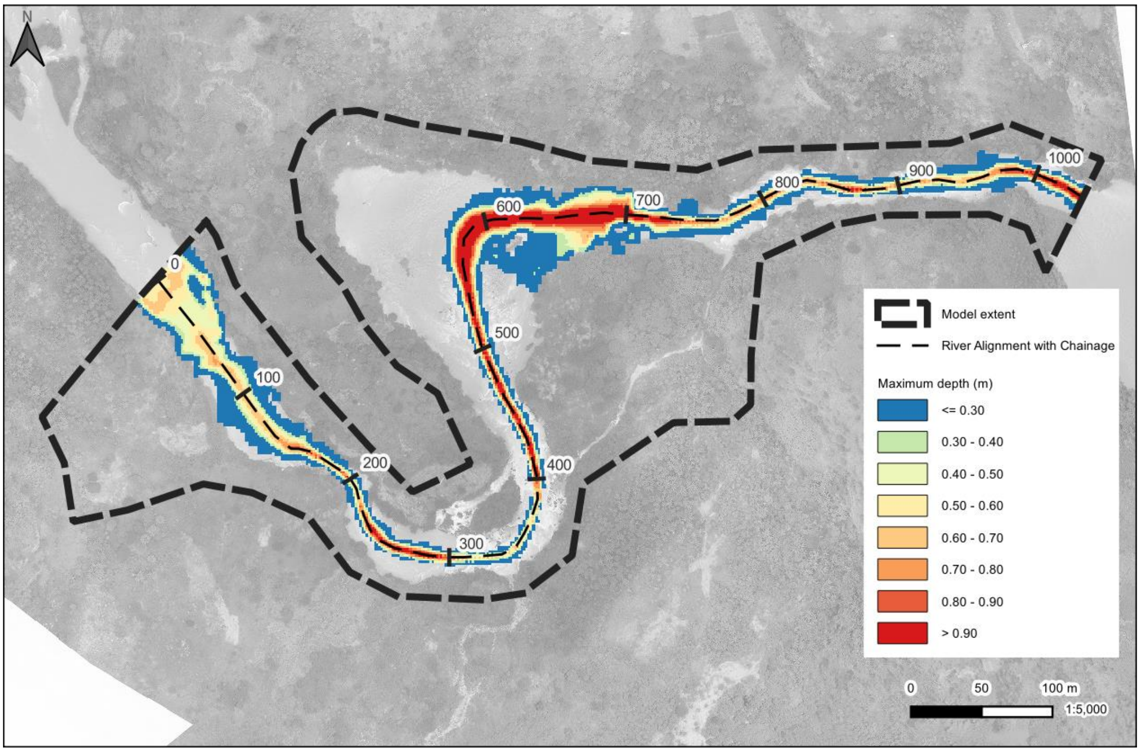

Figure 10-19 Modelled depth for an EFlow of 10 m^3/s in the reach below Ruzizi III dam wall

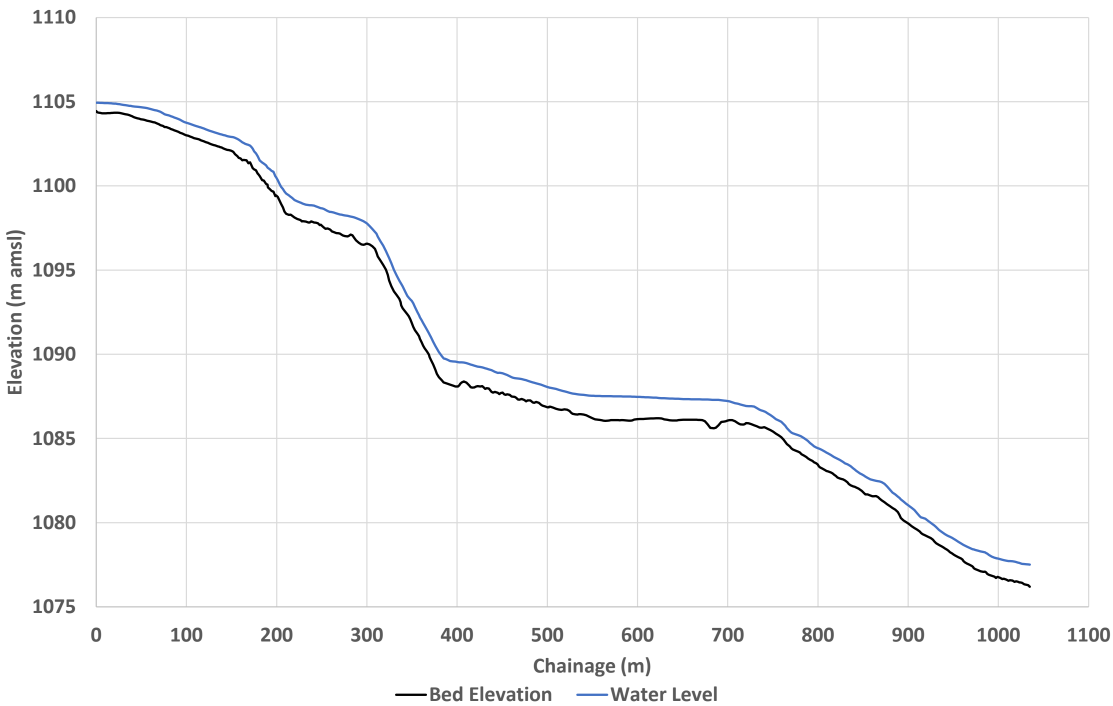

Figure 10-20 Longitudinal slope and water level for an EFlow of 10 m^3/s in the 1-km reach immediately below Ruzizi III dam wall

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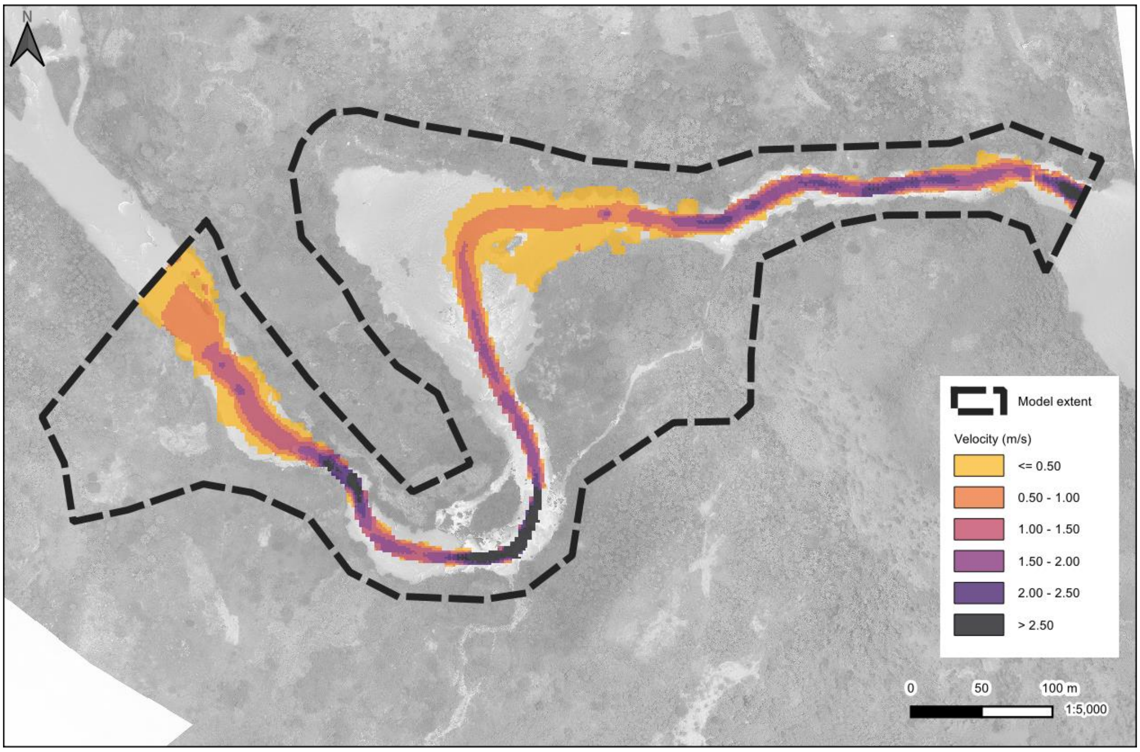

Figure 10-21 Modelled velocity for an EFlow of 10 m^3/s in the reach below Ruzizi III dam wall

It can be seen that the reach below the Ruzizi III dam wall is typically very steep, dropping almost 30 m in a little over 1,000 (slope = 0.027 m/m). The stretch between approximately 300 m and 400 m downstream of the dam wall is particularly steep, dropping almost 10 m (slope = 0.103). There is a good continuity of minimum depth of water (greater than the 0.3 m depth considered necessary for fish movement) throughout the reach, with lower marginal depths particularly in the flatter parts of the reach. Velocity tends to be high in the steeper parts of the reach (exceeding 2.5 m/s in places) with lower velocities (less than 0.5 m/s) on the channel margins and in the flatter areas. These modelled predictions are important for assessing potential impacts on the aquatic ecosystem, particularly fish.

B Geomophological, Ecological and Social Context

B.1 Geomorphology

The dewatered reach is located along a confined valley setting of the Ruzizi River with an average gradient of 0.0238 m/m over the 5.5 km distance between the dam wall and tail race. Due to the confined nature of the river, there is no or limited floodplain development. The riverbed is largely bedrock and boulder dominated with pool-rapid or pool-riffle reach types. This steep reach is characterised by short pools (except one long pool) and long rapids. The calcrete/bedrock and large stable blocky material form rapids. Small bedrock islands form anastomosing channels.

Sediment deposition on these islands supports vegetation establishment. The banks are composed of large blocky material filled with a finer sand and clay matrix. The channel is relatively straight to wandering and follows the abrupt bends of the valley floor. Agriculture is widespread on the hillslopes, and landslide scars suggest sediment input directly to the river or tributary channels.

There is a right bank tributary approximately 3.2 km downstream of Ruzizi III dam wall location supplying significant sediment volumes to this reach (frequent blanket sediment deposits and channel avulsions on the tributary fan can be seen on satellite images). These lateral inputs contribute both fine suspended sediment and coarser bedload material to the channel.

B.2 *Aquatic Ecology*

Macroinvertebrates:

Aquatic biotopes within the dewatered reach comprised the following:

- Five stretches of Deep-Very Fast Cascade, with a total length of approximately 1.6 km, and seven stretches of Deep-Fast Rapids, with a total length of approximately 2.7 km. Limited information was available on aquatic macroinvertebrates in these biotopes, suggesting that they are likely to support mostly grazing and filter-feeding taxa that tolerate extreme current speeds. Taxa expected include freshwater limpets (*Burnupia* sp), Tricorythid mayflies and certain species of blackflies, such as *Simulium damnosum* and *S. dentulosum.* Macroinvertebrate production in these areas is typically very high, so these areas constitute potentially important nodes of secondary production (i.e., food for fish).
- One area of Shallow-Fast Riffle, approximately 0.6 km downstream of the proposed HEPP. This area is likely to support a high diversity of macroinvertebrates that would include most functional feeding categories. The high diversity of macroinvertebrates expected in this area is attributed partly to interstitial spaces between bed substrates that provide a large surface area for colonisation by macroinvertebrates, the bed substrates that provide protection to macroinvertebrates from predation and flood events, and shallow conditions that are conducive to benthic algal growth, which provide food for vegetarian macroinvertebrates (and fish). The quality of such biotopes is typically reduced by the accumulation of fine sediments, and this highlights the need for periodic high flow events to flush and mobilise fine sediments from these areas.
- Two stretches of Deep-Slow Pools, with a total length of approximately 1.2 km. No information was available on macroinvertebrates in such pools, but diversity and abundance in these areas is likely to be low because of light limitation and the limited diversity of hydraulic conditions.

Fish:

This reach is characterised by alternating Fast Deep, Very-Fast Deep and Slow Deep habitat classes. In this high- to medium-gradient transitional geomorphic zone of the Ruzizi River, Slow Deep habitats are uncommon and important both as maintenance habitat for fish guilds selecting for semi-lotic pool and lentic fish guilds, including the haplochromine cichlids and *Enteromius* barbs. These areas will also provide hydraulic cover and resting areas for the migratory Lithophilic guild including the *Labeo* and *Labeobarbus* species. The Fast Deep and Very-Fast Deep habitats are important for the non-migratory lotic riffle-rapid guilds including the *Amphilius* genera. The large bed-elements – cobble and boulder – will provide important interstitial habitat for these species, as well as providing spawning beds for the *Labeo* and *Labeobarbus* species that are typically migratory.

Maintenance flows to provide adequate depth cover (greater than 0.3 m) over shallow riffles and rapids for most of the year is important, especially over the migration season (likely August to October) together with flushing flows for moving sediment from the bed elements. Maintaining the quality of the interstitial substrate habitats will also be important.

B.3 *Terrestrial Ecology*

Riparian Vegetation:

Natural riparian habitat is limited on the riverbanks along this reach and can be found on small islands in the river. Two types of riparian vegetation are represented, namely Riparian Thicket and Riparian Wetlands. Riparian Thicket is most prevalent on the rocky islands in the long section of rapids about 600 m downstream of the dam wall site, although narrow, fragmented strips of thicket are located on riverbanks at a few places. Riparian Wetlands are mostly located on islands away from the rapids and not along the riverbanks on this reach, and several are cultivated. Species dependent on a wet bank are more prevalent in the Riparian Wetland community, while flow-dependent species are not well represented in either Riparian Wetland or Riparian Thicket. The thicket on islands in the rapids comprise species that are more associated with rocky substrate than a wet bank or river flows. No threatened species were recorded in either of these two riparian vegetation types.

Riparian Fauna:

The riparian avifauna, mammal and herpetofauna assemblages are species-poor in this reach. Riparian mammals such as marsh mongoose and otter species may be present occasionally, but larger herbivores such as hippopotamus are not represented along this reach. The riparian avifauna assemblage contains surprisingly few fish-eating species although a limited number are expected to be present in this reach, e.g., white-breasted cormorants were recorded foraging in the rapids during fieldwork. Herpetofauna will be mostly represented by widespread generalist amphibians as well as a few riparian reptile species such as water snakes (*Lycodonomorphus* species) and terrapins (*Pelusios* species). No threatened species of fauna were recorded in the dewatered reach.

B.4 *Social*

The following paragraphs provide an overview of local communities' reliance on Ruzizi's water for livelihoods and domestic needs in the dewatered reach. Issues related to water quality and sediment load will not be covered in this analysis, as no discernible difference from current conditions is expected, due to the low residence time of water in the Ruzizi III reservoir.

The dewatered reach is characterised by a low level of social reliance on the river, due to difficulty of access from surrounding villages (mostly located much higher up above the steep Ruzizi valley slopes) and high velocity of water. Agriculture is dominated by a mix of steep slope cultivation alongside farming of taro, maize, cassava, banana, and fruit trees on riverside plots. These riverside plots are irrigated directly from the river, mainly by using buckets and less frequently irrigation pumps. The collection of water for consumptive use is not as high as it is downstream of the powerhouse, due to the higher distance from surrounding villages. Activities such as bathing or clothes-washing in the river have also not been observed in the dewatered reach and river crossing here is rare due to high water velocities. Fishing is practiced, but not as frequently as it is downstream of the powerhouse, and it does not represent an important source of livelihood for many households in the local communities.

In this stretch, there are two intangible cultural heritage sites which require villagers to physically enter the river on a regular basis. The first site is an island which is used for praying downstream of the reservoir. This site was inaugurated in August 2021 by a group of Congolese Christians, who regularly cross the river at night or during the day to reach the praying area. The second site is a flat riverside opening used for baptisms which is located within the footprint of the proposed Disposal Area.

C **Indicators Linked to Hydrological and Hydraulic Characteristics**

Table 10-3 provides and overall summary of the ecological and social functional relationships with hydrological and hydraulic characteristics within the dewatered reach.

The change in hydrological and hydraulic characteristics from a highly varying hydropeaking reach in which sub-daily flows vary from 10 m^3/s to 160 m^3/s to a reach in which ecological and social reliance is maintained by an environmental flow release is predicted to result in a significant increase in in-channel sedimentation and a significant improvement in aquatic ecology for non-migratory / migratory fish and macro-invertebrates.

These functional relationships and impacts have been assessed assuming a constant EFlow of 10 m^3/s. During the assessment, higher environmental flows of 16.5 and 22 m^3/s were also considered but have been assessed as not providing a material increase in ecological and social reliance value in the dewatered reach. Indeed, it is important to note that **a stable EFlow of 10 m^3/s has been assessed as likely to provide an improvement in aquatic ecology for non-migratory / migratory fish and macro-invertebrates** in the dewatered reach. Although wetted area and depth will be significantly reduced in this reach, an improvement in aquatic ecosystem condition is predicted due to the more stable flow conditions that will be created. This includes the removal of sub-daily variation in depths associated with the existing hydropeaking that repeatedly dewater riffle-rapid habitats leading to aquatic biota mortality, and the removal of sub-daily variation in velocities that reduces the interstitial delivery of well-oxygenated water through bed elements following down-ramping. These potential aquatic ecology benefits will depend on maintaining continuity of flow across the dewatered reach that is not prevented from significant sediment inputs from landslides and limiting fishing pressures in the shallow water dewatered reach.

Table 10-3 Summary of Ecological and Social Functional Relationship / Impacts within the Dewatered Reach

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Geomorphology		
Increased channel erosion Stable channel bed due to large bed material, cemented bed material (calcrete) and bedrock. Small gravel and sand bars present, but frequent flow level fluctuations have armoured the bed, so low potential for further channel incision.	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	Minor
	Ramping Rates	No / Insignificant
Increased sedimentation in channel Lateral sediment inputs could overwhelm the transport capacity of the reduced flow, resulting in sedimentation (coarse sediment bars downstream of tributaries and fine sediment blankets in slack waters) in low velocity habitats. Extreme mass movements of sediment, such as landslides could block the channel, resulting in back flooding. Due to the reduced flow rate, the dam will fill slower (longer period of damming) and cut/entrain through the deposited material at a lower rate.	Flow	Moderate
	Elevation / Depth	Minor
	Velocity	Moderate
	Area	Moderate
	Ramping Rates	Significant
Bank erosion Bank erosion is generally associated with reduced longitudinal sediment input, possibly leading to channel erosion and associated bank collapse and/or direct fluvial erosion. The fixed nature and large clast size of the banks are unlikely to be eroded due to the reductions in sediment load and flow energy. The banks have been exposed to high velocity flows with frequent variations in water level, thus erosion has already taken place along sensitive reaches. Some localised bank erosion might take place as vegetation and agriculture change along the banks. The riverbanks are low in elevation, so the risk is fairly low if bank erosion should take place.	Flow	Minor
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	Minor
Aquatic Ecology		
Non-migratory fish: abundance and diversity Fish habitat downstream of the powerhouse is comprised predominantly of the Fast Deep habitat class, with minimal Slow Deep habitat. Fish habitats of highest importance are the shallower riffle-rapid habitats with larger bed elements to provide habitat for the lotic riffle-rapid fish guilds (e.g. *Chiloglanis* and *Amphilius)* although fish abundance of these smaller fish species is likely to be lower than other reaches downstream due to the high and variable velocity of water caused by upstream hydropeaking.	Flow	
	Elevation / Depth	Significant Positive
	Velocity	Significant Positive
	Area	Significant Positive
	Ramping Rates	N/A
Migratory fish: abundance and diversity Fish habitat downstream of the powerhouse is comprised predominantly of the Fast Deep habitat class, with minimal Slow Deep habitat. Fish habitats of highest importance are the shallower riffle-rapid habitats with larger bed elements to provide habitat for the lotic lithophiic migratory fish guilds (e.g. *Labeobarbus* sp.). Fish abundance of these species is likely to be lower in the upper portion of this reach than further downstream due to the presence of a long steep rapid which pay pose a barrier to some migratory fish.	Flow	
	Elevation / Depth	Significant Positive
	Velocity	Significant Positive
	Area	Significant Positive
	Ramping Rates	N/A
	Flow	Minor
	Elevation / Depth	

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Macro-invertebrates: abundance and diversity Both are expected to increase compared to the current operation because stable daily and sub-daily water levels will improve the quality of instream habitats, particularly for taxa that are sensitive to hydraulic conditions. Stable hydraulic conditions and clear water released from the Ruzizi III are also likely to create conditions suitable for growth of submerged aquatic plants, such as *Potamogeton schweinfurthii*, and this will increase the availability of substrates for macro-invertebrate colonisation.	Velocity	Significant Positive
	Area	No / Insignificant
	Ramping Rates	N/A
Terrestrial Ecology		
Riparian vegetation: abundance and diversity The two types of riparian vegetation currently present in this reach, namely Riparian Thicket and Riparian Wetland, will be impacted in different ways by the project-related changes to the river that are likely to occur. This is mainly because of the differing ecological characteristics of the species in each habitat, such as the proportion of species requiring a constant wet bank or flow-dependent species. Riparian Wetlands have the higher proportion of these species and are thus more likely to be impacted as changes in depth and area of the river result in changes to the availability of a wet bank and accessibility of riparian species to flowing water. Neither habitat is dependent on the other, and merely occupy different microhabitats in the riparian zone.	Flow	Minor
	Elevation / Depth	Minor
	Velocity	Minor
	Area	Moderate
	Ramping Rates	No / Insignificant
Riparian fauna: abundance and diversity The riparian fauna assemblage is associated with the two vegetation types described above, as well as open water habitat in the river. The species composition of the faunal assemblage is currently dominated by widespread habitat generalists and overall species richness is low. Changes in flow, depth and velocity are factors likely to have non-significant impacts on riparian fauna species.	Flow	Minor
	Elevation / Depth	Minor
	Velocity	Minor Positive
	Area	Minor
	Ramping Rates	No / Insignificant
Social		
Consumptive Water Use Local communities are frequently using this stretch of the river for domestic water collection and irrigation with buckets. Water is generally not collected for drinking in this area. Social reliance on this stretch of the river for consumptive use is moderate.	Flow	Minor
	Elevation / Depth	Minor
	Velocity	Minor
	Area	Minor
	Ramping Rates	N/A
Non-Consumptive Water Use: Fishing Local communities are currently using this stretch of the river infrequently for casual fishing activities.	Flow	Minor Positive
	Elevation / Depth	Minor Positive
	Velocity	Minor Positive
	Area	Minor Positive
	Ramping Rates	N/A
Community Safety Local communities do not regularly physically enter or cross the river due to the hazardous nature of this stretch, aside from regular crossing to reach a praying spot downstream of the future dam. Social exposure to river crossing hazards is high.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	N/A

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10.4.3 The Hydropeaking Reach – Ruzizi III Powerhouse Tailrace to Burundi Border

A detailed assessment of hydropeaking has been undertaken for the approximately 10 km reach downstream Ruzizi III powerhouse to immediately downstream the Burundi border.

The following reach hydrological and hydraulic characteristics are presented:

- Minimum and maximum flow, and flow range (m^3/s): This provides an overall summary of the hydrological conditions experienced during a 24-hour period.
- Minimum and maximum elevation (masl) and elevation range (m): This provides a summary of the variation in water level. River cross-section profiles are also graphically presented such that depths – and impacts that are depth dependent – can be visually interpreted.
- Minimum and maximum average velocities, and average velocity range (m/s): This provides an overview to inform impacts that are velocity dependent.
- Minimum and maximum cross-section area, and cross-section area range (m^2): This provides an overview of the 'size' of the Ruzizi River and its overall available habitat area.
- Ramping-up and ramping-down rates (cm/min): This provides a summary of how quickly water levels change over different durations. Ramp-down rates of greater than 1 cm/minute can be associated with fish stranding impacts. Ramp-up rates of greater than 5 cm/minute can be associated with community safety impacts.

The hydrological and hydraulic characteristics are presented for five selected key representative locations:

- Downstream Ruzizi III powerhouse release location (DRIIIPH);
- Upstream Bugarama Bridge / Kamanyola Monitoring Station (UBBKMS);
- Upstream Rubyiro tributary (URUBTR);
- Upstream Burundi border / Ruhwa tributary (URUHTR); and
- Downstream Burundi border / Ruhwa tributary (DRUHTR).

Based on an expert assessment of similarity, the resultant hydrological and hydraulic characteristics are functionally related to the geomorphological, ecological, and social context in the following three sub-sections. Individual sub-sections are presented for (i) Downstream Ruzizi III powerhouse tailrace and (ii) Bugarama Bridge / Kamanyola Monitoring Station. The third sub-section groups together the hydrological and hydraulic characteristics for the locations from upstream Rubyiro tributary to downstream Burundi border / Ruhwa tributary.

Figure 10-22 shows the location of each of the selected key representative locations.

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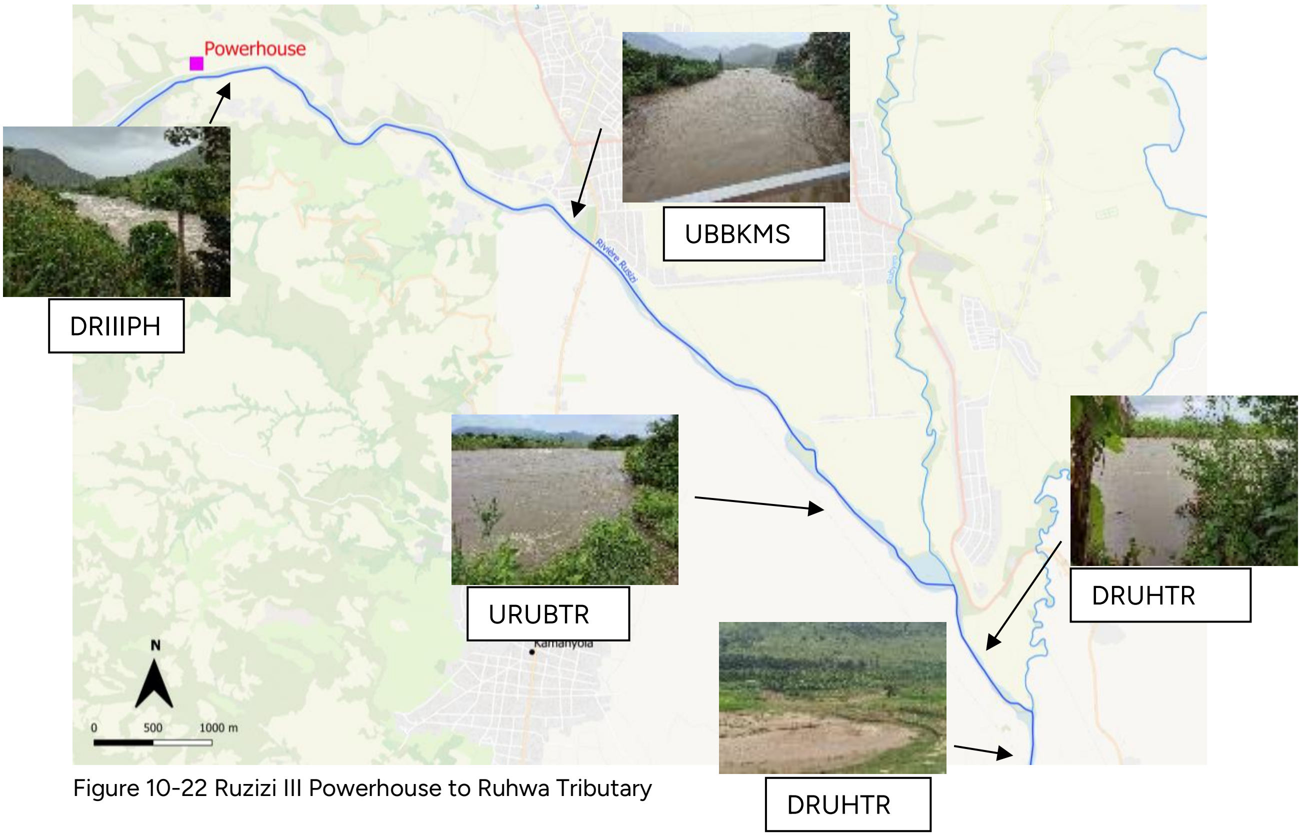

Figure 10-22 Ruzizi III Powerhouse to Ruhwa Tributary

Five flow conditions are presented, based on the optimised reservoir operation schedules presented in the Feasibility Report:

- "Very dry" conditions (95% exceedance probability);
- "Dry" conditions (90% exceedance probability);
- "Normal" conditions (50% exceedance probability);
- "Wet" conditions (10% exceedance probability); and
- "Very wet" conditions (5% exceedance probability).

The accompanying annex illustrates the seasonality of such flow conditions. An understanding of seasonality (intra-annual conditions) and inter-annual conditions is an important dimension when considering the ecological and social impacts associated with the prevailing hydrological and hydraulic conditions. Typically, longer-term variation in flow conditions is more pronounced than season variation in flow conditions.

Table 10-4 and Table 10-5 summarise the model inflows adopted for each of these flow conditions, for the current baseline and future post-project scenarios:

- The model inflows for the current baseline scenario include: i) Ruzizi II environmental flow; ii) Ruzizi II powerhouse release; iii) 'intervening catchment' inflows; iv) River Rubyiro inflows; and v) River Ruhwa inflows.
- The model inflows for the future post-project scenario include: i) Ruzizi III environmental flow; ii) Ruzizi III powerhouse release; iii) River Rubyiro inflows; and iv) River Ruhwa inflows.

Table 10-4 Summary of current baseline hydrological inflows in the Ruzizi II – Burundi Border Reach

Scenario	Ruzizi II Environmental Flow (m^3/s)	Ruzizi II powerhouse release (m^3/s)	Intervening Catchment Flow (m^3/s)	Total Flow to Ruzizi III (m^3/s)	River Rubyiro Flow (m^3/s)	River Ruhwa Flow (m^3/s)
Very Dry	10.8	Figure 10-23	1.3	78.3	4.0	8.6
Dry	10.8		1.6	84.3	4.9	10.6
Normal	10.8		2.4	108.4	7.0	15.2
Wet	10.8		3.7	131.1	11.3	24.5
Very Wet	10.8		4.9	139.2	14.9	33.4

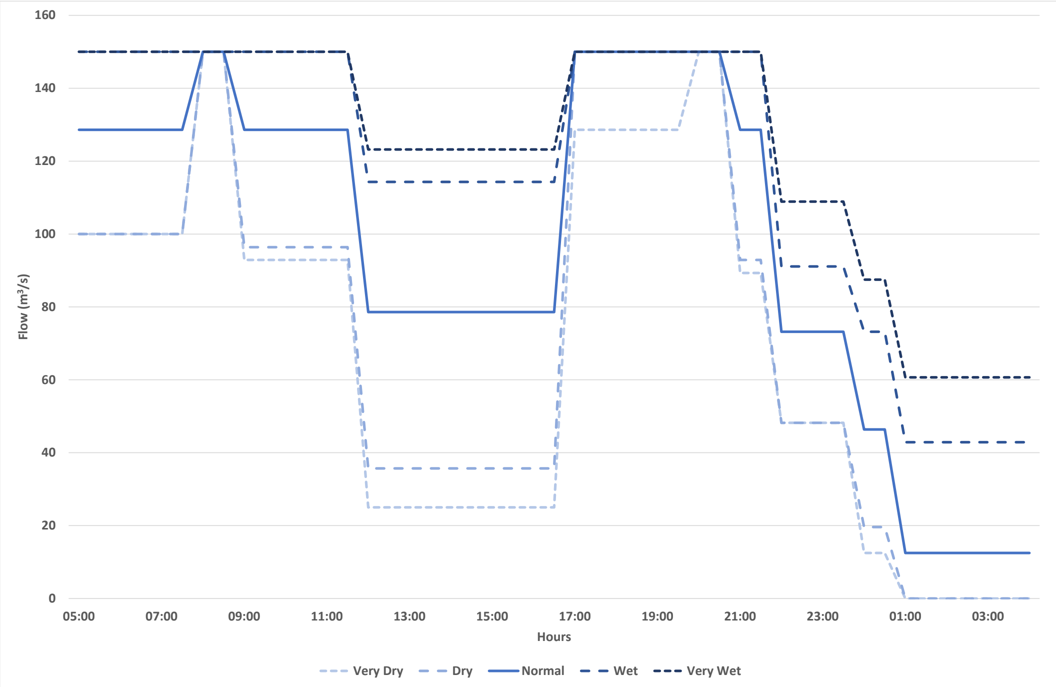

Figure 10-23 Ruzizi II Powerhouse Release Schedules

Table 10-5 Summary of future post-project hydrological inflows in the Ruzizi II – Burundi Border Reach

Scenario	Ruzizi III Environmental Flow (m^3/s)	Ruzizi III powerhouse release (m^3/s)	Total Flow to Ruzizi III (m^3/s)	River Rubyiro Flow (m^3/s)	River Ruhwa Flow (m^3/s)
Very Dry	10.0	Figure 10-24	78.5	4.0	8.6
Dry	10.0		84.5	4.9	10.6
Normal	10.0		108.6	7.0	15.2
Wet	10.0		131.3	11.3	24.5
Very Wet	10.0		139.4	14.9	33.4

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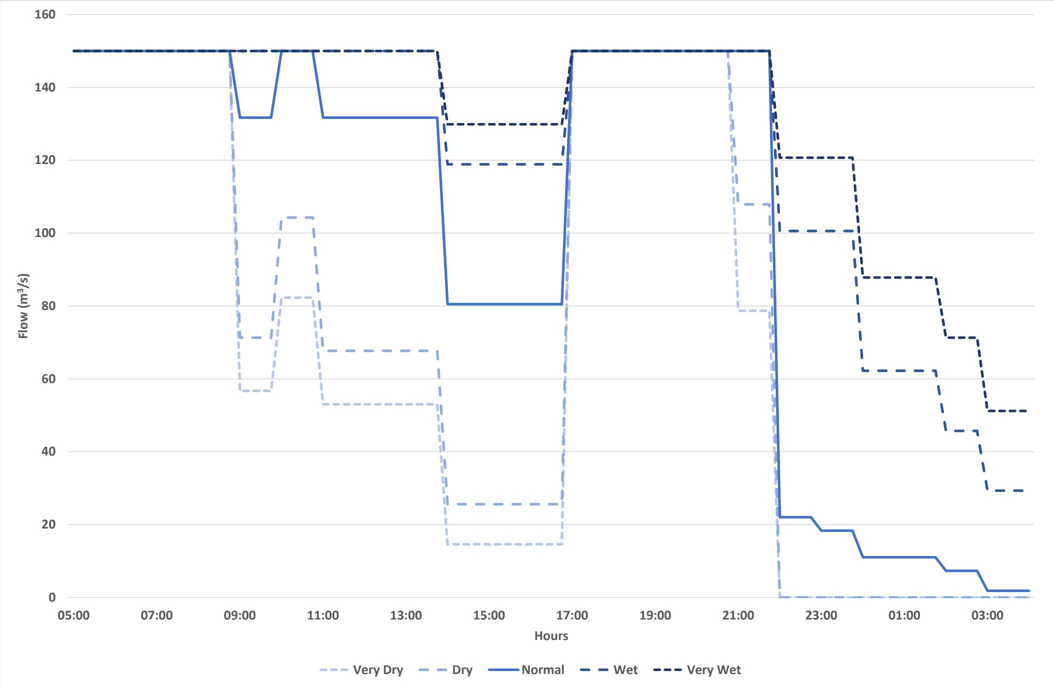

Figure 10-24 Ruzizi III Powerhouse Release Schedules

10.4.3.1 Downstream Ruzizi III powerhouse release location

A Hydrological and Hydraulic Characteristics

This section is located immediately downstream of the proposed Ruzizi III powerhouse. Figure 10-25 and Figure 10-26 provide a general overview of the river reach characteristics in this location. The model cross-section approximate reach is highlighted.

Figure 10-25 Downstream Ruzizi III Powerhouse Location

Figure 10-26 Downstream Ruzizi III Powerhouse Location – Photo

A summary of the hydrological and hydraulic characteristics of this reach for normal flow conditions is provided as follows. Full details for the various different flow conditions (ranging from very dry to very wet) are provided in the accompanying annex.

Table 10-6 and Figure 10-27 show that the future maximum flow downstream of the tailrace is similar to the current maximum flow, but that the future minimum flow tends to be lower (by half) than the current minimum flow. As such, the change in flow range, i.e., the change in the amount of daily variation of flow, tends to be higher under the future post Ruzizi III scenario.

Table 10-6 Downstream Ruzizi III Powerhouse Location – Flow Summary

	Baseline	**Future**
Maximum Flow (m^3/s)	163	164
Minimum Flow (m^3/s)	26	13
Flow Range (m^3/s)	138	151

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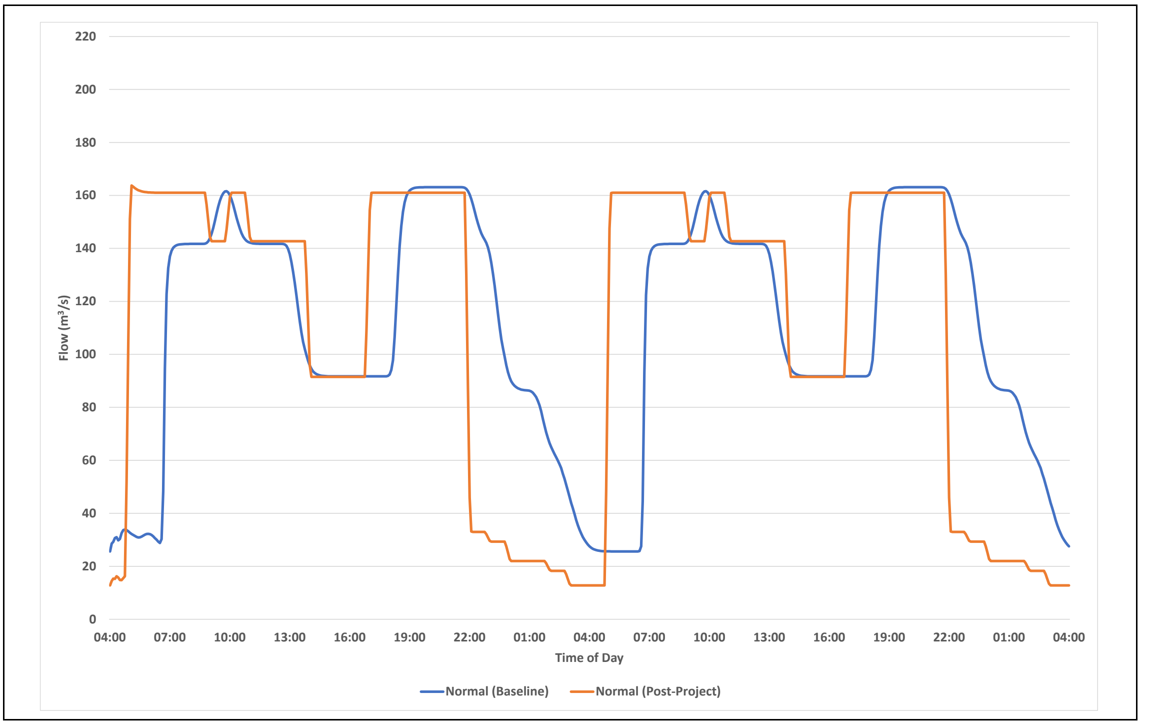

Figure 10-27 Downstream Ruzizi III Powerhouse Location – Flow Summary

Table 10-7 and Figure 10-28 show that the future maximum level (and hence depth) is similar to the current maximum level, but that the future minimum level tends to be lower than the current minimum level. As such, the level range, i.e., the amount of daily water level variation, tends to be higher under the future post Ruzizi III scenario.

The water level daily variation increases by 33 cm (from a daily variation of 1.33 m to 1.66 m) primarily due to the reduction in minimum water levels.

Table 10-7 Downstream Ruzizi III Powerhouse Location – Level Summary

	Baseline	Future
Maximum Elevation (mAOD)	979.64	979.64
Minimum Elevation (mAOD)	978.31	977.98
Elevation Range (m)	1.33	1.66

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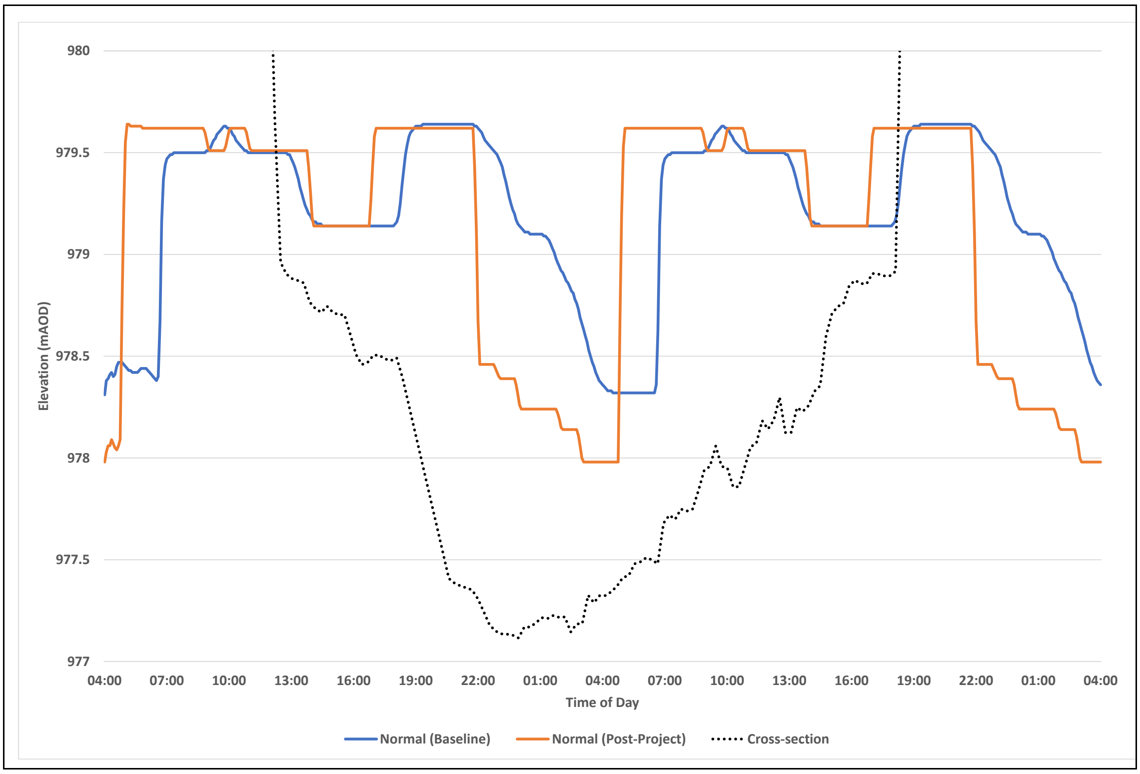

Figure 10-28 Downstream Ruzizi III Powerhouse Location – Level Summary

As with the flow and elevation variation, Table 10-8 and Figure 10-29 show that the future maximum velocity is similar to the current maximum velocity, but that the future minimum velocity tends to be lower than the current minimum velocity. As such, the velocity range tends to be higher under the future post Ruzizi III scenario.

The velocity daily variation increases by 0.19 m/s (from a daily variation of 1.12 m to 1.31 m) due to the reduction in minimum velocity.

Table 10-8 Downstream Ruzizi III Powerhouse Location – Velocity Summary

	Baseline	Future
Maximum Velocity (m/s)	2.50	2.50
Minimum Velocity (m/s)	1.38	1.19
Velocity Range (m/s)	1.12	1.31

PUBLIC DISCLOSURE AUTHORIZED

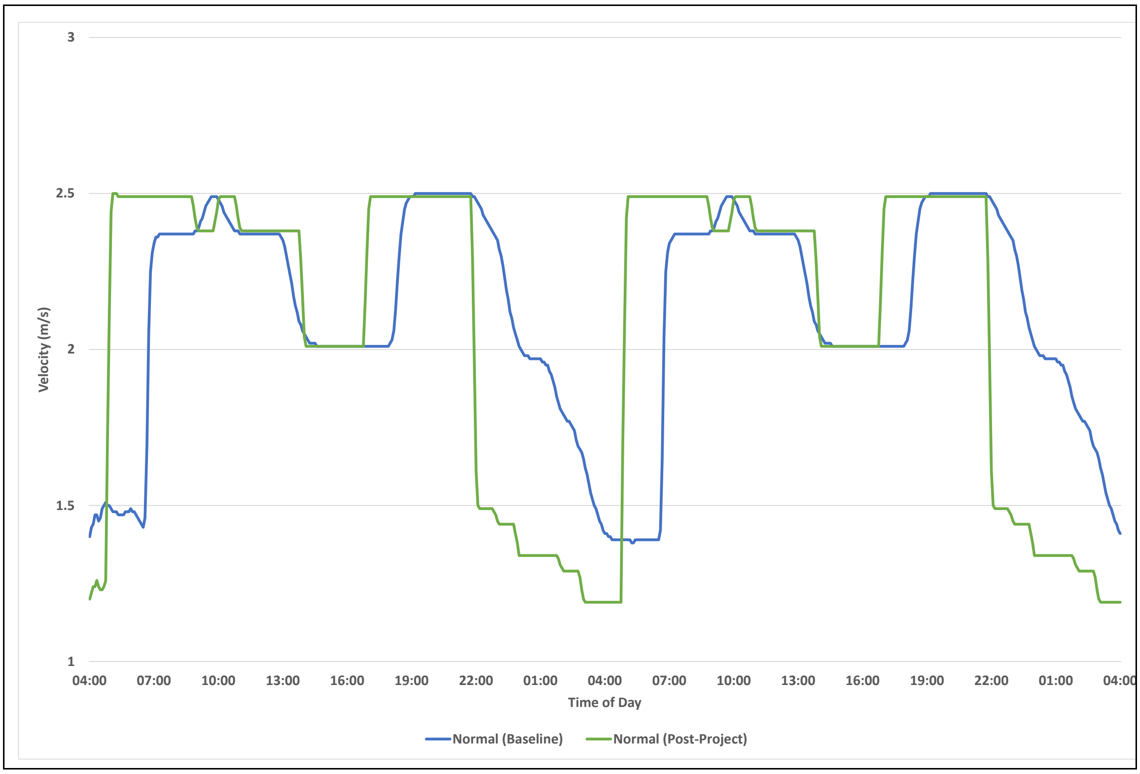

Figure 10-29 Downstream Ruzizi III Powerhouse Location – Velocity Summary

Table 10-9 and Figure 10-30 show the maximum, minimum, and daily range in cross-section area, providing an indication of the overall habitat area available. As with the other hydrological and hydraulic characteristics presented, the future maximum area is similar to the current maximum area, but the future minimum area tends to be lower than the current minimum area. As such, the area range tends to be larger under the future post Ruzizi III scenario.

The cross-section area daily variation increases by 7.8 m^2 (from a daily variation of 47 m^2 to 54.8 m^2) due to the reduction in minimum area.

Table 10-9 Downstream Ruzizi III Powerhouse Location – Cross-section Area Summary

	Baseline	**Future**
Maximum Area (m^2)	65.3	65.4
Minimum Area (m^2)	18.3	10.6
Area Range (m^2)	47.0	54.8

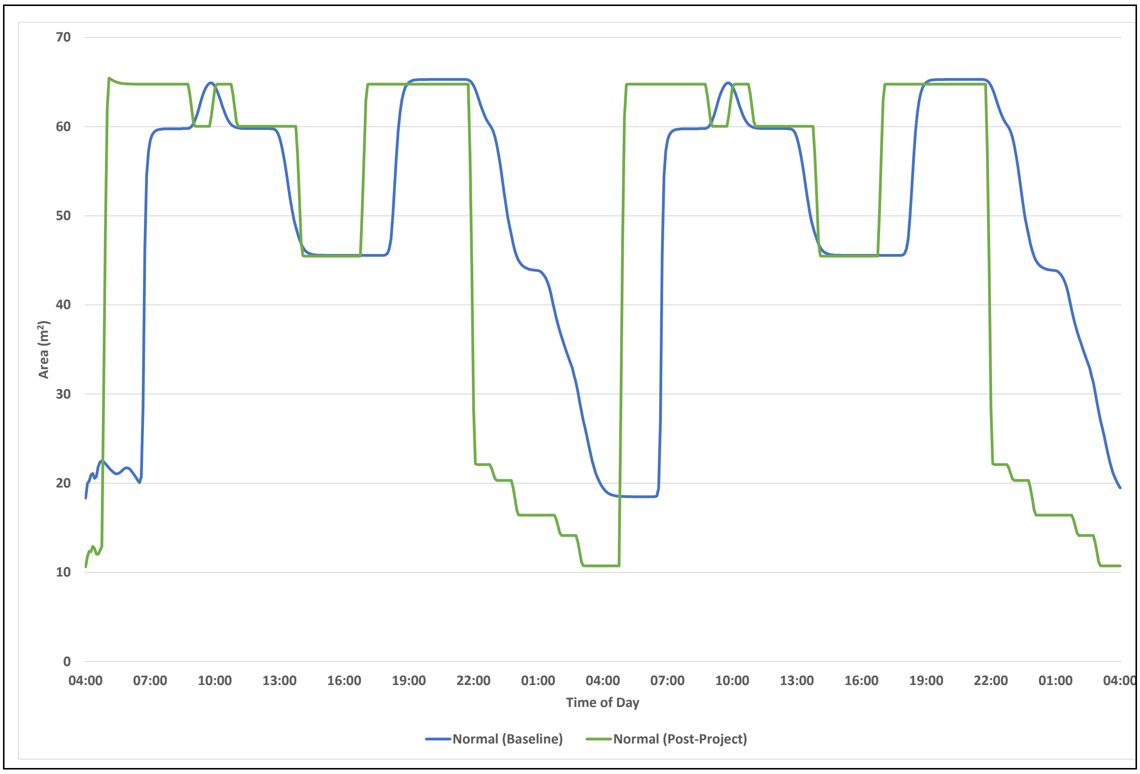

Figure 10-30 Downstream Ruzizi III Powerhouse Location – Cross-section Summary

Table 10-10 provides a summary of the average vertical ramp-up rates and ramp-down rates experienced.

It is notable that future ramp-up and ramp-down rates tend to be greater than current ramp-up and ramp-down rates. This is a reflection of the operating conditions for Ruzizi III where it is understood that operation changes between "off-peaking" and "peaking" will be quicker than they currently are at Ruzizi II.

Table 10-10 Downstream Ruzizi III Powerhouse Location – Ramp-up and Ramp-down Rates Summary

	Baseline	Future
Ramp-up (cm/min)	6.7	10.3
Ramp-down (cm/min)	-0.7	-6.5

B **Geomorphological, Ecological and Social Context**

B.1 *Geomorphology*

This moderately steep reach with a confined valley setting has a mixed boulder and cobble bed, supporting pool-rapid and pool-riffle reach types. The river morphology alternates between shorter pools interspersed by longer rapids and riffles. The bed elevation is controlled by bedrock/calcrete and larger immobile rocks.

Islands form where calcrete protrude from the channel floor or larger immobile sediment is deposited. Sediment deposition on these features supports vegetation establishment. The banks are composed of coarser alluvial material (boulders and cobble) filled with sandy and clayey material. The banks appear well-vegetated and relatively stable on satellite images despite the fluctuating water levels from Ruzizi II releases. Narrow floodplain sections are present along the inside bends of the lower section.

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Agriculture is common on the steep hillslopes and narrow floodplains, possibly contributing fine sediment to the main river channel. Most of the tributaries are small and drain the local slopes along the confined upper section. No recent landslide scars are visible along this reach, thus sediment inputs from mass wastings are less likely.

B.2 *Aquatic Ecology*

Macroinvertebrates:

Aquatic biotopes at the powerhouse outlet comprised Deep-Fast Rapids. These biotopes are likely to support mostly grazing and filter-feeding taxa that tolerate extreme current speeds. Taxa expected include freshwater limpets (*Burnupia* sp), Tricorythid mayflies and certain species of blackflies, such as *Simulium damnosum* and *S. harvreavesi*. Macroinvertebrate production in these areas is typically very high, so these areas often constitute potentially important nodes of biological production. However, macroinvertebrates sampled in this biotope near Bugarama (Site R12) on two occasions in February 2022 found that the diversity and abundance of macroinvertebrates was low, and this was attributed to short-term variation in water levels associated with the operation of Ruzizi II. The information suggested that the abundance and diversity of macroinvertebrates in this reach could be improved by reducing short-term fluctuations in water level. Notable taxa recorded in this biotope included the stonefly *Neoperla spio,* the leach *Salifa perspicax,* and the caddisfly *Hydropsyche* sp., all of which are predators. *Neoperla spio* is sensitive to water quality deterioration and is therefore a potentially useful indicator for monitoring ecological change.

Fish:

Fish habitat downstream of the powerhouse is comprised predominantly of the Fast Deep habitat class, with minimal Slow Deep habitat. The most important fish habitats will be the shallower riffle-rapid habitats with larger bed elements to provide habitat mainly for the lotic lithophilic guild (*Labeobarbus* sp.) but potentially also for the lotic riffle-rapid fish guilds (e.g. *Chiloglanis* and *Amphilius*). Surveys between 2018 and 2022 recorded the larger migratory species in this reach including *Labeo cylindricus, Labeobarbus altianalis* and *Labeobarbus somereni*.

The absence of deeper, slower flowing reaches means that the channel margins and slack waters are more important for the lentic and semi-lotic pools species including the haplochromine cichlids and *Enteromius* barbs.

B.3 *Terrestrial Ecology*

Riparian Vegetation:

There is almost no Natural Habitat along on the riverbanks between the powerhouse and Bugarama, with almost all alluvial soils cultivated to the riverbanks. The few islands located along this reach have some Natural Habitat in the form of Riparian Wetlands dominated by *Phragmites*. Species dependent on a wet bank are relatively prevalent in the Riparian Wetland community, although this is quite a mobile vegetation type and recolonises new areas fairly quickly if river levels change.

Riparian Fauna:

The riparian avifauna, mammal and herpetofauna assemblages are extremely species-poor in this reach, particularly the avifauna assemblage since there is limited overhanging riparian vegetation. The riparian avifauna assemblage contains surprisingly few fish-eating species although a limited number are present such as reed and white-breasted cormorants, and striated heron. Riparian mammals such as marsh mongoose and otter species may be present in very low numbers. Hippopotamus occurs infrequently upstream of the Bugarama – Kamanyola bridge and is not resident along this reach. Herpetofauna will be mostly represented by widespread generalist amphibians as well as a few riparian reptile species such as water snakes (*Lycodonomorphus* species) and terrapins (*Pelusios* species).

B.4 *Social*

The following paragraphs provide an overview of local communities' reliance on Ruzizi's water for livelihoods and domestic needs in the downstream powerhouse release stretch. Issues related to water quality and sediment load will not be covered in this analysis, as no discernible difference from current conditions is expected, due to the low residence time of water in the Ruzizi III reservoir.

This area is characterised by a strong social reliance on the river. In Rwanda, crops are irrigated directly from the river, using buckets or water pumps. Areas of manioc fermentation and drying have also been observed, using water directly abstracted from the river. The riverside of the villages of Kabusunzu and Gatebe is characterised by a confluence of domestic activities around the river, including washing clothes and objects, bathing and playing in the river. These activities tend to take place in areas where access is easy and the velocity of waster is low, as in the large opening at the entrance of Kabusunzu where river crossing is also frequently practiced by children, women, and men alike. One fish farming industry is also found in Gatebe, abstracting small amounts of water directly from the Ruzizi. Fishing is practiced regularly by the majority of households, but it does not represent a significant source of income or means of livelihood for the local community.

In DRC, water from the Ruzizi is fetched daily by the villagers of Kafunda and Bugano not only for all consumptive and drinking uses, but also for healing and spiritual practices, which require villagers to physically enter the river for bathing, washing, and drinking. On the riverside of these two villages, cultivation with bucket irrigation and recreational activities have often been observed.

There are two baptism and prayer sites which require villagers to regularly enter the river in this stretch, one in Bugano and one in Gatebe. Small-scale unpredictable flooding has been reported around Gatebe's baptism site, which has been previously submerged by sudden increases in water levels.

C Indicators Linked to Hydrological and Hydraulic Characteristics

Table 10-11 provides and overall summary of the ecological and social functional relationship with hydrological and hydraulic characteristics downstream of the Ruzizi III powerhouse location.

The change in hydrological and hydraulic characteristics are predicted to result in significant increase in social community safety impacts (due to increased ramp-up rates).

Table 10-11 Summary of Ecological and Social Functional Relationship / Impacts at Downstream Ruzizi III powerhouse location

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Geomorphology		
Increased channel erosion The channel is largely composed of large immobile clasts, calcrete or bedrock. This makes the channel bed resistant to incision. Hydro peaking and reductions in longitudinal sediment connectivity has resulted in possible bed erosion and bed armouring over the past decades.	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	Minor
	Ramping Rates	No / Insignificant

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Increased sedimentation in channel Due to the reduced sediment supply downstream of the dam, and the increase in the frequency of high energy flows, it is unlikely that sedimentation will take place. Localised sedimentation might take place in slack waters.	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	Minor
	Ramping Rates	No / Insignificant
Bank erosion The banks are largely composed of boulders and cobbles with a finer gravel, sand and silt matrix. The banks are not steep or high and relatively stable and immobile. The banks have been exposed to hydropeaking for decades, thus bank erosion might have stabilised over time.	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	No / Insignificant
	Ramping Rates	Minor
Aquatic Ecology		
Non-migratory fish: abundance and diversity Fish habitat downstream of the powerhouse is comprised predominantly of the Fast Deep habitat class, with minimal Slow Deep habitat. It includes fish adapted to fast deep water with rapids in the Lotic riffle-rapid fish guild including species, such as *Amphilius* and *Chiloglanis.*	Flow	
	Elevation / Depth	Minor
	Velocity	Minor
	Area	Minor
	Ramping Rates	Minor
Migratory fish: abundance and diversity Fish habitat downstream of the powerhouse is comprised predominantly of the Fast Deep habitat class, with minimal Slow Deep habitat. It includes fish adapted to fast deep water with rapids in the Lotic lithophilic fish guild, including migratory fish (e.g. *Labeo, Labeobarbus, Bagrus*). Fish migration to the powerhouse reach will still be possible despite high flow velocity during peaking periods. However, the lower water depth and reduced wetted area during inter-peaking periods may be a limiting factor for fish migration if connectivity between pools is reduced and/or due to increased human fishing pressures in shallow reaches.	Flow	
	Elevation / Depth	Minor
	Velocity	Minor
	Area	Minor
	Ramping Rates	Minor
Macro-invertebrates: abundance and diversity Diversity and abundance of macroinvertebrates in the Ruzizi River, including this reach, was low, and this was attributed to short-term variation in water levels associated with the operation of Ruzizi II. These are expected to remain unchanged compared to the current baseline because of the large variation in daily and sub-daily water levels.	Flow	Minor
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	N/A
Terrestrial Ecology		
Riparian vegetation: abundance and diversity There is almost no Natural Habitat along on the riverbanks between the powerhouse and Bugarama, with most Riparian Wetlands present on a few islands in the river. These wetlands have species that are dependent on a wet bank and are thus likely to be impacted by changes in depth and area of the river because of changes to the availability of a wet bank.	Flow	Minor
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	Minor
	Ramping Rates	No / Insignificant
Riparian fauna: abundance and diversity. The species-poor riparian fauna assemblage is associated with the fragments of Riparian Wetland on islands, as well as open water habitat in the river. The species composition of the faunal assemblage is currently dominated by widespread habitat generalists and overall species richness is low. Changes in flow, depth and velocity are likely to impact riparian fauna species. Hippopotamus occurs infrequently upstream of the Bugarama – Kamanyola Bridge and is not resident along this reach.	Flow	Minor
	Elevation / Depth	Minor
	Velocity	Minor
	Area	Minor
	Ramping Rates	Minor

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Social		
Consumptive Water Use: Local communities are currently using water from this stretch regularly, as the only available source of domestic water supply. Social reliance on this stretch of the river for consumptive water use is high.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	No / Insignificant
Non-Consumptive Water Use: Fishing Local communities are currently fishing regularly in this stretch. One Tilapia fish farming industry currently exists, with ponds covering a small area of 0.1 hectares.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	Moderate
Community Safety: Local communities frequently cross the river in this stretch. Additionally, villagers are physically entering the river on a regular basis for recreational purposes, baptisms and medicinal / spiritual practices. Social exposure to hazards due to the river's flow and velocity are high.	Flow	Minor
	Elevation / Depth	Minor
	Velocity	Significant
	Area	N/A
	Ramping Rates	Significant

10.4.3.2 Upstream Bugarama Bridge / Kamanyola Monitoring Station

A Hydrological and Hydraulic Characteristics

This section is located immediately approximately 4 km downstream of the start of the proposed Ruzizi III powerhouse. Figure 10-25 and Figure 10-26 provide a general overview of the river reach characteristics in this location. The model cross-section approximate reach is highlighted.

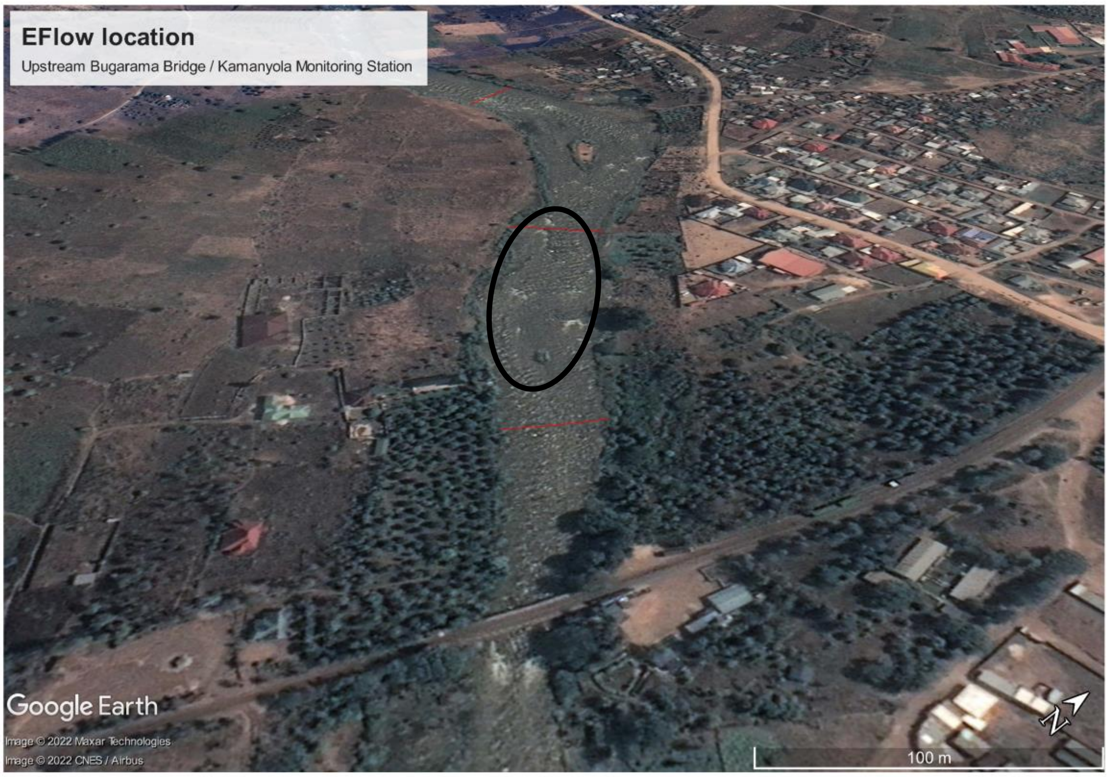

Figure 10-31 Upstream Bugarama Bridge / Kamanyola Monitoring Station

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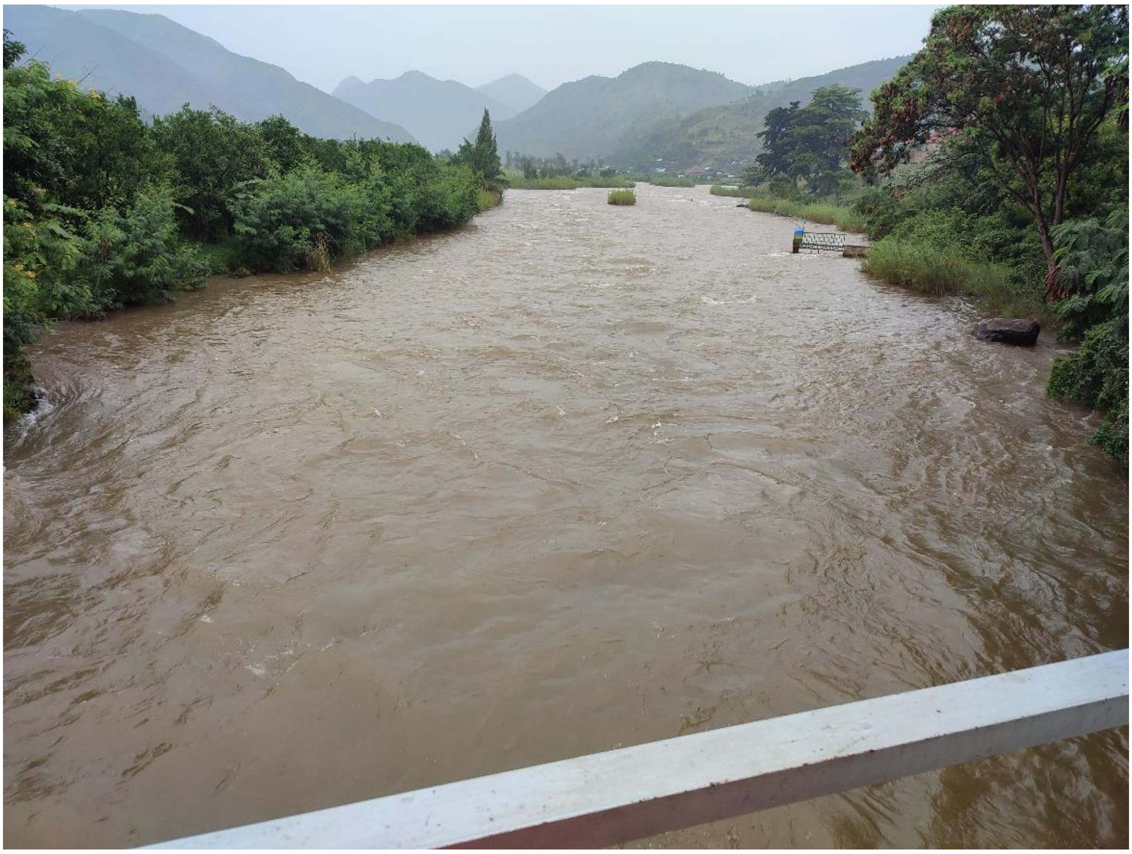

Figure 10-32 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Photo

A summary of the hydrological and hydraulic characteristics for this reach for normal flow conditions is provided as follows. Full details for the various different flow conditions (ranging from very dry to very wet) are provided in the accompanying annex.

Table 10-12 and Figure 10-33 show that the future maximum flow is similar to the current maximum flow, but that the future minimum flow tends to be lower than the current minimum flow. As such, the change in flow range, i.e., the change in the amount of daily variation of flow, tends to be larger under the future post Ruzizi III scenario by approximately 11m^3/s.

Table 10-12 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Flow Summary

	Baseline	Future
Maximum Flow (m^3/s)	163	162
Minimum Flow (m^3/s)	26	13
Flow Range (m^3/s)	138	149

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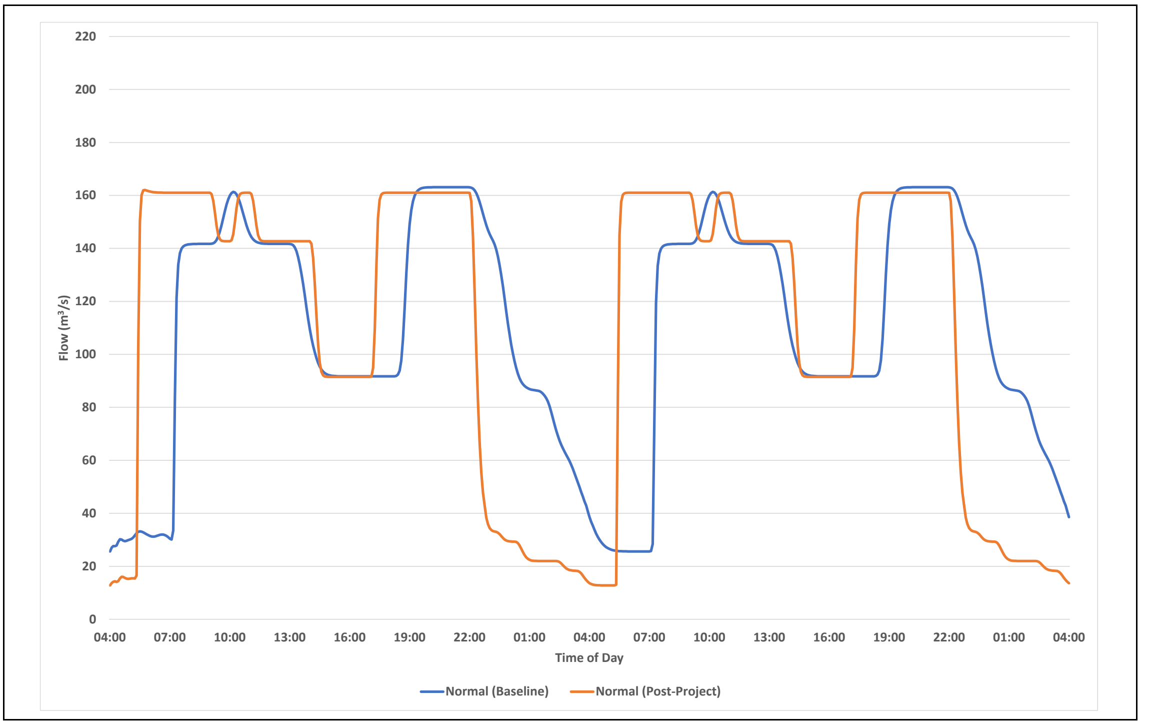

Figure 10-33 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Flow Summary

Table 10-13 and Figure 10-34 show that the future maximum level (and hence depth) is similar to the current maximum level, but that the future minimum level tends to be lower than the current minimum level. As such, the level range, i.e., the amount of daily water level variation, tends to be higher under the future post Ruzizi III scenario.

The water level daily variation is predicted to increase by 32 cm (from a daily variation of 1.49 m to 1.81 m) primarily due to the reduction in minimum water levels by a predicted average of 33 cm when the project is not hydropeaking.

Table 10-13 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Level Summary

	Baseline	**Future**
Maximum Elevation (mAOD)	947.58	947.57
Minimum Elevation (mAOD)	946.09	945.76
Elevation Range (m)	1.49	1.81

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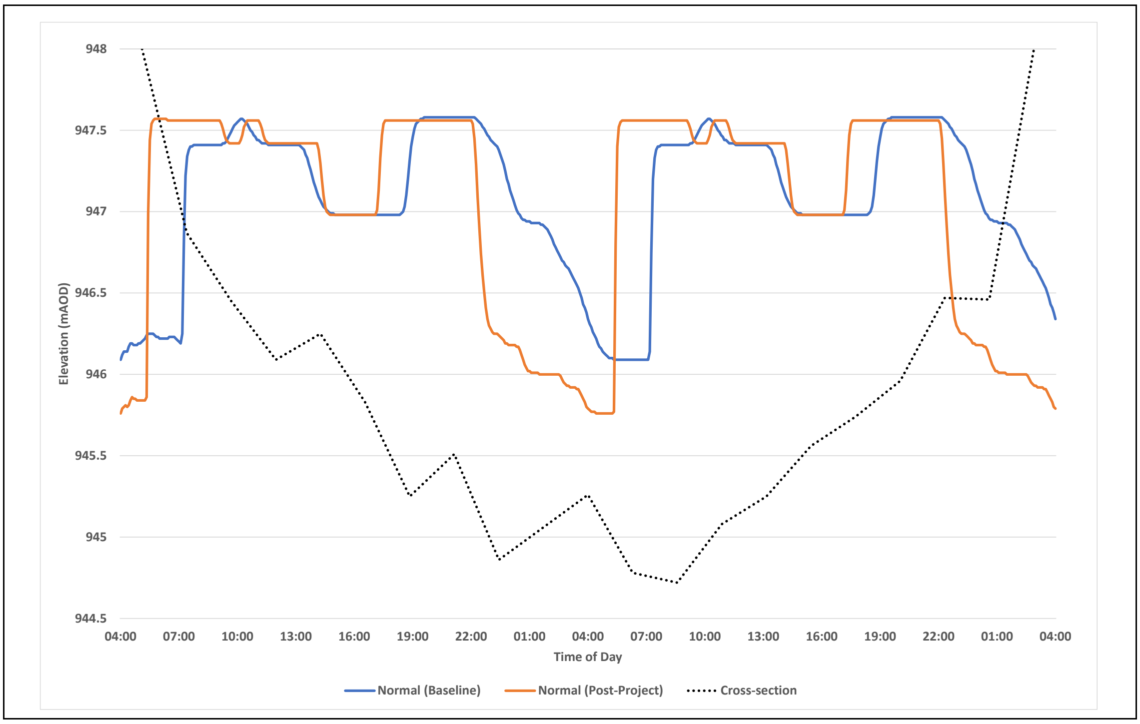

Figure 10-34 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Level Summary

As with the flow and elevation variation, Table 10-14 and Figure 10-34 show that the future maximum velocity is similar to the current maximum velocity under all flow conditions, but that the future minimum velocity tends to be lower than the current minimum velocity. As such, the velocity range tends to be larger under the future post Ruzizi III scenario.

The velocity daily variation increases by 0.20 m/s under normal conditions (from a daily variation of 0.82 m to 1.02 m) due to the reduction in minimum velocity by 0.2 m/s.

Table 10-14 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Velocity Summary

	Baseline	**Future**
Maximum Velocity (m/s)	1.87	1.87
Minimum Velocity (m/s)	1.05	0.85
Velocity Range (m/s)	0.82	1.02

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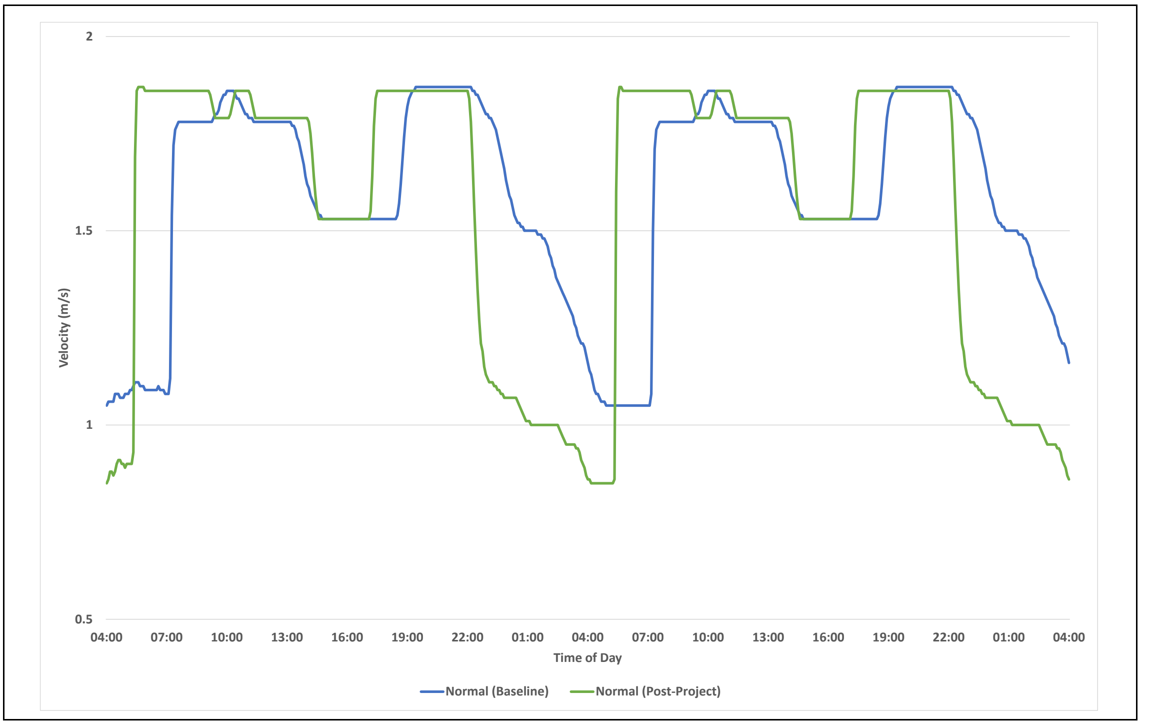

Figure 10-35 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Velocity Summary

Table 10-15 and Figure 10-36 show the maximum, minimum, and daily range in cross-section area, providing an indication of the overall habitat area available. As with the other hydrological and hydraulic characteristics presented, the future maximum area is similar to the current maximum area, but the future minimum area tends to be lower than the current minimum area. As such, the area range tends to be larger under the future post Ruzizi III scenario.

The cross-section area daily variation increases by 11.1 m^2 (from a daily variation of 62.8 m^2 to 71.7 m^2) due to the reduction in minimum wetted area from 24.4 to 15.1 m^2 under Ruzizi III HPP operation

Table 10-15 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Cross-section Area Summary

	Baseline	**Future**
Maximum Area (m^2)	87.3	86.8
Minimum Area (m^2)	24.4	15.1
Area Range (m^2)	62.8	71.7

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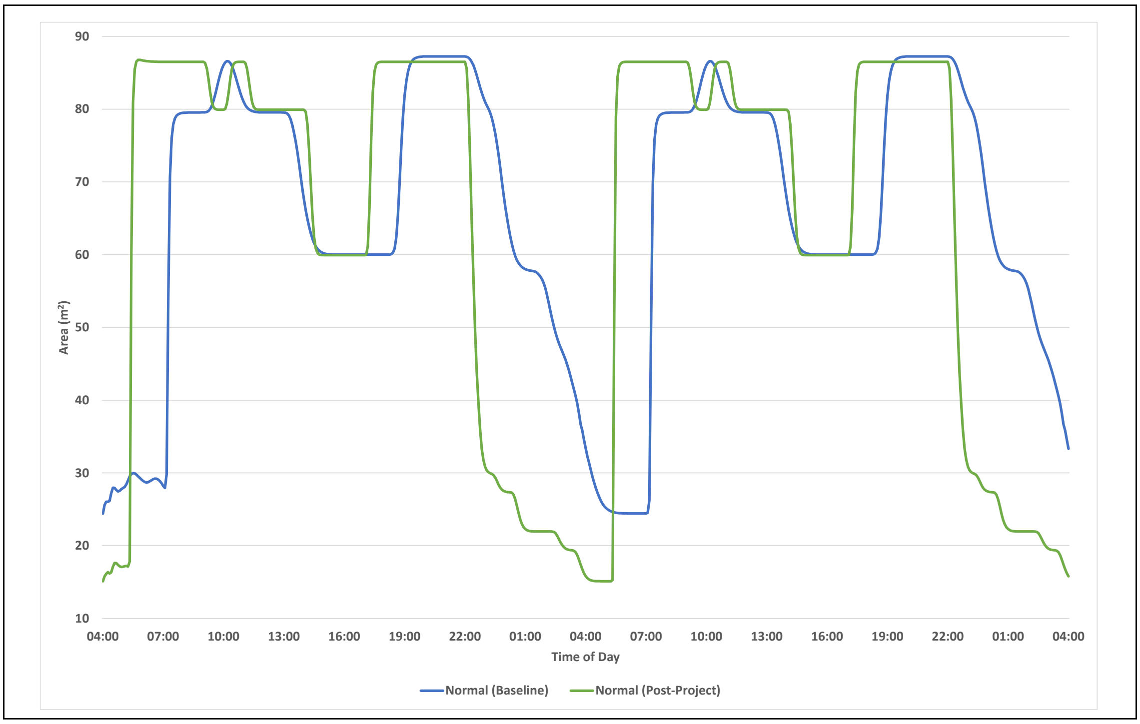

Figure 10-36 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Cross-section Summary

Table 10-16 provides a summary of the average vertical ramp-up rates and ramp-down rates experienced.

It is notable that future ramp-up and ramp-down rates tend to be greater than current ramp-up and ramp-down rates. This is a reflection of the operating conditions for Ruzizi III where it is understood that operation changes between "off-peaking" and "peaking" will be quicker than they currently are at Ruzizi II.

Table 10-16 Upstream Bugarama Bridge / Kamanyola Monitoring Station – Ramp-up & Ramp-down Rates Summary

	Baseline	**Future**
Ramp-up (cm/min)	7.9	11.7
Ramp-down (cm/min)	-0.8	-3.7

B Geomorphological, Ecological and Social Context

B.1 Geomorphology

This reach has a partly confined valley setting (the channel is incised into the plain) and a moderately steep channel gradient. It has a mixed boulder and cobble bed, with localised sections of resistant calcrete, supporting pool-rapid and pool-riffle reach types. The river morphology alternates between shorter pools, rapids and riffles. The bed elevation is controlled by bedrock/calcrete and larger immobile rocks.

Islands form where calcrete protrude from the channel floor or larger immobile sediment is deposited. Sediment deposition on these features supports vegetation establishment and agriculture. The river course is relatively straight across the plain to the confluence with the Rubyiro river with a narrow floodplain (approximately 100 m wide). The river and narrow floodplain are incised into the surrounding plain (5 to 10 m based on the SRTM dataset). The banks are composed of coarser alluvial material (boulders and cobble) supported or filled by sandy and clayey material. The banks appear well-vegetated and relatively stable on satellite and ground-based images despite the fluctuating water levels from the Ruzizi II releases, but localised bank erosion has been observed along agricultural fields. It is not clear if the localised bank erosion is due to vegetation clearing (associated with floodplain agriculture) or fluctuating water levels, but possibly driven by both processes.

Agriculture is common on the floodplains, surrounding plains and islands, contributing fine sediment to the channel. There is no significant sediment input from tributaries along this reach.

B.2 *Aquatic Ecology*

Macroinvertebrates:

Aquatic biotopes within this reach comprised the following:

- Mostly Deep-Fast Rapids. These biotopes are likely to support mostly grazing and filter-feeding taxa that tolerate extreme current speeds (as described in the downstream powerhouse location section).
- One area of Deep-Slow Pool. No information was available on macroinvertebrates in such pools, but diversity and abundance in these areas is likely to be low because of light limitation and the limited diversity of hydraulic conditions.
- One area of Shallow-Fast Riffle, approximately 4.3 km downstream of the proposed tailrace outlet. This area is likely to support a high diversity of macroinvertebrates (as described in the dewatered reach section).

Fish:

Fish habitats upstream and in the vicinity of Bugurama Bridge include Fast Deep and Fast Shallow habitat classes, with some Slow Shallow areas in the immediate vicinity of the sampling site (R12). Species of *Enteromius* barbs and migratory *Labeo* and *Labeobarbus* species were recorded here as well as several Haplochromine cichlids. *Labeo* cf. *cylindricus* and *Bagrus docmak* was reported in fisher catches downstream of the bridge.

As with the other reaches, the Deep and Shallow Fast habitats with large bed elements are important as living space for the lotic riffle-rapid guild (*Chiloglanis* and *Amphilius*) and for spawning and feeding by the lotic lithophilic guild (*Labeobarbus* species). The Slow Shallow and Fast Shallow habitats are especially susceptible to hydropeaking if these areas are regularly inundated and desiccated on a daily basis.

B.3 *Terrestrial Ecology*

Riparian Vegetation:

Even though this reach of the Ruzizi River is in a densely settled area, there is slightly more Riparian Wetland habitat than along the upstream reach (near the powerhouse), mostly on scattered islands but also occasionally in narrow strips along riverbanks. Riparian Thicket is poorly represented, although several groves of Raffia palms (*Raphia farinifera*) were observed on the right bank (DRC) during fieldwork. Riparian Wetlands are dominated by *Phragmites*, as well as other wetland species that are dependent on a wet bank such as *Leersia hexandra*, *Cyperus* species and *Pluchea ovalis*. Scattered trees in Riparian Wetlands along this reach include *Senegalia polyacantha, Phoenix reclinata* and *Ficus sycomorus*.

Riparian Fauna:

The riparian avifauna, mammal and herpetofauna assemblages have higher species richness in this reach compared to upstream reaches. Even though the avifauna assemblage has an unusually low proportion of few fish-eating species, more of these species were observed here than along upstream reaches, including species such as white-breasted and reed cormorants, striated heron and great egret. Insect-eating bird species that forage from riverside vegetation are also more prevalent along this reach, such as little bee-eater, greater swamp warbler and red-faced cisticola.

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Riparian mammals such as marsh mongoose and otter species are likely to be present but in higher numbers than in the previous reach. A small population of hippopotamus is resident along this reach. Herpetofauna will be mostly represented by widespread generalist amphibians, reed-dwelling frogs such as *Hyperolius* and *Aixalus* species, as well as a few riparian reptile species such as water snakes (*Lycodonomorphus* species) and terrapins (*Pelusios* species).

B.4 *Social*

The following paragraphs provide an overview of local communities' reliance on Ruzizi's water for their livelihoods and domestic needs in the Upstream Bugarama Bridge / Kamanyola Monitoring Station. Issues related to water quality and sediment load will not be covered in this analysis, as no discernible difference from current conditions is expected, due to the low residence time of water in the Ruzizi III reservoir.

This stretch is characterised by a high social reliance on the river and by significant hazards to the safety of the population. The villages of Mubombo and Mwaro abstract water from the Ruzizi on a daily basis for domestic purposes and to irrigate their fields using either buckets or water pumps. Various openings on the river are used for recreational activities, bathing and clothes washing. Fishing is practiced regularly by the majority of households, but it does not represent a significant source of income or means of livelihood for the local community.

Crossing the river is common in this stretch. Starting from the Bugarama Bridge area, some people cross the river daily by swimming across carrying large sacks or containers. Most of these people cross the river around 10 times a day every day to transport produce such as rice, maize and sugar from Rwanda into DRC, and cooking oil from DRC into Rwanda. Others cross twice a day every day for wage employment on fields, and a smaller minority visits family regularly on the other side of the river. Villagers have reported frequent incidents due to unpredictable sudden changes in water levels and velocity.

Regular flooding is also experienced in this area. In 2021, there were three flood events, one in May-April and two in June, on the 4th and on the 18th, which destroyed around 25 hectares of land according to local agronomists. The impact of these flood events on the loss of income and livelihoods is significant.

C Indicators Linked to Hydrological and Hydraulic Characteristics

Table 10-17 provides and overall summary of the ecological and social functional relationship with hydrological and hydraulic characteristics upstream Bugarama Bridge / Kamonyola Monitoring Station.

The change in hydrological and hydraulic characteristics are predicted to result in significant increase in social community safety impacts (due to increased ramp-up rates).

Table 10-17 Summary of Ecological and Social Functional Relationship / Impacts at Upstream Bugarama Bridge / Kamanyola Monitoring Station

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Geomorphology		
Increased channel erosion The channel is largely composed of large immobile clasts, calcrete or bedrock. This makes the channel bed resistant to incision. Hydro peaking and reductions in longitudinal sediment connectivity has resulted in possible bed erosion and bed armouring.	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	Minor
	Ramping Rates	No / Insignificant
Increased sedimentation in channel Due to the reduced sediment supply downstream of the dam, and the increase in the frequency of high energy flows, it is unlikely that sedimentation will take place. Localised sedimentation might take place in slack waters.	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	Minor
	Ramping Rates	No / Insignificant

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Bank erosion The banks are largely composed of boulders and cobbles with a finer gravel, sand and silt matrix. The banks are not steep or high and relatively stable and immobile. The banks have been exposed to hydropeaking for decades, thus bank erosion might have stabilised over time.	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	No / Insignificant
	Ramping Rates	Minor
Aquatic Ecology		
Non-migratory fish: abundance and diversity Fish habitats upstream and in the vicinity of Bugurama Bridge include Fast Deep and Fast Shallow habitat classes, with some Slow Shallow areas. These provide habitat for fish in the Lotic riffle rapid fish guild such as *Enteromius* barbs and *Chiloglanis* and *Amphilius.*	Flow	
	Elevation / Depth	Minor
	Velocity	Minor
	Area	Minor
	Ramping Rates	Minor
Migratory fish: abundance and diversity Fish habitats upstream and in the vicinity of Bugurama Bridge include Fast Deep and Fast Shallow habitat classes, with some Slow Shallow areas. These provide spawning and feeding habitat for fish in the Lotic lithophilic fish guild such as *Labeo* and *Labeobarbus* species.	Flow	
	Elevation / Depth	Minor
	Velocity	Minor
	Area	Minor
	Ramping Rates	Minor
Macro-invertebrates: abundance and diversity These are expected to remain unchanged compared to the current operation because of the large variation in daily and sub-daily water levels.	Flow	Minor
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	N/A
Terrestrial Ecology		
Riparian vegetation: abundance and diversity Even though this reach of the Ruzizi River is in a densely settled area, there is slightly more Riparian Wetland habitat than along the previous reach, mostly on scattered islands but also occasionally in narrow strips along riverbanks. Riparian Thicket is poorly represented. Riparian Wetlands have species that are dependent on a wet bank and are thus likely to be impacted by changes in depth and area of the river result in changes to the availability of a wet bank.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	No / Insignificant
Riparian fauna: abundance and diversity The riparian avifauna, mammal and herpetofauna assemblages have higher species richness in this reach compared to upstream reaches. The species composition of the faunal assemblage is currently dominated by widespread habitat generalists and overall species richness is low. Changes in flow, depth and velocity will have a negligible impact on riparian fauna species. The small population of Hippopotamus that is resident along this reach is unlikely to be impacted by minor changes in flow, depth, velocity, area, and ramping rates.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	No / Insignificant
Social		
Consumptive Water Use Local communities in this stretch are currently using the river for domestic and drinking water supply. Social reliance on the river for consumptive water use is high.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	No / Insignificant

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Non-Consumptive Water Use: Fishing Local communities are currently fishing regularly in this stretch.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	Moderate
Community Safety Local communities cross the river regularly in this stretch. Additionally, villagers are physically entering the river on a regular basis for recreational purposes, and medicinal / spiritual practices. Social exposure to hazards due to the river's flow and velocity are high.	Flow	Minor
	Elevation / Depth	Minor
	Velocity	Significant
	Area	N/A
	Ramping Rates	Significant

10.4.3.3 Upstream Rubyiro tributary to Downstream Burundi Border/Ruhwa Tributary

A Hydrological and Hydraulic Characteristics

A.1 Upstream Rubyiro Tributary

This section is located immediately downstream of the proposed Ruzizi III powerhouse. Figure 10-25 and Figure 10-26 provide a general overview of the river reach characteristics in this location. The model cross-section approximate reach is highlighted.

Figure 10-37 Upstream Rubyiro Tributary

Figure 10-38 Upstream Rubyiro Tributary – Photo

A summary of the hydrological and hydraulic characteristics for this reach for normal flow conditions is provided as follows. Full details for the various different flow conditions (ranging from very dry to very wet) are provided in the accompanying annex.

Table 10-18 and Figure 10-39 show that the future maximum flow is similar to the current maximum flow, but the future minimum flow tends to be lower than the current minimum flow. As such, the change in flow range, i.e., the change in the amount of daily variation of flow, tends to be higher under the future post Ruzizi III scenario.

Table 10-18 Upstream Rubyiro Tributary – Flow Summary

	Baseline	Future
Maximum Flow (m^3/s)	163	161
Minimum Flow (m^3/s)	26	13
Flow Range (m^3/s)	138	148

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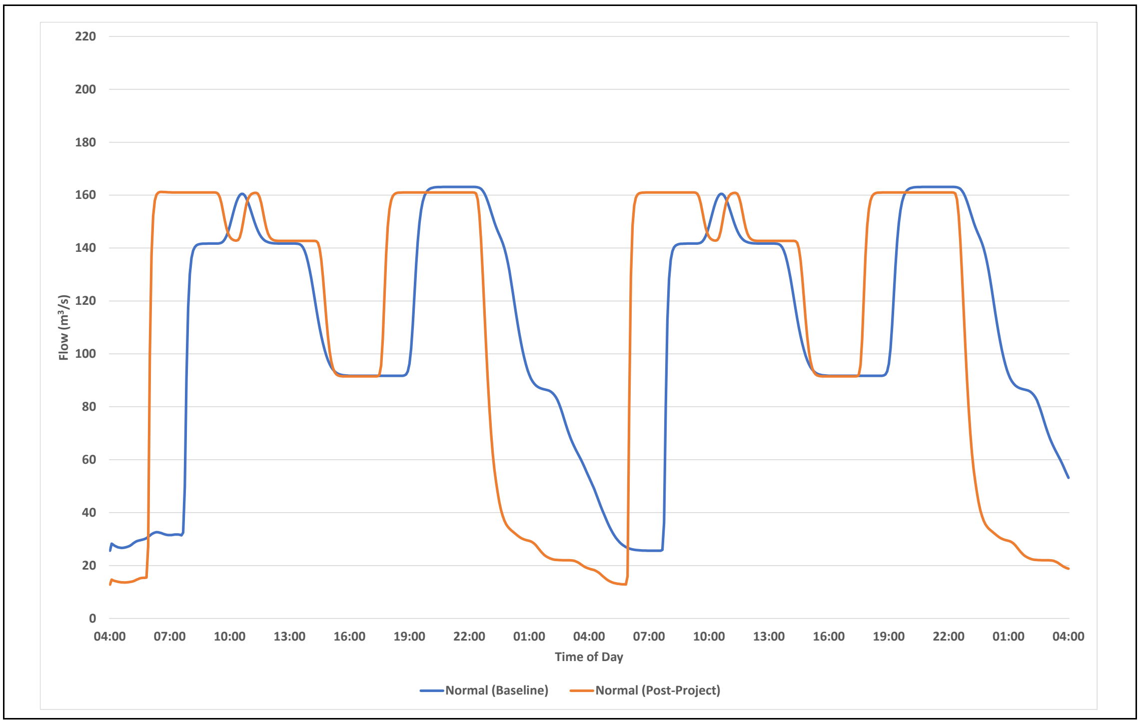

Figure 10-39 Upstream Rubyiro Tributary – Flow Summary

Table 10-19 and Figure 10-40 show that the future maximum level (and hence depth) is similar to the current maximum level, but the future minimum level tends to be lower than the current minimum level by 37 mm. As such, the level range, i.e., the amount of daily water level variation, tends to be higher under the future post Ruzizi III scenario.

The water level daily variation increases by 36 cm under normal conditions (from a daily variation of 1.63 m to 1.99 m) primarily due to the reduction in minimum water levels.

Table 10-19 Upstream Rubyiro Tributary – Level Summary

	Baseline	Future
Maximum Elevation (mAOD)	929.84	929.83
Minimum Elevation (mAOD)	928.21	927.84
Elevation Range (m)	1.63	1.99

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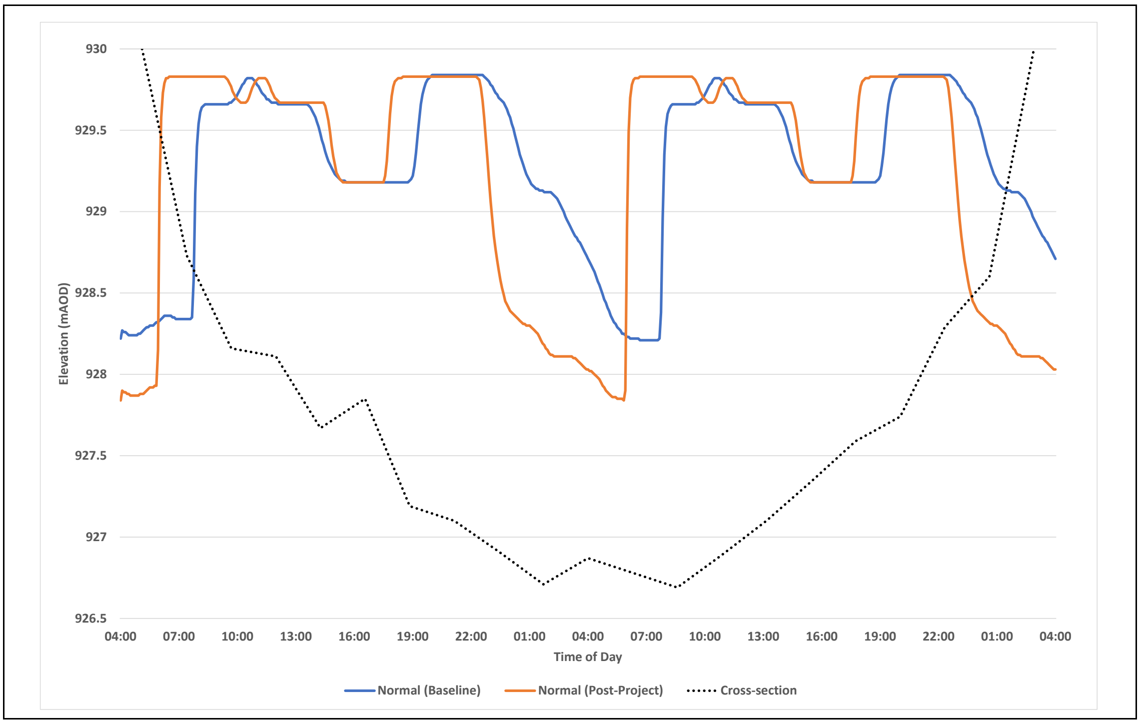

Figure 10-40 Upstream Rubyiro Tributary – Level Summary

As with the flow and elevation variation, Table 10-20 and Figure 10-35 show that the future maximum velocity is similar to the current maximum velocity, but the future minimum velocity tends to be lower than the current minimum velocity. As such, the velocity range tends to be higher under the future post Ruzizi III scenario.

The velocity daily variation increases by 0.16 m/s under normal conditions (from a daily variation of 0.86 m to 1.02 m) due to the reduction in minimum velocity.

Table 10-20 Upstream Rubyiro Tributary – Velocity Summary

	Baseline	Future
Maximum Velocity (m/s)	1.65	1.64
Minimum Velocity (m/s)	0.79	0.62
Velocity Range (m/s)	0.86	1.02

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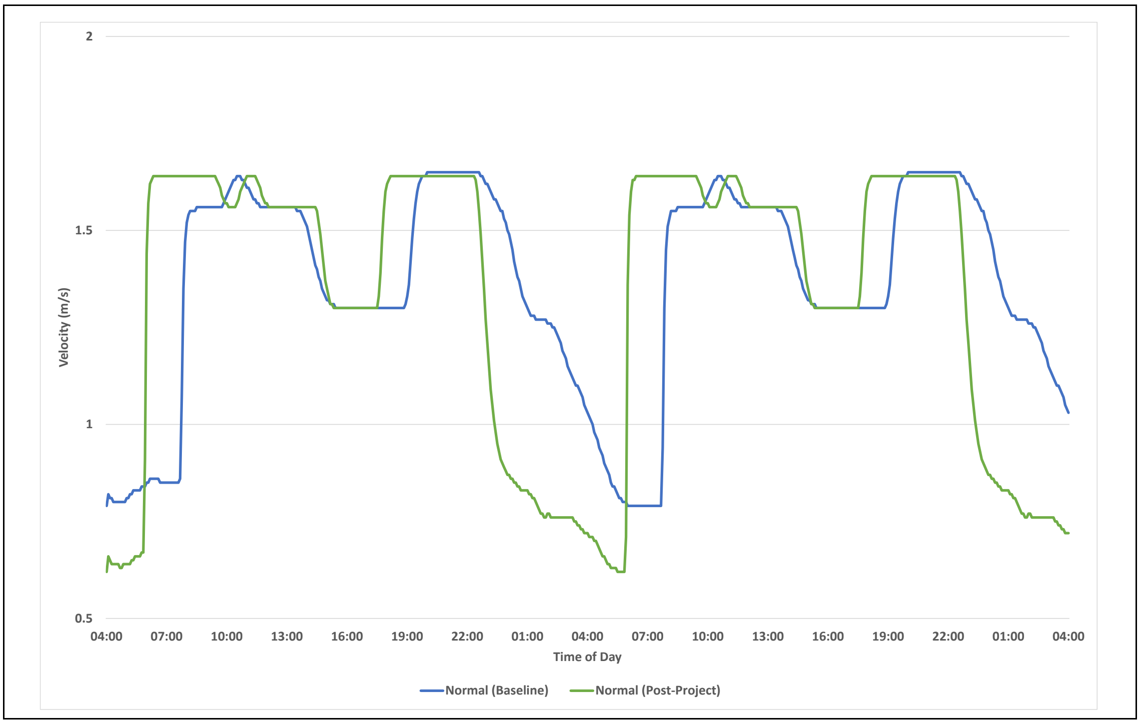

Figure 10-41 Upstream Rubyiro Tributary – Velocity Summary

Table 10-21 and Figure 10-42 show the maximum, minimum, and daily range in cross-section area, providing an indication of the overall habitat area available. As with the other hydrological and hydraulic characteristics presented, the future maximum area is similar to the current maximum, but the future minimum area tends to be lower than the current minimum area. As such, the area range tends to be higher under the future post Ruzizi III scenario in normal to very wet conditions.

The cross-section area daily variation increases by 11.2 m^2 in the normal conditions (from a daily variation of 66.4 m^2 to 77.6 m^2) due to the reduction in minimum area.

Table 10-21 Upstream Rubyiro Tributary – Cross-section Area Summary

	Baseline	**Future**
Maximum Area (m^2)	98.9	98.3
Minimum Area (m^2)	32.5	20.6
Area Range (m^2)	66.4	77.6

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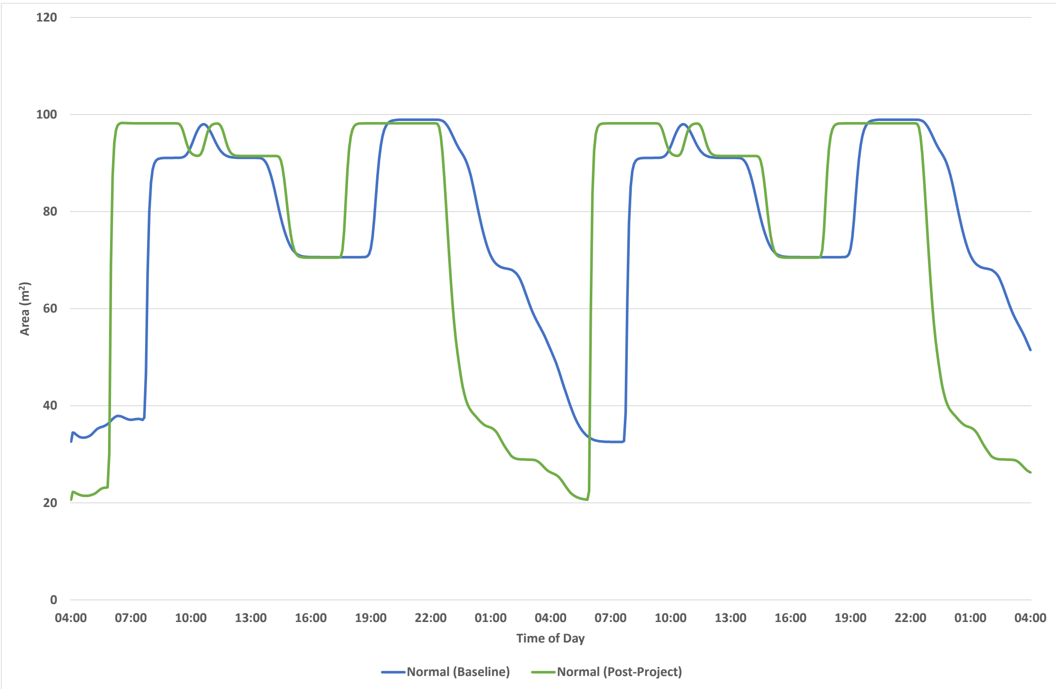

Figure 10-42 Upstream Rubyiro Tributary – Cross-section Summary

Table 10-22 provides a summary of the average vertical ramp-up rates and ramp-down rates experienced.

It is notable that future ramp-up and ramp-down rates tend to be greater than current ramp-up and ramp-down rates. This is a reflection of the operating conditions for Ruzizi III where it is understood that operation changes between "off-peaking" and "peaking" will be quicker than they currently are at Ruzizi II.

Table 10-22 Upstream Rubyiro Tributary – Ramp-up and Ramp-down Rates Summary

	Baseline	**Future**
Ramp-up (cm/min)	7.6	12.0
Ramp-down (cm/min)	-0.8	-2.6

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A.2 Upstream Burundi border / Ruhwa tributary

This section is located immediately downstream of the proposed Ruzizi III powerhouse. Figure 10-25 and Figure 10-26 provide a general overview of the river reach characteristics in this location. The model cross-section approximate reach is highlighted.

Figure 10-43 Upstream Burundi border / Ruhwa Tributary

Figure 10-44 Upstream Burundi border / Ruhwa Tributary – Photo

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A summary of the hydrological and hydraulic characteristics for this reach for normal flow conditions is provided as follows. Full details for the various different flow conditions (ranging from very dry to very wet) are provided in the accompanying annex.

Table 10-23 and Figure 10-45 show that the future maximum flow is similar to the current maximum flow, but the future minimum flow tends to be 11 m^3/s lower than the current minimum flow. As such, the change in flow range, i.e., the change in the amount of daily variation of flow, tends to be higher under the future post Ruzizi III scenario.

Table 10-23 Upstream Burundi Border / Ruhwa Tributary – Flow Summary

	Baseline	Future
Maximum Flow (m^3/s)	170	168
Minimum Flow (m^3/s)	33	20
Flow Range (m^3/s)	138	148

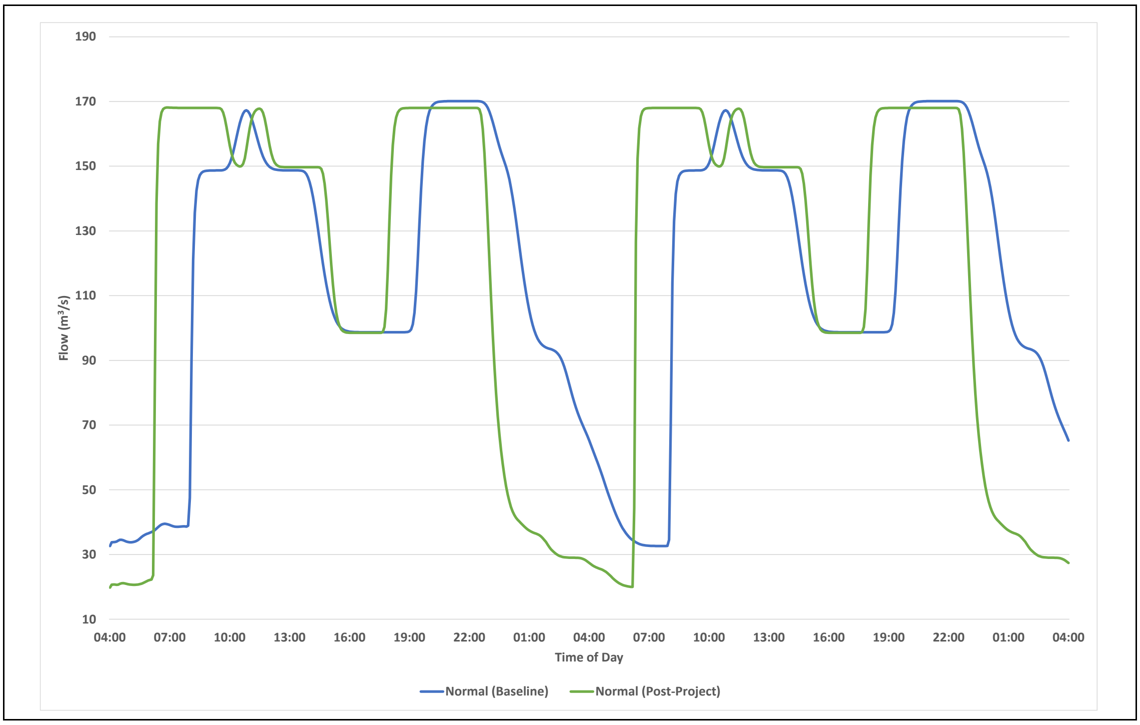

Figure 10-45 Upstream Burundi Border / Ruhwa Tributary – Flow Summary

Table 10-24 and Figure 10-46 show that the future maximum level (and hence depth) is similar to the current maximum level, but the future minimum level tends to be lower than the current minimum level. As such, the level range, i.e., the amount of daily water level variation, tends to be higher under the future post Ruzizi III scenario.

The water level daily variation increases by 18 cm (from a daily variation of 0.98 m to 1.16 m) primarily due to the reduction in minimum water levels.

Table 10-24 Upstream Burundi Border / Ruhwa Tributary – Level Summary

	Baseline	Future
Maximum Elevation (mAOD)	920.04	920.03
Minimum Elevation (mAOD)	919.06	918.87
Elevation Range (m)	0.98	1.16

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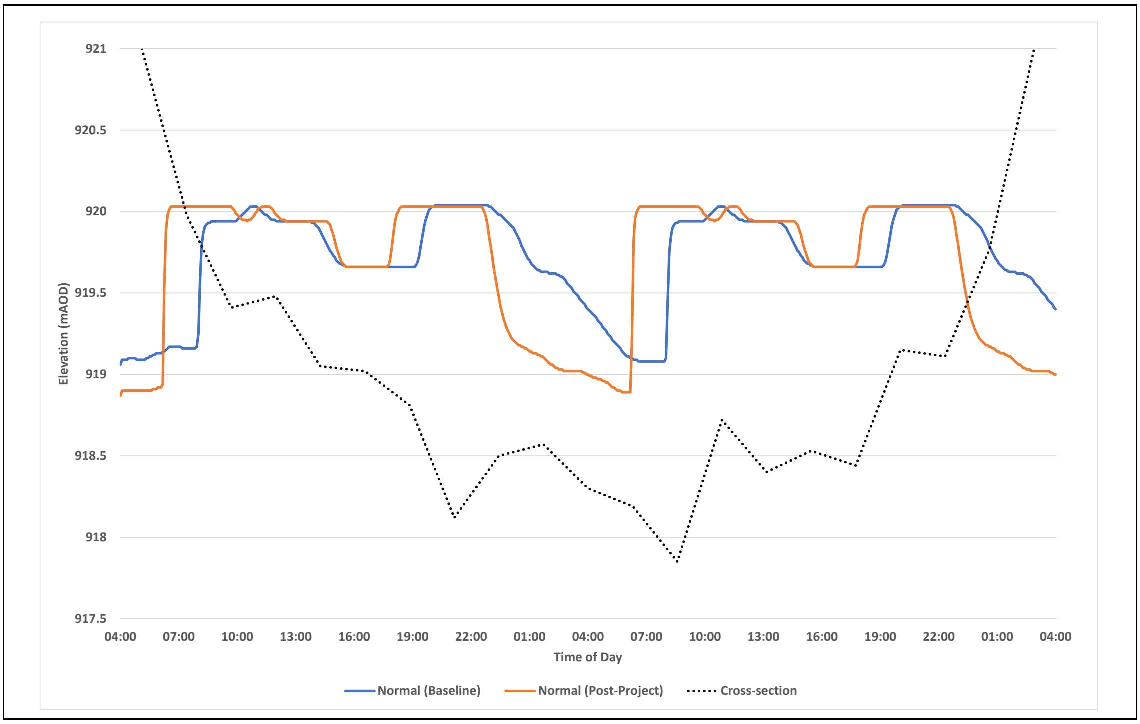

Figure 10-46 Upstream Burundi Border / Ruhwa Tributary – Level Summary

As with the flow and elevation variation, Table 10-25 and Figure 10-47 show that the future maximum velocity is similar to the current maximum velocity, but the future minimum velocity tends to be lower than the current minimum velocity. As such, the velocity range tends to be higher under the future post Ruzizi III scenario.

The velocity daily variation increases by 0.16 m/s (from a daily variation of 0.94 m to 1.10 m) due to the reduction in minimum velocity.

Table 10-25 Upstream Burundi Border / Ruhwa Tributary – Velocity Summary

	Baseline	**Future**
Maximum Velocity (m/s)	2.34	2.33
Minimum Velocity (m/s)	1.40	1.23
Velocity Range (m/s)	0.94	1.10

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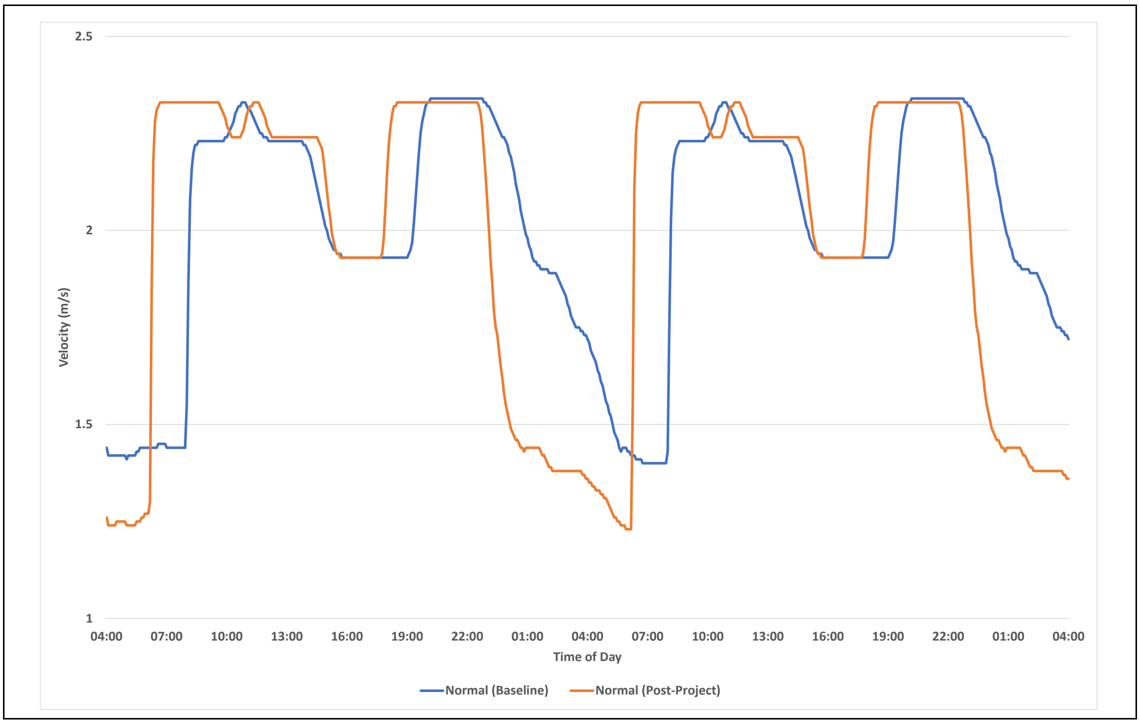

Figure 10-47 Upstream Burundi Border / Ruhwa Tributary – Velocity Summary

Table 10-26 and Figure 10-48 show the maximum, minimum, and daily range in cross-section area, providing an indication of the overall habitat area available. As with the other hydrological and hydraulic characteristics presented, the future maximum area is similar to the current maximum area, but the future minimum area tends to be lower than the current minimum area. As such, the area range tends to be higher under the future post Ruzizi III scenario in normal to very wet conditions.

The cross-section area daily variation increases by 6.4 m^2 (from a daily variation of 50.0 m^2 to 56.4 m^2) due to the reduction in minimum area.

Table 10-26 Upstream Burundi border / Ruhwa Tributary – Cross-section Area Summary

	Baseline	**Future**
Maximum Area (m^2)	72.7	72.1
Minimum Area (m^2)	22.7	15.8
Area Range (m^2)	50.0	56.4

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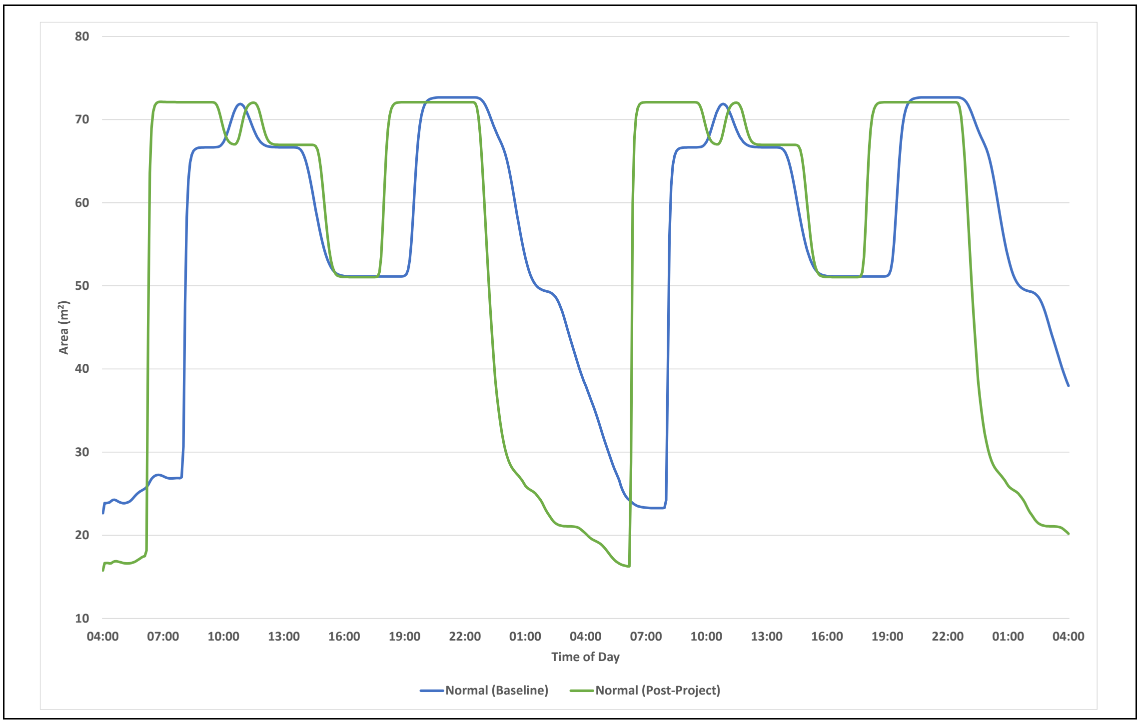

Figure 10-48 Upstream Burundi Border / Ruhwa Tributary – Cross-section Summary

Table 10-27 provides a summary of the average vertical ramp-up rates and ramp-down rates experienced.

It is notable that future ramp-up and ramp-down rates tend to be greater than current ramp-up and ramp-down rates. This is a reflection of the operating conditions for Ruzizi III where it is understood that operation changes between "off-peaking" and "peaking" will be quicker than they currently are at Ruzizi II.

Table 10-27 Upstream Burundi Border / Ruhwa Tributary – Ramp-up and Ramp-down Rates Summary

	Baseline	**Future**
Ramp-up (cm/min)	5.0	7.1
Ramp-down (cm/min)	-0.5	-1.3

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A.3 Downstream Burundi border / Ruhwa Tributary

This section is located 10 km downstream of the proposed Ruzizi III powerhouse. Figure 10-49 and Figure 10-50 provide a general overview of the river reach characteristics in this location. The model cross-section approximate reach is highlighted.

Figure 10-49 Downstream Burundi Border / Ruhwa Tributary

Figure 10-50 Downstream Burundi Border / Ruhwa Tributary – Photo

Table 10-28 and Figure 10-51 show that the future maximum flow is similar to the current maximum flow under all flow conditions, but that the future minimum flow tends to be lower

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than the current minimum flow. As such, the change in flow range, i.e., the change in the amount of daily variation of flow, tends to be higher under the future post Ruzizi III scenario.

Table 10-28 Downstream Burundi Border / Ruhwa Tributary – Flow Summary

	Baseline	**Future**
Maximum Flow (m^3/s)	185	183
Minimum Flow (m^3/s)	48	35
Flow Range (m^3/s)	138	148

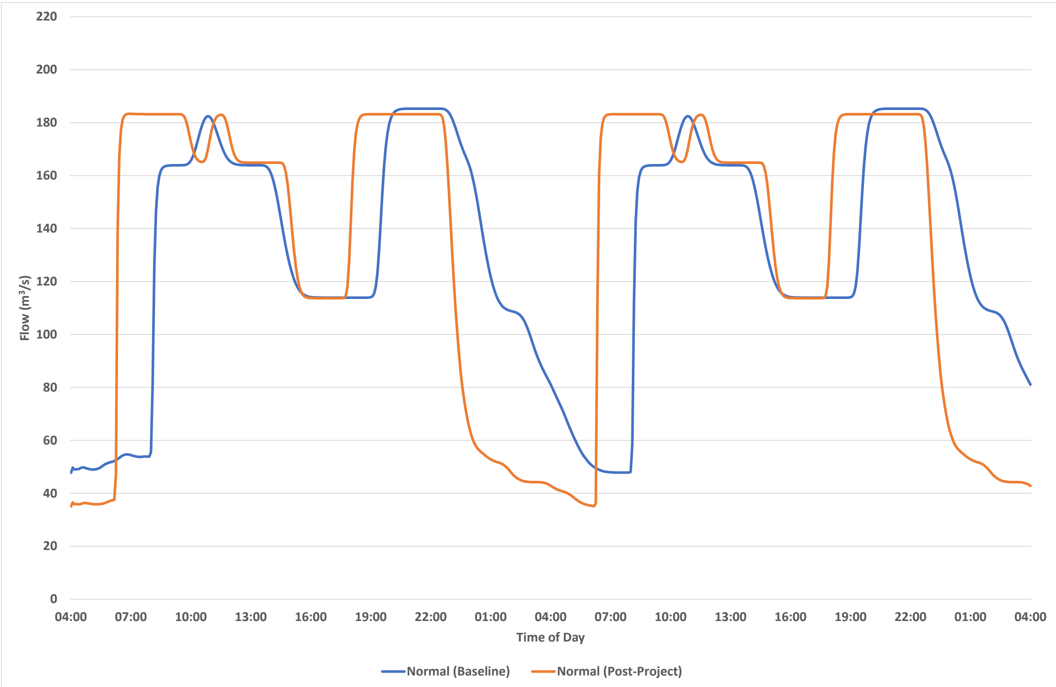

Figure 10-51 Downstream Burundi Border / Ruhwa Tributary – Flow Summary

Table 10-29 and Figure 10-52 show that the future maximum level (and hence depth) is similar to the current maximum level, but the future minimum level tends to be lower than the current minimum level. As such, the level range, i.e., the amount of daily water level variation, tends to be higher under the future post Ruzizi III scenario.

The water level daily variation increases by 14 cm (from a daily variation of 0.94 m to 1.08 m) primarily due to the reduction in minimum water levels.

Table 10-29 Downstream Burundi border / Ruhwa Tributary – Level Summary

	Baseline	**Future**
Maximum Elevation (mAOD)	908.89	908.89
Minimum Elevation (mAOD)	907.95	907.81
Elevation Range (m)	0.94	1.08

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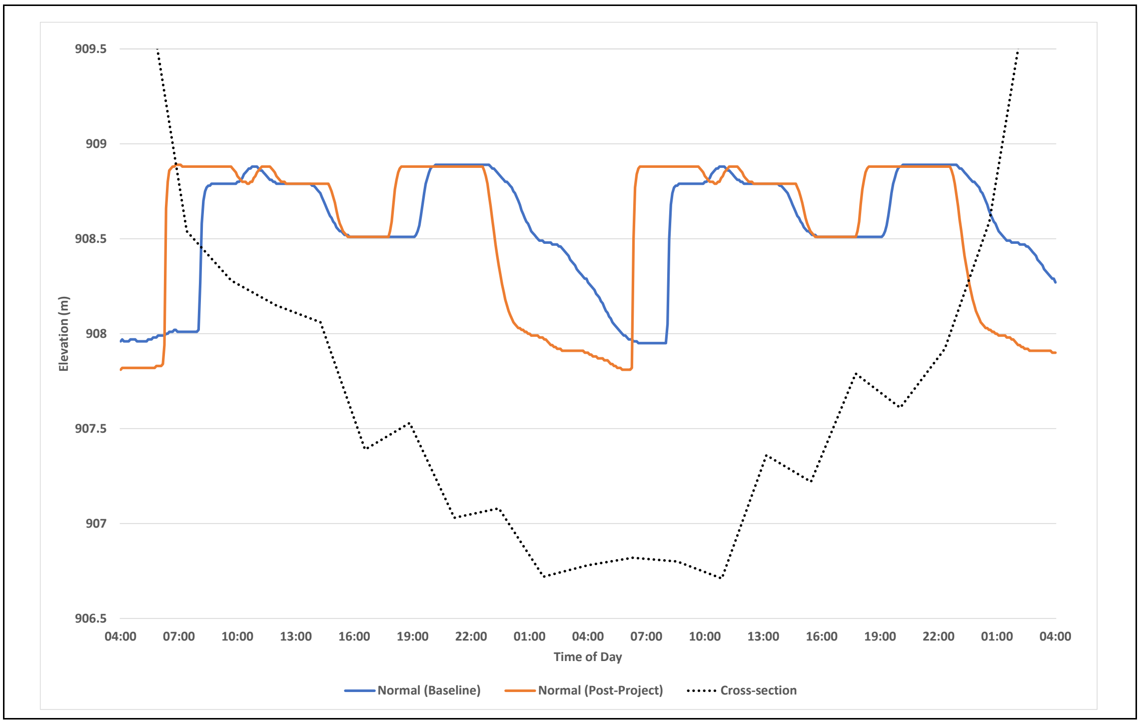

Figure 10-52 Downstream Burundi Border / Ruhwa Tributary – Level Summary

As with the flow and elevation variation, Table 10-30 and Figure 10-53 show that the future maximum velocity is similar to the current maximum velocity, but the future minimum velocity tends to be lower than the current minimum velocity. As such, the velocity range tends to be higher under the future post Ruzizi III scenario.

The velocity daily variation increases by 0.19 m/s (from a daily variation of 1.07 m to 1.26 m) due to the reduction in minimum velocity.

Table 10-30 Downstream Burundi border / Ruhwa Tributary – Velocity Summary

	Baseline	Future
Maximum Velocity (m/s)	3.00	2.99
Minimum Velocity (m/s)	1.93	1.73
Velocity Range (m/s)	1.07	1.26

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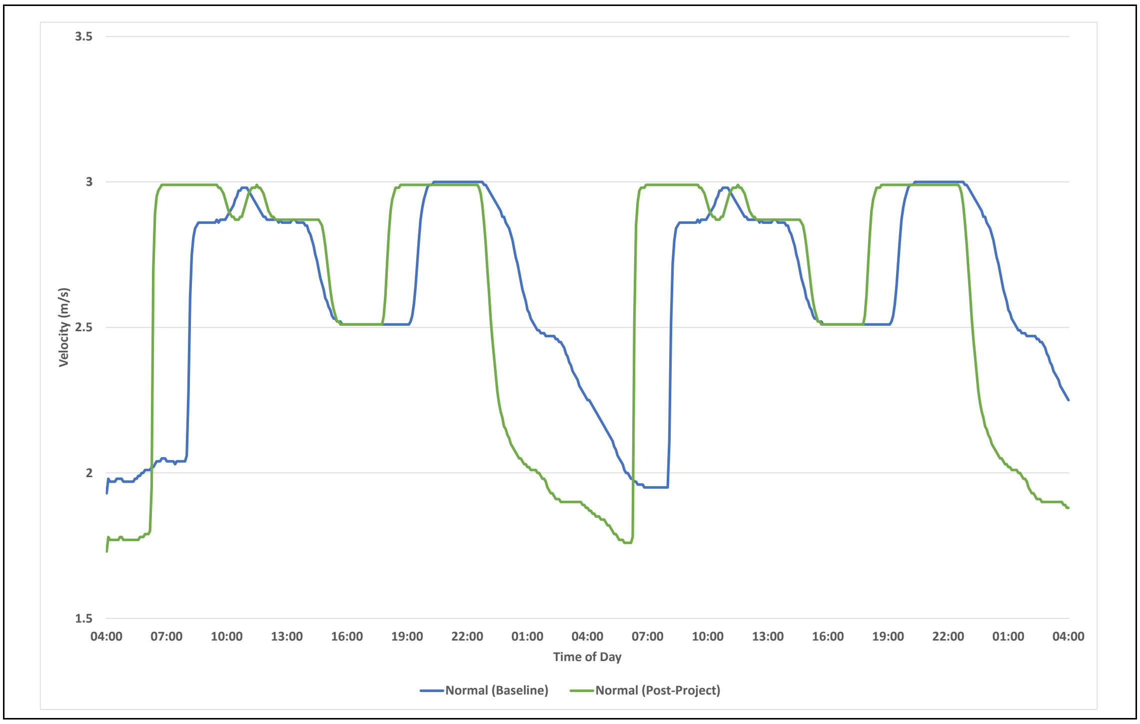

Figure 10-53 Downstream Burundi border / Ruhwa Tributary – Velocity Summary

Table 10-31 and Figure 10-54 show the maximum, minimum, and daily range in cross-section area, providing an indication of the overall habitat area available. As with the other hydrological and hydraulic characteristics presented, the future maximum area is similar to the current, but the future minimum area tends to be lower than the current minimum area. As such, the area range tends to be higher under the future post Ruzizi III scenario.

The cross-section area daily variation increases by 4.1 m^2 (from a daily variation of 37.3 m^2 to 41.4 m^2) due to the reduction in minimum area.

Table 10-31 Downstream Burundi Border / Ruhwa Tributary – Cross-section Area Summary

	Baseline	Future
Maximum Area (m^2)	61.8	61.4
Minimum Area (m^2)	24.5	20.0
Area Range (m^2)	37.3	41.4

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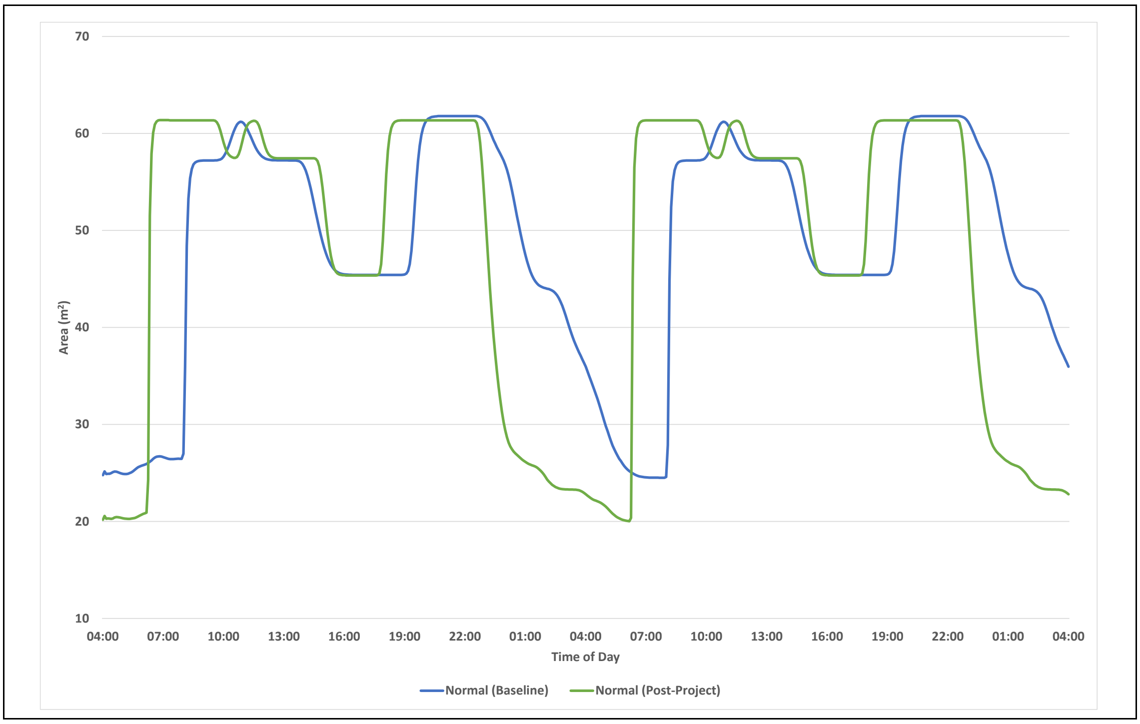

Figure 10-54 Downstream Burundi Border / Ruhwa Tributary – Cross-section Summary

Table 10-32 provides a summary of the average vertical ramp-up rates and ramp-down rates experienced.

It is notable that future ramp-up and ramp-down rates tend to be greater than current ramp-up and ramp-down rates. This is a reflection of the operating conditions for Ruzizi III where it is understood that operation changes between "off-peaking" and "peaking" will be quicker than they currently are at Ruzizi II.

Table 10-32 Downstream Burundi border / Ruhwa Tributary – Ramp-up and Ramp-down Rates Summary

	Baseline	Future
Ramp-up (cm/min)	4.9	6.8
Ramp-down (cm/min)	-0.5	-1.3

B Geomorphological, Ecological and Social Context

B.1 Geomorphology

This reach has a partly confined valley setting and a moderately steep channel gradient. It has a mixed boulder and cobble bed, with localised sections of resistant calcrete/bedrock, supporting pool-rapid and pool-riffle reach types. The river morphology alternates between rapids and riffles, with small poorly defined pool habitats. The bed elevation is controlled by bedrock/calcrete and larger immobile rocks.

Islands form where calcrete protrude from the channel floor or the river bifurcates around large immobile sediment deposits. Fine sediment deposition on these features support vegetation establishment. The river course is relatively straight across the plain to the confluence with the Ruwha River with a narrow floodplain (approximately 100 m wide). The river and narrow floodplain are incised into the surrounding plain (5 to 10 m based on the SRTM dataset) and are flanked by a ridge along the left bank at the Rubyiro river confluence. The banks are composed of coarser alluvial material (boulders and cobble) supported by sandy and clayey material. The banks appear well-vegetated and relatively stable on satellite and ground-based images despite the fluctuating water levels from Ruzizi II release. Agriculture is common on the floodplain, surrounding plains and hillslope, contributing fine sediment to the channel.

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Two large tributaries (Rubyiro and Ruhwa) contribute significant volumes of flow and sediment from the northern parts of the drainage basin. The Ruhwa appears more laterally active and turbid on satellite images and shows evidence of transporting and storing large quantities of sand and gravel. This suggests large sediment input from the Ruhwa.

B.2 Aquatic Ecology

Macroinvertebrates:

Aquatic biotopes within this reach are as per the upstream reach and comprised the following:

- Mostly Deep-Fast Rapids. These biotopes are likely to support mostly grazing and filter-feeding taxa that tolerate extreme current speeds (as described in the downstream powerhouse location section).
- One area of Deep-Slow Pool. No information was available on macroinvertebrates in such pools, but diversity and abundance in these areas is likely to be low because of light limitation and the limited diversity of hydraulic conditions.
- One area of Shallow-Fast Riffle. This area is likely to support a high diversity of macroinvertebrates (as described in the dewatered reach section).

Fish

Much like the previous reach, a combination of Fast Shallow and Fast Deep habitats characterise this reach. Lotic lithophilic species such as *Labeo* cf. *cylindricus; Labeobarbus altianalis* and *Bagrus docmak* have been recorded in this reach during previous surveys due to the suitability of spawning and feeding habitats.The Deep and Shallow Fast habitats with large bed elements are important as living space for the lotic riffle-rapid guild (*Chiloglanis* and *Amphilius*). The Slow Shallow and Fast Shallow habitats are especially susceptible to hydropeaking if these areas are regularly inundated and desiccated on a daily basis.

B.3 Terrestrial Ecology

Riparian Vegetation:

Even though this reach of the Ruzizi River is in a densely settled area, there is greater complexity of riparian habitats compared to upstream reaches, primarily because of the presence of large islands and associated braided river channels, and an extensive system of fishponds along the right bank. Riparian Thicket is poorly represented, mostly on island edges. Riparian Wetlands are dominated by *Phragmites*, as well as other wetland species that are dependent on a wet bank such as *Leersia hexandra*, *Cyperus* species and *Pluchea ovalis*. Scattered trees in Riparian Wetlands along this reach include *Senegalia polyacantha, Phoenix reclinata* and *Ficus sycomorus*.

Riparian Fauna:

The riparian avifauna, mammal and herpetofauna assemblages has the highest species richness of any of the reaches assessed, mostly because of the fishponds along the right bank, which provide significant waterbird habitat, as well as the complexity of microhabitats provided by the islands and adjacent channels. The avifauna assemblage showed a slightly higher proportion of fish-eating species and waterfowl such as white-faced duck, most likely because of the shallow water habitat provided in the fish ponds. Insect-eating bird species that forage from riverside vegetation are relatively common along this reach, such as little bee-eater, greater swamp warbler and red-faced cisticola.

Riparian mammals such as marsh mongoose and otter species are likely to be present in similar numbers to the previous reach. A small population of hippopotamus is resident in the vicinity of the confluence with the Ruhwa River and the territory of the population resident in the previous reach overlaps with the islands near the confluence with the Rubyiro River. Herpetofauna will be mostly represented by widespread generalist amphibians, reed-dwelling frogs such as *Hyperolius* and *Afrixalus* species, as well as a few riparian reptile species such as water snakes (*Lycodonomorphus* species) and terrapins (*Pelusios* species).

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B.4 Social

The following paragraphs provide an overview of local communities' reliance on Ruzizi's water for their livelihoods and domestic needs in the section from the Upstream Rubyiro Tributary to Downstream Ruhwa Tributary. Issues related to water quality and sediment load will not be covered in this analysis, as no discernible difference from current conditions is expected, due to the low residence time of water in the Ruzizi III reservoir.

This stretch is characterised by a high social reliance on the river. Various access points to fetch water for consumptive use were observed, alongside areas used for livestock drinking. For agriculture, some irrigation canals are used in DRC, but the population relies mostly on bucket or water pump irrigation. Unpredictable flooding of cultivated fields has been reported as a frequent event in this area, with a serious impact on local communities' livelihoods. Local communities are also crossing over to the neighbouring country regularly for work or visiting family, by swimming across the river. Fishing is practiced regularly by the majority of households, but it does not represent a significant source of income or means of livelihood for the local community.

In DRC, water is also abstracted for fish farming on several ponds, covering an area of around 5-6 hectares. This activity does not represent a major source of income or livelihood for the communities involved.

C Indicators Linked to Hydrological and Hydraulic Characteristics

Table 10-33 provides and overall summary of the ecological and social functional relationship with hydrological and hydraulic characteristics for the reach just upstream of the Rubyiro confluence to the Burundi border, just downstream of the Ruhwa River confluence.

The change in hydrological and hydraulic characteristics are predicted to result in significant increase in social community safety impacts (due to increased ramp-up rates), although it is noted that the increased social community safety impacts notably reduce along the length of this reach.

Table 10-33 Summary of Ecological and Social Functional Relationship / Impacts at Upstream Rubyiro Tributary to Downstream Burundi Border / Ruhwa Tributary

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Geomorphology		
Increased channel erosion The channel is largely composed of large immobile clasts, calcrete or bedrock. This makes the channel bed resistant to incision. Hydro peaking and reductions in longitudinal sediment connectivity has resulted in possible bed erosion and bed armouring	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	Minor
	Ramping Rates	No / Insignificant
Increased sedimentation in channel Due to the reduced sediment supply downstream of the dam, and the increase in the frequency of high energy flows, it is unlikely that sedimentation will take place. Localised sedimentation might take place in slack waters	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	Minor
	Ramping Rates	No / Insignificant
Bank erosion The banks are largely composed of boulders and cobbles with a finer gravel, sand and silt matrix. The banks are not steep or high and relatively stable and immobile. The banks have been exposed to hydropeaking for decades, thus bank erosion might have stabilised over time	Flow	Moderate
	Elevation / Depth	Moderate
	Velocity	Moderate
	Area	No / Insignificant
	Ramping Rates	Minor

Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Aquatic Ecology		
Non-migratory fish: abundance and diversity This reach has a combination of Fast Shallow and Fast Deep habitats. The Deep and Shallow Fast habitats with large bed elements are important for the lotic riffle-rapid guild. The Slow Shallow and Fast Shallow habitats are especially susceptible to hydropeaking if these areas are regularly inundated and desiccated on a daily basis. Depth of water and wetted area is a key criterion determining habitat suitability for this guild, which could be impacted by reduced baseflow during inter-peaking periods.	Flow	
	Elevation / Depth	Minor
	Velocity	Minor
	Area	Minor
	Ramping Rates	Minor
Migratory fish: abundance and diversity This reach has a combination of Fast Shallow and Fast Deep habitats. The Deep and Shallow Fast habitats with large bed elements are important for spawning and feeding by fish in the lotic lithophilic guild (*Labeobarbus* species). The Slow Shallow and Fast Shallow habitats are especially susceptible to hydropeaking if these areas are regularly inundated and desiccated on a daily basis. Depth of water and wetted area is a key criterion determining habitat suitability for this guild, which could be impacted by reduced baseflow during inter-peaking periods.	Flow	
	Elevation / Depth	Minor
	Velocity	Minor
	Area	Minor
	Ramping Rates	Minor
Macro-invertebrates: abundance and diversity These are expected to remain largely unchanged compared to the current operation because of the large variation in daily and sub-daily water levels despite a slight reduction in wetted area during inter-peaking operations.	Flow	Minor
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	N/A
Terrestrial Ecology		
Riparian vegetation: abundance and diversity Even though this reach of the Ruzizi River is in a densely settled area, there is greater complexity of riparian habitats compared to upstream reaches, primarily because of the presence of large islands and associated braided river channels, and an extensive system of fishponds along the right bank. Some flow-dependent species are present in the scattered fragments of Riparian Thicket and species dependent on a wet bank are present in the Riparian Wetland community. While these species may be impacted in the upper reaches of the project, the changes in flow, velocity, depth and wetted area in this reach are minor and thus unlikely to have a significant impact.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	No / Insignificant
Riparian fauna: abundance and diversity The riparian avifauna, mammal and herpetofauna assemblages have higher species richness in this reach compared to upstream reaches. The species composition of the faunal assemblage is currently dominated by widespread habitat generalists and overall species richness is low. Changes in flow, depth and velocity will have a negligible impact on riparian fauna species. The small population of hippopotamus that is resident along this reach is unlikely to be impacted by minor changes in flow, depth, velocity, area, and ramping rates.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	No / Insignificant
Social		
Consumptive Water Use Local communities in this stretch are currently using the river for domestic and drinking water supply. Social reliance on the river for consumptive water use is high.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	No / Insignificant

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Indicator & Brief Description	Hydrological / Hydraulic Characteristic	Functional Relationship / Impact (FR/I)
Non-Consumptive Water Use: Fishing Local communities are currently fishing regularly in this stretch. Local communities are currently farming fish in a number of ponds alimented by the Ruzizi on a surface of around 5-6 hectares.	Flow	No / Insignificant
	Elevation / Depth	No / Insignificant
	Velocity	No / Insignificant
	Area	No / Insignificant
	Ramping Rates	Moderate
Community Safety Local communities cross the river regularly in this stretch. Additionally, villagers are physically entering the river on a regular basis for recreational purposes, and medicinal / spiritual practices. Social exposure to hazards due to the river's flow and velocity are high.	Flow	Minor
	Elevation / Depth	Minor
	Velocity	Significant
	Area	N/A
	Ramping Rates	Significant

10.4.4 The Extended Hydropeaking Reach – Downstream Burundi Border to Lake Tanganyika

The assessment of EFlows in the Ruzizi River between downstream the River Ruhwa / Burundi Border and Lake Tanganyika (123 km) has been undertaken using a broad-scale 1D hydraulic model (see Figure 10-7) and with reference to observed water level data recorded during the period 10/02/2023 and 11/03/2023 at the Ruzizi Monitoring Station 14 km upstream of Lake Tanganyika.

The 1D hydraulic model has been used to predict hydrological and hydraulic conditions associated with the Ruzizi II hydropeaking regime (current baseline situation) and Ruzizi III hydropeaking regime (future post-project situation), with reference to change in water level and ramp-up and ramp-down rates. Under normal flow conditions, it is noted that:

- Immediately downstream of the Burundi border, water levels vary by up to 1.5 m on a daily basis under current baseline conditions, taking approximately 2 hours to increase and 8.5 hours to decrease by this amount. However, under proposed future post-Ruzizi III hydropeaking conditions water levels vary by up to 1.7 m on a daily basis (i.e. 20 cm more), taking approximately 1.5 hours to increase (i.e. 30 minutes faster than baseline) and 8 hours to decrease (i.e. 30 minutes shorter). Ramp-down rates increase slightly from 0.29 cm/minute to 0.36 cm/minute (i.e. 7 cm/min faster) and ramp-up rates increase from approximately 1.2 cm/minute to 2.2 cm/minute (i.e. 1 cm/minute faster).
- Further downstream, at the upper end of the potential Critical Habitat reach, approximately 18 km downstream of the Burundi border, water levels vary by up to 1.1 m on a daily basis under current baseline conditions, taking approximately 3 hours to increase and 10 hours to decrease by this amount. However, under proposed future post-Ruzizi III hydropeaking conditions, water levels vary by up to 1.2 m on a daily basis (i.e. 10 cm higher than baseline), taking approximately 2.5 hours to increase (30 minutes quicker than baseline) and 10 hours to decrease by this amount. Ramp-down rates remain the same as the baseline at approximately 0.2 cm/minute whereas ramp-up rates increase slightly from 0.6 cm/minute to 0.9 cm/minute.
- At approximately 60 km downstream of the Burundi border, water levels vary by up to 0.80 m on a daily basis under current baseline conditions, taking approximately 4.5 hours to increase and 10 hours to decrease by this amount. Under proposed future post-Ruzizi III hydropeaking conditions, water levels vary by up to 1.0 m on a daily basis (i.e. 20 cm higher), taking approximately 5 hours to increase and 10 hours to decrease by this amount. Ramp-down rates increase slightly from 0.13 cm/minute to 0.17 cm/minute, whereas ramp-up rates remain constant at approximately 0.3 cm/minute.

The observed water level data at 14 km upstream Lake Tanganyika (136 km downstream from Ruzizi II dam) shows that the current average daily range of water levels is 0.07 m, with a rate of change of 0.3 cm/hour. This represents further significant attenuation of hydropeaking effects and is expected to be in part attributable to the backwater effect of Lake Tanganyika.

In summary, based on the broad-scale modelled assessment of hydropeaking and observation of current baseline water levels in the extended study area, the effects of Ruzizi II / III hydropeaking are expected to significantly attenuate with distance downstream in Burundi. Flow fluctuations 60 km downstream of the Burundi /Rwanda border (just upstream of the Ruzizi National Park and Ramsar site) will only be slightly detectable or measurable. Current observed water level variation at 14 km upstream of Lake Tanganyika is less than 10 cm.

A small incremental effect in water level increase and speed of change of water levels can be attributed to the proposed operation of Ruzizi III. Importantly, the associated **community safety related ramp-up rates remain well below threshold values of 5 cm/minute**. Similarly, the associated **fish-stranding related ramp-down rates are well below threshold values of 1 cm/minute**. As such, it is concluded that **the hydrological and hydraulic hydropeaking effects present no significant transboundary impacts with Burundi nor impact potential Critical Habitat in the lower Ruzizi River system.**

10.5 Summary and Conclusions

The hydrological, hydraulic, and geomorphological characteristics of the Ruzizi River and how they are modified by the Ruzizi III HEPP drive the predicted responses of the ecological and social components or receptors.

This section focuses on summarising the predicted changes in hydrology and geomorphology and the current baseline environmental and social context related to the river as a basis for interpreting the downstream impacts of the project that are described and assessed, together with identified mitigation measures, in the Impact Assessment & Mitigation chapter.

The hydrological and hydraulic changes identified have been determined by the application of 1D and 2D hydraulic modelling. Such modelling can provide useful general information for assessing the hydraulic characteristics but has particular limitations in describing the heterogeneity found at the micro- and meso-habitat scale required for a full assessment of the expected aquatic ecosystem impacts associated with different EFlow regimes.

This EFA has adopted a medium-resolution and this is considered suitable by the ESIA Consultant and REL, it is nevertheless recognised that the suitability will be assessed by the IPoE and if necessary will be revised to address the panels comments post financial closure.

10.5.1 Hydrological and Hydraulic Changes

10.5.1.1 The Dewatered Reach – Ruzizi III Dam Wall to Powerhouse Tailrace

A Current Baseline Conditions

The reach downstream of Ruzizi III dam wall is currently subject to large daily variations in flow, water levels and depths, velocities, and wetted area due to the hydropeaking operation of Ruzizi II.

Based on the 1D hydraulic modelling, under normal conditions, flows in the reach between the dam wall and powerhouse vary between approximately 25 m^3/s and 163 m^3/s on a daily basis – although are at least 86 m^3/s throughout daylight hours and for 75% of the time. The greatest impact in terms of hydraulic characteristics is on wetted area (available aquatic habitat). This varies between 61% and 100% - and is at least 86% throughout daylight hours and for 75% of the time. Variations in average depth and average velocity are also apparent. Average depth varies between approximately 1.1 m and 1.8 m (1.7 m for 75% of the time), average velocity varies between approximately 0.7 m/s and 1.4 m/s (0.8 m/s for 75% of the time).

B Future Post-project Conditions

The reach from Ruzizi III dam wall to the powerhouse tailrace will be dewatered – flows will be maintained by environmental flow releases.

Given a constant flow of 10 m^3/s as proposed by the Feasibility Study, significant reductions in wetted area, average depths and average velocities would occur in this reach. The wetted area reduces to 44% and 48% of peak and natural AAF respectively, average depth reduces to 0.55 m and average velocity reduces to 0.55 m/s. It is important to note though that the reported figures are averages – depths and velocities vary markedly within the dewatered reach and such variation may have important impacts on the ecological and social health of the reach. Although wetted area and depth will be significantly reduced in this reach, an improvement in aquatic ecosystem condition is predicted due to the more stable conditions that will be created. Furthermore, a constant flow, whatever the magnitude, does not contribute to the ecological and social health of the aquatic ecosystem for those aspects associated with intra-annual and inter-annual variation.

10.5.1.2 The Hydropeaking Reach – Ruzizi III Powerhouse tailrace to Burundi Border

In the reach downstream of the Ruzizi III powerhouse tailrace to the Burundi border, differences between the current hydrological regime and the predicted future hydrological regime are associated with the capture of the 177 km^2 right-bank tributary inflows (located 7.2 km upstream of Ruzizi III dam wall) and operational control curves relating to powerhouse releases. It is predicted that there will be no / insignificant change in maximum flows, depths, and velocities as the maximum powerhouse capacities of Ruzizi II and III are both 150 m^3/s. However, **differences in both ramp-up rates and ramp-down rates are predicted, with the critical ramp-up threshold (5 cm/minute) and critical ramp-down threshold (1 cm/minute) likely to be exceeded more often under Ruzizi III operating conditions**.

It is also notable that **the effects of hydropeaking are predicted to reduce along the hydropeaking reach** such that ramp-up and ramp-down rates decrease due to in-channel attenuation and the effect of downstream tributary inflows (primarily from the Rubyiro and Ruhwa rivers). For example, under predicted Ruzizi III operating conditions, maximum ramp-up rates near the powerhouse are approximately 10 cm/minute under normal flow conditions, reducing to approximately 7 cm/minute downstream of the Ruhwa River. Similarly, maximum ramp-down rates reduce from 6.5 cm/minute to 1.3 cm/minute over this same stretch.

10.5.1.3 The Extended Hydropeaking Reach – Downstream Burundi Border to Lake Tanganyika

In the 123-km-long reach downstream of the Burundi border to Lake Tanganyika, the effects of Ruzizi II / III hydropeaking are expected to significantly attenuate with distance. Flow fluctuations at the Ruzizi National Park and Ramsar site (118 km downstream from the Ruzizi III powerhouse) will only be slightly detectable or measurable. Current observed water level variation at the location (14 km upstream of Lake Tanganyika) is less than 10 cm.

A small incremental effect in water level increase and speed of change of water levels can be attributed to the proposed operation of Ruzizi III. Importantly, the associated **community safety related ramp-up rates remain well below threshold values of 5 cm/minute**. Similarly, the associated **fish-stranding related ramp-down rates are well below threshold values of 1 cm/minute**. As such, it is concluded that **the hydrological and hydraulic hydropeaking effects present no significant transboundary impacts with Burundi nor impact potential Critical Habitat in the lower Ruzizi River system.**

10.5.1.4 Alteration of Minimum Water Depth Along the Whole of the Ruzizi River

The Cumulative Impact Assessment (CIA) provided in Chapter 12 includes an assessment of the impacts on hydrology of the Ruzizi River caused by the operation of the existing Ruzizi-I and -II hydropower schemes and the incremental changes caused by the operation of the proposed

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Ruzizi-III Project. The metric used for the assessment is the % alteration to natural minimum water depth of the river, i.e. the water depth before implementation of Ruzizi-I HEPP in 1959.

The minimum water depths at different points along the river for the natural conditions and with operation of Ruzizi I/II and with Ruzizi-III were estimated using the results from this EFA which computes water depth for different flow conditions at several EFlow sites.

The key findings of the CIA for hydrology are as follows:

- Operation of Ruzizi-I and -II has altered flow conditions of the Ruzizi River over the total distance between Ruzizi-I and the outflow into Lake Tanganyika (165 km).
- In the reach between Ruzizi-I and Ruzizi-II reservoir, variations in flow rate of 10 to 150 m^3/s occur on a sub-daily basis. The peak flows do not exceed the upper limit of inter-annual variations. However, the off peak flows create water depths that are ~50% lower than for natural conditions.
- Downstream from Ruzizi-II, the lowering of minimum water depth decreases with distance because of flow attenuation effects and the inflow of tributaries. In the reach immediately downstream, the off peak water depth is ~50% lower than natural conditions, and at the outflow into Lake Tanganyika the depth is <1% lower.
- The proposed Ruzizi-III Project will alter flow conditions of the Ruzizi River and overlap the alterations caused by Ruzizi-I and -II. The Ruzizi-III Project is located 12 km downstream from Ruzizi-II and consequently the alterations to the Ruzizi River extend slightly further downstream than the alterations caused by Ruzizi III.

A Degree of Alterations to Minimum Water Depth

The % alterations to natural conditions minimum water level for each of the hydropower schemes are presented in Table 10-34 and Figure 10-55.

Table 10-34 Alteration to Natural Conditions Minimum Water Level vs River Length

Reach (km)	Alteration to natural conditions minimum water level (%)			Comments
	Ruzizi-I	Ruzizi-II	Ruzizi-III	
0-3	-	-	-	No alteration
3-4	-	-	-	No alteration - Ruzizi-I reservoir
4-16	-50%	-	-	Ruzizi-I off peak flows
16-19	-	-	-	No alteration - Ruzizi-II reservoir
19-28	-50%		-	Ruzizi-II off peak flows
28-31	-		-	No alteration - Ruzizi-III reservoir
31-37	-50%		-50%	Ruzizi-III dewatered reach, also altered by Ruzizi-I/II, Alterations overlap, but do not cumulate
31- 41	-50% to -38%		-50% to -41%	Ruzizi-III dewatered reach also altered by Ruzizi-I/II
41-61	-38% to -14%		-41% to -19%	Alterations from Ruzizi-I, -II and -III overlap, but do not cumulate.
61-81	-14% to -5%		-19% to -9%	
81-101	-5% to -1.5%		-9% to -3.7%	
101-121	-1.5% to <-1%		-3.7% to -1.5%	
121-141	<-1%		-1.5% to <-1%	
141-168	<-1%		<-1%	

B Alteration from Ruzizi-I and -II and Incremental Changes Caused by Ruzizi III Project

It is concluded that the operation of Ruzizi-I and II has caused a significant impact on river hydrology, ~60 km of river (36%) has been affected by a significant (>10%) lowering of minimum water level. The operation of the proposed Ruzizi-III Project is expected, to cause minor (<10%) lowering of water levels along an additional 40 km (24%) of the river. The degree of alteration decreases with distance downstream from the Project.

It is noteworthy that river flow rates and water levels during Ruzizi-I, -II and -III peak flows do not exceed the seasonal high flows / high water levels encountered under natural conditions.

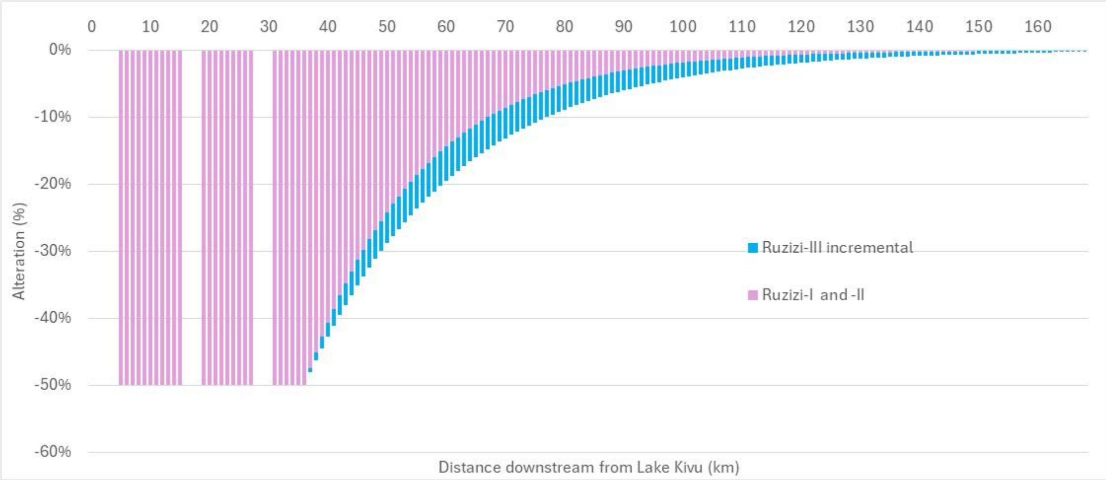

Figure 10-55 % Alteration to Natural Conditions Minimum Water Level vs River Length (Illustrative)

10.5.2 Geomorphology and Sedimentology

The Ruzizi River from the Ruzizi III dam to the confluence with the Ruwha River has a stable bed composed of large immobile material, bedrock and calcrete (cemented boulders, cobble and gravel). The banks are composed of large material, with a finer matrix amongst the larger clasts. The banks are relatively low, of a low to moderate angle and well vegetated for most parts. The upper confined reach has no floodplain, but once the river flows across the plain, a narrow floodplain exists. The floodplain is incised into the larger plain.

The Ruzizi River has been exposed to significant hydropeaking over the last few decades from Ruzizi I and II HEPPs. The trapping of bedload in the upstream reservoirs and frequent high flows would have armoured most of the confined and semi-confined reaches. This might include localised bank erosion where agriculture is taking place close to the bank edge.

The proposed Ruzizi III development is likely to trap the longitudinal supply of bed material and will possibly lead to further armouring (removal of fine sediment from the bed matrix) directly downstream of the reservoir along the dewatered reach. The effect of this on the bed elevation lowering is predicted to be minor and localised. Where tributaries or hillslope processes from the steep valley sides contribute large volumes of sediment to the Ruzizi along the dewatered reach, sediment fans or bars could develop as the river transport capacity will be reduced in this reach. This can improve the aquatic and riparian habitat diversity but may lead to sedimentation of slack waters. In extreme mass wasting events (i.e. during landslides), the channel could be blocked, leading to blockage of flow and damming of the valley. In such an event, it will take longer to fill, breach, and erode this natural dam as the proposed flow of 10 m^3/s is relatively low.

Downstream of the Ruzizi III powerhouse the increased flow rate fluctuations will increase the peak energy (shear stress) of the river, driving sediment entrainment of slightly larger sediment particles. This is likely to drive the process of armouring, stripping the channel further of finer substrates in this reach. No significant sediment contributions take place between the Ruzizi III

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powerhouse and the confluence with the Rubyiro River to mitigate this armouring process, although some lateral contributions from localised landslides, bank erosion, and surface runoff and erosion may occur. The removal of finer substrates is likely to happen along the banks too, but due to the stable bed-rock controlled nature of the channel perimeter, no significant incision or widening is likely to occur. The sediment inputs from the Rubyiro and Ruhwa are likely to increase the occurrence of finer sediment habitat, but the extent of the possible amelioration of finer habitats is unknown with the current information on daily flow variability and sediment supply downstream of the Ruhwa River.

The geomorphological and sedimentology assessment has been undertaken primarily as a desk-based assessment supported by field inputs from team members. Recommendations for monitoring geomorphological and sediment changes in the project Area of Interest are required to confirm these predictions and are documented in Vol. IV ESMP.

10.5.3 Aquatic Ecology

10.5.3.1 Aquatic Habitats and Macroinvertebrates

Aquatic habitats in the Project Area of Interest were classified as *'modified'*, primarily due to the altered flow regime from upstream hydropower projects and reflected in the very low macroinvertebrate diversity and abundance, mostly dominated by hardy, tolerant species, while ecological functions of the Ruzizi River within the Project Area of Influence were assessed as '*seriously modified'*.

While overall diversity and abundance of macroinvertebrates was very low, the most sensitive macroinvertebrate recorded was the Stonefly *Neoperla spio*, a common species that provides a potential useful indicator for monitoring ecological change. The most common taxa recorded were non-biting midges (Chironomidae). The Proportion of Sediment-Sensitive taxa (PSI) was low, and this suggests elevated levels of suspended sediments. Whilst the proportion of air-breathing taxa was moderate, and higher than expected for a river that appears to be well-oxygenated. Functional feeding groups comprised a dominance of predators, and this is typically associated with disturbance and an ecosystem that is in poor health. However, no alien macroinvertebrate taxon was recorded.

The main cause of the modified ecological state was attributed to short-term fluctuations in water level associated with the operation of Ruzizi II. Marginal habitats and all instream habitats above the lowest water level were largely devoid of aquatic life because of frequent exposure associated with short-term (daily) fluctuations in water level. Other drivers of ecological deterioration were elevated nutrients and solid waste associated with the City of Bukavu, and elevated sediments associated with the cultivation of most catchment areas that drain into the Project Area of Influence. Aquatic flora was dominated by a monoculture of the filamentous alga *Cladophora glomerata*, a typical indicator of polluted water. The presence of this alga on the stream bed at about 0.5 m depth indicated that light was not limited, although deeper areas are likely to be light limited because of elevated turbidity. The composition of benthic diatoms also indicated elevated concentrations of nutrients and suspended sediments.

The proposed development will permanently inundate aquatic habitats and associated macroinvertebrate biota within the reservoir inundated area (as defined at Full Supply Level). In the 5.5 km dewatered reach, the reduced flow will potentially impact macroinvertebrates due to the reduction in wetted area but the more stable flow is predicted to compensate for this. However, the proposed development is unlikely to have a measurable detrimental impact on aquatic macroinvertebrates within the hydropeaking reach compared to the baseline conditions.

The proposed development provides an opportunity to improve aquatic ecological conditions in the dewatered and hydropeaking reaches, and in doing so, compensate for the potential negative impacts within the area of inundation.

10.5.3.2 Fish

Despite the modified condition of the Ruzizi River, historical catch data indicates it hosted a number of threatened, restricted range and migratory fish species although the current distribution and abundance of these and extent of migration is not well understood. However, it appears that several restricted range and migrator fish that were historically documented for this river may no longer exist in reaches impacted by the upstream hydropower projects, or if they do, only in low abundance. For instance, surveys in the last five years have not recorded species such as *Labeobarbus leleupan*us and *Acapoeta tanganicae* which were recorded in surveys in the mid 1950's with some last recorded in the early 1980's based on records of the Central African Museum in Brussels. It also includes threatened and restricted range species such as *Chiloglanis ruziziensis* (CR) and *Chiloglanis asymetricaudalis* (EN) which are typically associated with rapids and riffles, as well as several other migratory species endemic to the Ruzizi Basin or region.

Although the aquatic ecosystem of the upper and Ruzizi River in the area of project influence is assessed as modified habitat, and does not have critical habitat qualifying species, it provides habitat for several non-threatened migratory species, particularly in the *Labeo* and *Labeobarbus* genera. This is described in detail in the Aquatic Ecology section of the Environmental Baseline chapter and Critical Habitat Assessment.

Besides the obvious barrier effect of dams that restrict upstream fish migration, hydropeaking downstream of hydropower facilities affects foraging, refuge seeking, and predator avoidance behaviours in fishes as well affecting migration, growth, and survival. Such projects typically alter the natural hydrological cues that stimulate fish migration and breeding through altering the seasonal periodicity of water levels. Behavioural shifts to adapt to these changes can result in increased energetic costs relative to natural conditions, often resulting in decreased fish recruitment. Hydropeaking effects can also result in increased exposure to unsustainable fishing practices if fishing is easier during lower flow conditions.

The extent to which fish will be affected by the project is linked to the degree to which water depths are reduced in the dewatered reach and during off-peaking periods in downstream reaches (when the reservoir is filling). Fish typically require a depth of 0.3 m particularly over the migration and spawning season to move through the water body. Maintaining a minimum flow in this reach will also need to ensure continuity of water connectivity to assist migration by ensuring pools are not isolated from each other or do not become sedimented from lateral sediment inputs (e.g., landslides or erosion). Such effects may require the release of additional water (freshets) to flush the dewatered reach and to enhance fish migration.

Downstream impacts on fish are also linked to the rate of river level drop after peaking depending on the ramp-down rates applied, as hydropeaking operations can result in fish mortality from stranding on riverbanks or in pools if water levels drop faster than 5 cm/hour, as seen downstream of Ruzizi II HEPP. This can be managed through extending ramp down rates to reduce rate of water level drop below this threshold. Ultimately, fish monitoring will be essential to confirm the extent of impacts and adaptively manage flow releases if required.

10.5.4 Terrestrial Ecology

10.5.4.1 Riparian Vegetation

Natural Habitat on the riverbanks along all reaches of the river is limited but most of all in the dewatered zone and in the reach between the dewatered zone and Bugarama, where Natural Habitat is mostly confined to small islands in the river.

Two types of riparian vegetation are represented, namely Riparian Thicket and Riparian Wetlands. Species dependent on a wet bank are more prevalent in the Riparian Wetland community, while flow-dependent species are not well represented in either Riparian Wetland or Riparian Thicket. Riparian Thicket species are more positively associated with rocky substrate than a wet bank or river flows.

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The project-related changes are likely to be most apparent in the dewatered reach, where some limited loss of Riparian Wetland habitat is likely to occur as a result of a reduced wet bank. However, this is of minor consequence since this habitat is represented along all the reaches of the river covered in this assessment.

Downstream changes in flow, depth, velocity, and area of wet bank will be attenuated with increasing distance from the dewatered zone and are unlikely to result in any significant changes in riparian vegetation.

10.5.4.2 Riparian Fauna

The riparian avifauna, mammal and herpetofauna assemblages are characterised by low species richness and diversity along the entire stretched of the Ruzizi River covered in this assessment. Species richness is particularly low in the reach between the dewatered zone and Bugarama as a result of the small extent of Natural Habitat present in this reach.

The riparian avifauna assemblage contains surprisingly few fish-eating species although a limited number are present, with diversity increasing slightly in the reaches closer to the Burundi border. Riparian mammals such as marsh mongoose and otter species may be present throughout in small numbers, but larger herbivores such as Hippopotamus are mostly represented downstream of the Bugarama – Kamanyola Bridge and are thus unlikely to be significantly impacted by project-related changes to the river. Herpetofauna are mostly represented by widespread generalist amphibians as well as a few riparian reptile species.

None of these assemblages is likely to be significantly impacted by the by minor changes in flow, depth, velocity, area of wet bank and ramping rates.

10.5.5 Social

The social dependence of local communities on the Ruzizi River is high downstream of the power release location down to the Ruhwa confluence, but slightly lower in the dewatered stretch due to difficulty of access from surrounding villages. Downstream of the powerhouse, the social reliance on water from the Ruzizi revolves around (i) all consumptive needs, including drinking water, cooking water supply and sanitation water, (ii) fishing and fish farming and (iii) all recreational and cultural activities involving physically entering or crossing the river.

In the dewatered stretch, none of the cited elements of social dependence are likely to be affected by any discernible deviation from current conditions. Equally, downstream of the powerhouse release, water collection for consumptive use and water use for fish farming are not expected to be affected by a discernible deviation from current conditions. However, in terms of community safety the expected higher frequency of ramping up rates is likely to have a significant negative impact on local communities crossing or physically entering the river. In fact, it is expected that ramp-up rates over 5 cm/minute, a threshold which has been selected as critical for community safety, are likely to be exceeded more frequently than they are in current conditions. In the downstream stretches of the Ruzizi, the expected higher frequency of ramping down rates is also likely to have a negative impact on the availability of fish in the long term, potentially threatening the productivity of fishing activities.

The assumptions and limitations of the assessment of social dependence are related to the adopted methodology as described more fully in the Social Baseline Situation chapter. Identified limitations include poor definition of village boundaries, time constraints in conducting formal interviews, gender-imbalance of the DRC social team, and limited, partial consultation of Historically Marginalised People.

10.5.6 EFlows

The EFlow assessment that has been undertaken has considered the ecological and social functional relationships with the hydrological and hydraulic characteristics of the reach between the Ruzizi III dam wall and powerhouse tail race (the dewatered reach), the reach downstream of the powerhouse tail race to the Burundi border (the hydropeaking reach), and the extended hydropeaking reach from the Burundi Border to Lake Tanganyika.

A **medium-resolution assessment has been applied** considering key characteristics of the Project. Although the Project is located in a context which would appear to suggest that a high-resolution assessment is required (i.e. potential significant transboundary issues and lowest position in a cascade), it is located in a reach that is already heavily modified (due to the presence and operation of upstream Ruzizi I and II HEPP). These aspects suggest that a medium-resolution assessment, as performed for the Project, is sufficient to adequately assess the flow-related impacts of the project on the downstream environment.

The sufficiency of a medium-resolution assessment in the project affected area has been confirmed by a broad-scale assessment of the hydrological and hydraulic characteristics in the extended study area downstream of the border with Burundi (**no potential significant transboundary issues have been identified**), and by the results of the accompanying Critical Habitat Assessment that has confirmed the project is not located in or will impact on potential Critical Habitat qualifying features.

The **impacts associated with a constant EFlow of 10 m^3/s in the dewatered reach and expected hydropeaking operations (based on optimised energy revenue), and the proposed associated mitigation measures, are presented in the Impact Assessment & Mitigation chapter** of this report. Associated mitigation measures include hydrological measures (e.g., improved hydrological and hydraulic characterisation of micro-/meso-scale habitats and monitoring), sediment management measures (e.g., development of a Dewatered Reach Sediment Management Plan), and aquatic habitat and biodiversity measures (e.g., release freshets of at least 50 m^3/s over a few days on a biannual basis, fish monitoring).

An associated framework level Environmental Flow Management Plan (EFMP) that outlines and describes activities required to implement, monitor, and review the proposed operational flow regime from the perspective of adaptive management is included in the associated Environmental and Social Management Plan (ESMP).

This 'framework' EFMP will need to be updated to an operational EFMP through further investigation and collaboration with key stakeholders including, *inter alia*, upstream HEPP operators, with the aim of agreeing and implementing an optimised flow regime that is at once socially equitable, economically efficient, and ecologically sustainable.