NGONYE FALLS HYDROELECTRIC PROJECT

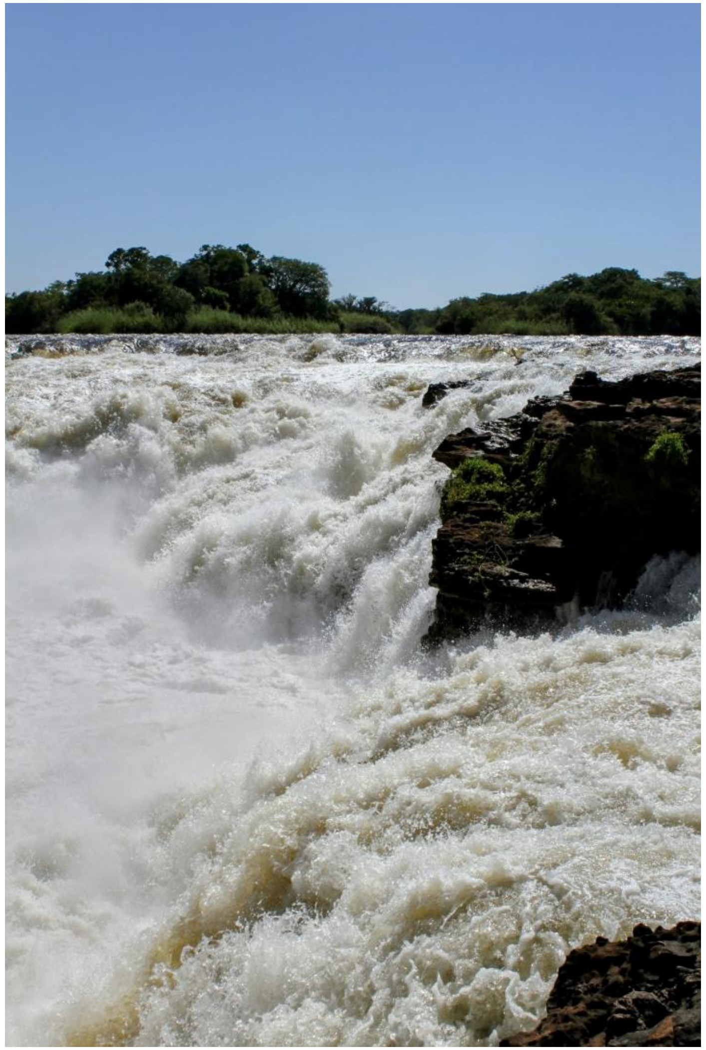
CLIMATE VARIABIITY AND CLIMATE CHANGE RESILIENCE

10 Oct 2024

Western Power

EXECUTIVE SUMMARY

- The Ngonye Falls Hydroelectric Project is a $700m, 180MW, run-of-river hydroelectric power station that will be built on the Zambezi River in the Western Province of Zambia. The project will produce seasonally variable base-load energy with high degree of predictability and stability.
- The possible risks and impacts of climate change and climate variability are critical aspects of the design, financing, construction and operation of the project.
- The project is following a multi-phase climate change resilience and risk assessment according to the International Hydropower Association (IHA) guidelines.
- Climate change and variability risks could impact on the project economics, infrastructure safety, operations & maintenance and community health and safety.
- Aspects of the projects design, the hydrology of the catchment, the hydraulic conditions at the Ngonye Falls and the nature of run-of-river power hydropower stations mean that the project has a very low inherent climate change and climate variability risk during construction and during operation.
- In addition, these particular features of the project mean that its annual energy yield will be largely decoupled from the energy yield of the large storage-dam type hydroelectric power stations downstream on the Zambezi such as Kariba and Itezhi-tezi which reliable annual energy production even in significant drought years such as 2018-19 and 2024-25.
- A climate change stress test based on the latest global climate change models and using a basin rainfall and temperature – runoff model prepared specifically for the project is currently being completed by the Project's engineer, Mott MacDonald.



Ngonye Falls, March 2024.

NGONYE FALLS HYDROELECTRIC PROJECT

The Ngonye Falls Hydroelectric Project is a $700m, 180MW, run-of-river hydroelectric power station that will be built on the Zambezi River in the Western Province of Zambia.

Following its commissioning in 2028, the power station will produce approximately 800GWh per year of clean, reliable and climate resilient, base-load electricity, enough to supply nearly 200,000 households in Zambia or to support 100,000 tpa of new copper production.

The Ngonye Falls project is a run-of-river design without any large dam or storage reservoir.

The run-of-river design has a low environmental and social impact and a much simpler, low risk design during both construction and operation. However, unlike storage type hydroelectric power stations - with a storage reservoir behind a dam that can hold back and store water at certain periods and then release it for generation at later times - the Ngonye Falls project can only generate power proportional to the natural flow of water in the river at any given time.

The Project has a simple, low-risk design without any high dams or tunnelling and can be built as linear-infrastructure resulting in a low-risk construction timeline.

The finance for the Project will be secured against a 25 year Power Purchase Agreement (PPA) with the Zambian national electricity utility, ZESCO on a take-or-pay, energy only basis.

The Ngonye Falls hydroelectric scheme is located on the Zambezi River in the Western Province of Zambia, 110km upstream of Sesheke and 250km upstream of Victoria Falls.

CLIMATE VARIABILITY AND CLIMATE CHANGE

Climate change and natural long-term **Climate variability** are two processes which may impact on river flows and therefore energy generation over the life of the Ngonye Falls project.

Climate variability refers to cyclical patterns of change in the global or continental-scale climate causing cyclical changes in the flow of water in the river over multi-decadal periods of time. These cycles may impact the average, maximum and minimum annual flow as well as the timing of changes in flow. Climate Variability may lead to periods lasting tens of years of flows that are higher or lower than the overall average. However, the duration of these periods is not fixed, and it is impossible to know how long any particular period will last in advance.

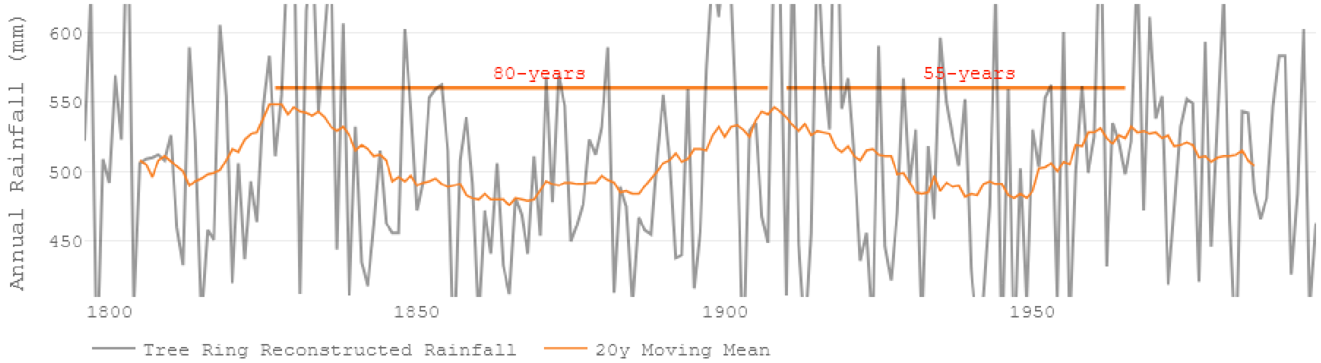


Fig 3. Total annual rainfall reconstructed from tree ring measurements in northern Zimbabwe. 20 year moving average overlaid. From: Therrell et. al. (2006).

Variable-period, cyclic climate variability evident in long-term rainfall patterns in the Zambezi basin.

Climate change refers to gradual trends in global climate, including changes caused by human processes, which will impact the flow of water in the river over the coming decades. The effects of Climate Change mean that a basic assumption - that the future pattern of flow in the river will be approximately the same as the past pattern of flow - may no longer hold true.

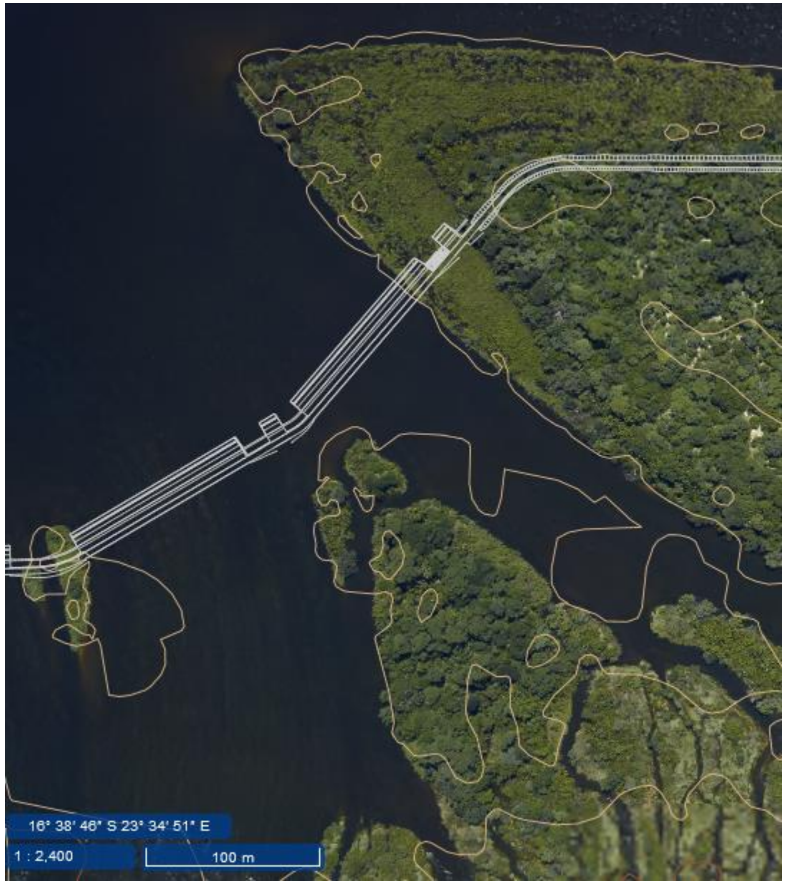
Because of the run-of-river design and unusual hydrology of the Ngonye Falls project, there is not a simple relationship between total flow and energy production. This means that variability in energy production is very much less than variability in the underlying hydrology would indicate.

A comparison of past climate variability cycles and worst-case future climate change impact on the basin shows that climate variability will remain the dominant factor in changing river flow for many decades to come.

PROJECT EXPOSURE TO CLIMATE VARIABILITY AND CLIMATE CHANGE

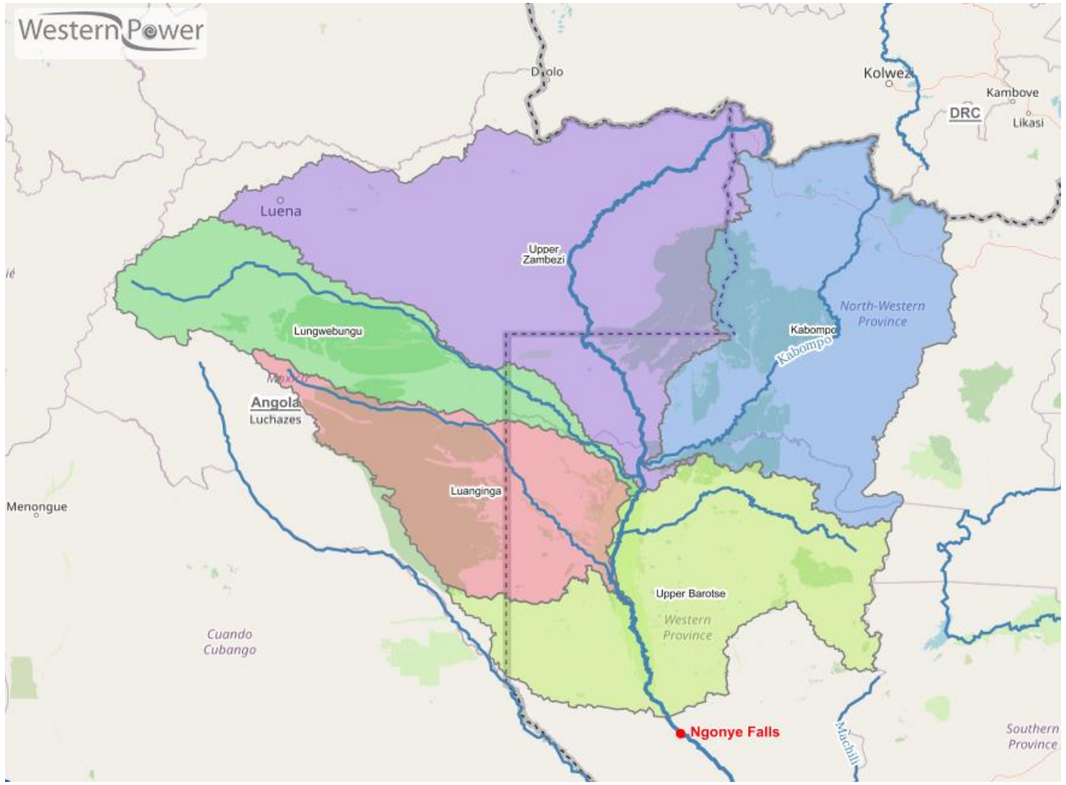
There are four main ways by which climate change and unexpected climate variability could impact the project:

1. **Impact on energy yield, revenue and project economics -** due to changes in river flow including changes in peak flow, minimum flow and flood timing
2. **Impact on operations and maintenance of the power generation infrastructure** – e.g. increased temperature reducing the life of some parts or flow changes leading to increased sediment load
3. **Impact on infrastructure and dam safety** – more frequent and severe localised flooding and large and more frequent river floods
4. **Impact on employee and community health and safety** – due to increased flooding, and ecosystem and biodiversity impacts



Part of the project headworks weirs and embankments in the Zambezi river upstream of the Ngonye Falls.

THE CATCHMENT



Major sub-basins of the Zambezi River catchment upstream of Ngonye Falls.

The Ngonye Falls are around 1,000km downstream of the source of the Zambezi river - near Mwinilunga in Zambia.

The total catchment size of the Project is 315,500km² - similar to the area of Norway.

There is very little population in the catchment area, no large-scale agriculture and very little abstraction of water. Because of the size of the catchment area and the characteristics of the Ngonye Falls project, any future abstraction of water for agricultural development would have negligible impact on energy potential.

The Zambezi catchment is extremely well gauged and studied with daily flow records at Victoria Falls going back to 1924 and at Ngonye Falls back to 2007. Rainfall records from a number of stations go back to the early 1900's.

Rainfall follows the same pattern across the whole of the catchment with a cold, dry season lasting at least six months (April - Sept) with no rain followed by a hotter, wet season (Oct - March) when all of the rainfall occurs.

Higher rainfall in the north of the catchment means that although the Upper Zambezi sub-basin makes up only 32% of the total catchment area it provides 63% of the runoff at the Ngonye Falls.

CATCHMENT RAINFALL & RIVER FLOW

The catchment upstream of Ngonye Falls has no man-made regulation (no existing dams or reservoirs) but there is significant natural regulation provided by the Barotse Floodplains – a vast area of swamps and wetlands stretching 200km upstream of the project.

The seasonal pattern of rainfall in the catchment area combined with the attenuating and regulating effect of the Barotse Floodplain leads to a significant annual seasonality in flow at Ngonye Falls. Following the onset of rain in the upper catchment, flows generally begin to rise in December and reach a peak in March or April before falling again to a minimum in September through to November.

The buffering effect of the floodplains means that flows at Ngonye Falls change very slowly, and changes can be predicted weeks in advance by observing rainfall and flow patterns upstream in the catchment.

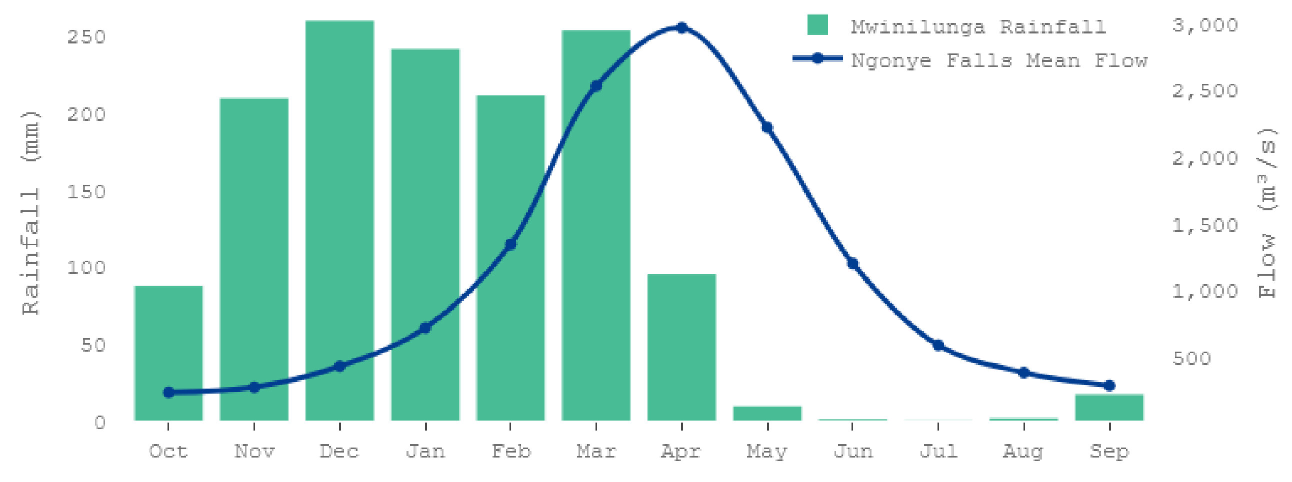


Fig 4. Due to the attenuating effect of the Barotse Floodplains the peak river flow is around 4 months later than the peak rainfall period.

The Barotse Floodplain stretches nearly 200km from Senanga in the south to Lukulu in the north.

RUN-OF-RIVER POWER GENERATION

The Ngonye Falls Project will operate as a true *run-of-river* scheme, without a high dam or reservoir, by using weirs to divert a portion of the flows of the Zambezi River upstream of the Ngonye Falls into a 3km long power canal before passing this generation flow through 4 bulb turbines to generate electricity before flowing back into the river.

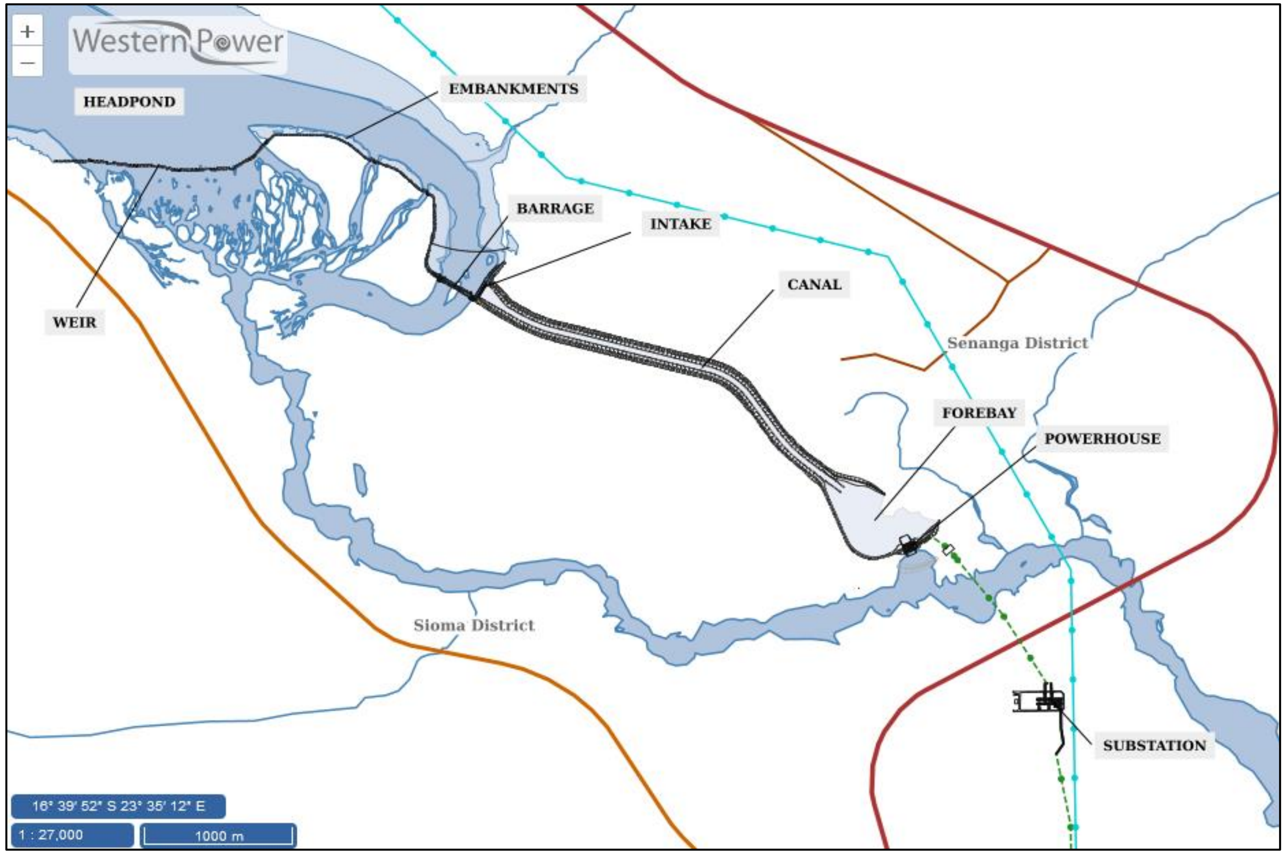
Power output for a run-of-river hydroelectric plant is determined only by the flow of water in the river, the proportion of that flow that can be used for generation (after environmental flow requirements) and the generation head – that is the difference in elevation between the upstream intake and downstream tailrace of the power station.

Power output will vary as the flow of water in the river varies through the natural annual cycle of floods and low flows and the total energy produced in any period will be the sum of all those varying power outputs over the period.

With no storage reservoir to hold back water, run-of-river power stations cannot vary their output on-demand and are non-dispatchable.

Natural cycles in river flow - whether annual cycles driven by annual rainfall patterns in the catchment or longer period (even multi-decadal) cycles – impact on any run-of-river power station by impacting the power output and energy production.

However, unlike with storage reservoir hydropower (e.g. Kariba) where energy production is simply proportional to the total volume of water in the reservoir, with run-of-river hydro there is a more complex (and resilient) relationship between flow and energy generation. This is particularly true for the Ngonye Falls Project because of its unusual hydraulic characteristics.



Layout of the Ngonye Falls hydroelectric scheme. A series of weirs and embankments divert a portion of the river flow into a 3km canal which opens into a forebay above the powerhouse containing 4 bulb-type generating units. A substation is located away from the sensitive river frontage. Excellent existing access is provided by the M10 all-weather road (red) and new Sioma Bridge. An existing 66kV power line traverses the site.

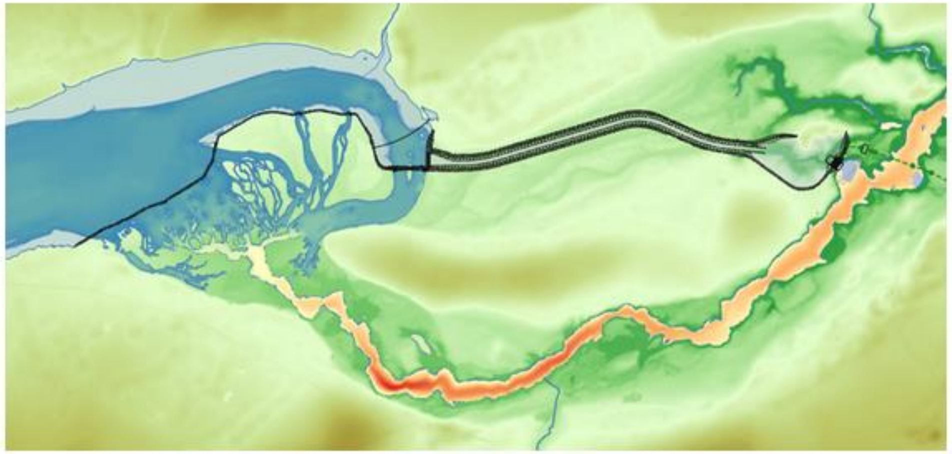
INVERSE HEAD AND FLOW RELATIONSHIP

Due to its hydraulic conditions, the Ngonye Falls has an unusual inverse relationship between generation head (difference in water elevation) and generation flow which balances its energy output over varying flow conditions.

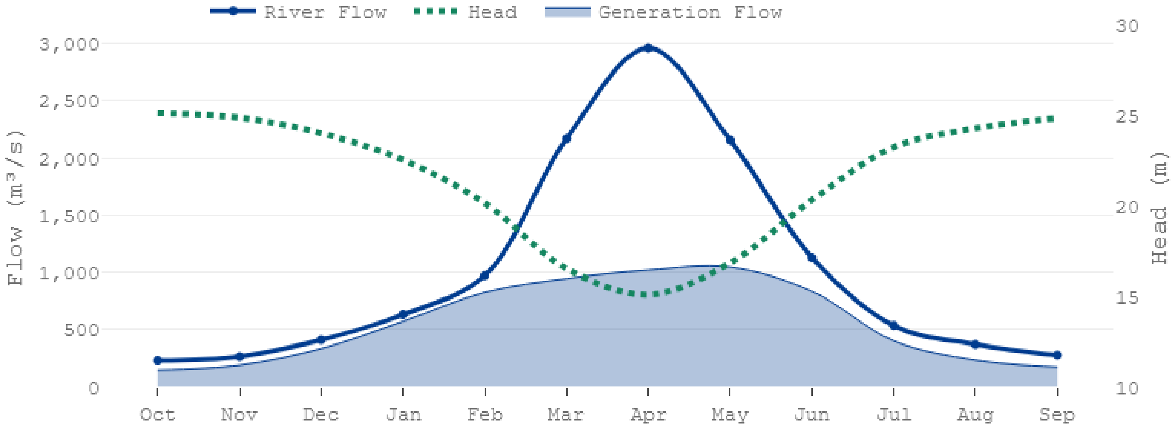
Above the Ngonye Falls, the Zambezi River is over 1km wide and relatively shallow and slow flowing. However, below the falls the river has cut into a deep, narrow gorge less than 100m wide. The water level in this constricted gorge varies considerably as the river flow varies through its natural, seasonal cycle of low and flood flows.

The varying level of the water in the gorge around the powerhouse means that the generation head (difference in height) also varies inversely with the flow of water in the river.

This inverse relationship between flow and head means that in drought years – or if conditions become drier due to climate change – then although production will fall, it will fall relatively much less than the fall in river flow.



The proposed Ngonye Falls hydroelectric power station on the Zambezi River (black linework) with the river flowing from left to right. The river above the falls is wide and shallow (blues). Below the falls it enters a deep, narrow gorge (reds).



Flow and head conditions for the Ngonye Falls Hydroelectric plant for an average hydrological year. Head decreased with increasing flow due to the unusual hydraulic conditions of the site. Generation flow is capped by the capacity of the power canal at 1,100 m³/s and river flows in excess of this are not used for generation.

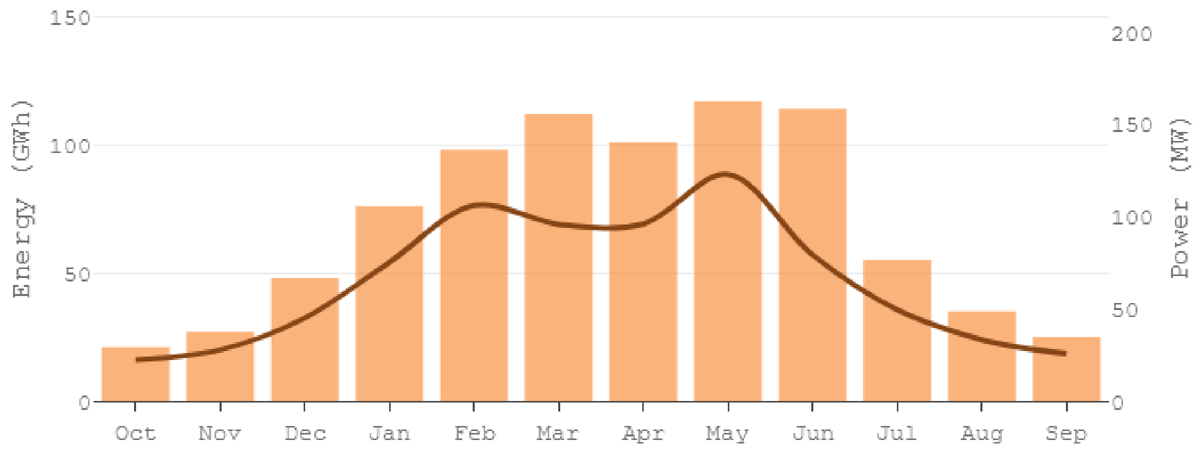
At Ngonye Falls, lower flows – due to drought or seasonal variation – leads to higher head which balances the power output from the station.

SEASONALLY VARIABLE BASELOAD

The natural seasonal variation in flow at Ngonye Falls and the low environmental impact run-of-river design mean that average energy production of the power station varies through the year from a low around September and October to a peak from March through June. Maximum output is constrained by the installed capacity of 180MW and a larger station would produce more energy on average but with less certainty.

The average energy production in April is, paradoxically, slightly lower than in March and May as this is the highest flow month. The high flow leads to a reduction in generation head which marginally reduces average energy production.

Despite the power station being run-of-river, because of the large size of the catchment and the unusual hydraulic conditions at Ngonye Falls, output is stable and predictable as shown by the P90 production level (exceeded in 9 years out of 10) being only slightly less than the average (median) output on a monthly basis. Variability is greatest in the flood months but this is mostly a timing issue relating to the onset of the floods rather than the flood level.

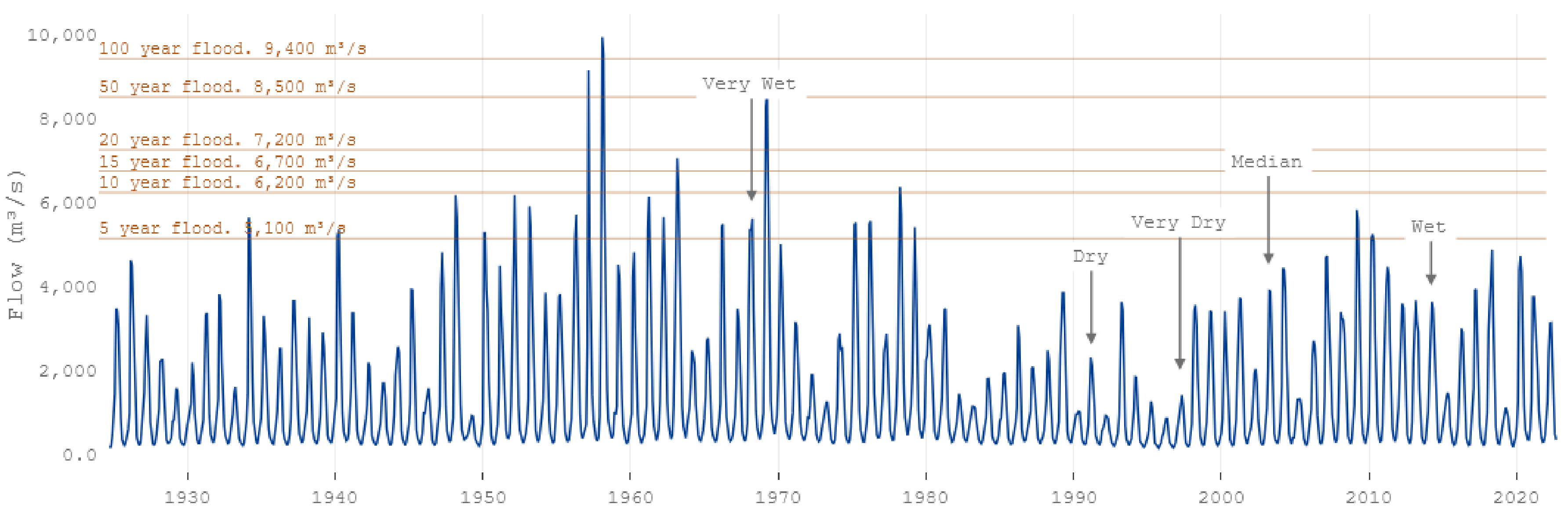


Forecast median P50 (bars) and P90 energy production by month for the Ngonye Falls hydroelectric plant.

FLOOD AND DROUGHT YEARS

As well as the natural annual cycle of low flow and flood flows in the Zambezi River, there is also a significant variation in the peak flow, total volume and, to a lesser extent, minimum flows from one year to the next.

This interannual variability can be seen from the long-term hydrology record where the 100-year maximum flood in early 1958 was close to 10,000 m³/s whereas the maximum flood flow in the drought year of 1996 was only 840 m³/s. This natural cycle of flood and drought years is driven by climate variability, predominantly variation in rainfall upstream in the catchment.

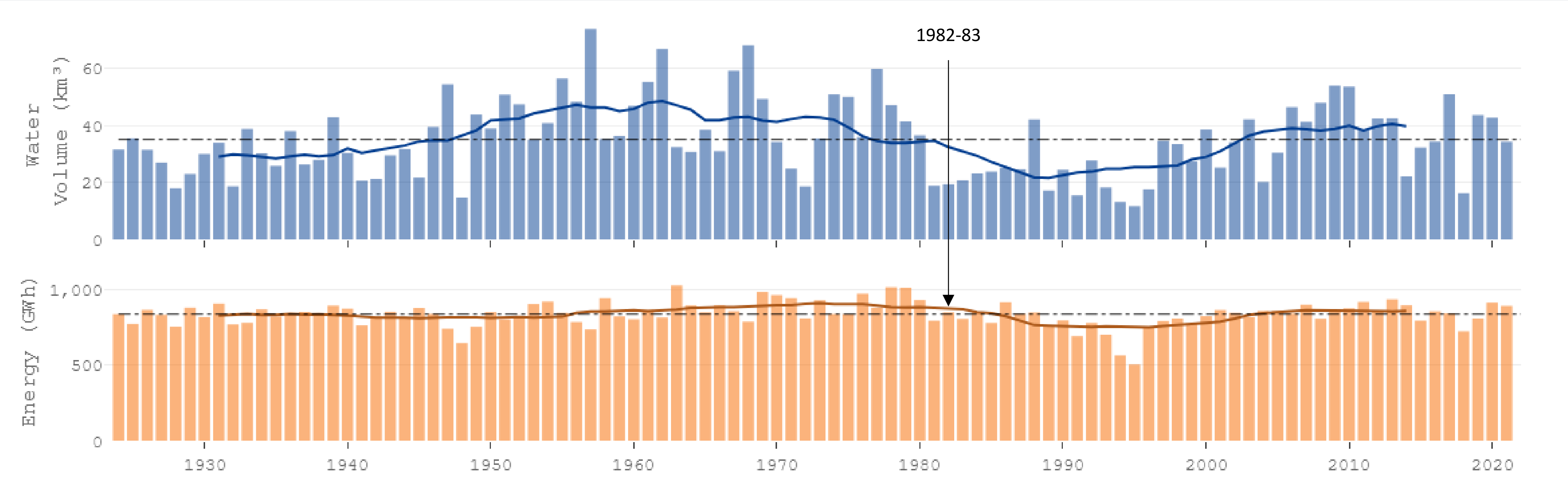


Historic flow at Ngonye Falls based on the record at Victoria Falls since 1924. Horizontal lines show flood return flows. Certain hydrological 'representative years' used for design of the power station are highlighted.

STABLE AND CONSISTENT ANNUAL ENERGY

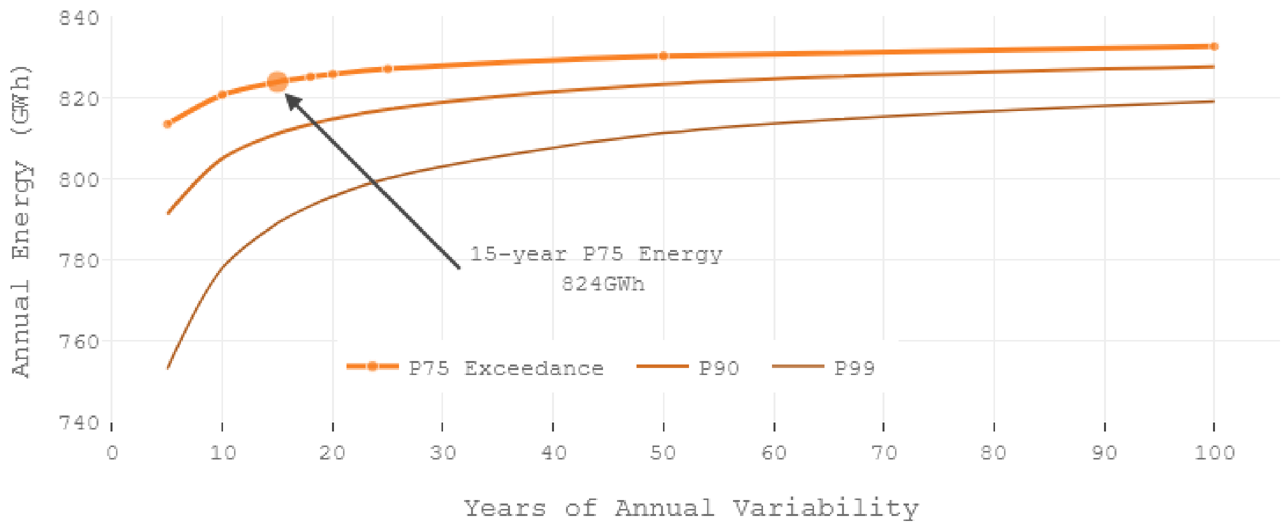
Due to the catchment characteristics, the hydrology of the Zambezi River, the project design and the unusual head-flow relationship of the Ngonye Falls site, annual energy production from the power station is extremely stable and consistent compared with the variation of river flow.

For example, the 1982-83 season was a significant drought with only around 50% of the average flow in the river. However, energy production in this year would have been very slightly higher than the long-term average.



Total volume of water passing Ngonye Falls by year (blue at top) and simulated total energy production for the Ngonye Falls Project (orange at bottom). There is significant variation in annual water volume with natural drought and flood years. There is very little variation in annual energy production.

STABLE AND CONSISTENT ANNUAL ENERGY



Duration-based annual energy probability curves.

The stability in annual energy production for the Ngonye Falls Project is evident in the flat duration-based annual energy probability curves. The 15-year P75 gross energy - i.e. the average annual energy exceeded in 75% of all possible 15-year periods - is 824GWh per year, only 14GWh per year or 1.7% less than the long-term average energy (median or P50).

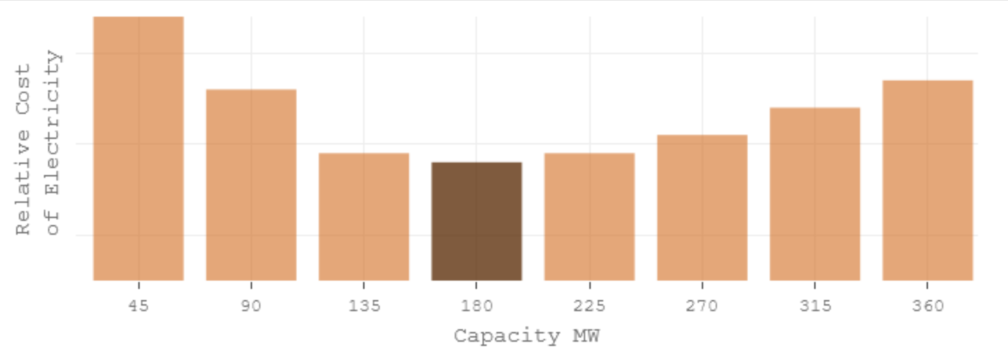
CAPACITY OPTIMISATION AND ECONOMIC RESILIENCE

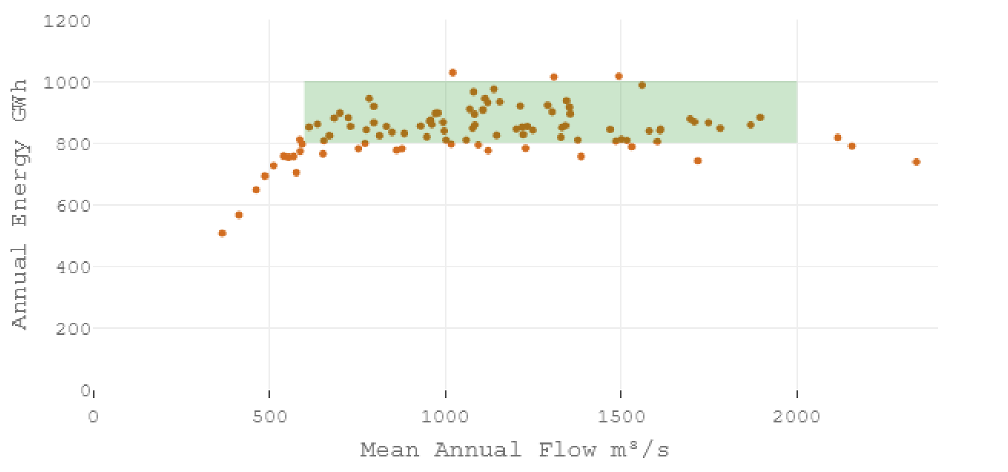
The flow of water in the Zambezi varies significantly through its natural annual cycle of flood and drought stages - often by more than one order of magnitude.

Whilst it would be possible to install a run-of-river power station at Ngonye with many 100s-of-MWs of turbine capacity that could use the majority of the water even during floods, most of these turbines would sit idle for most of the time. The capacity factor of the plant would be low, and its economics would be very poor.

The installed capacity of the Ngonye Falls project has been economically optimised at 180MW to balance utilisation of the physical resources (the river flow) and the economic resources (the cost of the plant).

The use of an installed capacity well below the theoretical maximum also makes the scheme extremely resilient to annual variation in river flow, whether due to climate change or the pattern of historic inter-annual variation, as the scheme only requires a small fraction of the total flow to operate at its economic optimum and any additional flow simply bypasses the power station.





Annual energy production against mean annual flow. Energy production is extremely stable for years with mean flows above 600 m³/s and below 2,000 m³/s.

RESILIENT DESIGN FOR CONSTRUCTION AND OPERATION

The design of the Ngonye Falls project makes it extremely resilient to unusual or unexpected climatic conditions both during construction and during operation whether these are due to climate change or natural climate variation.

The design has no tunnels, only an open canal, and there are no temporary diversion tunnels or channels which are particularly high-risk elements during construction.

The only high dams (as defined by ICOLD) are adjacent to the powerhouse and these short sections only hold back a relatively small volume of water in the forebay. This means that, should they fail, there would be little volume of water released and negligible impact on downstream safety.

The low weir, around 3m high across the Zambezi, that produces the headpond and directs flow into the power canal is inherently safe under high flood conditions when the height of this structure and the volume of water held back become insignificant compared to the natural flow of the river. The adjustable weirs are bottom hinged and will therefore fail in a ‘down’ position minimising their impact on the river flow under flood conditions if it becomes impossible to operate them.

Construction of the weir will happen in sections without any necessity to dewater any significant part of the river. Should unexpectedly high flood flows occur during construction only the small areas currently coffer-dammed for construction at that time may be put at risk and there is no wider community health and safety risk due to failure of any temporary works.

Construction of the powerhouse will be behind a cofferdam. Due to the particular shape of the riverbank at the powerhouse location, this coffer dam is well away from the main stream of the river in relatively shallow water and protected from unusual flood flows during construction.

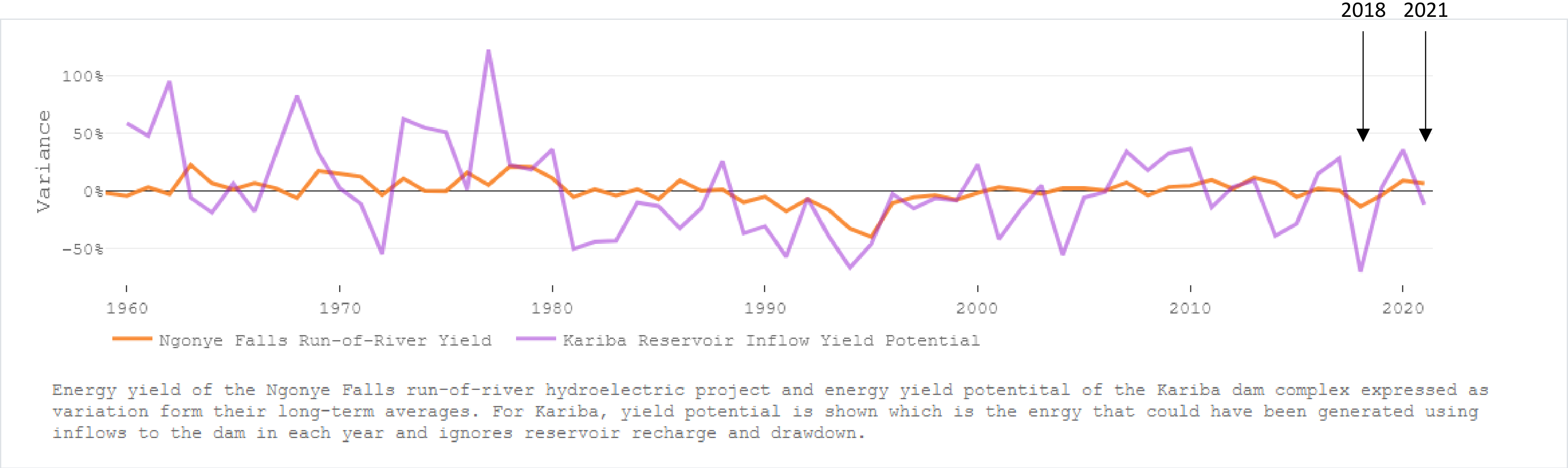
The powerhouse of the Ngonye Falls power station with the forebay behind and Zambezi river in front. The temporary construction cofferdam is shown in the Zambezi River.

DECOUPLED FROM OTHER ZAMBEZI HYDROPOWER

As a run-of-river power station and due to its unusual hydraulic characteristics, the energy yield from the Ngonye Falls power station is completely decoupled from the large storage reservoir hydro-electric power stations downstream in the Zambezi catchment - in particular the Kariba complex and Itezhi-tezhi / Kafue Gorge power stations.

Annual power generation potential for these power stations is directly proportional to the volume of water entering the reservoir each year, whereas at Ngonye Falls energy yield is determined by the period of time the river flow sits at certain levels and high flows can, counter-intuitively, lead to lower outputs.

In some years, for example 2021, energy yield at Ngonye Falls would have been above the long-term average while inflow yield potential at Kariba was below average and in severe drought years, such as 2018 and 2024, inflow yield potential can be significantly below average due to drought conditions whereas yield at Ngonye Falls would only be moderately affected. This means that the Ngonye Falls power station will be able to act as a ‘hedge’ against both natural and climate-change induced drought years effecting other power plants in Zambia and the region.



Energy yield of the Ngonye Falls run-of-river hydroelectric project and energy yield potentital of the Kariba dam complex expressed as variation form their long-term averages. For Kariba, yield potential is shown which is the enrgy that could have been generated using inflows to the dam in each year and ignores reservoir recharge and drawdown.

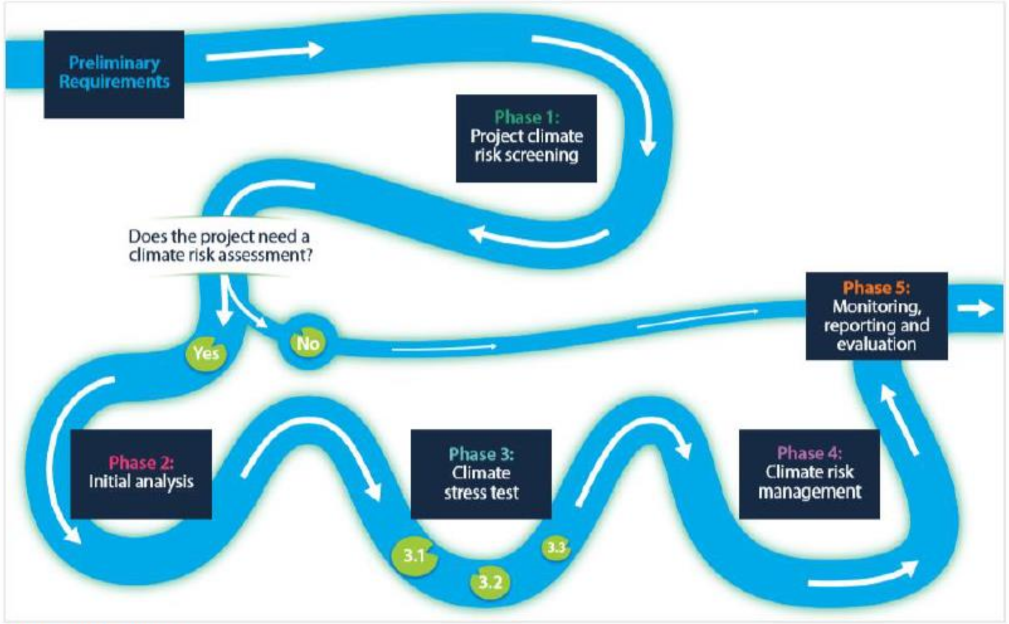
PROJECT CLIMATE CHANGE RESILIENCE ASSESSMENTS

The climate risk and resilience studies for the Project – which are still ongoing – are designed to analyse the possible risks to the Project due to climate change and to design mitigation measures to ensure that residual risks are well constrained so that the Project is economically sustainable and remains safe and efficient to operate.

The studies include modelling of the possible impacts on rainfall and river flow due to climate change (based on the latest global climate forecasts), the impact of these changes on river levels, energy generation and localised flooding and how these changes may interact with the design and operation of the station to produce unacceptable outcomes.

The climate risk and resilience studies are being conducted in a phased manner according to the International Hydropower Association (IHA) guidelines:

- The 2018 draft project Feasibility Study identified that the Project may be susceptible to climate change risk and suggested a more detailed study should be completed (*Phase 1 Screening*).
- In 2019 a Climate Change Stress Test was undertaken which was integrated into the Final Feasibility Study. This study used existing models - forecasting changes to flows in the Zambezi as a result of climate change – to assess the risks to the project economics of various climate change scenarios. (*Phase 2 Initial Analysis*)
- In 2024, based on the latest advice from the project technical advisors and in preparation for certification under the Hydropower Sustainability Standard of the IHA, the project commissioned two further phases of Climate Change Resilience Assessment: (*Phase 3 Stress Test*)
  a) A qualitative and semi-quantitative risk assessment. (completed October 2024)
  b) A rainfall and temperature – runoff regression modelling study based on the latest global climate models to quantitatively assess the project climate change resilience.



Source: (IHA, 2019)

The stages of the climate change risk assessment program for Ngonye Falls as setout by the International Hydropower Association and consistent with the World Bank Decision Tree Framework.

Western Power Company Ltd

Fig Tree House

17 Warthog Road

Box 320181, Kabulonga

Lusaka

Zambia

Tel: +260 211 262 773

Web: www.westernpower.org

Email: info@westernpower.org