

Azambi HPP – Private Hydropower Development in Africa

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1. INTRODUCTION

Throughout the world, there has been an increasing trend toward development of low impact small to medium sized hydropower schemes by Independent Power Producers (IPP's) and Private Developers.

The inflow of private investments into the dams and hydropower market, which has traditionally been the domain of public financing, is having a positive impact on this market. Compared to the risk-adverse public sector, the private developers approach to the project life-cycle is quite different. Private Developers are often more willing to absorb risk to ensure that the project progresses on schedule and within budget during construction and that the hydropower plant gets commissioned on the committed date, so that the investors begin to realize the committed returns.

Joint risk-based decision making has afforded the developer, engineer and contractor an opportunity to approach these projects from a different perspective. Under the correct conditions, and with the correct implementing team, it is possible to deliver small hydropower plants (HPP's) that are purpose-built, low impact and cost effective.

In this paper, the authors present the design and construction of Azambi Hydropower Project, the third HPP developed by the Kibali Gold Mine, located in the remote north-east province of Democratic Republic of Congo, Africa. The mines concession is not serviced by an electricity utility provider but is favourably enveloped by large untapped rivers.

Azambi HPP is configured as a run-of-river hydropower station, whose output is used to offset thermal power supply by supplementing the base load power generation during the mine operations. There is no Power Purchase Agreement (PPA) and the bankability is directly related to the capital cost of the hydropower plant itself and its peak spinning reserve, offset against the running of thermal power supply which is fueled by expensive imported diesel fuel. The term of the scheme is the Life of Mine (LoM) and the economic model does not consider future value. The hydropower station will ultimately become a legacy asset to the local communities once the mine has reached its end of life.

Central Africa, being notorious for instability is generally bereft of infrastructure, equipment suppliers or experienced hydropower contractors, particularly where small hydropower development may be attractive. To remain competitive, engineering design must be tailored to the available topographical and geotechnical site conditions, local construction materials sourced within the immediate vicinity of the site, and constructed with basic plant and equipment and generally semi- or unskilled manpower. Where specialist materials or equipment are required, importation from developed areas becomes the only alternative, at significant cost.

By describing the design basis adopted for Azambi HPP, the important constraints encountered and specific challenges overcome during the engineering and construction implementation, the reader will be introduced to the importance of formulating design on basic engineering and construction principles, reinforced with innovation and lateral thinking to mitigate risk and to allow an integrated implementation approach between the key parties.

Such an approach makes it possible to promote run-of-river hydropower development within uncertain conditions and unreliable communications, in a cost effective, fit for purpose and successful application.

2. BACKGROUND

Randgold Resources (RRL), together with AngloGold Ashanti and Sokimo purchased the Kibali Gold Mine, formerly the Moto Gold fields, situated in a remote area of the Orientale province, north-east Democratic Republic of Congo in 2009.

In an area with limited existing infrastructure, RRL developed the mine into what is now one of the largest gold mining operations in Africa. Extensive advanced establishment works were required, including provision of a diesel power station and an internal power grid, with all associated transmission lines and substations. The large Kibali and Nzoro Rivers flow nearby and RRL immediately recognised the importance of developing renewable energy resources in order to support its increasing power demands.

A preliminary design/scoping study for potential hydropower development opportunities was conducted and in 2011, RRL earmarked four run-of-river schemes, located within 30km from the main gold mine for further development. The hydropower projects included sequential implementation of the 22 MW Nzoro II HPP, 10 MW Ambarau HPP, 10 MW Azambi HPP and finally the 7 MW Sessenge HPP, over a 10 year period, to provide a combined output of 49MW base power to the mine grid.

The gold mine itself was developed in two overlapping phases and Nzoro II was constructed in the first phase between 2011 and 2013. Thereafter, Ambarau, Azambi and Sessenge were packaged into a single turn-key EPCM contract (named the Kibali River Hydropower Plant Projects) which was later awarded to South African and European contractors, who were already engaged on the main establishment works for the new mine.

The locality of the proposed hydropower stations is as shown in **Figure 1**.

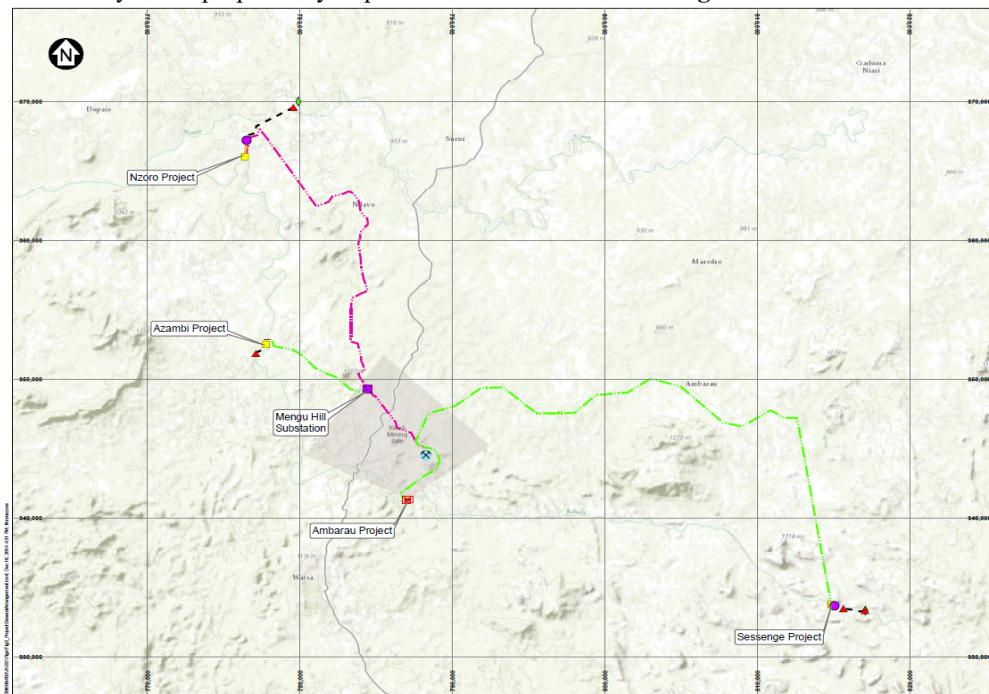


Figure 1: Locality Plan of Kibali Gold Mine Hydropower Stations.

From these preliminary designs, a duplicate set of Kaplan turbine and generating units were purchased and stored at the mine, intended for installation at both Ambarau and at Azambi. Ambarau was configured as a 23 m high symmetrical hardfill dam constructed to create the rated head for an integrated hydropower plant. Implementation of Ambarau HPP kicked off in 2013 and the station was completed in 2016.

During construction of Ambarau, RRL decided to terminate the original EPCM model and to instead develop Azambi following standard FIDIC white and modified red book contract form.

The design optimisations for Azambi commenced in late 2015, followed by detailed design, tendering and contract award toward the end of 2016.

The Azambi Hydroelectric Project is configured as a 10.1 MW run-of-river type hydropower station, operating over a gross head of 14.7 m and a design flow of 106 m³/s.

The project salient features are presented in **Figure 2**, comprising a rubble masonry concrete (RMC) gravity diversion weir, reinforced concrete intake structure, 1.06 km long power canal and reinforced concrete powerhouse and tailrace, equipped with 2 Kaplan turbine and generating units, an 11 kV switchyard and a 7 km long 66 kV transmission line.

Construction commenced in early 2017, over an 18 month period and the station was commissioned successfully in August/September 2018.

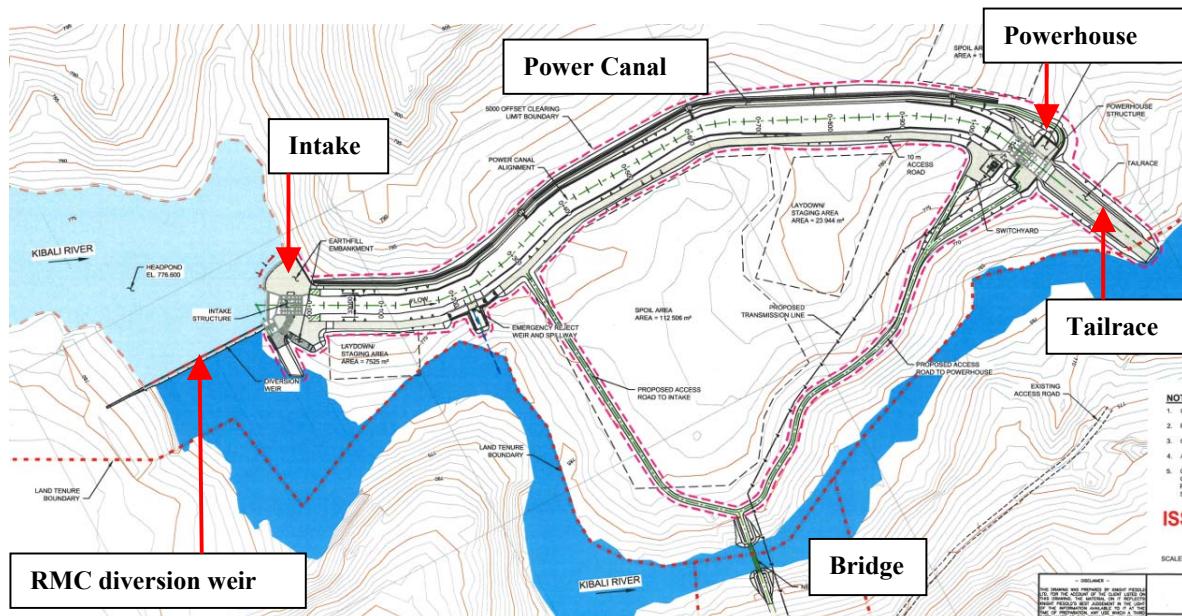


Figure 2 Plan view of Azambi HEP on the Kibali River

3. SITE GEOLOGY

General geology at the project site comprised schistose meta-sandstone, meta-siltstone and minor occurrences of meta-conglomerate. In the river section and outside river bends where erosion has been the greatest, a very fine grained, closely to moderately fractured hard rock has been exposed.

Overlying hard rock on the river banks, the site is covered by clayey transported soils (colluvium/pebble marker) and underlain by silty/clayey residual soils of meta-sandstone/siltstone origin. The transported soils are generally less than 1m thick, with residual soils varying in thickness between 2m and 3m. Completely weathered very soft rock meta-sandstone/siltstone occurs at depths of between 1,8m and 5m below natural ground surface. Isolated occurrences of dolerite rock were also identified.

Founding in the river section would require only nominal removal of loose rock boulders, but the extent of weathering on the flanks would require generally deep excavation to reach competent rock.

The regional dip of rock strata is between 30° to 35° to the NNE but tended to vary locally, as shown by the exposed bedrock at the right bank of the Kibali River in **Figure 3**.

A geotechnical investigation was planned and executed around the available equipment in the immediate vicinity of the Kibali Mine. No permanent access to the site was available at the time and the mine staff prepared a temporary river crossing which could only be used while the river flow was fairly low. The investigation finally comprised the excavation of 20 test pits by hand and the drilling of 29 rotary cored boreholes at the main structure and along the power canal length.



Figure 3: Typical dipping bedding of the exposed bedrock at the Intake.

4. HYDROLOGY AND RIVER MORPHOLOGY

The Kibali River is a tributary to the Uele River that originates in the mountains near Lake Albert. The river flows west for approximately 1000 kilometres before joining to the Dungu River. At the project site, the drainage area is over 9000 km² and with an annual rainfall of 1700 mm/annum, the mean monthly river discharge varies between 30 m³/s to 75 m³/s, from January to June, and 90 m³/s to over 250 m³/s for the latter half of the year.

Flood flows are frequent, having high volume and relatively flat peaks that range from 580 m³/s for a 5 year flood event up to 1500 m³/s for a 1000 year event.

The seasonal variation of river flow and frequent flooding implies that flood management and river diversion during construction formed a critical consideration to the overall design and construction works planning.

The Kibali River is ungauged and whereas rainfall/runoff models had been developed, two hydrologic monitoring stations were installed in February 2016 to provide a means for early flood warning notification and to estimate daily flow measurements. The monitoring stations comprise a pressure transducer connected to a data logger that records stage at fifteen minute intervals. An acoustic Doppler current profiler (ADCP) was used to measure the streamflow and water depth, and water level was measured to a local datum using a surveyor's a stage-discharge measurement level. The raw water level data collected at each station are corrected to their respective gauge datum following an assessment of stage and surveyed water levels, and then the applicable site rating curve was applied to the corrected continuous stage dataset to produce a preliminary measured discharge record.



Figure 4: River Profiling with an ADCP

The ADCP was also used to survey the river section at the intake location, the access road bridge and the powerhouse tailrace. The data was incorporated into the hydraulic and tailwater models used in the design the waterway system.

5. DESIGN & OPTIMISATION

A key objective to optimizing the Azambi HPP was to further reduce the reliance on diesel fuel used to power the Kibali Gold Mine, while reducing the overall blended power costs (i.e. \$/MWh for the blended thermal and hydropower facilities). In order to achieve this, dry season power production capabilities, in terms of energy generation and load following capabilities had to be maximised and options to reduce the overall capital cost of the facility itself had to be explored.

When the optimisation phase commenced, the project status was as follows:

- The Kaplan turbines, gearboxes and generators were already specified, built, and delivered to the Kibali Mine (based on preliminary design by the equipment supplier).
- Development of a dam wall with integrated hydropower works arrangement was envisaged, as had been applied previously at Ambarau HPP.
- Lidar Data, hydrological reports, energy generation estimates and preliminary/concept designs of the powerhouse were available.

The site for Azambi HPP is particularly isolated, with restrictive access and generally flat topography.

Dense vegetation and a requirement to develop the hydropower works on the opposite bank of Kibali River implied that the site was near inaccessible. The topography and availability of local construction materials were studied and although the option of constructing another large dam and integrated hydropower works was considered, this was soon eliminated on the basis of risk, cost and available topography and geology. Instead, a diversion weir and canal system was proven as the most economical, low risk option for Azambi HPP implementation.

The headworks were positioned on the left bank of the river, which has gentler topography and a westerly river curvature, resulting in a shorter length of the power canal to attain the required head drop for the turbine rated conditions.

Local Labour

The social benefits that construction of the hydropower scheme would bring to the local, rural population of the Watsa village were integral in the design premise adopted and particularly the weir type finally applied.

Although Azambi HPP will become a legacy asset to the community at the end of the mine operations, community involvement during the relatively short-term construction activity itself allowed a source of income and upliftment and an opportunity to facilitate transfer of skills into the local community. Construction methods that would maximise the local labour content were accordingly given preference.

Site Access Roads and Bridges



Figure 5: Girder Access Bridge

To avoid community disturbance due to driving through the local village with heavy construction equipment, a new bypass road was constructed, which also followed the alignment of the new 66 kV transmission line to the main substation. This provided road access for construction right-of-way and long term maintenance of the transmission line. A permanent bridge over the Kibali River was required to reach the works, forming a critical path activity for site handover at the time. A narrow section of the river was identified and reinforced concrete abutments were constructed on either side of the river bank. A single span, 36 m long weathering steel girder bridge with 80 tonne capacity was ordered from the USA, transported to the mine and fully assembled on the right bank. The girder was lifted into position with 300 tonne mobile crane, owned by the mine. The bridge construction was expedited and successfully commissioned within a week of the wet season arrival, which allowed site handover for the main construction works at Azambi to begin.

Headworks

The project headworks are positioned at an outside bend of the river, at a location where a small island divided the river naturally. The diversion weir axis was aligned across this island and approximately perpendicular to the river channel and regional dip of rock strata. This greatly simplified channelling and diverting the river during construction and minimised overall extent of foundation preparation works required for the weir.

The headpond is formed by the small reservoir created behind the weir and since Azambi HEP will not operate as a peaking station, only limited storage was provided. The weir is constructed to reduce the velocities of approaching river flow whilst directing water to the intake structure, and to pass flood events in a controlled manner. The headpond will only settle out a limited amount of sediments with the key silt purging facilities being installed and managed directly from the concrete intake structure.

Preliminary designs for three different weir types were completed, including:

- Rubble Masonry Concrete (RMC) Weir
- Reinforced Concrete (RC) Weir
- Hardfill Concrete (HFC) Weir

For each weir type, the availability of construction materials, source to site distances, weir configuration and associated quantities were evaluated. With a large volume blast rock becoming available from the canal, powerhouse excavations and numerous boulders scattered in the river bed, this was proved suitable for reuse as stone plums for RMC construction, with limited treatment being required.



Figure 7: RMC Diversion Weir

The diversion weir for Azambi HEP was configured as a standard gravity wall constructed out of RMC, having a maximum height of 6 m, a 185 m concrete lined ogee spillway and a total volume of approximately 7500 m³. The weir structure terminates on the left bank against the reinforced concrete intake structure and as a non-overflow crest (NOC) section on the right flank.

The application of RMC for the small weir structure proved to be very successful. Whilst promoting cost savings compared to a mass or reinforced concrete equivalent, it offers a durable structure that is resistant to flood damage, constructed using high labour utilisation. The selected layout also allowed construction of the weir to remain off the critical path and be implemented in parallel with the major civil structures.

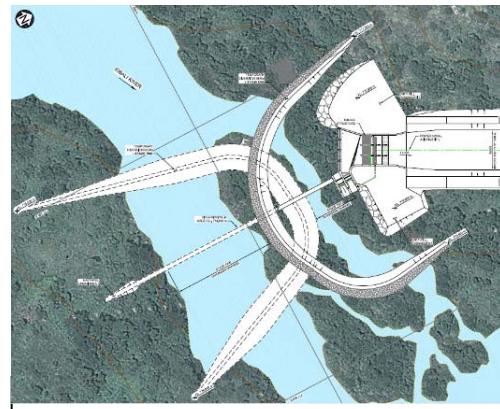


Figure 6: River Diversion Concept

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The intake structure conveys water from the headpond into the power canal. Its purpose is to control the water quality and the release rate entering the power canal. Excess water, above the design flow of the plant will be spilled over the diversion weir crest. The intake structure comprised the following main features:

- A set of coarse trash rack screens to prevent large items from entering the intake forebay.
- A set of fine trash rack screens to prevent smaller floating debris from entering the power canal waterway.
- A dedicated scour channel with 2 radial gates that will be opened routinely to flush deposited sediment collected in the headpond and/or the forebay.
- A set of five intake roller gates that regulate flow to the power canal under normal operating conditions.
- A set of stoplog gates to isolate flow in any bay from entering the canal when undertaking maintenance and repairs, or during emergency situations.
- A fine sediment trough/trap with low level flushing gates which removes fine sediment from the intake sump.
- A wave suppression structure to dissipate energy and turbulent flow conditions prior to release.

The intake is positioned to accentuate the outside bend in the left river bank and the approach angle is orientated to mitigate propensity for silt deposition directly upstream of the intake, with fast moving water being drawn off laterally into the structure.

River Diversion

Diversion phasing had to be viewed in tandem with the envisaged construction programme, as delay in the river diversion construction could endanger or cause undue delay to the completion of the Works.



Figure 9: 1st and 2nd Stage River Diversion

The river diversion philosophy comprised two stages of construction. For Stage 1, a temporary embankment was constructed from the left bank of the river, upstream of the Intake Works. The cofferdam axis was also aligned to traverse over the exposed island section, before wrapping back downstream of the concrete intake structure footprint. The river could be maintained in its natural channel right of the island, allowing for dewatering and construction of the entire hydropower works and the first 90 m of the permanent RMC diversion weir.

For Stage 2, an essentially mirrored cofferdam arrangement was applied, whereby the first stage embankment was deconstructed whilst a second embankment was initiated from the right bank of the river, aligned to abut against the completed portion of the permanent weir and terminating on a reinforced concrete crest splitter wall. During Stage 2, under normal river flows, water was diverted leftwards into the intake structure and back to the river through the two



Figure 8: View of Intake Structure

6 m wide by 4 m high sluice and scour radial gates. Water could also be conveyed into the power canal, allowing turbine commissioning in the powerhouse to advance concurrently with the construction of the remaining portion of the permanent RMC diversion weir. During high flow periods, additional flood discharge capacity was afforded over the completed spillway section of the permanent weir, constructed as part of the Stage 1 works.

Power Canal and Powerhouse

In order to convey the design flow of 106 m³/s, a large power canal was required. To limit capital expenditure, Kibali selected an unlined canal option, accepting periodic maintenance requirements. This consisted of an excavated canal with a 28 m base width and sides slopes at 2H:1V (in earth/soft section). Under the design flow conditions, a normal flow depth of 2.5 m is anticipated with an average velocity of 1.1 m/s. The canal was aligned to follow the contour so that the top of the section is maintained level during static operating conditions.



Figure 11: Emergency Spillway



Figure 10: Precision Blasting for Powerhouse

An emergency overflow spillway was also constructed on the power canal, to spill excess water in a controlled manner during flood or load reject events or unit shutdowns. The spillway has the capacity to spill 125% of the design flow of the plant and because the waterway system remains full, start up time of the units is significantly reduced. The power canal terminates in a forebay/headrace that is integrated with the reinforced concrete powerhouse.

In order to prevent erosion along the base, the canal depth was taken to the assumed bedrock elevation, based on the geotechnical investigations, which provided sound founding conditions over the majority of the canal length. This resulted in controlled blasting being undertaken to achieve line and level, but the excavated rock was reused where possible for rip rap slope protection, access road rehabilitation and RMC stone plums.

The powerhouse substructure was excavated in sound bedrock, approximately 170 m from the Kibali River. The tailrace was extended to the river and a plug section was constructed to provide a flood protection barrier during construction.

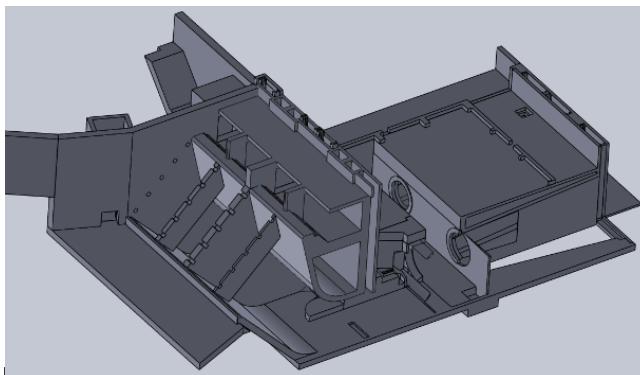


Figure 12: Powerhouse Layout & Construction

The excavation was achieved by precision blasting, comprising vertical presplit and cushion blasting approach and the excavated rock face later doubled as the outer form for the reinforced concrete structure construction.

The short, integrated water conveyance within the powerhouse consists of hydraulically bell-shaped twin structural concrete portals, directing water around the pit generators, and into circular openings feeding the twin turbines. The tailrace was designed to maintain the required submergence on the Kaplan turbines and return water to the Kibali River.

The design and configuration of the powerhouse had to accommodate the already-purchased turbine generator units. Special formwork for the draft tubes at Ambarau also had to be reused and many of the fundamental design decisions that had been adopted at Ambarau had to be retained. Based on the geotechnical investigations, the powerhouse was, however relocated further downstream, where superior founding conditions existed and an additional 1.85 m static head was gained.

6. CONSTRUCTION ASPECTS

Azambi HPP was put out on tender to nominated contractors from the mine vendor list. The contractors that submitted included those involved in both the preceding hydropower schemes, being favoured as the most experienced to undertake the work within the required timeframes.

After several rounds of negotiation, however, RRL decided that the construction contract would be awarded exclusively to Congolese construction enterprises, specifically to uplift and improve social economic status and promote skills transfer. Two civil contractors were appointed and a dedicated steel fabricator and installer. The contractors had no former hydropower or large water retaining structures construction experience, which raised several obvious concerns. This was regarded as a challenge and necessitated an intensified construction monitoring programme, focussed on team collaboration and risk management to achieve production, quality and schedule requirements.



Figure 13: Project headworks viewed from downstream



Figure 14: Powerhouse Forebay

RRL assigned a fulltime Owners Team, who acted as the overall project managers, undertook survey and managed the project budget, assisted with contractor's logistics planning, equipment procurement and programme monitoring. The scheme designers were retained as the Engineer, being design custodian and undertaking construction progress monitoring and overall quality supervision on site. The contractors managed their plant, labour and production targets, co-ordinating and executing the work in collaboration. Specialist South African subcontractors were engaged for precision blasting, mechanical installation of the turbine and generating equipment and for the electrical

installation for balance of plant and commissioning requirements.

Development of practical construction methodologies, materials procurement activities and the requirement to coach the contractor/s to ensure thorough understanding of the implementation requirements required stringent consistency. A smaller management team had its advantages in this regard, as regular meetings with the key role players could be held, approaches could be discussed and adopted more flexibly, decisions could be taken more quickly and parties were generally familiar with each other. Lines of communication were also shorter and interaction between the Owners Team, the Contractor and Engineer were effectively streamlined. All parties respected each other's individual responsibility and generally upheld authority.

Over the 18 month construction period, total reinforced concrete volumes of some 13 500 m³ were placed and total hard rock removed was estimated to be about 208 000 m³. For the RMC weir, the labour intensive demands and placement techniques were optimised and construction methodologies included mortar mixing, stone selection and transportation to site.

Strict compliance to quality, programming, safety and labour requirements were met and the major project milestones, including the 2-phase river diversion implementation were achieved. Safety performance was high and no serious injuries were recorded. Labour utilisation peaked at around 650 local labourers being employed throughout the core construction activities.

At Azambi HPP, all parties worked together to overcome the difficulties, sharing knowledge and experience to the project's benefit. This project demonstrated the importance of promoting a cohesive and collaborative team approach for developing hydropower in Africa successfully.

The Authors CVs

John Steele has a BSc (Hons) in Chemical Engineering and an MBL (UNISA). He is Randgold's Technical Director and has been responsible for the successful construction and commissioning of Randgold's Morila, Loulo, Tongon and Gounkoto mines and led the development and commissioning of the Kibali mine in the DRC. He also continues to provide operational and engineering oversight to the group.

Robert Greyling is registered as a Professional Engineer in South Africa. He has over a decade of experience as a civil engineer, having a key specialisation in dams and hydropower engineering. He has worked on several major projects including Polihali Transfer Tunnel for Phase 2 of the Lesotho Highlands Water Project, the Neckartal Dam Project in Namibia, and Changuinola 1 RCC dam in Panama. He is currently Knight Piésold's Lead Engineer for the Dams & Hydro business unit.

Egbert Scherman is a specialist Civil/Structural Engineer in the Knight Piésold Vancouver Office. He is registered as a Professional Engineer in both South Africa and British Columbia. He has more than 24 years' experience in the design and construction of structural and civil engineering projects with particular experience in the water, municipal and hydro electric industries, with extensive experience in the design of hydraulic structures, including dams, weirs, inlet and outlet structures, siphons, channels, pipelines, penstocks, pump stations, and powerhouses.