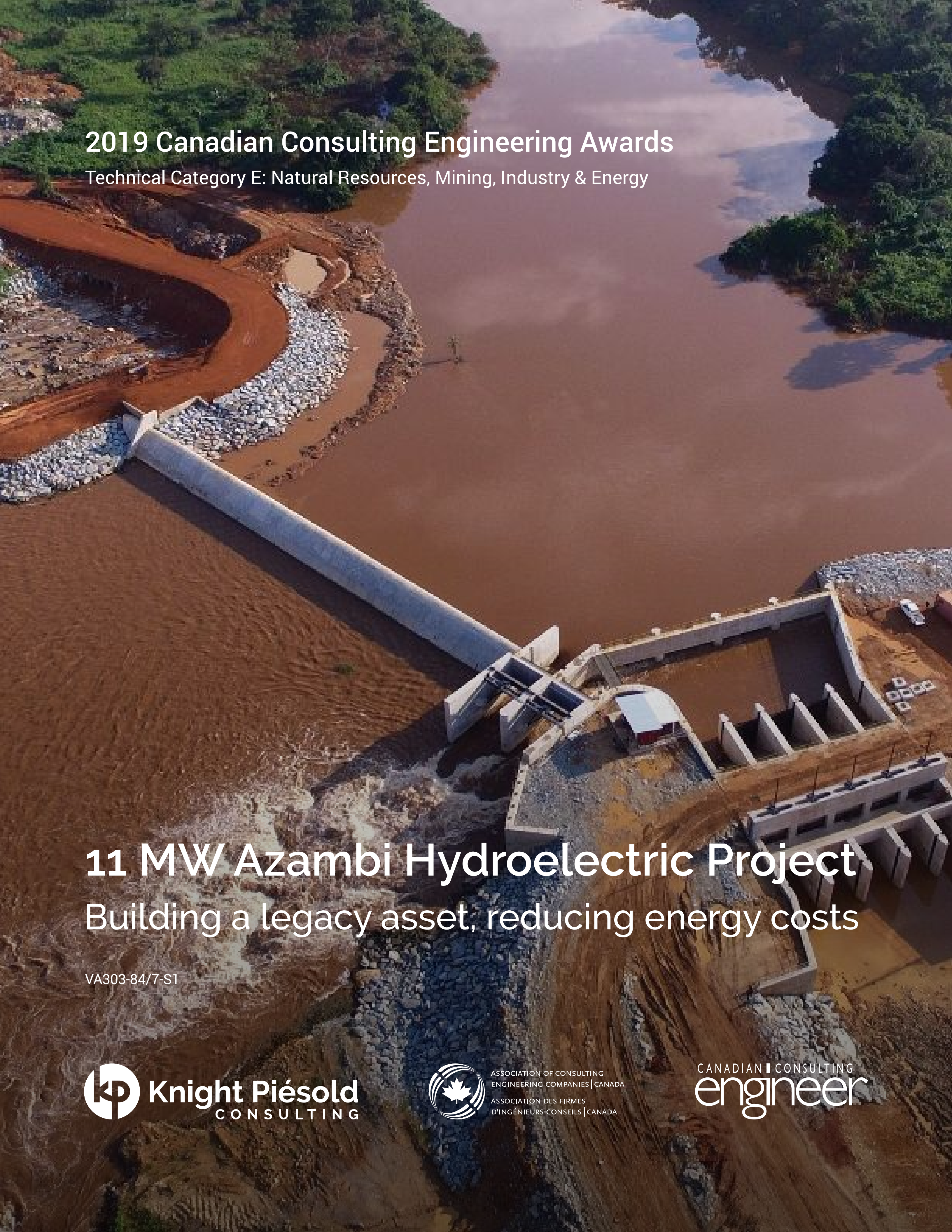

2019 Canadian Consulting Engineering Awards

Technical Category E: Natural Resources, Mining, Industry & Energy

11 MW Azambi Hydroelectric Project

Building a legacy asset, reducing energy costs

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Knight Piésold CONSULTING

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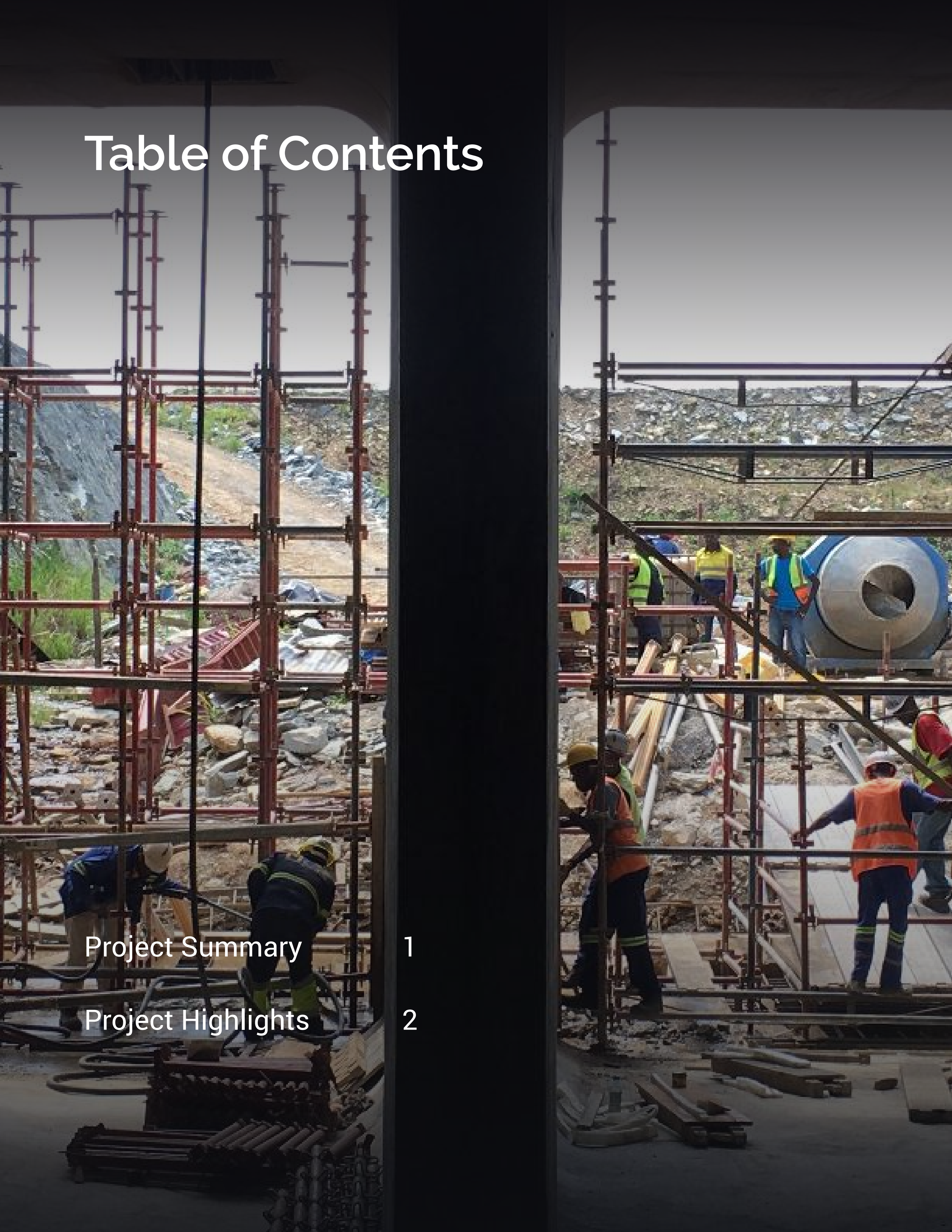

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PROJECT SUMMARY

The 11 MW Azambi Hydroelectric Project is located in a remote area of the Haut-Uele province in the Democratic Republic of the Congo. The Kibali Gold Mine, which is operated by Barrick and owned by a joint venture company composed of Barrick, AngloGold Ashanti, and Société Minière de Kilo-Moto, has developed the project to support the increasing power demands of one of the largest gold mining operations in Africa.

Knight Piésold assisted the Kibali Gold Mine to develop a purpose-built, low-impact, and cost-effective run-of-river hydroelectric project that produces approximately 64 GWh of renewable, reliable electricity each year to power the mine. The project reduces the mine's overall energy cost by approximately 75% and its reliance on diesel fuel—equivalent to US$19.2 million per year in savings. A portion from the mine's power grid capacity is provided for free to local communities, reducing their reliance on deforestation for energy supply. The project will ultimately become a legacy asset for local communities once the mine has reached its end of life.

Key achievements include:

- With the commissioning of the project, the mine now has three run-of-river hydroelectric projects, providing the majority of the mine's energy requirements. It has drastically reduced its reliance on diesel power supply, plus it has been able to reduce its energy costs from about $400/MWh to close to $100/MWh.
- The project development and construction strategies emphasized on uplifting the region through skills transfer by employing local workers and contractors and material procurement by purchasing goods and services from local and national suppliers.
- Local communities were consulted for the design of infrastructure affecting their communities to ensure a positive legacy, foster trust and confidence, and promote community safety.


View of the project arrangement

PROJECT HIGHLIGHTS

Q.1 Innovation

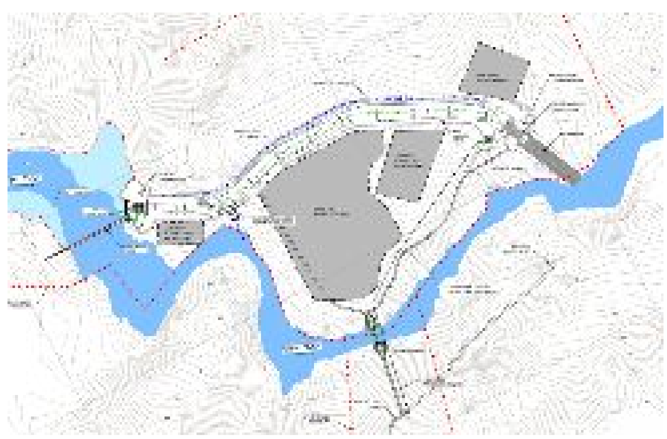
The Kibali Gold Mine, which is operated by Barrick and owned by a joint venture company composed of Barrick, AngloGold Ashanti, and Société Minière de Kilo-Moto, is located in a remote area of the Haut-Uele province, in northeast Democratic Republic of the Congo. Although located in an area with limited existing infrastructure and not serviced by an electricity utility provider, the Kibali Gold Mine is favourably enveloped by large untapped rivers.

Knight Piésold developed the 11 MW Azambi Hydroelectric Project, including project optimization, project development, detailed engineering, and construction and commissioning supervision. The project, which was successfully commissioned in July 2018, is the third of four hydropower schemes developed within 30 km from the mine, to support the increasing power demands of one of the largest gold mining operations in Africa.

The project was configured as a run-of-river hydropower facility wherein output is used to offset thermal power by supplementing base load power generation during mine operations. The bankability of the project is directly related to the capital cost of the facility itself and its peak spinning reserve, offset against the running of thermal power supply that is fueled by expensive imported diesel fuel.

Key project components include:

- The overall project concept was optimized to provide a low-impact, run-of-river operation using local materials, workforce, and contractors. This included optimizing the location of the diversion weir to reduce its height and cost and to allow for the construction of a rubble masonry concrete (RMC) weir.
- The 185-m-long RMC diversion weir was selected for its low cost and for allowing labour intensive construction.
- The intake structure was designed to facilitate bed load sediment removal by including a forebay sediment trap and desander to provide both continuous sediment removal downstream of the trash rack and a guaranteed continuous ecological flow release.
- The 1.1-km-long power canal with emergency spillway was designed for the required flow capacity and to not require additional canal lining, thereby reducing costs and promoting the use of local materials.
- Overall optimization of the project increased its initial average annual energy estimation by approximately 5.3 GWh/year, equivalent to US$2.6 million per year in diesel fuel savings.
- A portion of the mine's power grid capacity is provided for free to local communities and will ultimately become a legacy asset for future generations and the local communities once the mine has reached its end of life.



PROJECT HIGHLIGHTS

The project includes the following: a low height diversion structure and overflow weir, a run-of-river power intake equipped with sediment handling facilities and control gates, a power canal and emergency spillway, headrace structures including fine trashracks and control gates, a surface powerhouse housing the turbine-generator units, a tailrace channel isolated from the main river, and a switchgear and transmission line.

Project parameters are summarized below:


Intake and power canal, looking upstream

11 MW
rated capacity of the plant

96 m³/s
design flow

1.1 km
power canal length

13.85 m
gross head

Two horizontal Kaplan pit turbines
turbine(s)

11 kV to 66 kV transformers
switchyard

8.3 km of 66 kV transmission line
transmission line

64 GWh
annual energy supply to the mine

US$19.2 million
annual savings in diesel fuel costs

50,000 tonnes
annual reduction in greenhouse gas emissions

US$20 million
cost savings due to project optimization

700 people, 95% locals
people working on the project at peak of construction

PROJECT HIGHLIGHTS

Q.2 Complexity

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

Knight Piésold took into account various factors that added to the complexity of the optimization exercise, including:

- The Kaplan turbines, gearboxes and generators were already specified, built, and delivered to the mine (based on preliminary design by the equipment supplier).
- Development of a dam wall with integrated hydropower works arrangement was envisaged, as had been previously applied at another project.
- The construction contract was awarded exclusively to Congolese enterprises that had no former hydropower or large water retaining structure construction experience.

The location of the diversion and intake structures and surface powerhouse was optimized to target favourable foundation conditions. The headworks were positioned on the left bank of the river, which has gentler topography and river curvature, resulting in a shorter length of the power canal to attain the required generating head for the turbine rated conditions.

The power canal arrangement resulted in construction cost savings and gain in generation head from reducing hydraulic losses through the canal. The gain in generation head allowed the installed capacity to be increased by 1 MW.

Power canal and surface powerhouse, looking upstream

PROJECT HIGHLIGHTS

Rubble Masonry Concrete Diversion Weir

The diversion weir 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 7,500 m^3. The weir structure terminates on the left bank against the reinforced concrete intake structure and as a non-overflow crest section on the right flank. The overflow section has an ogee crest shape with a cast-in place concrete lining along the crest profile.

The application of RMC for the small weir structure proved to be very successful. While 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 utilization. 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.

Canal versus Dam Arrangement

The original option proposed by the mine was to build a 14-m-high dam, to provide the required generation head. Knight Piésold compared this dam against the option of a small diversion structure built at a higher location and canal arrangement. The comparison and optimization studies resulted in a preferred arrangement of a low-impact run-of-river development, with low diversion weir and canal.

Rubble masonry concrete construction on the diversion weir

Diversion gate, intake scour gate and desander gates, looking downstream of diversion and intake structure

PROJECT HIGHLIGHTS

Temporary River Diversion during Construction

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. Construction of the intake headworks required a two-stage temporary diversion of the Azambi River to allow construction of the diversion and intake structure. A temporary earthfill cofferdam was constructed on the south bank of the river isolating the intake site and a portion of the diversion structure. The temporary cofferdam was designed for the 1:10-year peak instantaneous flood event. The cofferdam was in-place for approximately 18 months while construction was ongoing. Once construction of the intake structure was completed, a smaller temporary cofferdam was installed allowing the completion of the diversion structure.

Kaplan Generating Units

A duplicate set of Kaplan turbine-generator units were supplied as part of a complete package and purchased by the mine during the preliminary design stage, prior to Knight Piésold's involvement in the project. This added to the complexity of Knight Piesold's optimization exercises, where any optimization approach would have to comply with the turbines' specified design flow and operating head ranges. The two 5.5 MW turbines have four variable pitch blades, allowing maximum hydraulic efficiency at various operation conditions.

Powerhouse construction and erection of powerhouse steel superstructure

Installation of the turbine components at the powerhouse

Q.3 Social and/or Economic Benefits

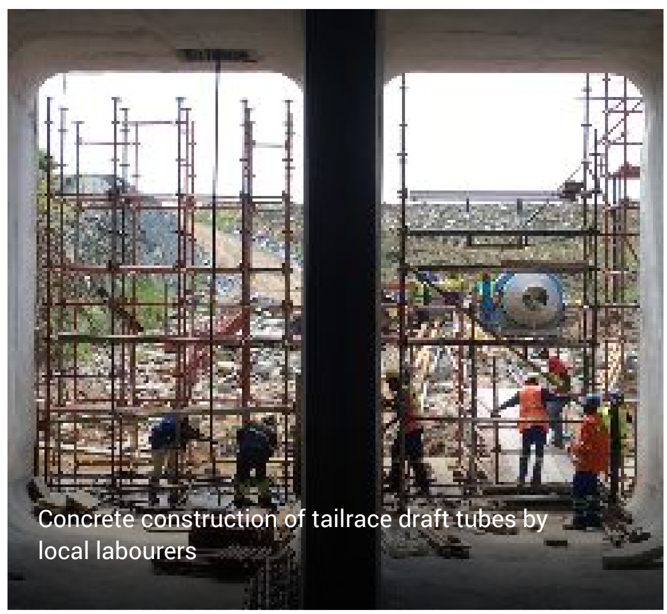
Through the project, the Kibali Gold Mine provides approximately 1.5 MW of electricity for free to local communities through their electrical grid, helping to power homes and businesses and to reduce reliance on deforestation for their energy requirements. The project will eventually become a legacy asset for local communities at the end of mine operations.

Local Labour Utilization

The Kibali Gold Mine, instead of hiring incumbent contractors, awarded the construction contract exclusively to Congolese construction enterprises. This was integral in the design premise adopted and particularly the weir type finally applied, whereby construction methods that would maximize the local labour content were accordingly given preference. The contractors, however, had no former construction experience with hydropower or large water retaining structures that necessitated an intensified construction monitoring program, focused on team collaboration and risk management to achieve production, quality, and schedule requirements.

Community involvement during the 18-month construction period provided a source of income and upliftment for an impoverished region and an opportunity to facilitate skills transfer into the local, rural population. At the peak of construction, over 700 people were working directly on the project, with over 95% being local residents. Safety performance was high and no serious injuries were recorded. The project also involved the purchasing of goods and services from local and national suppliers, contributing to the Congolese economy.


Surveying of the transmission line alignment by local contractors


Concrete construction of tailrace draft tubes by local labourers

PROJECT HIGHLIGHTS

Local Community Consultation

Throughout the project development and construction phase, local communities were consulted for the design of infrastructure affecting their communities to ensure limited disturbance to the area, foster community safety, and promote infrastructure improvement. Key infrastructure developed with local consultation include:

- The 8.3-km-long, 66 kV transmission line alignment was selected to minimize impact and interaction with local developments and populated areas. The transmission lines parallel the site access road to limit vegetation clearing required.
- New permanent project access roads were designed to reduce heavy traffic disturbance to local community developments. Local roads were improved, and new roads were designed to improve local travel efficiencies across the project area.
- Three new pedestrian and vehicle bridges were provided to allow safe crossing of the Azambi River and the project's power canal. The installed new bridges provide permanent, reliable, and safe river crossing points. Previously, river crossings were limited to boat crossings or unsafe pedestrian bridges.

Switchyard and transmission lines running parallel to the site access road to limit vegetation clearing

Construction of bridge over Kibali River for safe river crossing

Q.4 Environmental Benefits

Environmental impact was limited by reusing equipment, sourcing materials within the immediate vicinity, and reducing site disturbance. The operating facility now cuts the mine's reliance on diesel-fueled generation, reducing yearly emissions of approximately 50,000 tonnes of greenhouse gas.

Material and Equipment Reuse

Construction material availability, source-to-site distances and structure configuration were evaluated for the RMC weir construction. Requiring limited treatment, the large volume of blast rock, rock, and boulders available from the canal, diversion weir, and powerhouse excavations proved suitable and were reused for the RMC weir construction.

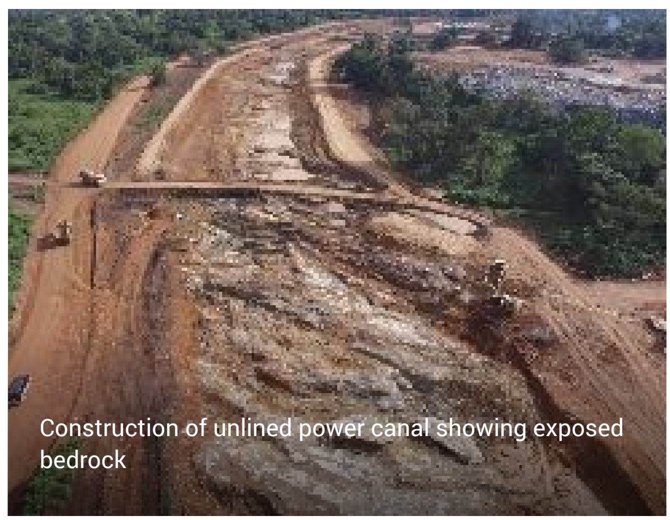
Special formwork for the draft tubes at another project also were reused and many of the fundamental design decisions that had been adopted at the other project were retained.

Low Site Disturbance

The concrete structures were optimized to reduce overall concrete volumes. The intake structure was founded on bedrock to reduce the extent of foundation treatment.

Several alternatives for the lining of the power canal were considered. The canal section and grade were designed for low flow velocity allowing the native soil to resist erosion. The unlined trapezoidal power canal, founded on rock or native soil was selected as a cost-effective, simple solution that promoted local involvement and made best use of local materials for a cost-effective and reliable solution.

Additionally, the sites disturbed by construction were fully reclaimed and revegetated with indigenous flora. Innovative ecological flow release systems were combined with continuous sediment facilities to guarantee a continuous ecological flow release to protect aquatic habitat in the diversion reach.



Construction of unlined power canal showing exposed bedrock

PROJECT HIGHLIGHTS

Q.5 Meeting Client's Needs

In an area notorious for instability and generally bereft of infrastructure, Kibali Gold Mine recognized the importance of developing renewable energy resources to support the increasing power demands of one of the largest gold mining operations in Africa.

Knight Piésold worked closely with Kibali Gold Mine to develop a purpose-built, low-impact, and cost-effective project. Knight Piésold designed the project to the available topographical and geotechnical site conditions, sourced local construction materials within the immediate vicinity of the site, and designed the facility with basic plant and equipment and generally semi- or unskilled labour force.

The project optimizations resulted in an estimated savings of approximately US$20 million. Significant cost savings included:

- ➔ The two-stage rather than single stage temporary diversion and bridges built in dry season brought US$80,000 in potential savings for each day that the project comes operational earlier.
- ➔ The reductions in concrete volume of the intake structure resulted in US$500,000 savings. The reductions in concrete volume of the powerhouse resulted in US$1,000,000 savings.
- ➔ The powerhouse was placed 170 m from the Kibali River to avoid the need to construct a tailrace cofferdam, a cost saving of roughly US$200,000.

The project, which produces approximately 64 GWh of renewable, reliable electricity each year to power the mine, reduces the mine's overall energy cost from about $400/MWh to close to $100/MWh. Kibali Gold Mine will recover the total cost of the project in approximately three years, continuing to reduce its reliance on diesel fuel—equivalent to US$19.2 million per year in savings.

Local labourers placing stone plums during RMC weir construction

Project Owner:

BARRICK

ANGLOGOLD ASHANTI

SOCIETE MINIERE DE KILO-MOTO