

# DETERMINING THE OPTIMUM SCHEME LAYOUT FOR THE SOMBWE HYDROPOWER PROJECT

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## Introduction

Legislation in the DRC has recently changed to allow Independent Power Producers (IPP) to compete in the local power market. To this end, Kipay Investments appointed Knight Piésold and Ingerop Consulting Engineers to conduct a feasibility study for the proposed Sombwe Hydropower Project in late 2016. The project is located approximately 290 km north of Lubumbashi in the Katanga Province of the DRC, shown schematically in Figure 1. Two existing hydropower stations have been operating for many years upstream of the proposed Sombwe site. The 71 MW Mwadingusha hydropower plant at the Tshangalele Dam and the 36 MW Koni hydropower plant, which is located immediately downstream of Mwadingusha.



*Fig. 1. Map showing the location of the proposed Sombwe hydropower project.*

The catchment area at Sombwe is approximately 47 337 km<sup>2</sup> and is characterised by two main sub-catchments. The Koni sub-catchment, with an area of approximately 12 877 km<sup>2</sup> upstream of Koni Hydropower Station and the Sombwe dam incremental catchment downstream of Koni, having an area of approximately 34 450 km<sup>2</sup>. The Tshangalele Dam regulates the river flow from the Koni sub-catchment, whereas river flow in the Sombwe dam incremental catchment is unregulated. Based on available statistics of the existing upstream HPP schemes, and considering that the Sombwe site drains a significantly larger catchment, the applicable range for installed capacity is expected to lie between 80 MW and 160 MW.

It was initially envisaged that a dam with a final height of 70m to 100m would be required at Sombwe to provide sufficient head and yield for the power generation. However, as it is a Greenfield project, a number of different scheme layouts were investigated to select the most appropriate configuration for the feasibility study investigation.

To select the optimum scheme layout and component sizes, several parameters were considered before focusing the feasibility investigation on the selected option. The key output required from the options analyses study was to determine;

- Dam site and type,
- Dam height,
- Power plant capacity,
- A single dam or a combination of dams in a cascade,
- A surface or an underground powerhouse,
- The initial estimated capital and operating cost estimates in sufficient detail to select a preferred option,
- The long term average energy yield, and
- The levelised cost of energy for all the plausible options.

There are too many parameters to optimise a scheme in a single analysis and a logical stepwise approach was undertaken to eliminate some parameters early on, but to retain those which may still influence the optimum scheme selection, until a decision could be made on the most economical solution. The objective was to select the most economical option for investigation at the feasibility level of detail with due consideration of technical, economic, environmental and social conditions.

## 1. Dam site and type selection

The first objective was to select between suitable dam sites and the most appropriate dam types for the specific sites within the available concession area. A LiDAR survey was done over the concession area and dam sites were identified from the contour data and were then flown over with a helicopter for visual appraisal, due to difficult access.

The Kiubo Falls, pictured in Figure 2, is a protected natural feature and the proposed Sombwe Dam should not impose on the impressive 60m high by 90m wide waterfall.



*Fig. 2. Kiubo Falls.*

Potential dam sites for Sombwe were targeted along a 6 km stretch of the Lufira River, located approximately 40 km downstream of Kiubo Falls. In this area, the river gradient is steep and flows through a rising quartzite ridge, which develops into a deep and narrow gorge, over 70m below the tailpond of Kiubo Falls.

The stretch of river is specifically preferred due to the premise of founding on hard quartzite foundations at shallow depth in a narrow valley. Three sites were identified for construction of large dams (the middle, intermediate and upstream sites) deemed suitable for conventional storage hydropower, as indicated in Figure 3.

Two weir sites, considered suitable for run-of-river HPP options were also identified. The first is upstream of Kiubo Falls which utilises the waterfall to attain head for hydropower generation, and the other is some 14 km downstream of Kiubo Falls, where a smaller natural waterfall of approximately 10m height occurs. Figure 4 shows a long section of the Lufira River with the five possible hydropower sites evaluated.

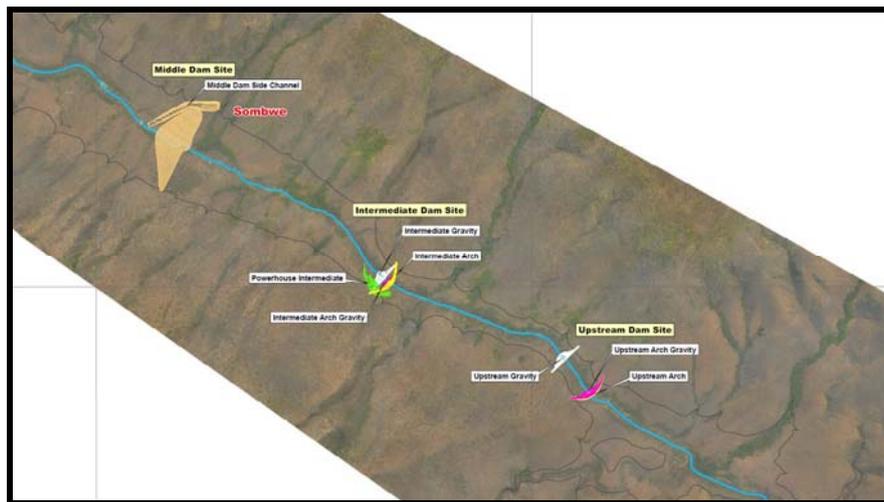


Fig. 3. Map showing the location of possible dam sites for the Sombwe hydropower project.

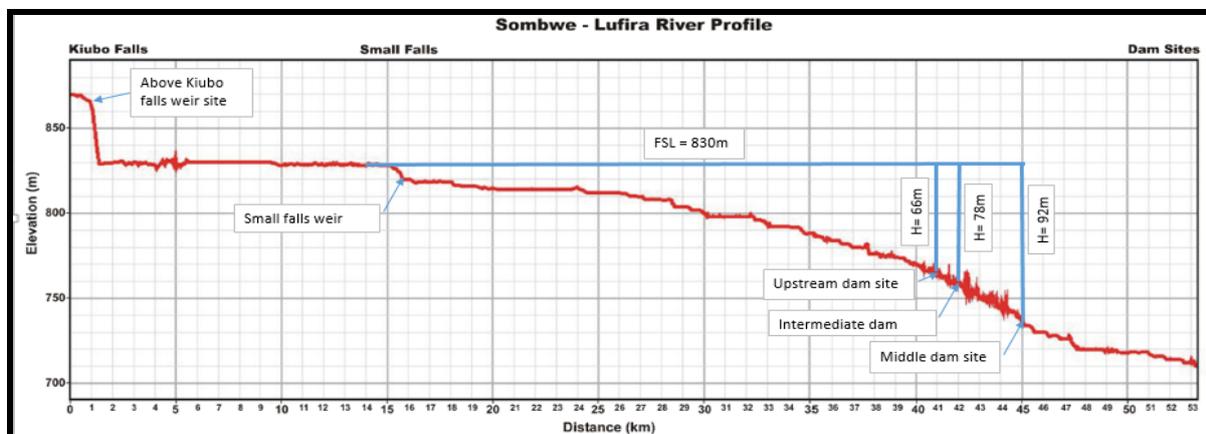


Fig. 4. Long section of possible dam sites for the Sombwe hydropower project.

From upstream to downstream the hydropower sites included;

1. A composite weir comprising embankment with RMC spillway above Kiubo Falls;
2. A concrete weir above the small waterfall, 15km downstream of Kiubo Falls;
3. A RCC or CVC Gravity, Arch or Arch/Gravity Dam at the Upstream Dam Site;
4. A RCC or CVC Gravity, Arch or Arch/Gravity Dam at the Intermediate Dam Site;
5. A Clay Core Rockfill or CFRD dam with side channel spillway at the Middle Dam Site.

The dam site/type evaluation showed that the middle site offered increased storage and water head for power generation, but at this position the valley widens considerable and more material is required to construct a dam, resulting in an expensive dam structure.

A dam type selection was undertaken for each of the potential sites for a range of selected dam heights. It soon became apparent that the optimum dam type at the middle site would be an embankment type of dam. However, at the intermediate and upstream sites, the narrow valleys and competent foundation rock masses observed allowed for the construction of a cost-effective hard dam type. At both upstream sites, the evaluated dam types included straight gravity, arch/gravity and an arch dam configuration for a range of dam heights.

Preliminary dam designs were prepared for each of the three sites and main quantities were measured. An arch dam type expectedly offered the most economical solution in terms of required material volume. However, considering the remote location of the project and unproven materials parameters and characteristics, an arch/gravity dam type was selected. The arch/gravity dam also provides significant materials reduction, compared to a conventional gravity dam, but with improved overall structural rigidity and redundancy, offering reduced construction and operational risk. Adoption of an arch dam will be reassessed, based on the outcome of the final geological, geotechnical and foundation investigations.

## 2. Dam height selection

A range of dam heights was evaluated for each dam site to determine the optimum head, storage, energy and cost relationship. Peak flow of the Lufira River follows the summer rainfall season and Sombwe Dam must provide as large a storage basin as possible for regulating reduced dry season inflows.

For the selected sites, dams with FSL's of (A) 835mASL, (B) 830mASL, (C) 820mASL, and (D) 763mASL were evaluated. An additional final height of 764mASL was also considered at the intermediate site to allow the development of a large dam at the intermediate dam and a medium dam at the middle site for a cascade scheme arrangement. The long section showing the range of heights analysed at each of the sites is shown in Figure 5.

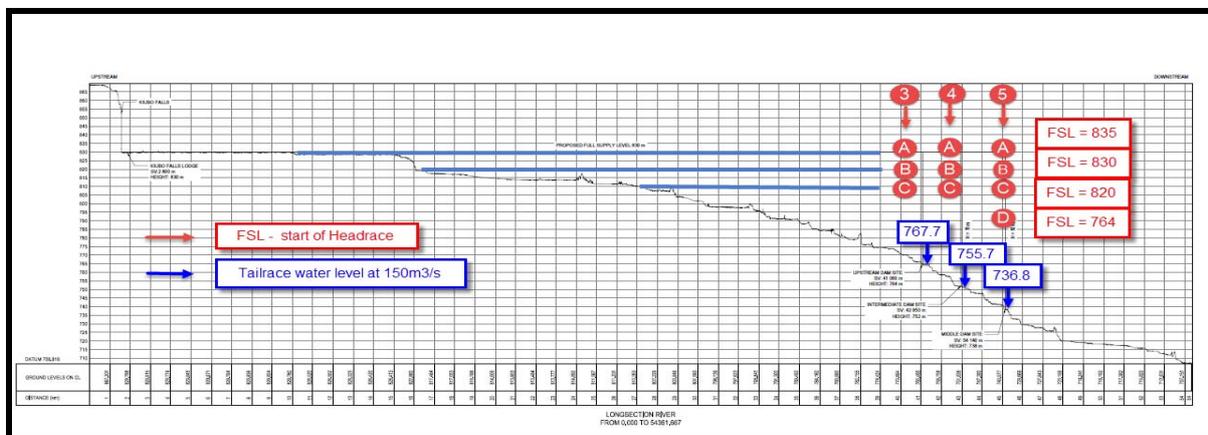


Fig. 5. The Long section of the possible dam heights for the three dam sites for the Sombwe hydropower project.

The evaluations showed that although a dam constructed to a final height of up to 850mASL is possible at the site, selection of the FSL is constrained by the fact that the new impoundment may not inundate Kiubo Falls, or cause heightened backwater for small flood events (up to the 100 year event) at the lodge that is constructed on the left bank of Kiubo Falls (At approximately 835 mASL). This significantly reduces the available storage and hydropower generation potential that could otherwise be achieved from the overall scheme and implied that the main dam could only be sized for a full supply level of approximately 830 mASL.

With the NOC at 840mASL, the 80m high dam will have a total crest length of approximately 385m, a 90m long uncontrolled chute and flip bucket type spillway, flanked on either side by gravity walls. The spillway is designed to pass the 200-year design flood with normal freeboard for 2136m³/s and a unit flow rate of 23m²/s.

### 3. Power plant capacity

The rated flow for the two existing upstream hydropower plants is 77m<sup>3</sup>/s at Mwadingusha HPP and 85m<sup>3</sup>/s at Koni HPP. The Sombwe hydropower scheme would aim for a high capacity factor to service mining clients in the Katanga Province.

The pitman model was used to generate a hundred year monthly runoff record at the Sombwe dam sites. The runoff was generated using rainfall data in the catchment and was calibrated against the measured flows into Tshangalele Dam. The mean annual average runoff for the Lufira River at Sombwe was estimated to be 106m<sup>3</sup>/s. Energy simulations were done using the Water Resource Yield model for a range of rated flow capacities from 90m<sup>3</sup>/s to 180m<sup>3</sup>/s. The range was selected considering that a rated flow of less than 90m<sup>3</sup>/s would be less than the capacity of the upstream HPP schemes and that rated flows greater than 180m<sup>3</sup>/s resulted in a very low capacity factor. Thus, the power plant and waterways were sized for; (1) 90m<sup>3</sup>/s, (2) 120m<sup>3</sup>/s, (3) 150m<sup>3</sup>/s and (4) 180m<sup>3</sup>/s.

Furthermore, in order to mitigate storage limitation and benefit from the steep natural river gradient, the hydropower scheme arrangement included an extended tailrace option, providing an additional static head for energy generation purposes.

The optimum size of the waterways for both short and long tailrace options for each scheme size was calculated on the premise of minimising the lifetime cost of the waterways and the expense reference value (ERV) was determined from the estimated lifetime expense of the waterway component to the scheme. This was done by estimating the energy lost through friction over the life of the scheme and assigning this a cost, then adding the capital cost of the waterway. The cost of the waterway was then divided by the annual average power production and plotted relative to the water velocities, as shown in Figure 6. The optimum waterway size was determined to be the value with the lowest ERV. This was 3m/s for a concrete-lined tailrace tunnel at the Sombwe site. This velocity of 3m/s was used for the sizing of the waterways with the long tailrace tunnel.

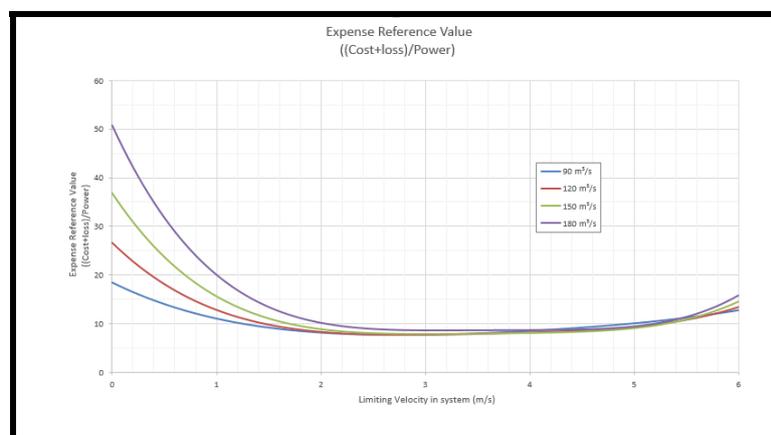


Fig. 6. Expense Reference Value (ERV) for the long tailrace concrete lined tunnel.

### 4. Single dam or cascade scheme

As large dams are an expensive undertaking, it was also required to consider smaller dams in a cascade scheme that could also be phased to reduce the initial capital outlay. Different combinations of smaller RoR schemes were considered.

For the cascading arrangements, a large dam could only be developed at one of the upstream sites as tailwater from the downstream dams would impact the upstream dam's hydropower plant. The only economic and technically feasible option to develop two dam sites was the option of a medium dam at the intermediate site and a large dam at the upstream site. The other feasible cascade option was to develop a run of river arrangement immediately upstream of Kiubo Falls, combined with the most economic large dam at the intermediate site.

## 5. Surface or underground powerhouse

With the intermediate site being recognised as the most economical dam site, the designers focus turned to develop the most efficient hydropower arrangement and options for both surface-and underground powerhouses were evaluated. Compared to a surface powerhouse on the left bank near to the dam wall, an underground powerhouse with downstream surge chamber and 3.3km tailrace tunnel would add 24m static head or alternatively a 5.2km tailrace tunnel would add 34m of an additional static head.

## 6. Cost estimates

A set of basic designs and drawings were prepared for all of the above options. The quantities were measured and cost estimates were made for each option using a cost model. The cost model applied unit rates from similar recent hydropower and dam projects. The following additional items were added as a percentage to the estimated cost of the civil works. A percentage was added for miscellaneous items, site establishment, contingencies and engineering.

The electrical and mechanical equipment were estimated separately, as was the transmission line, switchyard, access road and the operation and maintenance costs. The total and civil cost in US dollars for every scheme option is shown in Figure 7.

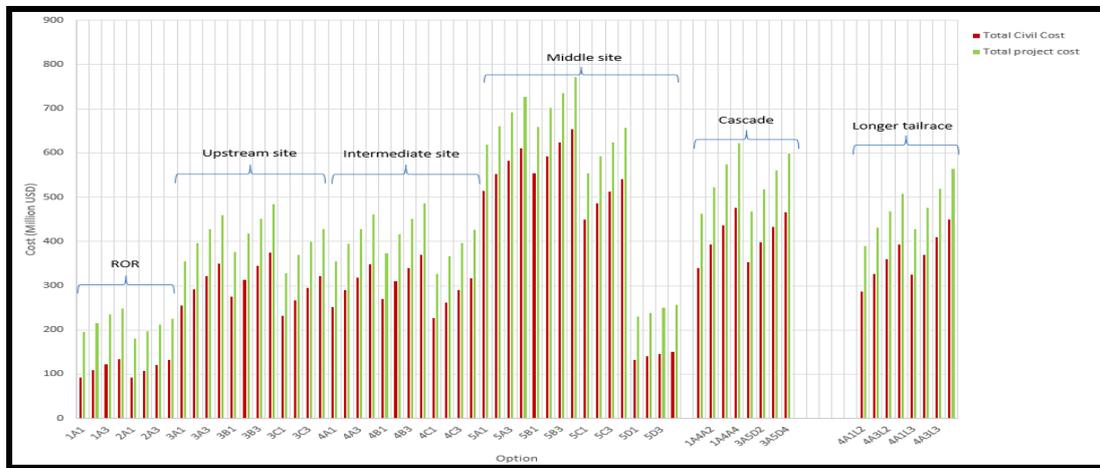


Fig. 7. Summary of total and civil scheme cost in US dollars.

In terms of initial capital outlay, the least cost schemes were expectedly the run of river options. The upstream and the intermediate dam site were less expensive to develop than the middle site.

## 7. Energy calculations

The Water Resource Yield Model (WRYM) was configured for each scheme layout and the energy generation was calculated for each option using the 100-year long monthly hydrological time series. The data inputs to the WRYM model are:

- The monthly hydrology time series
- The reservoir storage-area-elevation relationship measured from the LiDAR survey
- The hydropower plant characteristics, for rated flows of 90 m<sup>3</sup>/s, 120 m<sup>3</sup>/s, 150 m<sup>3</sup>/s and 180 m<sup>3</sup>/s.
- The head loss through the waterways was calculated based on the system hydraulics, and
- The tailwater rating curve at each site.

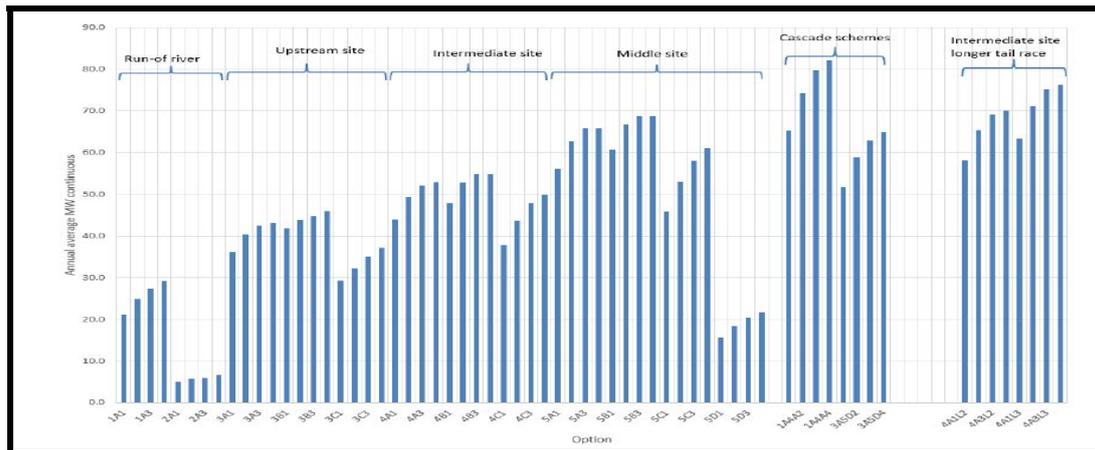


Fig. 8. Summary of annual average energy production in MW continuous.

The output from the WRYM model is a time series of continuous monthly energy production for the scheme. The average continuous energy in MW was then calculated from the 100-year long monthly energy time series. The average continuous energy for each option is shown in Figure 8. The cascade scheme produces the most energy and then the options with the longer tailrace tunnel.

## 8. Optimum Scheme Layout

The levelised cost of energy was determined for a range of discount rates using the scheme cost plus the long-term average energy production. It became apparent that of the five sites, an arch/gravity dam at the intermediate site with a full supply level of 830mASL and a rated flow of 150m<sup>3</sup>/s was the most economical option, selected for Feasibility Study.

The economics of the hydropower scheme at the intermediate site could be improved by increasing the static head, by way of a longer tailrace tunnel or higher dam in the event the constraint on the FSL can later be relaxed. There was only a marginal difference between this option and the scheme with higher rated flows capacity of 180m<sup>3</sup>/s and this option was also retained for full feasibility design.

The cascade scheme and the intermediate site with a long tailrace is eliminated based on environmental considerations. The levelised cost of energy for each option is shown in Figure 9 and the 3D CAD drawing of the optimum scheme layout is shown in Figure 10.

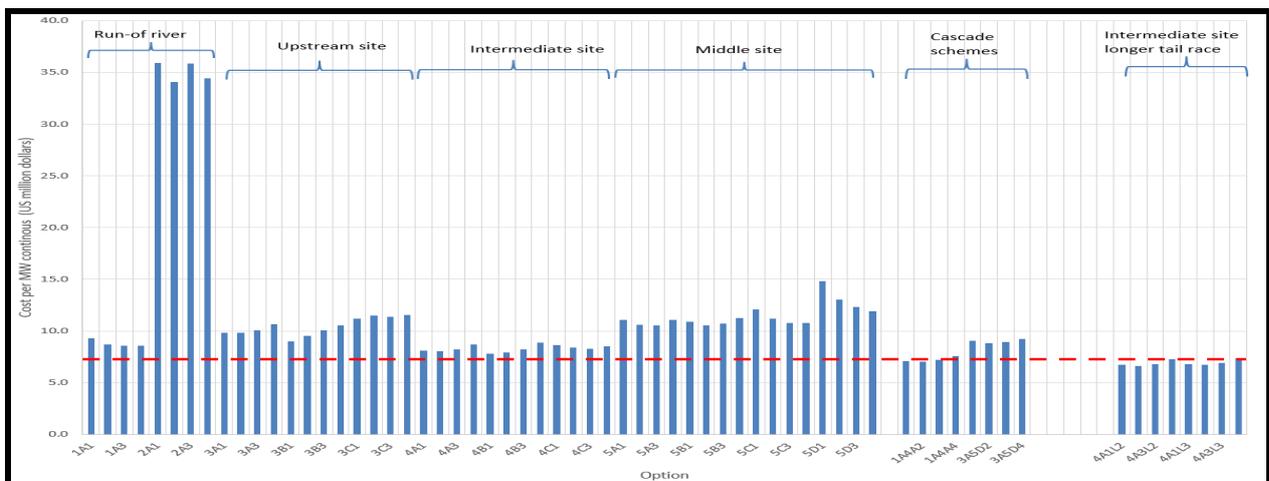


Fig. 9. Estimated levelised cost of energy MW continuous in millions of US dollars.

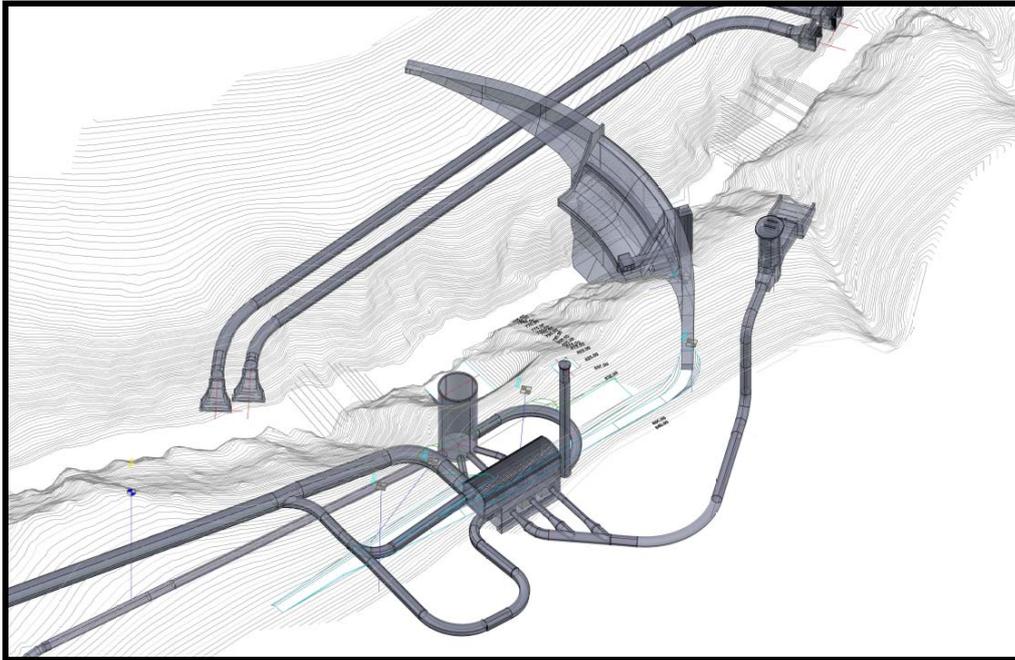


Fig. 10. 3D view of the optimum scheme layout selected for the feasibility study.

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