NEPAL ELECTRICITY AUTHORITY

(A Government of Nepal Undertaking)

Updated Feasibility Study and Detailed Design of DUDHKOSHI STORAGE HYDROELECTRIC PROJECT

in Khotang and Okhaldhunga Districts

FINAL DETAILED DESIGN

VOL. 0 – EXECUTIVE SUMMARY

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Final Detailed Design

Executive Summary

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1 KEY NOTES

The main conclusions of the Detailed Design of Dudhkoshi Storage Hydroelectric Project (DKSHEP) can be summarized as follows:

- The optimal layout for the DKSHEP is based on a maximum normal reservoir level of 640 masl and a Concrete Face Rockfill Dam (CFRD) with height of 220 m. The installed capacity is 670 MW (600 MW in the Main Powerhouse, also named as “Sunkoshi Baikhu Khola Powerhouse” and 70 MW at the Dam Toe Powerhouse) which will be highly appropriate for the fulfillment of power supply requirement during dry seasons.
- The field investigations carried out and basic data available so far are sufficient to support the present detailed design level and to confirm the technical feasibility of the proposed scheme.
- Final Detailed Design, envisages the following project layout:
  - an approx. 220 m high CFRD dam with a 630 m long crest at elevation 648 masl with the riverbed at approx. elevation 430 masl near the dam,
  - an underground powerhouse with installed capacity of 600 MW (Main Powerhouse) located on the left bank of Sunkoshi River; an underground powerhouse in Dam Toe with an installed capacity of 70 MW located on the right bank of the Dudhkoshi river immediately downstream of the dam,
  - 13.2 km long concrete lined headrace tunnel with finished diameter 8.3 m will be constructed adopting Tunnel Boring Machine (TBM),
  - a main spillway with combination of a radial gated spillway and a labyrinth spillway is able to pass flood discharges of 9.027 m^3/s (return period of 10,000 years) and 12,638 m^3/s (PMF),
  - an auxiliary or emergency spillway with combination of an embankment dam and a labyrinth spillway is able to pass additional flood discharge of about 11,500 m^3/s,
  - the layout includes as complementary structure the middle level outlet and low level outlet that regulate the impounding and accelerate the depletion in case of safety problems,
  - a plunge pool designed based on the scour that is likely to occur under the most significant operation conditions corresponding to the design flow (Tr = 10,000 yrs.). The pre-excavation depth of the pool is based on a design flow with Tr = 200 years.
- The average annual energy production is 3,377 GWh, with an energy deficit of approximately 4.5%, a dry season generation of 1,252 GWh, a wet season generation of 2,125 GWh and a dry season energy ratio of approximately 37.1%. The resulting average

Plant Factor is 0.43 in dry season and 0.72 in wet season, while the average annual spilled volume is 1,469 Mm^3.

- Dam Toe Powerhouse is designed to utilize the Environmental Flow (downstream release) of 30-40 m^3/s which will also guarantee the irrigation water demand of Sunkoshi-Kamala Diversion Multipurpose Project (SKDMP).
- The Project is planned to complete and commission in 7 years from the commencement of Main Works of the Project.
- The cost of the project layout at present day price levels is estimated to be in the order of 1,593.3 MUSD, excluding Interest During Construction (IDC), Customs Duties and Value Added Tax (VAT), Price Contingencies, Owner's Administration Cost, Project Construction Supervision Consultancy Services and Financial Costs.
- The Economic and Financial Analyses indicate that DKSHEP is economically and financially sound. The Economic Internal Rate of Return of Project is 18.9% with an Economic Net Present Value of 1,148 MUSD and a benefit-cost ratio of 1.61. The Financial Internal Rate of Return is 9.2%, the Project Net Present Value is 201 MUSD and the Average Debt Service Coverage Ratio is 2.5.

Nepal Electricity Authority (NEA) has established Dudhkoshi Jalvidyut Company Limited (DKJVCL) as a subsidiary company for the implementation and operation of DKSHEP.

The Client informed that the project will be funded through an optimal mix of sovereign and non-sovereign loans and equity. The equity portion will be invested by Government of Nepal (GoN) and NEA and other shareholders. Asian Development Bank (ADB) has been taking lead role to coordinate external financiers for investment in the DKSHEP. The loan portion of the project will be financed by Asian Development Bank (ADB), World Bank (WB), European Investment Bank (EIB), Asian Infrastructure Investment Bank (AIIB), OPEC Fund for International Development (OFID), Saudi Fund for Development (SFD), Exim Bank of Korea, SAARC Development Fund etc.

2 GENERAL

2.1 Updated Feasibility Study and Detailed Design

Nepal Electricity Authority (NEA) has employed ELC Electroconsult S.p.A. (Italy), in association with NEWJEC Inc. (Japan), to carry out the "Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project" under Asian Development Bank grant no. 0361-NEP:PPFE. The Contract no. NEA/DKSHEP/CS/01-2073 was signed on 30 May 2016.

This report complies with the requirements of the Terms of Reference for the "Final Detailed Design".

2.2 Project Area

DKSHEP is located on Dudhkoshi river between the boundaries of Okhaldhunga and Khotang Districts in Koshi Province of Nepal. The reservoir of the Project will also inundate some area of Solukhumbhu District.

The dam site is located in a gorge nearly one kilometer downstream of the confluence between Dudhkoshi River and Thotne Khola, where the river width is about 120 meters. The catchment area is 3,857 km^2, the average water budget is 6,601.5 Mm^3, the reservoir total storage volume is 1,581 Mm^3. The average slope steepness ranges around 40º on the left bank and 50º on the right bank. The rock outcrops are widely exposed on right bank, whereas on left bank the lower area is covered with colluvium.

2.3 Previous Studies

The previous studies related to Koshi River Basin are listed in the following:

- In **1985 :** JICA performed the Koshi Master Plan Study, targeted to the years 2005/2006, to prepare a comprehensive water resources development plan for the basin focused on power generation, irrigation, flood control and navigation, including inter-basin development schemes.
- In this frame several projects were identified in the catchment area, including the HEP on the Sun and Sapta Koshi (SK I, II and III and the High Dam on Sapta Koshi and the multipurpose project of Kamala Diversion) and the cascade of projects for power production on the Dudhkoshi, of which the DKSHEP, due to its reservoir, is the most important one.
- **1998:** CIWEC performed a feasibility study focused on the DKSHEP, analysing several solutions, mainly for rockfill dams in the section A downstream of Rabuwa Bazar. This

study describes in a consistent way all the technical aspects related to the Project. The solution proposed is described in section 4.2.1 of this report.

- **2013:** NEA performed a valuable Review of the Feasibility Study prepared by CIWEC in 1998. The target of the Review Study was the updating of the Feasibility and the solution of the constraint conditioning the DKSHEP to feed the Kamala Diversion Project. The DKSHEP output was increased to 210 MW for the toe solution and to 365 MW for the tunnel solution.
- The dam heightening was also envisaged to increase the reservoir volume, the water head and the design discharge, proposing possible alternatives up to 640 masl of Maximum Normal Water Level (NWL) and installed power up to 800 MW.

Other relevant studies having a connection with the DKSHEP are:

- **2014:** The Japan International Cooperation Agency prepared Nationwide Master Plan Study on Storage-type Hydroelectric Power Development in Nepal. The Study aims at preparing a master plan for storage-type hydroelectric power development for domestic demand in Nepal with time horizon of twenty years from 2013, from 65 potential projects identified by NEA. The study has an indirect relevance for the DKSHEP.
- **2016:** ADB prepared a Draft Study aimed at the optimization of the DKSHEP taking into account the projects planned in the catchment basin. This Study is considered as a preparatory study for DKSHEP.

3 PROJECT FEATURES

3.1 Key Salient Features

The following table summarizes the Project's Key Salient Features.

(A) Dam, Reservoir, Hydrology, Sedimentology, Spillways, Diversion and Outlet Structures

(a)	Main Dam and Reservoir	
	Type of Dam	Concrete Face Rockfill Dam (CFRD)
	Dam Height (on foundation)	220 m
	Dam Body Volume	26.7 Mm^3
	Dam Crest Elevation	648.0 masl
	Parapet Wall Top Elevation	649.5 masl
	Dam Crest Length	630.0 m
	Maximum Normal Water Level (Max. NWL)	640.0 masl
	Minimum Normal Water Level (Min. NWL)	530.0 masl
	Total Storage Capacity	1,581 Mm^3
	Live Storage	1,342 Mm^3
	Dead Storage	239 Mm^3
(b)	Hydrology	
	Catchment Area (at dam site)	3,857 km^2
	Dudhkoshi River Average Flow	209 m^3/s
	Construction Flood (50-year return period)	3,892 m^3/s
	Design Flood (10,000-year return period)	9,027 m^3/s
	Probable Maximum Flood (PMF)	12,638 m^3/s
(c)	Sedimentology	
	Total Sediment Annual Yield	8.82 Mm^3/year (15 Mt/year)
	Total Sediment Volume after 50 years	441 Mm^3
	Dead Storage Loss after 50 years	239 Mm^3 (100%)
	Active Storage Loss after 50 years	202 Mm^3 (15%)
	Average Annual Energy with Sedimentation (50 years)	3,331 GWh
	Average Dry Season Energy with Sedimentation (50 years)	1,204 GWh
	Average Wet Season Energy with Sedimentation (50 years)	2,127 GWh
(d)	Main Spillway	
	(i) Gated Spillway	
	Type	Concrete gated
	Design Discharge (10,000 year return period)	9,027 m^3/s
	Sill Elevation	624.0 masl
	Crest Length	60.0 m

	Radial Gates	4 nos, 15.0 m x 20.6 m (width x height)
	(ii) Labyrinth Weir	
	Type	Labyrinth Overflow
	Design Discharge	2,250 m³/s
	Crest Elevation	640.5 masl
	Length	56.55 m
(e)	Auxiliary/Emergency Spillway	
	(i) Labyrinth Weir	
	Type	Labyrinth Overflow
	Design Discharge	3,700 m³/s
	Crest Elevation	644.0 masl
	Length	154.5 m
	(ii) Embankment Dam	
	Type	Embankment Fuse Dam
	Design Discharge	7,800 m³/s
	Crest Elevation	647.3 masl
	Bottom Elevation	637.0 masl
	Length	154.5 m
(f)	Diversion Tunnels (DT)	
	Type and Number	Horseshoe-shaped, 2 nos
	Diameter (Excavation)	13.9 m (Finished Dia. 12 m)
	Lengths	DT1 = 1,115.2 m DT2 = 1,289.6 m
	Total Design Flow	3,892 m³/s (50 years return period)
(g)	Bottom Outlet (BO) (one of the Diversion Tunnels will serve as BO during operation)	
	Type and Number	Horseshoe-shaped, 1 no
	Diameter (Excavation)	13.9 m
	Maximum Discharge	2,400 m³/s (120 m gross head)
(h)	Low Level Outlet (LLO)	
	Type and Number	Horseshoe-shaped, 1 no
	Diameter (Excavation)	9.6 m
	Length	929.3 m
	Maximum Discharge	1,000 m³/s (120 m gross head)
(i)	Middle Level Outlet (MLO)	
	Type and Number	Horseshoe-shaped, 1 no
	Diameter (Excavation)	10.5 m and 13.2 m
	Length	695.0 m
	Maximum Discharge	1,000 m³/s (90 m gross head)

(B) Main Powerhouse

(a)	Headrace Tunnel	
	Type	Circular shaped Concrete Lined

	Diameter (Excavation)	9.32 m (with TBM), Finished Dia. 8.3 m
	Length	13.2 km
	Design Discharge at Rated Head	224.4 m³/s
(b)	Surge Shaft	
	Type and Number	Circular, 1 no
	Diameter (Excavation)	20 m
	Height	221 m
(c)	Steel Penstock	
	Type and Number	Circular, 1 no
	Diameter (Internal)	6.7 m (3.2 m Dia. in bifurcation)
	Length	528.0 m
(d)	Vertical Penstock Shaft	
	Type and Number	Circular, 1 no
	Diameter (Excavation)	8.5 m
	Length	180.0 m
(e)	Powerhouse	
	Type	Underground Powerhouse
	Capacity	600 MW (4 x 150 MW)
	Turbine	Francis (Vertical Axis)
	Turbine Rated Head	294 m

(C) Dam Toe Powerhouse

(a)	Headrace Tunnel	
	Type	D-Shaped, Concrete Lined
	Diameter (Excavation)	8.0 m x 8.0 m
	Length	880
	Design Discharge at Rated Head	40 m³/s
(b)	Surge Shaft	
	Number	Circular, 1 no
	Diameter	7.0 m
	Height	140.15 m
(c)	Steel Penstock	
	Type and number	Circular, 1 no
	Diameter (Internal)	2.8 m
	Length	186.5 m
(d)	Vertical Penstock Shaft	
	Type and number	Circular, 1 no
	Diameter (Excavation)	3.6 m
	Length	82.5 m
(e)	Powerhouse	

Type	Underground
Capacity	70 MW (2 x 35 MW)
Turbine	Francis (Vertical Axis)
Turbine Rated Head	182 m

(D) Transmission Line and Sub-Stations

(a)	Transmission Lines	
	Type and Voltage	Double Circuit, 400 kV
	Conductor	ACSR Moose (Quad bundle per phase)
	Length from Main Powerhouse substation (Dhitung Substation) to Dhalkebar substation	82 km
	Length from Dam Toe substation to Bhadaure substation - LILO	1.6 km
(b)	Substation/ Switchyard	
	Number	3 nos
	Location	one next to Main Powerhouse and the other two are located next to Dam Toe Powerhouse

(E) Energy, Costs, Economical and Financial Analysis, Implementation Plan

(a)	Energy Production	
	Average Annual energy Production	3,377 GWh
	Average Dry Season Energy Production	1,252 GWh
	Average Wet Season Energy Production	2,125 GWh
(b)	Costs	
	Total Capital Costs	1,593 MUSD
(c)	Economic Parameters	
	Economic Internal Rate of Return (EIRR)	18.9%
	Net Present Value (NPV)	1,148 MUSD
(d)	Financial Parameters	
	Financial Internal Rate of Return (FIRR)	9.2%
	Weighted Average Cost of Capital (WACC)	8.3%
	Net Present Value (NPV)	201 MUSD
	Average Debt Service Coverage Ratio	2.5
(e)	Project Implementation	
	Construction period	7 years

3.2 Project Optimization

Extensive studies were carried out to define the optimal suitable characteristics of the project. In general terms, these studies were aimed at achieving the maximum economic Net Benefit.

The evaluation of the installed capacity of the plant and of the Minimum Normal Reservoir Level on the project has been developed assuming one Minimum Normal Reservoir for all cases studied and fixed criteria for the selection of the constant plant Factor.

The general project layout is shown in the attached drawings. The basic optimization studies carried out, and the corresponding results achieved, are as follows.

3.2.1 River Diversion Structures and Return Period Selection

The optimization of the tunnel alignments of River Diversion considers the following factors:

- length should be as short as possible to minimize cost,
- sufficient rock cover is needed to simplify tunnel liner design and to minimize cost,
- the tunnels must not interfere with the design and construction of the power facilities,
- the discharge from the outlet structure into the atmosphere must be in an area remote from other permanent surface installations.

Two approximately 1,202 m long concrete lined diversion tunnels on the left abutment, are designed to discharge 1,946 m³/s per each tunnel without overtopping the cofferdam. Both tunnels will be horseshoe-shaped, with 12 m inside diameter. After diversion closure, the right one will be used as bottom outlet.

Upstream cofferdam: It is a 42 m high embankment structure, with crest at elevation 477 masl, not incorporated into the main dam body, and including a plastic diaphragm cut-off in the alluvial layer in the river bed.

Downstream cofferdam: a 10 m high embankment structure, with crest at elevation 438 masl.

The dimensions and cost of the diversion works were optimized with respect to the risk of overtopping damage and the resulting costs. Based on the optimization the river diversion system will assure 50 years return period flood.

3.2.2 Dam Type Selection

A detailed comparison was carried out between the roller compacted concrete gravity RCC and the rockfill CFRD types of dams. Taking into account cost and other economic and environmental aspects, as well as foundation characteristics; it is considered that the rockfill type the most suitable choice for the high Dudhkoshi dam: the rockfill dam is more suitable to the geological conditions of the site and inherently safer in relation to seismic events.

The main dam is a 220 m high Concrete Face Rockfill Dam (CFRD) with a 630 m long crest at elevation 648 masl and the river bed at elevation 430 masl. The total volume is about 26.7 million m³. A parapet wall is foreseen with top elevation 649.5 masl.

The dam axis has been located into the narrower portion of the valley, to minimize embankment volume. The downstream toe has been kept upstream of a deep gully dissecting the left abutment which will be part of the spillway discharge area.

A 1.6:1 H:V upstream slope and a 1.77:1 H:V (average along the entire face, including the steps, the slope between each steps is 1.6:1 H:V) downstream slope have been adopted. The stability of the proposed dam was evaluated.

The embankment materials will be founded on moderately weathered rock, where the highly weathered material will be removed on the right bank, and on alluvium in the river bed, removing the loose upper layer.

3.2.3 Power Waterways with particular focus on HRT

The optimal diameter of the various tunnel section was determined in accordance to the main parameters given by the geometrical cross section, the waterway hydraulic parameters, the rock support in agreement with geotechnical/geological hypothesis along the waterway axis alignment, the expected energy tariff and the construction costs.

Taking into account the outcomes of energy calculations it has been considered a mean design flow of 144 m^3/s for Main Powerhouse HRT, which is obtained from the reservoir operation modelling for the selected hydropower scheme. This value corresponds to the mean daily flow turbined in the Main Powerhouse Plant along the average year.

With reference to the steel lined portion of waterways, in addition to the civil cost constructions, it has been considered the impact of diameter variations also on hydraulic steel structures (penstocks, gates, stoplog) and on electromechanical equipment (inertia GD^2 of turbine-generator units).

The optimization of diameter is implemented comparing the total capitalized cost. The total capitalized cost is composed of annual negative benefit originated from output decrease due to head loss and annual cost calculated from construction cost.

Based on the conditions above mentioned in the case of the HRT the optimal diameter is 8.3 m.

3.2.4 Installed Capacity and Number of Units

The total installed capacity is based on the optimization studies and two powerhouses are foreseen, namely “Main Powerhouse” and “Dam Toe Powerhouse”.

(a) The main Powerhouse, including the main cavern powerhouse housing 4 generating units (4 x 150 MW) and transformers cavern; and

(b) Dam Toe powerhouse including the main cavern powerhouse housing 4 generating units (2 x 35 MW) and transformers cavern.

The total installed capacity, to keep one unit as reserve, as well as the number and size of the units was confirmed of the studies for the final selected of the plant factor.

3.2.5 Normal Maximum and Minimum Reservoir Level

Elevation 640 masl is considered the most suitable for the maximum NWL, as it corresponds to the maximum Net Benefit, while assuring economic parameters sufficiently high for the development of the project.

Elevation 530 masl Minimum Reservoir Level has been selected, as no further gains in the firm energy production are achieved by further increasing the reservoir draw-down.

3.2.6 Plant Factor Selection

A detailed economic comparison with equivalent alternative generation indicates that the best economic parameters (both the IRR and the Net Benefit) are achieved with a medium plant factor. In view of this results, a 0.6 Plant Factor is presently proposed.

3.3 Project Requirements

3.3.1 Release Discharge on Dudhkoshi River

The turbine E-flow or water release downstream (dam toe powerhouse) shall maintain 30 m^3/s from December to March, 40 m^3/s in April and 30 m^3/s in May. This condition guarantees the operation of Kamala and Marin Diversion located along the Sunkoshi (upstream and downstream of the confluence of Dudhkoshi and Sunkoshi River).

3.3.2 Ecological Discharge and Water Resources Management

The Consultant has studied the potential impact that the development of the DKSHEP may have on the water resources system, and how it may affect other water uses and related projects planned in the Koshi River Basin. The ecological discharge has been calculated considering the operation of Sunkoshi-Kamala Diversion Multipurpose Project (SKDMP) and Sunkoshi-Marin Diversion Multipurpose Project (SMDMP).

3.3.3 Major Projects

Main projects in the Koshi Basin are, from upstream to downstream along Sunkoshi River: Sunkoshi 3 Hydropower Project, SMDMP, Sunkoshi – 2 Hydropower Project, Dudhkoshi Dam Toe Powerhouse, Sunkoshi-1 Hydropower Project, SKDMP, Dudhkoshi Main Powerhouse and Sapta Koshi High Dam Multipurpose Project.

4 TOPOGRAPHY

The results of the topographic surveys carried out in the DKSHEP are summarized below and discussed in detail in Vol. 4 – Topographic Report. Field surveys were carried out during three site surveying campaigns, in February 2017, April 2017 and March 2018 respectively.

This is a detail of field activities carried out:

- Global Navigation Satellite System (GNSS) survey of 21 temporary reference points, materialized with 50 cm x 50 cm targets and used for geo-referencing the Terrestrial Laser Scanner surveys carried out at Dam Site, Intake of Dam Toe Powerhouse on Thotne Khola left side and Dudhkoshi Main Powerhouse.
- Terrestrial Laser Scanner (TLS) survey at the dam site, Dam Toe Powerhouse Intake and Dudhkoshi Main Powerhouse geo-referenced with temporary GNSS reference points. Moreover, in April 2017 a TLS survey at the location of a potential powerhouse located downstream from the dam site was carried out. The Terrestrial Laser Scanner (TLS) surveys have been used for both performing detailed topographic maps and extracting geomechanical parameters of the rock mass from the analysis of the 3D model with dedicated software packages.
- The topographical survey with conventional ground topographic equipment was carried out to cover the 100 km alignment of Transmission Lines (scale 1:1000).
- LiDAR survey with helicopter (2022) of the project area with an extension of 100 km^2
- Bathymetry along the reservoir and downstream of the dam site along the Dudhkoshi till the confluence with the Sunkoshi River.

Presently available topographic maps cover the full area of the dam site (1:500) and Toe Powerhouse and Sunkoshi Powerhouse (scale 1:500). Topographical maps processed from TLS at various scales are also available for the planned access road, for the construction material borrow and quarry areas around on the project area.

In April 2019 two surveying campaigns were carried out at the downstream of the Dam site and along the section of Baikhu Khola and the Sunkoshi River for approximately 5 and 7 km respectively.

LiDAR survey with helicopter (2022) was carried out of the project area with an extension of 100 km^2 to provide topographic data supporting the hydropower project.

5 HYDROLOGY AND METEOROLOGY

The present chapter summarized the hydrological studies detailed in Vol. 2 – Hydrological and Meteorological Report.

5.1 Climate and Hydrology

The climate in the Hindu Kush Himalayan region is strongly influenced by the varying dominance of two independent climatic systems, i.e. the Asian monsoon and westerly winds. In particular, Central and Eastern Himalayas are mainly influenced by the Asian Monsoon pattern, the more the closer to the Indian Ocean, where the monsoon originates.

The flow regime of Himalayan rivers is strictly connected with the Indian summer monsoon, and the Dudhkoshi river reflects the seasonal precipitation patterns. Thus, discharge peaks occur during the summer monsoon, meaning that sustained high flows are observed in July, August and September; part of the summer discharge is expected to derive from ice and snow melt water as well. After the monsoon, the river flow slowly decreases, as melting may still occur; the lowest flows are observed during winter months, when little or no rain falls in the lower part of the catchment and snowfall at high altitudes delays the runoff. Finally, the spring pre-monsoonal season corresponds to the rising limb of the annual hydrograph, as snow (and to a lesser extent ice) melt takes place.

5.2 Climatic Data of Dudhkoshi River Basin

The study was pursued based upon a relevant data base, as follows:

1) Data of daily discharges (1964-2018, with variable length), and maximum yearly peak discharge (1964-2014, with variable length) for 13 catchments, provided by DHM in fulfilment of the present study;
2) Data of daily precipitation (1948-2016 with variable length), and maximum yearly daily precipitation (1985-2015) for 8 precipitation stations, provided by DHM in fulfilment of the present study;
3) Data of daily temperature (1962-2015, T_{min}, T_{max}) for the station of Okhaldhunga within the catchment, provided by DHM in fulfilment of the present study;
4) Data of hourly temperature (2003-2014) for 4 high altitude stations within the catchment, of hourly precipitation for 3 high altitude stations, and of radiation and snow level in 1 high altitude station provided by EVK2CNR in the frame of previous studies;
5) Data of hourly water level (2012-2014) at Pherice, provided by CNR-IRSA Brugherio, in the frame of previous studies;
6) Field data of ice melt, debris cover, ice flow velocity, snow density coring, and various information of DTM, land use, ice and debris cover, precipitation, and surface temperature from remote sensing in the frame of previous studies.

Such data were used for the flood study, and the hydrological study.

5.3 Discharges Data of Dudhkoshi River

Two datasets of hydrometric levels and stream flows for the Dudh Kosi River are available within the study area, i.e. those gauged at Rabuwa Bazar and at Periche. Rabuwa Bazar time series covers the 1964-2018, missing year 2009 and 2015 whereas discharge at Periche is only available from 2012 to 2014 courtesy of CNR-IRSA Brugherio of Italy, here kindly acknowledged (Soncini et al., 2016). Rabuwa bazar station belongs to the Department of Hydrology and Meteorology (DHM) network.

The discharge data series at Rabuwa Bazar gauging station has been processed with stochastic techniques, in order to obtain a complete, homogeneous and reliable dataset covering period 1964-2014. The following are the activities performed:

1. Application of a stochastic autoregressive model for the infilling of data gaps in the discharge series (monthly data);
2. Implementation of a stochastic nonparametric technique for the disaggregation of monthly discharge data to a daily time scale.

The complete time series of daily streamflow data of Dudhkoshi river for the period 1964-2014, upscaled from Rabuwa Bazar to the dam site, is provided in Annex A of Vol. 2 - Hydrological and Meteorological Report, part of the present Detailed Design.

It is highlighted that the daily discharge variability is governed by the Indian Monsoon, with high flows between June and October and low flows between November and May. The average daily discharge ranges from a minimum of approximately 32 m^3/s in February-March to a maximum of approximately 703 m^3/s in July. The long-term average discharge is equal to 209 m^3/s.

The annual water budget ranges from a minimum of 4,499 Mm^3 (1999) to a maximum of 10,417 Mm^3 (1998), while the average year volume is 6,602 Mm^3.

The dry season (from December to May) average and median discharges are 49 m^3/s and 45 m^3/s respectively, while wet season (from June to November) average and median are 369 m^3/s and 312 m^3/s respectively.

5.4 Flood peaks estimation and Climate Change

An upscaled flood distribution at the dam site is provided here below, featuring a slightly larger contributing area than the Dudhkoshi catchment, by scale-invariant translation, giving an estimated index flood $Q_{i,dam}$ = 1895 m^3/s. In the table below the so calculated peak floods are given.

R [years]	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**	**10000**
Q_R* GEV *[m^3/s]	1742	2348	2790	3247	3892	4418	4981	5788	**6451**	7163	8186	**9027**

Flood estimation for the Dudhkoshi basin closed at Rabuwa and dam site nearby can be pursued with reasonably low uncertainty, especially considering the large return periods involved until 10,000 years or so, by applying a regional flood estimation method. This method allows exploiting hydrological information from a number of catchments nearby, integrating the local knowledge.

Assessment of future changes of R-years peak flows against future climate changes until 2100, here investigated based upon the index flood approach, does not show large significant changes of the flood quantiles.

The probable maximum flood Q_{PMF} has been calculated based on the probable maximum precipitation h_{PMP} consistently with CIWEC (1998). The resulting PMF Flood is equal to 12,638 m^3/s and the estimated total flood volume is $V_{f,PMF,UP} = 1.33x10^9 m^3$.

5.5 Glacial Lake Outburst Floods (GLOF)

The main outcomes of the study on GLOF phenomena and their possible interaction with the Dudhkoshi Hydroelectric Project are listed below:

- According to the most recent literature, a substantial increase of GLOF events is expected in the 21st century as a response to global warming.
- Glacier retreat, global temperature rise, ice-rock avalanches into glacial lakes and moraine ice core melting are among the main causes of GLOF initiation.
- International literature analysis suggests that the effects of the flood can be observed up to more than 100 km from the GLOF source; sediment transport is generally limited to 30-40 km downstream. This is an empirical consideration. In fact, the sedimentation process depends on the GLOF rheology (mud or debris-flow) and therefore the extension of sediment process downstream of the source is difficult to quantify.
- From the comparison of a new original inventory carried out on Sentinel 2 satellite images with the most recent official inventory performed by ICIMOD, only few major lakes have shown an areal extent increase from 2011 to 2016. It is the case of end moraine dammed lakes still in contact with ice, like Imja and Lumding, where calving process is increasing the glacier snout retreat, resulting in a rapid growth of lake extent and volume. On the other hand, the extent of supraglacial lakes is about doubled during the last six years, while an increase of about 25-28% occurred during the last year.
- Four major GLOF events were documented in Dudhkoshi basin during the last forty years. Peak discharge values related to the reported events have been recorded by the Rabuwa bazar hydrometric station. According to measured data, an additional peak discharge not higher than 10,000 m^3/s associated with the GLOF was observed. This value has been quantified indirectly based on the levels reached during the GLOF event using a rating curve representative only for smaller discharges. Nevertheless, independently for the peak discharge, the most significant parameter is the GLOF event

volume. The hydrograph reported in literature could represent the effect of cascade breaches along the river, i.e. the breaches of natural dams generated by landslides.

- The drainable volume of Imja lake is about 37 million m^3 which has not been increased significantly since the last estimation carried out in 2012.
- A GLOF from Imja lake is presently the most threatening event that could have implications for the DKSHEP. The outburst was modelled by ICIMOD (2011), providing an estimated discharge peak of about 1,500 m^3/s at Rabuwa Bazar, approximately located 100 km downstream. This event is considered as representative of a GLOF event at Rabuwa Bazar. Nevertheless, the project includes an emergency spillway able to discharge, in concomitance with the labyrinth spillway, the 10,000 years return period with all the gates block, and to discharge the PMF with reduction of the freeboard on the dam crest.
- During construction stage, the reasonably potential GLOF event from Imja Lake can be safely managed by the diversion system. Moreover, after the third monsoon season after dam construction begins, the dam itself will act as a barrier containing any GLOF event.
- During operation stage, the available reservoir rim volume above Full Supply Level plus the combined discharge capacity of the Auxiliary and Emergency Spillways can safely manage any GLOF event, even those beyond what is foreseeable after the study of the river basin.
- So, it is recommended that hydrological (water level and discharge) and meteorological (air temperature, relative humidity, rainfall, snowfall, radiation, wind speed and direction, pressure) stations with real-time data transmission facilities be installed at different locations in the upstream and downstream parts of the basin and dam site. These stations should be configured to analyse their data timely.
- It is essential to monitor the potential for landslide damming or blocking of flood water during GLOF (based on GLOF modelling results) or monsoonal flood events, particularly in the upstream parts of the dam site. This should be achieved by installing automatic water level sensors with real-time data transmission facilities.
- It is recommended to install two sets of Early Warning System upstream from the proposed dam site.

5.6 Climate change

A study regarding climate change and its impacts of DKSHEP has been studied considering 5 different meteorological model. The study was performed till the 2100 calibrating the mathematical model with the data available.

Expectedly, climate change may modify extreme floods, however, for the Dudhkoshi closed at Rabuwa as reported, snow and ice melt provide a somewhat small contribution on extreme floods, so this facet can be neglected in a first approximation. Also, given the short duration of flood events, in the order of 1-2 days, evapotranspiration fluxes, of interest at seasonal scale, seem less important at the event scale. Also, even if hourly peak flow data could be accurately projected until 2100, and used as proxies for instantaneous peak flood, normally evaluation of extreme flow distribution for nonstationary conditions (i.e. for statistical distributions changing with time under climate change) is a not trivial exercise given the large extent of variation of annual maxima, possibly masking any trend in time.

5.7 Sedimentation

The construction of the dam at Dudhkoshi river will interrupt the sediment transport, which is flowing into the reservoir, releasing clear water and at the same time increasing the erosion capacity downstream. To quantify the total amount of sediment carried by the rivers during the year and to determine how it will be deposited in the reservoir a field investigation campaign was carried out between the 2016 and the 2019.

Suspended load samples are taken out from Dudhkoshi river, at Rabuwa Bazar bridge, and from Thotne river, concrete bridge close to the confluence, with a depth integrating US D-74 sampler.

Bed sediment samples are taken into pits along Dudhkoshi and Thotne river at confluences or in the presence of potential source of sediment, such as landslides, to characterize the lithology and the granulometry of the sediment at the riverbed.

The locations for the sampling are fixed at Rabuwa Bazar bridge at distances of 25, 50 and 75% of the total average width of Dudhkoshi river, to collect samples representative of the average concentration of the river flow.

The total quantity of material includes the wash load of fines that comes into the rivers in the form of runoff from the land as well as the bedload and local concentrated injections from mass wasting events such as landslides. The sedimentation in the reservoir constrains the life of the project and therefore the economic and financial feasibility of the project.

After the evaluation of the collected data the total volume of sediments accumulated in 50 years in the reservoir is estimated.

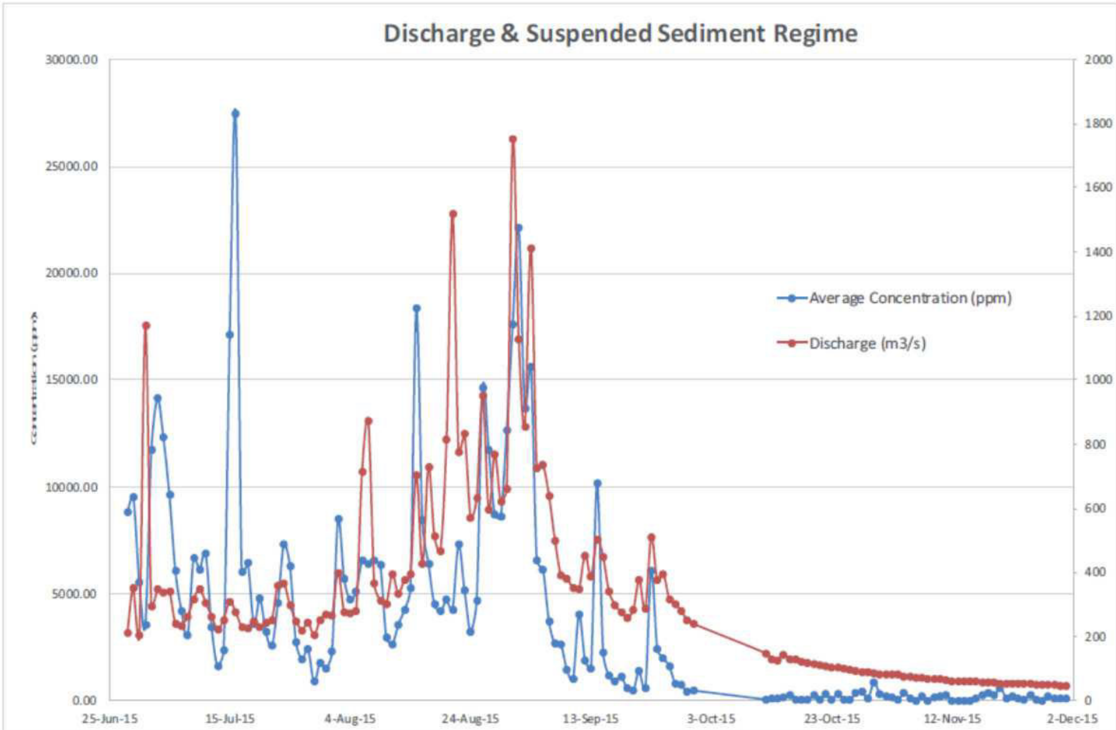


Figure 5-1 : Comparison Between Concentration and Discharge Trend Relating to 2015 Samples

The following table shows that the storage volume lost in 50 years due to the suspended and bedload sediment transport is about 441 Mm^3, which reduces all the dead storage volume (initial capacity 239 Mm^3) and partially the active storage (initial capacity 1342 Mm^3), due to the deposition of the delta in the upper part of the reservoir and of the remaining part of the suspended sediments.

In any case the volume of 441 Mm^3 includes the dead volume generated by suspended material 294.12 Mm^3 and the volume deposited in the delta produced by the bed load, 147 Mm^3. In these conditions, given the sedimentation pattern inside the reservoir, the project life of the dead volume is 50 years.

Furthermore, analyzing in detail the volume of the accumulated delta and the altitudinal distribution of the same in the reservoir is possible to evaluate the variation of the storage volume curve after 50 years. All the suspended sediments are progressively accumulated on the bottom and, after about 40 years, result completely contained by the dead storage. The part of suspended sediments able to pass through the dam with the water flow was not considered.

Table 5-1 : Sediment Accumulation Rate and Total Sediment Volume in 50 years for Each Tributary

	DUDHKOSHI			THOTNE		
	Mm^3/year	Mm^3 50 years	Volume lost %	Mm^3/year	Mm^3 50 years	Volume lost %
Suspended sediment Volume	4.35	217.55	14.47	0.50	24.84	1.65
Bedload Volume	2.18	108.77	7.24	0.25	12.42	0.83
Total Sediments Volume	6.53	326.32	21.71	0.75	37.26	2.48
	SOLU			**RAWA**		
	Mm^3/year	Mm^3 50 years	Volume lost %	Mm^3/year	Mm^3 50 years	Volume lost %
Suspended sediment Volume	0.64	32.07	2.13	0.39	19.66	1.31
Bedload Volume	0.32	16.04	1.07	0.20	9.83	0.65
Total Sediments Volume	0.96	48.11	3.20	0.59	29.49	1.96

	TOTAL		
	Mm^3/year	Mm^3 50 years	Volume lost %
Suspended sediment Volume	5.88	294.12	19.57
Bedload Volume	2.94	147.06	9.78
Total Sediments Volume	8.82	441.18	29.35

5.7.1 Sediment Management Measures Applied to DKSHEP

The introduction of a reservoir into a river system induces other sediment related impacts on the river channel upstream and downstream of the reservoir.

To avoid the impact of the sediment accumulation on the storage capacity there are four main management alternatives: 1) reduce sediment yield from the watershed, 2) route sediments minimizing the sediment deposition, 3) remove or redistribute deposited sediment increasing or recovering reservoir volume and 4) implement adaptive strategies.

According to ICOLD some of the options for reservoir sedimentation control include the following:

- Minimize sediment loads entering reservoirs through:
  - Soil and water conservation programs will be applied to the DKSHEP;

- o Upstream trapping of sediment (debris dams or vegetation screens). This type of solution is not technical and economical sustainable in the DKSHEP;
- o Bypassing of high suspended loads using the regulation structure (MLO (Medium Level Outlet) and LLO (Low Level Outlet));

– Minimize deposition of sediments in a reservoir through:
  - o Sluicing: passing of sediment-laden floodwaters through the reservoir by means of drawing the water level down – this solution is excluded in the DKSHEP. The BO (Bottom Outlet) will be used only as safety structure in the case of a depletion of the reservoir;
  - o Density current venting will be used LLO during the impounding of the reservoir.

– Increase or recover reservoir volume through:
  - o Excavation by means mechanical system of dredging and deposit the material in other reservoir area where the velocity impact is negligible
  - o Maintaining long-term reservoir storage by raising the dam.

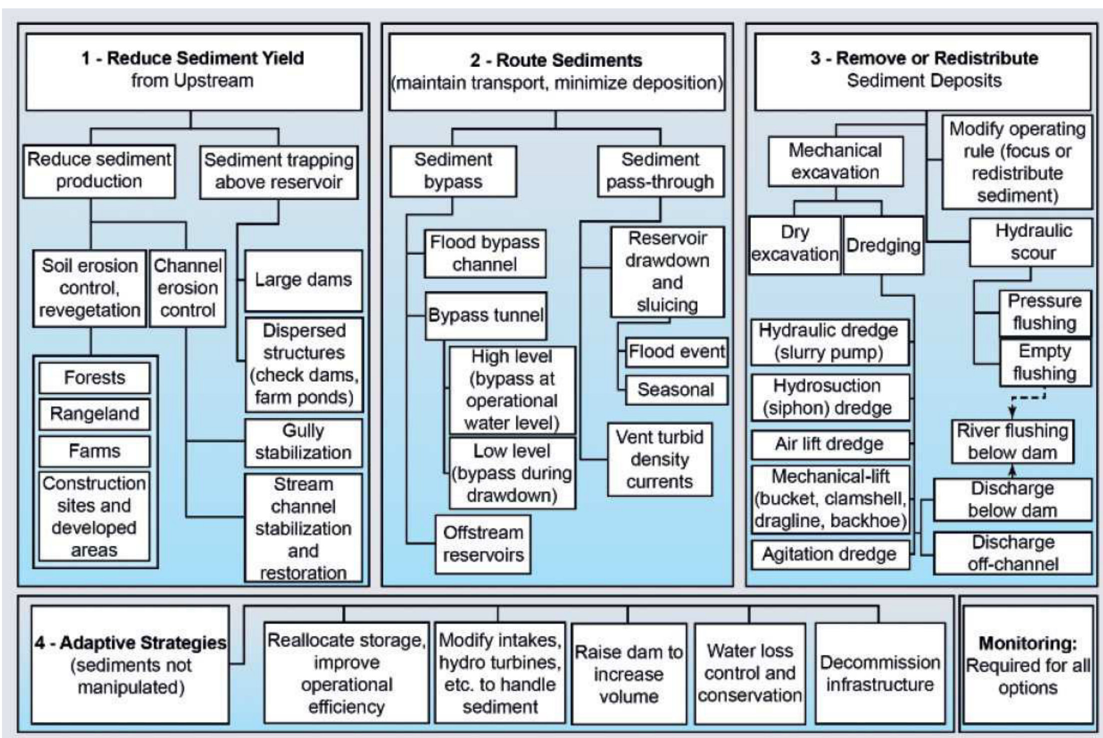


Figure 5-2 : Classification of Reservoir Sedimentation Management Techniques (Annandale, Morris, Karki - 2016)

As per the sediment analysis results, approaches that are proposed for the DKSHEP are sluicing, dredging and bypassing of the suspended material using LLO and MLO during the impounding and normal operation

6 GEOLOGY

This chapter summarizes Vol. 5 - Geology, Engineering Geology, Geotechnical Investigations and Vol. 6 - Seismic Hazard Assessment part of the Final Detailed Design of DKSHEP.

In order to frame a general overview of the Project area about the main geological features, three figures are laid out below: a plan-view geo-structural sketch map, a correspondent deep crust profile and the geological profile of the Headrace Tunnel corridor.

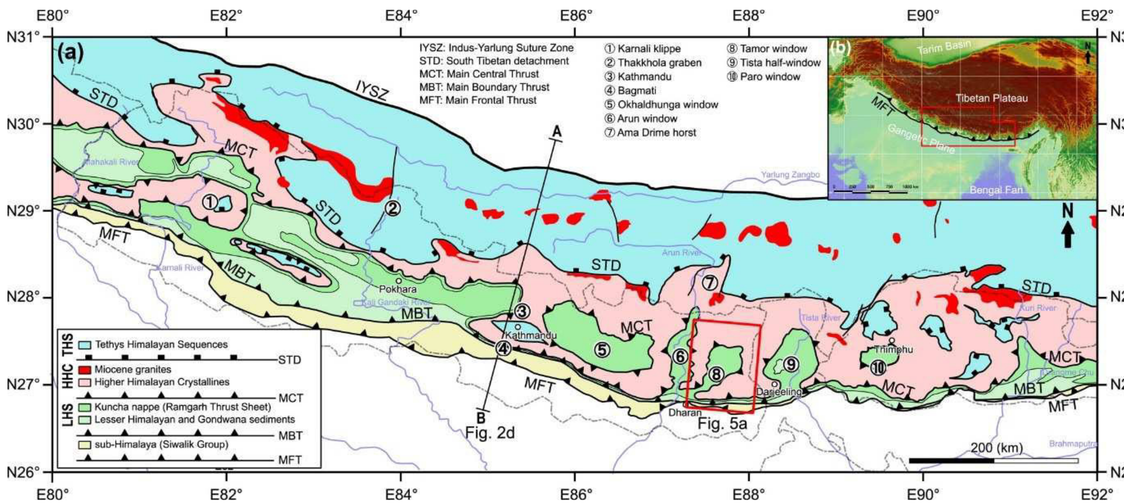


Figure 6-1 : Geo-Structural Sketch-Map of Nepal Himalaya

Nakajima *et al*. (2021) had located the DKSHEP area (yellow star) in the regional-scale geological context of the Nepal Himalaya as shown in Figure 6-1. The A-B segment (thin black line in the middle of the map) is the reference for the orogen-perpendicular geo-structural profile of related Figure 6-2. The Project area is located in the Okhaldhunga tectonic window (number 5 in the Figure, near its south-eastern limit), exposing the Lesser Himalayan Sequence (in green), and in a narrow band of Higher Himalayan Sequence (in pink). The South Tibetan Detachment System (STDS) and the Main Boundary Thrust (MBT) are the northern and the southern geo-structural boundaries of the Project area. According to Schelling *et al*. (1991), the total north-south shortening has been occurred at an average rate of 7.4 mm to 15.3 mm per year since the initiation of the Main Central Thrust (MCT) i.e. between 16 and 25 Ma. MCT is generally considered to have been active between 12 and 10 Ma (Serravallian-Tortonian) whereas MBT is as an active fault.

The location of Project area (dark red star on both Lesser Himalayan rocks is indicated by the green color and Higher Himalayan rocks, in pink) as shown in Figure 6-2. The two aforementioned super-units, the Lesser Himalayan Sequence (indicated in green) and the Higher Himalayan Sequence (in pink) are separated by the MCT. A detailed description of both geological super-units such as Lesser and Higher Himalayan Sequence and the related rock types is provided in Vol. 5, Geological Report.

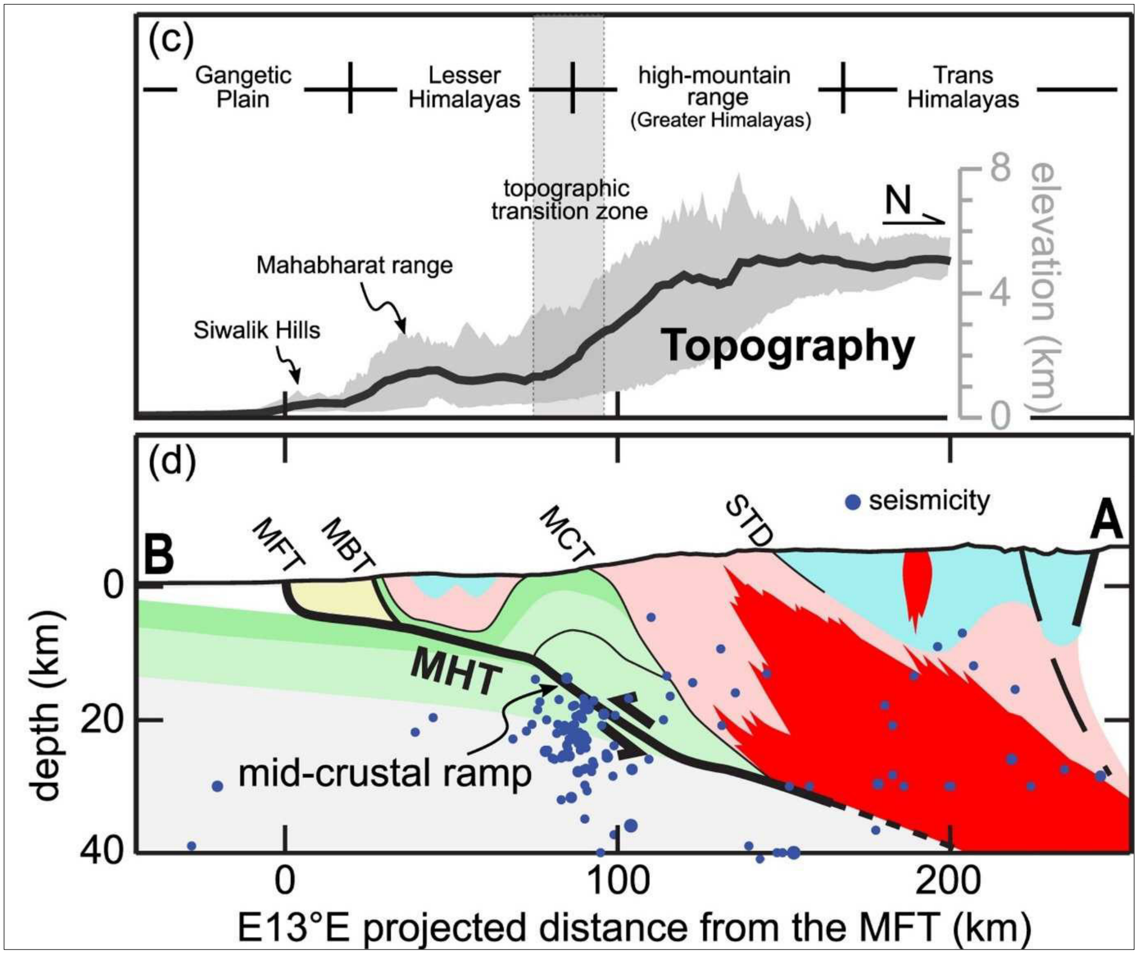


Figure 6-2 : Geo-Structural Profile of Deep Crust in Nepal Himalaya

The geological profile of headrace Tunnel is drawn with some vertical exaggeration, so the actual geometry of the thrusts (black lines; thick are active, thin are considered as inactive) is flatter. The counter-slope (southward) dip of MCT is a local feature of DKSHEP area due to the upward bulging of Lesser Himalaya rocks where the combination of tectonics and erosion gave rise to the Okhaldhunga tectonic window.

The Figure 6-3 is excerpted from the Geological Report, Vol. 5. The profile is approximately N-S and therefore crosses transversally E-W trended main geological features of the Project area such as thrusts, metamorphic fabric, lithological boundaries etc. As shown in the profile, Dam site, Powerhouse and the northern part of Headrace Tunnel are in the Lesser Himalaya zone, while the southern part of Headrace Tunnel is in the Higher Himalayan zone. From chainage 2700 m approximately towards the Sunkoshi River (on the right in the profile), the geological structures are all south dipping, except in the last 1000 m due to a mild antiform. This entire central-southern belt (2700 m to 12500 m approximately) is strongly influenced by the MCT to whose geometry all the other secondary geometries parallelize. On the surface, MCT's dip oscillates around 45° - 55°. From north (on the left in Figure 6-3) to the south, the main five types of rock have been encountered which are phyllite, quartzite, orthogneiss, and carbonate are bearing unit and mica schist and gneiss.

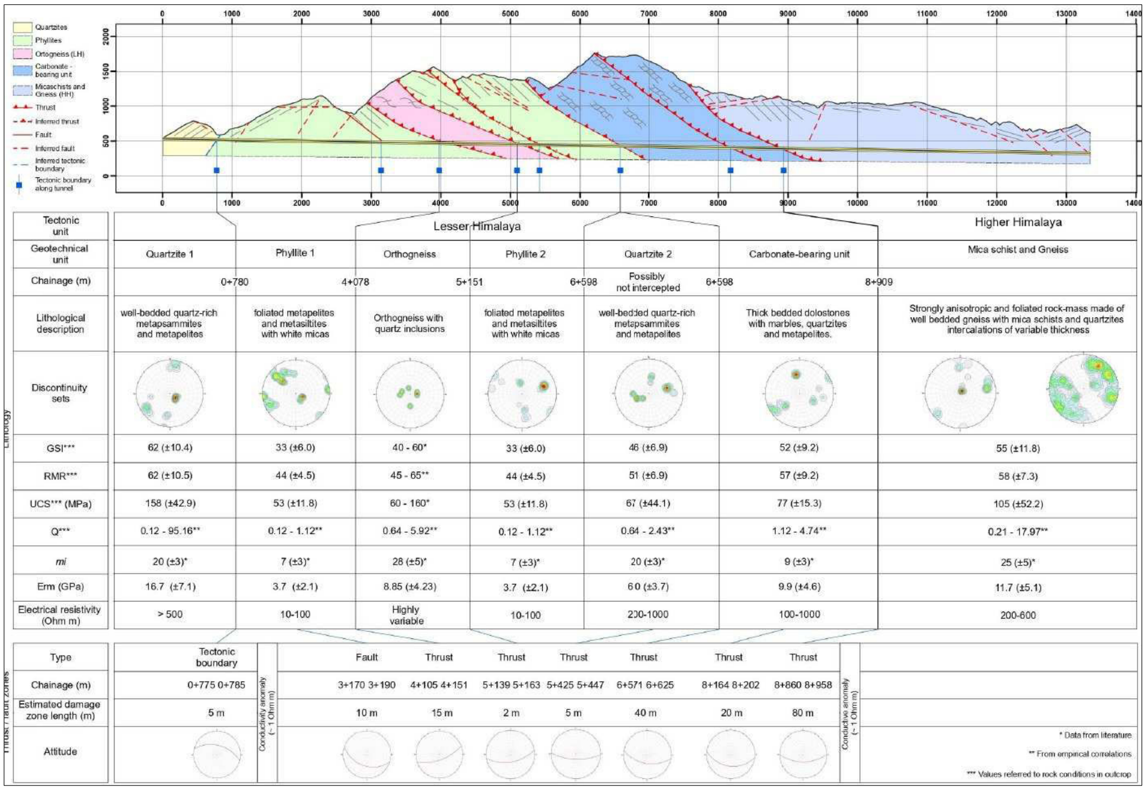


Figure 6-3 : Geological Profile along the Headrace Tunnel Alignment

The main results of geological investigations at Reservoir and Headrace Tunnel scale are listed below:

- Structural lineaments within the project area have been identified by processing satellite images and SRTM 30 m Digital Elevation Model. A crosscheck with the results of aerial imageries analysis has been carried out. All the identified features have been classified and exported in ESRI shapefile format.
- The presence of two non-active faults (according to literature and preliminary seismic hazard analysis) along Thotne Khola and in the Dam area have been identified.
- A Geological Map with the main lithotypes and structural lineaments surveyed on site and from the aerial photos is provided in the Vol. 4. All the identified geological features have been classified and exported in ESRI shapefile format.

- A Geological Map of the Headrace Tunnel with the main lithotypes and structural lineaments surveyed on site and from the aerial photos is provided in the Vol. 4. All the identified features have been classified and exported in ESRI shapefile format.

The following site investigations have been performed:

- *Boreholes*, no. 34 for a total of 2,488 m.
- *Adits*: 6 adits of total length 745 m have been excavated (4 at dam site, one along the headrace tunnel near Langur Khola and one close to the Main Powerhouse site).
- *Geophysical Investigations*: Eleven profiles of ERT surveys and ten points of MASW surveys and 9 profiles of SRT survey have been carried out at dam site and borrow.
- *Geomechanical Survey:* Altogether 76 geomechanical stations have been surveyed including DKST and TLS stations.

6.1 Dam Site Geology

The Dam Site lies in the outcropping area of Lesser Himalaya Sequence metasedimentary rocks, here mainly represented by phyllite and quartzite. Phyllites include thin lenses and beds derived from a coarser-grained (and harder) sedimentary protolith; quartzites have thin intercalations of phyllite. At rock-mass scale, quartzites give rise to massive, rigid outcrops of high morphological relief. The geological boundary remains buried under the alluvial sediments until it crosses the valley floor and obliquely cuts the right bank, remaining well exposed in the outcrop. The main lithological and structural characteristics of the Dam Site area are explained in Vol. 5 Geological Report, Annex N Dam Site Geology. The interpretation of the geophysical profiles depicts that a buried local-scale fault is detectable but the fault fades out toward the west (downstream). It is very probable that the mentioned fault is partly guided along the phyllites/quartzites contact since this is an important geo-mechanical discontinuity (sudden, sharp gap of rock competence from hard quartzite and much softer phyllite). Going from regional to local-scale, the DKSHEP area is affected by first order (orogeny-scale) of MHT and it is active.

6.2 Integrated Interpretation: Conclusions

Based on the whole set of geodata collected so far, it can safely be stated that no relevant and active tectonic structures have been identified as potential threat for the the Dam construction.

No evidence of a downstream continuity of the ESE-WNW fault between phyllites (block 2 in Figure 6-8) and quartzites (block 1 in the same Figure) was found.

The geo-structural analysis of all phyllite outcrops downstream from Dam footprint found regularly piled beds with almost constant strike and dip of the foliation and overall fair geomechanical characteristics. This is also confirmed by the results of the hydrofracturing tests performed in Dam site right adit in June 2024.

Overall, the phyllite on the right bank are rather compact and basically watertight.

The quartzite on the left bank are hard and competent (with local GSI values up to 65 - 67) but locally affected by large, open, tensional fractures due to slope decompression. These fractures shall be treated by means of an opportunely designed grouting campaign aimed at avoiding southward water filtration.

6.3 Seismic Hazard Assessment

Area Source which is one of Seismic Source for Seismic Hazard Analysis (SHA) is constructed by historical earthquake records. The historical earthquake events (records) are collected from published databases of the followings;

- ISC (International Seismological Centre)[1],
- USGS (U.S. Geological Survey)[2],
- NSC (National Seismological Centre, Department of Mines and Geology, Nepal)[3], and
- BCDP 1994 (developed in Building Code Development Project 1994, Disaster Preparedness Network Nepal)[4].

The outline of each database is shown in Table 6-1.

Table 6-1 : Outline of Databases

Database	ISC	USGS	NSC	BCDP1994
Area Range of Database	R = 500 km	R = 500 km	In and around Nepal	In and around Nepal
Range of Magnitude	2.2 ~ 7.6	3.1 ~ 7.8	3.7 ~ 7.0	3.8 ~ 8.4
Period (year. month. day)	1908.8.20 ~ 2015.8.31	1973.1.2 ~ 2018.3.21	1994.6.25 ~ 2018.3.2	1255 ~ 1992.4.4
Event Number	3,129	1,384	923	691
Note	Some events have not magnitude.	All events have magnitude.	All events have magnitude but events outside 500 km are included.	The events before 1913 are discrete based on old document information and have not magnitude. Events outside 500km are included.

[1] : http://www.isc.ac.uk/iscbulletin/search/catalogue/

[2] : https://earthquake.usgs.gov/earthquakes/search/

[3] : http://seismonepal.gov.np/earthquakes

[4] : https://www.dpnet.org.np/index.php?pageName=earthquake,
https://www.dpnet.org.np/pdf/earthquake_catalog_of_nepal.pdf

These databases including a huge numbers of events are proceeded/screened through the steps shown in the following to make the recurrence model of the seismic area sources.

Basing on the above studies, the result (maximum) of Peak Ground Acceleration (PGA) was analysed by probabilistic and deterministic approach are shown in *Table 6-2*.

Table 6-2 : Maximum of PGA led by Seismic Analyses

Approach			Other Structures	Dam and Spillway	
			On Bedrock	On Bedrock	On Alluvial
PSHA	Return period of 475 year	OBE	0.307	0.307	0.382
PSHA	Return period of 1,000 year	SEE	0.401	-	-
PSHA	Return period of 10,000 year	SEE	-	0.786	0.969
DSHA	84 percentile	SEE	-	0.532	0.610
PGA		OBE	0.307	0.301	0.382
PGA		SEE	0.401	0.786	0.969

6.3.1 Evaluation of Seismic Coefficient (Pseudo-Static Horizontal Force)

The seismic coefficient corresponding to OBE and SEE in each case are estimated as shown in the below Table. 0.48 g is estimated in the Existing Seismic Hazard Map. This could also be a material to judge the suitability of SEE.

Table 6-3 : OBE and SEE as Pseudo-Static Horizontal Forces

Approach			Other Structures	Dam and Spillway	
			On Bedrock	On Bedrock	On Alluvial
PSHA	Return period of 475 year	OBE	0.21	0.21	0.26
PSHA	Return period of 1,000 year	SEE	0.34	-	-
PSHA	Return period of 10,000 year	SEE	-	0.53	0.65
DSHA	84 percentile	SEE	-	0.36	0.41
Applied Value		OBE	0.21	0.21	0.26
Applied Value		SEE	0.34	0.53	0.65

7 MAIN DAM DESIGN

Main Dam: It is a 220 m high embankment structure, with 630 m long crest at elevation 648 masl. The total volume of the dam is 26.7 million m^3. The proposed section is shown in the attached drawings and it includes a conventional CFRD Dam protected by concrete face, filters and transitions and supported at upstream and downstream rockfill.

The alluvial material is present in the dam site with approximate thickness of 20 m. An articulated plinth to a diaphragm wall crossing through the thick alluvium. The adopted dam zoning is shown in the attached drawings. Upstream slope is 1.60 H:1 V and downstream slope is 1.77 H:1 V.

In general terms, from construction planning point of view the rockfill dam layout present more difficulties than the concrete dam, as it involves much larger quantities of different construction materials, to be handled over large distances and in difficult morphological conditions. In the case of DKSHEP the sources of the dam materials are as follows (See quarry areas in Vol. 5 – Geological Report):

- Zone 1B, Soil or Clay material. Although the available quantities are far above the requirements, the clay of the closest borrow area, is probably dispersive and will require costly treatments to be used. Alternative sources are very far from the site, and their use would be very expensive.
- Zone 2 A and T, Sand for fine filters. Natural river sand available within economic hauling distance is apparently much less than the quantity required, making necessary to use crushed sand.
- Rockfill 3B and transition material for the dam are available in unlimited quantities and come from spillway excavation.
- For the concrete dam layout, the bulk of both the coarse and fine concrete aggregates will have to be produced by crushing, as the available alluvial material is not sufficient. In addition, according to the laboratory tests carried out aggregates produced from most potential sources may cause alkali-silica reaction in concrete, requiring either to specify a low alkali content of the cement to be used, or to replace part of the cement with fly ash or pozzolan.

Regarding the dam stability analysis, bedrock foundation is classified in 2 types: Bedrock type F and Bedrock type S. Bedrock type F (F: Fractured) is formed by highly fractured quartzites of medium to high strength. Permeability is high due to the intensive fracturing condition.

Bedrock type S (S: Sheared) is formed by a mixture of rock materials poorly interlocked, heavily broken with presence of extensive areas of sand and silt materials, with higher deformability and lower shear strength properties than Bedrock type F. This zone seems to correspond to a sheared zone crossing the riverbed along the upstream-downstream direction.

Due to the relatively high deformability expected in the upstream toe area, a flexible, articulated plinth is designed to help accommodate deformations.

Due to the high permeability expected in the foundation, a cut-off wall is needed. A plastic concrete diaphragm wall is proposed, to ensure effective seepage control in the foundation, in the central part corresponding to the valley bottom.

The design foresees the water tightness continuity between the concrete slab, the plinth and the plastic concrete diaphragm wall.

A preliminary analysis of elastic settlements expected at the dam crest in the short term after construction have been estimated. The results show that with the foreseen elasticity modulus for the dam materials and alluvial zone, the expected settlement is around 3% of the dam height.

A preliminary elastic deflection at the face slab has been estimated. The results show that with the foreseen elasticity modulus for the dam materials and alluvial zone, the expected deflection in the central zone of the slab would around 0.6 m.

The seepage analysis has been carried out adopting the 2D Finite Difference, considering the maximum normal supply level at 640 masl. The analysis has been carried out only for the steady-state solution in these following conditions:

Even if, in general, the damaging of the slabs has a “local” effect in most cases, the damaging of the slabs has been simulated increasing the overall average permeability of the concrete to the permeability characterizing the 2B layer. This assumption implies a general impairment of the U/S face, therefore it is very demanding and in the sake of safety.

An advanced 3D numerical analyses to assess deformations and settlements in static and dynamic (seismic) conditions have been performed based on literature data available for CFRD Dam. In literature, the data set of mechanical and hydraulic properties for the rockfill is sufficiently wide to ensure a reliable detail design. The general expected performance of the Dudhkoshi dam can be considered adequate (see Vol. 22). In particular, the vertical displacement is about 0.7% of the dam height, the permanent displacements of the dam after SEE shock (v: 0.3 m, h: 0.1 m) preserve the free board and the post-seismic safety factor is well above the minimum required (1.25, Eurocode).

At the initial phase, comprehensive site investigations and geological studies was conducted to gain a thorough understanding of the geological, hydrological, and geotechnical conditions of the site. This data was incorporated into the design process to inform decisions about dam layout, foundation design, and construction methods, mitigating risks associated with site-specific conditions.

In the design of the dam, with a wealth of experience and expertise in CFRD construction and design principles, leads to critical decisions regarding dam layout, foundation design, and construction methodologies, ensuring optimal performance and longevity of the structure.

Hydraulic modeling and analysis were employed to evaluate the dam's performance under various flow conditions and hydraulic loads. Computational tools were utilized to simulate water flow patterns, identify potential flow obstructions, and optimize spillway design and reservoir operation strategies for safe and efficient water management.

Structural design and stability analysis were also integral components of the Consultant's approach, employing advanced techniques to assess the structural integrity of the dam under different loading conditions. Rigorous stability analyses were conducted to identify potential failure modes and implement design measures to enhance the dam's stability and resilience.

Additionally, the Consultant incorporated risk assessment and risk management principles into the design process. Based on the results of these assessments, mitigation measures and design redundancies were prioritized to reduce the likelihood of dam failure and minimize potential consequences.

Furthermore, modern monitoring and instrumentation technologies were integrated into the design, enabling real-time monitoring of key parameters to detect early warning signs of potential safety issues. This proactive approach to dam safety allows for timely intervention and corrective actions to prevent catastrophic failures and ensure the long-term safety and reliability of dam infrastructure

8 HEADRACE TUNNEL

The present chapter summarizes Vol. 7 – Geotechnical Baseline Report.

8.1 Dudhkoshi Tunnels Design Approach

The envisaged Dudhkoshi Main Powerhouse Headrace Tunnel (HRT) inner diameter is 8.3 m, and it runs according to an almost N-NE S-SW direction, starting from the Dam Site river left bank and reaching the penstock location close to the Baikhu Khola site. The tunnel route crosses a mountain range characterized by deep valleys. The rock cover reaches and exceeds some 1100 m within a phyllitic rock mass type, whereas the minimum rock cover is some 150 m, in the vicinity of the Langur Khola valley, not far from the tunnel intake. The geotechnical characterization on the rock masses has been carried out mainly on the base of the field investigation campaign.

With the geomechanical station the following data have been collected:

- rock type;
- orientation, persistence, spacing, aperture, alteration roughness, filling and water flow condition of each joint family;
- GSI (Geological Strength Index) and RQD (Rock Quality Designation);
- Schmidt's Rebound values.

In each adit, the following investigation activity has been carried out:

- identification on the rock type and geological mapping of the discontinuities (fault, shear zone, joint);
- evaluation of the seepage inflow (if any);
- assessment of the Barton's factors Jr (roughness), Ja (alteration), Jw (water flow);
- assessment of the GSI;
- Schmidt's Hammer Tests.

The interpretation of investigation and testing carried out so far in the Dudhkoshi project has provided data which have been used for a definition of the support measures to be worked out. Difficult geological conditions, especially several changes along the strong but fractured quartzite, the relatively strong phyllite, phyllite/quartzite alternations and faulted materials, the overthrust zone and other lithological and structural contacts have been taken into account for the design and construction of the temporary (primary) and final lining.

8.1.1 TBM

As the mechanized excavation of the HRT is considered, Figure 8-1 shows a conceptual scheme of the adopted TBM. The shield is 12 m long and is divided in three parts to increase the conicity. The total gap between the nominal excavation diameter and the outer ring diameter is 21 cm.

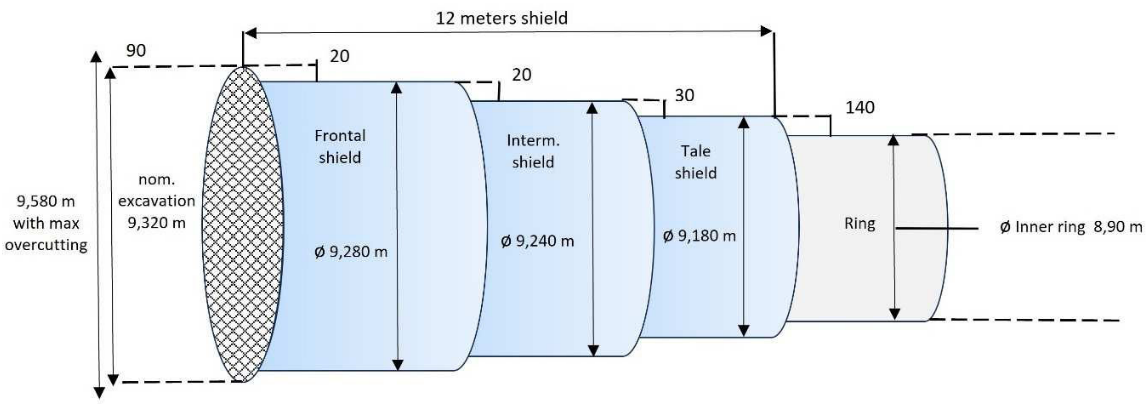


Figure 8-1 : Conceptual Scheme of the Adopted TBM

The choice of a single shield machine has been driven by the following main reasons:

1. the longer stretch at higher overburden of the HRT is expected to be excavated in phyllite which is a relatively soft rock with a low-medium grade metamorphism which is deemed to undergo to squeezing. In this case, a shorter shield would reduce the jamming risk;
2. it is expected that about 2 km will be excavated in carbonate formations which are prone to dissolution so, water circulation and inflow into the gallery cannot be disregarded.
3. the production of a single shield TBM is compatible with the time schedule of the Project. Moreover, nowadays, single shield TBM can be equipped to advance, at a lower rate, during segments installation;
4. a shorted shield reduces the logistic problems related to transportation and allows for a smaller turning radius with respect to a double shield machine;
5. single shield machine is less expensive than double shield one.

As the rock masses to be crossed by the TBM ranges from soft to hard rocks, the adoption of an EPB (Earth Pressure Balance) TBM is deemed not strictly necessary even if, as a karst environment is also expected along the tunnel alignment, the possibility of sudden water inflow should not be neglected. In the event of intense water inflow, working in EPB mode could represent an advantage with respect to an open TBM. However, in the following analyses, no pressure at the tunnel face has been considered so, the excavation open mode has been taken into account.

8.1.2 Drill and Blast (D&B)

Where it is foreseen to adopt the D&B method along the HRT and/or when it will be necessary to use, the Preliminary (Temporary, First Stage) Support System, consisting of a combined system of rock bolting, fiber reinforced shotcrete and reinforced ribs of shotcrete (possibly substituted by steel ribs), was dimensioned in order to provide preliminary support against the deforming rock mass during the excavation progress.

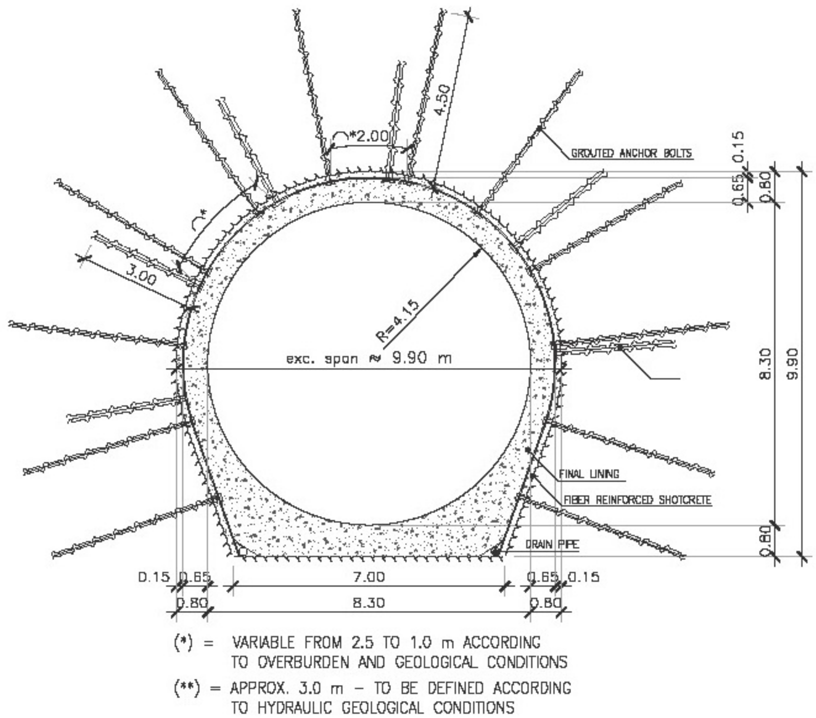


Figure 8-2 : Sunkoshi Headrace Tunnel Typical Cross Section (Horseshoe Shape)

The design process started, for each identified tunnel, with the definition of the regions characterized by similar geological characteristics, the so-called homogeneous regions. For these regions, the geo-mechanical significant parameters (key parameters) have been defined. Then the structural key parameter GSI (Hoek, 2002) value for each rock mass type has been defined.

The next design step was the calculation of the strength (cohesive and frictional) and elastic parameters of the rock mass, as shown for the units which are representative for the project.

The temporary supports are constituted by shotcrete, rock bolts and reinforced ribs of shotcrete (RRS, possibly substituted by steel ribs), to be realized according to a certain pattern. The evaluation of the squeezing potential is used as a first estimation of the failure mechanism, defining regions where plasticization and squeezing rock conditions can be expected.

Installation of the supports in the region immediately after the front, i.e. application of shotcrete, is restricted to the support classes where immediate support and rock sealing is necessary, or where support with RRS or steel ribs as an immediate support is foreseen, in weaker rock mass.

8.2 Permanent lining

8.2.1 TBM

As the TBM advances, the tunnel walls are, for shielded TBMs, lined with precast concrete segments, which provide support and stability to the tunnel. The segments are installed by the erector arm, which places them in the correct position. The segments are then bolted together to form a ring, which supports the weight of the ground above the tunnel. For open TBMs (main beam TBMs), generally adopted for good rock conditions (high stand-up time), the temporary supports and permanent lining (if needed) can be executed in a conventional way, as in the D&B method.

Concerning the geometry to be adopted, for the HRT, it has been assumed an internal diameter equal to 8.3 m, as per the Project Requirements. Considering a thickness of 30 centimetres for the segments, the outer diameter of the rings is 8.90 m. Based on these considerations, a single shield machine with a shield length of 12 m and a nominal excavation diameter of 9.32 m has been taken as a reference.

The construction method considers a universal ring (see Figure 8-3 below), composed of no. 6 segments and a key-segment with transversal and longitudinal joints as well. The concrete class considered is C 35/45.

Figure 8-3 : Universal Ring Scheme (Axonometric View)

8.2.2 Drill and Blast (D&B)

The Final (Permanent) Support System, constituted by reinforced concrete lining, shall be designed to bear:

- the radial pressure interaction load formerly loading the temporary support system, and progressively transferred to the permanent lining due to the possible deterioration of the temporary supports with time;
- the dead weight of the loosened rock body coinciding, when applicable, with the plastic zone developed above the roof, already loading the first stage support system, and progressively transferred to the permanent lining due to the possible deterioration of the supports with time;
- instead of the previous loads, the load induced by the unbalanced portion of the weight of rock wedges insisting on the supports;
- any intrados loading pressure distribution due to internal pressurized water flowing in permanent or transient conditions.

With reference to the latter, for the pressure tunnels stretches along which the groundwater pressure in the rock surrounding the lining is lower than the internal pressure value, a reinforced concrete liner is foreseen. The need arises for the possible leakage from such lining to be controlled. The design concepts to be applied are based on HENDRON, FERNANDEZ and LENZINI analysis. Reinforced concrete linings may crack and permit some leakage out of the tunnel.

9 SPILLWAY AND OTHER HYDRAULIC FACILITIES

The present chapter summarizes Vol. 10 - Spillway and Other Hydraulic Structures Design, part of the Final Detailed Design.

9.1 Spillway

The surface spillway complex is located on the left bank of Dudhkoshi River, and it is constituted by a combination of a gated spillway and a labyrinth spillway.

The gated spillway ogee crest and the labyrinth spillway crest are aligned with the CFRD Dam Crest. The two spillways discharge into two separate canals, exhibiting different initial elevations and slopes, joining into a single canal 2% sloped, at a distance of some 140.0 m from the crests. The flows discharged by the two spilling crests are kept separate by an intermediate wall.

9.1.1 Main Spillway - Gated Spillway

The spillway ogee crest was designed based on the head corresponding to the Tr = 10,000 yrs. Flood. Considering both spillways operating concurrently, the head required to evacuate the portion corresponding to the gated spillway is about 17 m.

The ogee crest was set at el. 624.0 masl, i.e. 16 m lower than the reservoir Max. NWL. Downstream of the ogee crest, a concrete lined discharge canal 73.5 m wide is foreseen, some 500 m long, with terminal flip buckets. Partition walls are provided at each intermediate pile of the ogee crest, so that the flow discharged at each gate is led to the relevant flip bucket through a dedicated canal.

The initial reach of the canal, some 190 m long, exhibits a slope equal to 2%, whereas the following reach is 30% sloped. The transition between the two reaches is constituted by a vertical curve with 100 m radius. The profile of the water in the canal was calculated for the discharge corresponding to Tr = 10,000 yrs, as well as for the discharge under gates opening of 1 m (700 m^3/sec). Following the selected lengths and slopes of the discharge canal, the 4 flip buckets lips were set at elevations comprised between 550.0 and 532.0 masl approx.

Buckets were located at different chainages along the sloped canal, at some 20 m distance each other, so that the uppermost flip bucket is at 60 m upstream from the last one, and 18 higher.

The Plunge pool design is based on the scour that is likely to occur under different operation conditions. At this stage, the scour depths for the Tr = 10,000 yrs flow and for 700 m^3/s flow have been evaluated by means of the Coleman formula.

The tailwater elevations for the above indicated flows are 437.0 and 427.8 masl respectively.

As a consequence, the resulting rounded average elevations of the final scouring at the impact of the jets are 370 and 410 masl respectively.

The Plunge pool layout has been designed based on the scour that is likely to occur under the most significant operation conditions corresponding to the design flow (Tr = 10,000 yrs). This condition shall be used to determine the maximum extent of the scour, in order to define the overall dimensions and the general excavation shape. The pre-excavation depth of the pool proper is defined based on a design flow with Tr = 200 yrs.

9.1.2 Main Spillway - Labyrinth Weir

The labyrinth weirs nowadays are adopted in a number of existing plants in which the increased requirements of dam safety call for a higher discharge capacity, to face the occurrence of extreme floods. On the other hand, as they require a space minor than that needed by a conventional straight overflow ogee, their adoption in new constructed hydro plants is more and more frequent, in consideration of possible savings or due to morphological constraints.

In the case of DKSHEP, the selection of a labyrinth weir to complement the discharge capacity of the gated spillway originates from the need to avail of a device that can deal with unexpected floods (like GLOF) without need for operating gates or other release equipment.

The labyrinth weir is adequate to provide this kind of service, as it is constituted by a free overflow crest which, thanks to its particular arrangement, can discharge flows comparable with those of a straight ogee spillway in a reduced width.

9.1.3 Auxiliary / Emergency Spillway

The emergency spillway is located at the left side of the main spillway approach canal. It is combination of embankment dam and labyrinth weir. The embankment dam is approximately 40 m wide at the base and 10.3 m high, resting at el. 637.0 masl, whereas its approach canal is set at el. 636.5 m asl. The total length of embankment is 154.5 m. Crest is at 647.3 m asl. The upstream face of the embankment is made 500 mm of blanket of concrete (aggregate size 40 mm) until elevation 644 m asl. The rest of the section is designed with granular material, gravel type, to maximize erodibility after overtopping. Between the upstream clay layer and the fuse plug body transition materials will be placed acting as sand filters and impervious core. A rip-rap protection will be placed in the upstream slope until elevation 644 masl.

On the left side of the approach channel, a lateral labyrinth weir is designed. The labyrinth weir will have its crest at elevation 644 masl. The length of the weir will be 154 m. For water level at 647.3 masl the discharge through the labyrinth weir will be 3,700 m^3/s. The spilled volume will fall into the lateral trapezoidal channel. This channel has a straight alignment, with base width 40 m and side slopes 1H:3V. The elevation at the upstream end of the channel in front of the overflow section is 630.75 masl, and the elevation at the downstream end in front of the overflow section is 630 masl.

When water level reaches elevation 647.3 m, the embankment dam will start overtopping. For water level at 648 m the embankment dam would have been washed away.

9.2 Diversion System

The complex of works for river diversion during the construction of the CFRD dam embankment is constituted by:

- Two Diversion tunnels, one 1,115.2 m long and the other 1,289.6 m long, with a horseshoe shaped excavation diameter of 13.9 m, located on the left bank of Dudhkoshi River. The tunnels slope is equal to 0.5%.
- Upstream cofferdam, located at some 50-60 m upstream of the dam toe, with crest elevation at 477.0 masl.
- Downstream cofferdam, located at some 40 m downstream of the dam toe, with crest elevation at 438 masl.

The system was designed for a flow of 3,892 m^3/sec, corresponding to a Tr = 50 yrs.

From the discharge curve it can be seen that with two tunnels the design flow can be evacuated with the upstream water level at el. 471.64 masl.

The upstream cofferdam crest was then set at elevation 477.0 masl, with a freeboard above the Max. WL of 5.36 m.

In both the diversion tunnels intake, it is foreseen to install a fixed trashrack during the construction of the project, to be removed before the impounding of the reservoir.

9.3 Outlet Facilities

The following outlet facilities are capable to guarantee the depletion and impounding of the reservoir in safety conditions are provided:

9.3.1 Middle-level Outlet

The middle level outlet allows the dewatering of the reservoir for an emergency situation or for carrying out maintenance works to any permanent structure lying inside the reservoir.

The intake is at elevation 550.0 masl. The tunnel, 1.6% sloped, is provided with radial control gates. The initial pressure reach the exhibits circular section with 8.0 m diameter, whereas downstream of the gates the free-flow tunnel section is designed with trapezoidal lower portion topped with a circular crown. The tunnel discharges in the terminal chute of the labyrinth spillway.

The middle level outlet was designed for a maximum discharge capacity of 1,000 m^3/s under the reservoir Max. NWL, the maximum water velocity in the pressure reaches about 20 m/s.

This is obtained by controlling the flow through the radial control gates, dimensions of which (4.7 m x 3.5 m) was calculated so to allow passing the design flow under the maximum working head.

The water velocity at gates cross section is of 30.7 m/s, which requires the provision of steel lining and proper aeration measures. The following outlet facilities capable to guarantee the depletion and impounding of the reservoir in safety conditions are provided.

It is foreseen to install a movable trashrack at the intake.

9.3.2 Low-level Outlet

The low level outlet allows the dewatering of the reservoir for an emergency situation or for carrying out maintenance works to any permanent structure lying inside the reservoir.

The intake was set at el. 500.0 masl. The tunnel, 1.6% sloped, is provided with radial control gates. The initial pressure reaches exhibits circular section with 8.0 m diameter, whereas downstream of the gates the free-flow tunnel section is designed with trapezoidal lower portion topped with a circular crown.

The low level outlet was designed for a maximum discharge capacity of 1,000 m^3/s under a head of 120 m, the maximum water velocity in the pressure reach will be of about 20 m/s.

This is obtained by controlling the flow through the radial control gates, dimensions of which (4.25 m x 3.2 m) was calculated so to allow passing the design flow under the maximum working head.

The water velocity at gates cross section is of 36.6 m/s, which requires the provision of steel lining and proper aeration measures.

As the tunnel drops to the diversion tunnel level, the subsequent reach was designed with a vertical alignment profile such that detachment of the jet from the tunnel invert is avoided.

The circular radius that better fits the jet trajectory is equal to 160 m.

It is foreseen to install a movable trashrack at the intake.

9.3.3 Bottom Outlet

With the aim of making possible the complete dewatering of the reservoir, a bottom outlet was foreseen in the right Diversion Tunnel. This assures that this operation is possible in very short time in case of an emergency situation that requires a rapid draw-down of the reservoir.

The diversion tunnel intake was set at elevation 435.0 masl. The tunnel exhibits inner horseshoe shaped section with 12.0 m diameter and 0.5% slope, and is provided with radial control gates. Downstream of the gates, the tunnel will work under free-flow conditions.

The bottom outlet is designed for a maximum discharge capacity of about 2,400 m^3/s under a head of 120 m, which is the maximum allowed for operation, the maximum water velocity in the pressure reach will be of about 20 m/s.

9.4 Depletion of the Reservoir

As above mentioned, in case of an emergency a rapid draw-down of the reservoir may be required. The middle level outlet and the low-level outlet cannot fulfil this requirement, due to both their elevation and their discharge capacity.

Therefore, the sequential and combined operation of all hydraulic facilities capable to evacuate water would be required to obtain a rapid and complete depletion of the reservoir.

It implies making use of the following facilities in the below sequence and ranges of operation:

- Surface Spillway – gates opening to dewater the volume comprised between the Max. W.L. and the ogee crest (el. 624 masl);
- Middle Level Outlet – can operate concurrently with the Surface Spillway, from Max. W.L. down to its intake elevation, at 550.0 masl;
- Low Level Outlet – can operate starting from el. 620.0 masl, concurrently with the MLO, down to its intake elevation, at 500.0 masl;
- Bottom Outlet – can operate starting from el. 555.0 masl, concurrently with the LLO, down to its intake elevation, at 435.0 masl.

In order to avoid that high “artificial” floods are originated from suddenly opening the gates, in particular in the case of the surface spillway and bottom outlet, which have large discharge capacity, a gradual opening of the control devices was adopted in simulating the operation of reservoir depletion.

In general, the operation of gates opening was assumed to be performed with partial operation.

The results of this simulation show a depletion of 90 m up to elevation 550 masl in 26 days, corresponding to a volume of 1,190 Mm^3 and a depletion rate of 3.5 m/day. This value can be considered high, though optimization is possible.

9.5 Power Waterways

According to the proposed scheme of DKSHEP, the project includes two power plants, identified by the relevant powerhouse, namely:

- Dam Toe powerhouse, and
- Dudhkoshi Main powerhouse.

Layout and technical features of both power plants are shown in the set of drawings annexed to the study.

In order to evaluate the energy production of each power plant, the head losses of the relevant power waterways have been evaluated, taking into account the technical features of all components of the same, namely:

- Headrace tunnel: power intake, upstream gates structure (which includes maintenance and operation gates), and the tunnel itself.
- Steel lined penstock: initial gates structure upper and lower bends, manifold, and the penstock itself.

The Main Power House discharges the turbined flow into the Baikhu Khola, tributary of Sunkoshi River. The reference tailwater elevation is about 305 masl, ("high water level" of Saptakoshi High Dam power plant).

Following the draft tubes, a single tunnel 12.3 m high and 12.3 wide rises to elevation 298.15 m, then the water discharged by the units flow is in free-flow conditions through a horseshoe shaped tailrace tunnel, with 10 m diameter, 0.05 % sloped. The water height corresponding to the discharge of 224 m^3/s is equal to 7.4 m.

Dam Toe powerhouse located at dam toe on the right bank is an underground structure. The overall size of both the powerhouse cavern and the transformers hall are 65.5 x 21.0 x 42.5 (L x W x Hmax) and 50.0 x 20.0 x 18.5 (L x W x Hmax) respectively. The turbine elevation of 291.05 masl, and following the draft tubes, a tailrace with outlet at elevation of 438 masl.

The assumed Dam Crest Elevation, maximum, minimum reservoir water levels and tailrace water levels are summarized in the following table. The assumed water level range (640 masl - 530 masl = 110 m) is large enough to guarantee the reservoir emptying during the dry season to further allow the water volume storage during the wet season, limiting as much as possible (to 1,528 Mm^3) the average annual spilled volume.

Table 9-1 : Operating Levels

Powerhouse	Dam Crest El.	Max. Wat. Lev.	Min. Exc. W. L.	Min. Nor. W. L.	Tailrace W. L.
Dam Toe	648 masl	640 masl	545	545 masl	438.0 masl[5]
Main	648 masl	640 masl	n. a.	530 masl	304.8 masl

[5] Referred to a discharge of 200 m^3/sec, covering the Dry Season and the average value during the Wet Season.

10 DESIGN OF ELECTRO-MECHANICAL COMPONENTS

The present chapter summarizes Vol. 13 - Powerhouses Civil, Electromechanical and Hydromechanical Report, part of the Final Detailed Design.

10.1 Hydroelectric Scheme for Main Powerhouse

The Detailed Design of the Dudhkoshi Storage Hydroelectric Project has considered a scheme which comprises a main underground powerhouse near Sunkoshi River with 4 units of 150 MW and a powerhouse located near the Dam Toe on the right bank with two small hydro units of 35 MW each designed to operate with the environmental discharge. In case of unavailability of the small hydro units, a dissipation valve installed in the powerhouse will allow to discharge 40 m^3/s in the tailrace pond. This will guarantee the ecological flow.

The power waterways of the Main powerhouse comprise a power intake, a 13.2 km long headrace tunnel of 8.3 m diameter, a surge shaft, a vertical pressure shaft with horizontal penstock of 6.7 m diameter branching into 4 penstocks of 2.9 m diameter. The 4 draft tubes merge into a single tailrace tunnel.

10.1.1 Main Powerhouse Units Dimensions

The reservoir selected head variation range for the Main Powerhouse units are resumed here below:

Maximum NWL:	640 masl
Minimum NWL for Main Powerhouse:	530 masl (Dead Vol. 239 Mm^3)

The Main Powerhouse Units net head variation ranges from 213 (H_{min}) m to 334.8 m (H_{Max}).

For the Main Unit the Design Net Head is so fixed to 294 m

Each unit Rated Discharge of Main Powerhouse amounts to 56.1 m^3/s. The corresponding turbine Rated Power amounts to 150 MW. The generator should be designed for a 10% continuous overload. In this way the Maximum Power with a Maximum head of 334.8 m can reach 165.0 MW.

Table 10-1 : Main Powerhouse - Units Power Range

Continuous Power Range = P (MW) = ρ g Q_R H_N $\eta/10^6$ = 43.5 MW to 150 MW
Q: rated turbine discharge, 56.1 m^3/s
Q: turbine discharge range, 22.5 m^3/s to 56.1 m^3/s
H_N rated net head, 294 m
continuous operating H_N range: 213 m to 334.8 m

10.2 Hydroelectric Scheme for Dam Toe Powerhouse

The power waterway of the powerhouse at the dam toe on the right bank comprise a power intake, a 880 m long headrace tunnel of 7 m diameter, a surge shaft, a vertical pressure shaft with horizontal penstock of 2.8 m diameter entering the surface powerhouse. The draft tube discharge directly into the tailrace pond.

10.2.1 Dam Toe - Units Dimensions

In the following table are listed the main characteristics of the Dam Toe unit with P = 70 MW to be installed in the Dam Toe powerhouse, result of the pre-dimensioning, for an environmental flow up to 40 m^3/s.

Table 10-2 : Dam Toe Unit Power Range

Power range = P (MW) = ρ g Q_R H_N $\eta/10^6$ = 12 MW to 35 MW
Q_R turbine rated discharge = 21.3 m^3/s
Q: turbine discharge range, 8.9 to 21.3 m^3/s
H_N rated net head: 182 m
H_N range: 117 m to 214 m

11 ACCESS TO SITE, ACCESS ROADS AND BRIDGES

11.1 Access to Site

Accessibility to site is a critical aspect of the project. Given the size and scale of the Dudhkoshi Storage Hydroelectric Project it would be necessary to transport large quantities of construction materials (cement, steel, bricks, pipes, cables, wires, etc.), and construction equipment for ancillary installations (silos, water tanks, batching plants, crushing plants, formworks, scaffoldings, cranes, generators, pumps) to project site.

Warehouses and workshops for hydro-mechanical and electro-mechanical works would also be needed. Heavy construction equipment should be able to reach the site or to be transported there (rollers, bulldozers, excavators, loaders, trucks, motor graders, dumpers, drilling equipment, jumbos, Tunnel Boring Machine etc.) and the road network is the only possibility to do so.

Project Sites are accessible:

(a) from Nepal-India Border: by two national highways namely Sagarmatha Highway (NH16), and Siddhicharan Highway (NH20) via Gaighat and Katari of Udayapur District respectively, and

(b) from Kathmandu: BP Highway (Banepa-Khurkot-Bardibas) upto Khurkot and then join Mid-Hill Highway via Ghurmi of Udayapur District.

About 101.0 km long Public Access Roads (PAR) are required to reach project's main construction areas, viz., Main Dam and Main Powerhouse Sites from National Highways/major roads.

Road networks from Kathmandu and Nepal-India Borders upto the Project Sites are shown in Figure 11-1.

As shown Figure 11-1, the Dam Site is accessible via Katari-Ghurmi section of Siddhicharan Highway (NH20) in following three alternative ways:

(a) Alternative #1 : Ghurmi-Jayaramghat-Mainatar-Bhoje Bridge = about 40.0 km

(b) Alternative #2 : Ghurmi-Jayaramghat-Bijule-Bhoje Bridge = about 78.0 km

(c) Alternative #3 : Ghurmi-Okhaldhunga-Rabuwa = about 72.0 km

Length of Katari-Ghurmi section of Siddhicharan Highway is 46 km. Jayaramghat-Mainatar-Bhoje and Lamidada-Bhoje Road Sections are required to construct and/or upgrade.

Similarly, Powerhouse Site is accessible via Gaighat-Phoksingtar-Mohure section of Sagarmatha Highway (NH16) from Regmitar. About 11.5 km long access road is necessary to construct and/or upgrade from Regmitar to the Powerhouse Area. Length of Gaighat-Regmitar section of Sagarmatha Highway is 67 km.

After the construction/upgrading of all Project’s access roads, dam site will be about 213 km away from Kathmandu by motorable road.

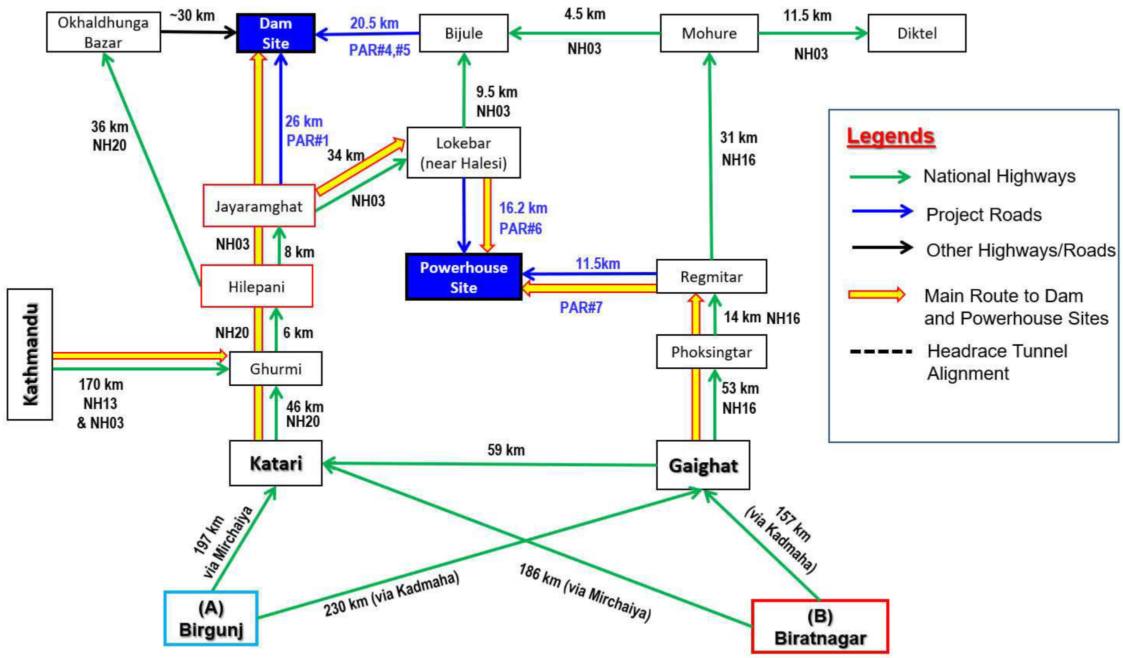


Figure 11-1 : Indicative Map of Access Routes to Project Sites

11.2 Access Roads

The access roads are divided into the following three major categories:

(a) **<u>Public Access Road (PAR)</u>**: 7 (Seven) Public Access Roads (PARs) have been planned and designed connecting from National Highways/major roads. These roads will be used by general public too. Out of total length 101 km, tracks of about 71 km have been opened/constructed by Federal, Provincial and Local Governments. Commencement of upgrading of these roads will be started by the Project and expected to complete before the Main Contractors start the works. Track opening of remaining roads or road sections will be started in Fiscal Year 2025/26. In case those upgrading works have not been completed or expected to complete prior to the submissions of Bids for Lot 1 and/or Lot 2 Contracts, remaining upgrading works including remaining Track Openings will be included on those contract Lots. Details of PARs are as below:

Table 11-1 : List of Public Access Roads (PAR)

ID	Descriptions	Total Length (km)	Track (km)		Remarks
			Opened	Remaining	
PAR#1	Jayaramghat - Mainatar - Bhoje	26.0	18.7	7.3	This road is located towards Dam Site
PAR#2	Bhoje - Bhadaure (Gate Shaft)	4.6	-	4.6	-do-

ID	Descriptions	Total Length (km)	Track (km)		Remarks
			Opened	Remaining	
PAR#3	Bhoje - Langur Khola - Lamidada	11.0	4.0	7.0	-do-
PAR#4	Lamidada - Majhi Gaon - Rabuwa	10.8	10.8	-	-do-
PAR#5	Bijule – Lamidada	9.8	9.8	-	-do-
PAR#6	Lokebar - Bhakhuwa - Dhitung	27.2	22.5	4.7	This road is located towards Powerhouse Site
PAR#7	Regmitar - Bhadbesi - Dhitung	11.4	5.3	6.1	-do-
	Total	**100.8**	**71.1**	**29.7**	

There will be about 1.4 km long Right Bank Access Tunnel (RBAT) with excavation diameter 8.0 m connecting a location near Thotne Khola (~elev. 520.0) and PAR#2 near Bhoje Gaon (~elev. 510.00) under Lot 1 Contract. This tunnel will be utilized as Headrace Tunnel for 70 MW Dam Toe Powerhouse. This tunnel will eliminate about 2.6 km long transportation distance between upstream and downstream of dam having up-hill and down-hill road sections.

(b) **Connecting/Construction Road (DCR and PCR)**: There are about ten (10) Dam Connecting Roads (DCRs) and two (2) Powerhouse Connecting Roads (PCRs) which will be constructed by Lot 1 and Lot 2 Contractors respectively. Total length of DCRs and PCRs are about 11.5 km and 4 km respectively. Out of 11.5 km DCRs, 75% will be permanent while the remaining will be temporary while both roads of PCRs are permanent.

(c) **Reservoir Connecting Road (RCR)**: Impoundment of reservoir affects existing mobility in several areas upstream of the dam location. To restore connectivity interrupted by the reservoir, three (3) Reservoir Connecting Roads (RCRs) of total length about 40.0 km have been proposed as part of the mitigation works. Some sections of RCRs are upgrading of existing roads, some are entirely new. These roads will be constructed through separate contractors during the construction of the main structures of the Project prior to the impounding of the reservoir.

11.3 Bridges

There are five new bridges are required to construct to access the Project Sites and along Reservoir Connecting Roads (RCRs). Bridge No. 1 and 5 are located along PARs and the remaining three bridges are located on the RCRs. These bridges are presented below:

Table 11-2 : List of Bridges

Bridge	Length (m)	Remarks
Bridge no. 1 (Dudhkoshi River)	150.0	Contract has been signed with local contractor in June 2024 for the construction of this bridge with construction period of 36 months.

Bridge	Length (m)	Remarks
Bridge no. 2 (Thotne Khola)	60.0	Contract has been signed with local contractor in June 2024 for the construction of this bridge with construction period of 36 months.
Bridge no. 3 (Kharte Khola)	40.0	This bridge is planned as part of the mitigation and to be constructed prior to reservoir impounding.
Bridge no. 4 (Rawa Khola)	40.0	-do-
Bridge no. 5 (Laikhu Khola)	40.0	-do-
Rabuwa Bailey Bridge (in Dudhkoshi River)	94.0	Contract has been signed with local contractor in February 2025 for the construction of this bridge with construction period of 18 months. This bridge is used during construction for the project and will be relocated prior to reservoir impounding.

12 BENEFITS ASSESSMENT

The present chapter summarizes Vol. 9 - Reservoir Operation and Energy Production Report.

12.1 Introduction

The Reservoir Operation simulations of DKSHEP were carried out in order to provide a forecast of energy production under different operation protocol and varying hydrological and sedimentological conditions.

The operation simulations were performed by means of an ELC Electroconsult numerical model, Milano, which allows the numerical integration of the continuity equation applied to the reservoir, adopting a daily time step and considering inflow, evaporation losses, environmental flow and spilled flow. The adopted numerical model has been widely tested in other ELC Electroconsult projects.

The analyses were carried out as a function of the installed capacity and project layout, according to the following general criteria:

The following definitions and reliability criteria were applied to the power oriented operation in load operation.

- Optimization of the average annual energy production;
- Optimization of the average dry season energy production;
- Minimization of the energy deficit (frequency of power plant stoppage, i.e. percentage of time when water level in the reservoir is below the Minimum Normal water level), with a maximum allowed value of 4%;
- Optimization of the dry season firm power (firm energy), defined as the daily power output exceeded for the 95% of the dry season;
- Maximization of the seasonal plant factor.

12.2 Reservoir simulations performed for the Project layout

The main considerations and conclusions of the analysis performed are:

- The reference reservoir simulation before starting operations of planned SKDMP (Sunkoshi-Kamala Diversion Multipurpose Project) in presence of under construction SMDMP (Sunkoshi-Marin Diversion Multipurpose Project) for the present study is performed for the layout 670 MW, with Max. NWL 640 masl, 24 hours turbine daily operation both in dry and wet season and environmental discharge 20 m^3/s. The results are the following: average annual generation 3,458 GWh, dry season energy 1,310 GWh, wet season energy 2,148 GWh, energy deficit approximately 4.2%, dry season energy ratio 37.9% and average annual spilled volume 1,435 Mm^3.

- The reference reservoir simulation with the operations of SKDMP and SMDMP for the present study is performed for the layout 670 MW, with Max. NWL 640 masl, 24 hours turbine daily operation both in dry and wet season and environmental discharge 30/40 m^3/s. The results are the following: average annual generation 3,377 GWh, dry season energy 1,252 GWh, wet season energy 2,125 GWh, energy deficit approximately 4.5%, Dry season energy ratio 37.1% and average annual spilled volume 1,469 Mm^3.

- The reference reservoir simulation with the operations of SKDMP and SMDMP considering the synthetic discharge time series for the period 2016-2100, associated to nine different IPCC climate change scenarios, showed that the critical scenario for the layout 670 MW, with Max. NWL 640 masl, 24 hours turbine daily operation both in dry and wet season and environmental discharge 30/40 m^3/s. The results are the following: average annual generation 3,464 GWh, dry season energy 1,287 GWh, wet season energy 2,177 GWh, energy deficit approximately 3.6%, dry season energy ratio 37.1% and average annual spilled volume 1,353 Mm^3. The result of the increase of mean flows, the average annual inflow volume is consequently higher in most of the scenarios and quite in accordance with increase of energy production, even if it is also associated to lower amounts of spilled water.

- An additional reservoir simulation has been performed considering the combined effect of reservoir sedimentation and climate change, applied on a 50-years' time frame from 2016 to 2066. The assessment of sediment accumulation, illustrated in in Vol. 3 - Sedimentological Report, has been used to estimate the reduction of reservoir capacity in 50 years of operation, with live storage decreasing from 1,342 Mm^3 to 1,140 Mm^3 (approximately 15% reduction). The results of the most critical are the following: average annual generation 3,392 GWh, dry season energy 1,208 GWh, wet season energy 2,183 GWh, energy deficit approximately 2.6%, Dry season energy ratio 35.6% and average annual spilled volume 1,534 Mm^3. This simulation considers only the material deposit on the reservoir tail, which is roughly 400 Mm^3 and the dead body of 250 Mm^3, the lost of volume is compensated by the increment in run-off.

- Therefore, considering the available information on natural factors that may affect the energetic performance of the power plant projected in future (in particular climatic conditions, hydrology, river morphology, sediment transport, etc.), the aforementioned analyses and assessments allow to delineate specific trends and a general framework for the operation of the power plant.

  For example, all the explored climatic change scenarios (please refer to Volume 2) seems to acknowledge a general increase of mean yearly stream flows till the end of the present century, consistently with increased temperature and precipitation.

- According to the previous considerations, it can also be expected that the decrease of energy production associated to the progressive loss of reservoir storage capacity due to sedimentation will be partially counter-balanced by the increase of energy production resulting from the forecasts of climate change scenarios, as verified in the combined energy simulations.

- The detailed design assumes as reference the scenario, 670 MW installed power, baseload of 30 m^3/s from Dam Toe Powerhouse and 107 m^3/s from Dudhkoshi Main Powerhouse in Dry season. Max generation in wet season, annual deficit 4%. The total energy is 3,377 GWh, subdivided in: 2,953 GWh at the Dudhkoshi Main Powerhouse, and 424 GWh at the Dam Toe Powerhouse. This scenario can guarantee the compatibility with SMDMP and SKDMP, considering an additional release in April-May and sustainable from economic and financial point of view.

13 COST ESTIMATE

The cost estimate is based on the construction time schedule and on the design of the selected project layout. Cost of resettlement and environment as estimated by the ESIA Study were duly incorporated in the overall estimate.

The cost estimate has been carried out during the time spanning from end of 2017 to end of 2024 on the ground of basic costs (labour, materials and construction equipment) which have been investigated in Nepal and in other countries during the early stage of the study.

The unit price analyses, and the cost summaries have been elaborated in United States of America Dollars (USD), with break down into local and foreign currency. In order to simplify the calculations for obtaining the unit prices, the local component has been converted into USD equivalent.

Unit prices have been based on a database developed by the Consultant on similar international projects implemented under FIDIC Construction Contracts and taking into account some planned projects in Nepal. In particular, the following Nepalese projects were considered:

- Upper Tamakoshi (started production)
- Tanahu Hydroelectric Project in Nepal (currently under construction).
- Nagmati CFRD Project in Nepal (2016).
- Budhi Gandaki HPP in Nepal (2015)
- Pancheshwar Multipurpose Project (1995).

Unit Price Analyses is composed of the following parts:

- Basic Costs – Labour Wages
- Basic Costs – Local Materials
- Basic Costs – Imported Materials
- Construction Equipment - Hourly Costs
- Unit price analysis for: Concrete Works, Dam Works, Drilling and Grouting, Open Air Excavation and Supports, Steel Reinforcement, Underground Excavation and Supports.

The base cost for the construction of the project is 1,593.3 MUSD. This cost is exclusive of excluding Interest During Construction (IDC), Customs Duties and Value Added Tax (VAT), Price Contingencies, Owner's Administration Cost, Project Construction Supervision Consultancy Services and Financial Costs.

14 CONSTRUCTION PLANNING

The present chapter deal with the Construction Schedule performed in the frame of DKSHEP studies and summarizes Vol. 11B – Construction Schedule.

The Construction Schedule was prepared as a justification of the total implementation time proposed for DKSHEP and covers the period of the pre-construction activities related with the Tendering Process and the proper project construction time, as well as the commissioning of the generating units.

14.1 General

The major construction works of DKSHEP has been split into four following Contract Lot 1 and the Construction Schedule is prepared accordingly.

- Lot 1 – Dam, Intake and Spillway including Hydraulic Steel Equipment (FIDIC Emerald Book, 2019)
- Lot 2 – Main Tunnel and Power House including Hydraulic Steel Equipment (FIDIC Emerald Book, 2019)
- Lot 3 – Electro-mechanical Works (FIDIC Yellow Book, 2017)
- Lot 4 –Transmission Lines (FIDIC Yellow Book, 2017)

As for the beginning of activities, taking into account the time required for financial agreements, approval by involved entities and tendering, it was assumed that the preparation of proposals by bidders would start in January 2025.

14.2 Milestones

The following "milestones", that represent critical moments in the implementation of the project, are highlighted in the schedule:

- **LOT 1 - Dam, Intake and Spillway including Hydraulic Steel Equipment**

Description	Days from Commencement Date of Lot 1 Contract	Note
Commencement date:	0	Commencement of Lot 1 Contract
Start of Access:	61	
River Diversion:	507	When the diversion tunnels will be ready to operate, allowing the start of activities in the riverbed relevant to the dam construction, the first

Description	Days from Commencement Date of Lot 1 Contract	Note
		of which will be the upstream pre-cofferdam and cofferdam
1st Stage Dam Embankment:	693	The dam embankment should start on this date and thus, the spillway excavation (main source of material for the dam construction) shall start 90 days before it.
Dam Toe PH 1st Stage Concrete up to Spiral Case Level	1,139	When the 1st stage concreting shall be ready to allow erection of draft tube and spiral case by the Lot 3 Plant Contractor. However, later commencement is considered (see Lot 3 milestones) due to the diversion closure time drive activity for Unit Test and Commissioning.
Dam Toe PH Concreting of walls, including overhead travelling crane beams	1,238	When the 1st stage concreting shall be ready up to the level of concrete beams for overhead travelling crane, to allow its erection by the Lot 3 Plant Contractor However, later commencement is considered (see Lot 3 milestones) due to the diversion closure time drive activity for Unit Test and Commissioning.
Diversion Closure:	2,333	When the dam will be completed up to parapet wall level at elevation 649.5 masl and the impounding shall start. By that date, all works are substantially completed, so that impounding can start in view of the commissioning of the Unit

- **LOT 2 – Main Tunnel and Powerhouse including Hydraulic Steel Equipment**

Description	Days from Commencement Date of Lot 1 Contract	Note
Commencement date:	0	
Start of Access:	61	

Description	Days from Commencement Date of Lot 1 Contract	Note
Main PH 1st Phase Concreting:	1,335	When all 1st Phase Concreting works at Main Powerhouse shall be completed, including the concreting of Access Tunnel Invert Slab, so that Lot 3 Plant Contractor can start the erection of Electromechanical Equipment. However, later commencement is considered (see Lot 3 milestones) due to the diversion closure time drive activity for Unit Test and Commissioning.
Main PH Transformer Cavern Concreting:	1,661	When all concreting works at transformers hall shall be completed, so that Lot 2 Plant Contractor can start the erection of transformers and other related equipment. However, later commencement is considered (see Lot 3 milestones) due to the diversion closure time drive activity for Unit Test and Commissioning.
TBM Start Excavation:	821	Even though this activity is not on the critical path, the rule of "as soon as possible" is adopted also for this underground challenging activity. Only after the completion of such work, the intake structure concreting and H&M Works can start.

- **LOT 3 - Electro-Mechanical Works**

Description	Days from Commencement Date of Lot 1 Contract	Note
Commencement date:	1,462	
Design of E&M Equipment:	1,492	Contractor starts the detail design of the equipment that is in the Scope of Work
Start of E&M Work:	1,732	When the E&M Work will start with the Crane and Rail Installation at Main PH
Start of the Main PH	1,604	When the Lot 3 Contract should start the switchyard civil work of the Main PH

Description	Days from Commencement Date of Lot 1 Contract	Note
Switchyard Civil Work:		
Start Test Commissioning first unit in Main PH	2,379	When the first unit it's ready for test/commissioning
Completion of the Commissioning:	2,632	Commissioning of all units of main powerhouse and of toe powerhouse shall be completed and all units will be in commercial operation.

- **LOT 4 - Transmission Lines**

Description	Days from Commencement Date of Lot 1 Contract	Note
Commencement date:	1,478	
Design of TL Equipment:	1,539	Contractor starts the detail design of the equipment that is in the Scope of Work
Start of Construction Activities:	1,569	When field construction work will start
Completion of the Work:	2,468	When the construction activities should finish to allow the testing and commissioning

Figure 14-1 : Global Implementation Schedule

ID	Task Mode	WBS	Task Name	Duration	Start	Finish
1						
2		1	WET SEASON	1475 days	21 May '25	20 Nov '32
3		2	LOT 1 and 2 - CIVIL WORKS	2897 days	01 Jan '25	06 Dec '32
4		2.1	BIDDING PROCESS AND PROJECT INCEPT	628 days	01 Jan '25	20 Sep '26
14		2.2	DESIGN	1170 days	26 Oct '25	07 Jan '29
17		2.3	LOT 1 - DAM, INTAKE AND SPILLWAY	2392 days	24 Jan '26	11 Aug '32
18		2.3.1	DIVERSION WORKS	2272 days	24 Jan '26	14 Apr '32
45		2.3.2	ACCESS ROADS AT DAM SITE	2272 days	24 Jan '26	14 Apr '32
59		2.3.3	DAM	2216 days	06 May '26	29 May '32
77		2.3.4	SPILLWAY	1646 days	20 Jul '27	21 Jan '32
81		2.3.5	EMERGENCY SPILLWAY	650 days	11 Apr '30	21 Jan '32
88		2.3.6	DAM AND SPILLWAY ANCILLARY WOR	120 days	14 Apr '32	11 Aug '32
91		2.3.7	MIDDLE LEVEL OUTLET	998 days	16 Jan '29	10 Oct '31
107		2.3.8	LOW LEVEL OUTLET	955 days	29 Aug '29	09 Apr '32
128		2.3.9	BOTTOM OUTLET	559 days	11 Jul '30	20 Jan '32
145		2.3.10	MAIN INTAKE	530 days	14 Nov '30	26 Apr '32
152		2.3.11	MAIN GATES SHAFT	385 days	24 Dec '30	12 Jan '32
158		2.3.12	DAM TOE HEADRACE TUNNEL (RBAT)	1734 days	01 May '27	28 Jan '32
165		2.3.13	DAM TOE POWERHOUSE ACCESS	1706 days	09 Aug '27	09 Apr '32
173		2.3.14	DAM TOE POWERHOUSE CAVERN CIVIL WORKS	1223 days	27 Feb '28	03 Jul '31
185		2.3.15	DAM TOE POWERHOUSE CABLES AND VENTILATION SHAFT	299 days	26 Jul '28	20 May '29
190		2.3.16	DAM TOE POWER INTAKE	261 days	08 Aug '28	25 Apr '29
195		2.3.17	DAM TOE GATES SHAFT	335 days	22 Jan '29	22 Dec '29
200		2.3.18	DAM TOE SURGE SHAFT	290 days	09 Jan '30	25 Oct '30
204		2.3.19	DAM TOE PENSTOCK	324 days	06 Oct '30	25 Aug '31
212		2.3.20	DAM TOE TAILRACE AND DRAFT TUBES	472 days	31 Oct '28	14 Feb '30
218		2.4	LOT 2 - MAIN HEADRACE TUNNEL AND POWERHOUSE	2509 days	24 Jan '26	06 Dec '32
219		2.4.1	ACCESS ROADS AT MAIN POWERHOUSE	1611 days	24 Jan '26	23 Jun '30
230		2.4.2	TBM YARD (S4) CONSTRUCTION	1955 days	24 Apr '26	30 Aug '31
234		2.4.3	ADIT TO HRT AND TBM ERECTION CHAMBER	2352 days	23 Jun '26	29 Nov '32
239		2.4.4	MAIN POWERHOUSE HEADRACE TUNN	1585 days	13 Jul '27	13 Nov '31
253		2.4.5	MAIN POWERHOUSE SURGE SHAFT	485 days	09 May '26	05 Sep '27
257		2.4.6	MAIN POWERHOUSE PENSTOCK	866 days	03 Sep '27	15 Jan '30
268		2.4.7	MAIN POWERHOUSE	2359 days	23 Jun '26	06 Dec '32
301		3	LOT 3 - ELECTRO-MECHANICAL WORKS	1441 days	28 Feb '29	07 Feb '33
302		3.1	BIDDING PROCESS AND PROJECT INCEPT	315 days	28 Feb '29	08 Jan '30
310		3.2	DESIGN OF ELECTROMECHANICAL EQUIPMENT	730 days	25 Dec '29	24 Dec '31
311		3.3	TRANSPORTATION	600 days	23 Jun '30	12 Feb '32
312		3.4	MAIN POWERHOUSE HYDRO-ELECTROMECHANICAL	901 days	21 Aug '30	07 Feb '33
795		3.5	MAIN PH 400 kV CABLES	212 days	17 Jun '31	15 Jan '32
800		3.6	MAIN PH 400 kV GIS SUBSTATION	764 days	16 Apr '30	18 May '32
852		3.7	DAM TOE POWERHOUSE HYDRO-ELECTROMECHANICAL	865 days	21 Aug '30	02 Jan '33
1089		3.8	DAM TOE PH 400 kV GIS SUBSTATION	1069 days	17 Nov '29	20 Oct '32
1125		4	LOT 3 - 400 KV TRANSMISSION LINES	1348 days	31 May '29	06 Feb '33
1126		4.1	BIDDING PROCESS AND PROJECT INCEPT	225 days	31 May '29	10 Jan '30
1134		4.2	CONSTRUCTION	1123 days	11 Jan '30	06 Feb '33

15 ECONOMIC AND FINANCIAL ANALYSIS

The present chapter summarizes Vol. 12 - Economic and Financial Analysis part of the Detailed Design.

DKSHEP foresees a construction period of 7 years starting from 2025[6], the project is supposed to start generation after 7 years (second half of 2032) when the commissioning of the generating units is expected to start.

Perimeters of the Analyses

The analyses consider the cost for the construction and subsequent operation & maintenance of the Hydroelectric Project and its appurtenant substations and transmission lines, as well as the cost of the environmental and social impact mitigation measures (land acquisition, resettlement costs etc.) and the Benefits / Revenues obtained from the electricity produced.

Economic Analysis

An Economic Analysis of a potential investment project has an intrinsic almost tautologic link with the concept of Alternative Decisions; i.e. an economic analysis is performed to support a decision among alternative investments (even “do nothing” is an investment decision).

It may consequently be useful wording a definition of the economic objective of DKSHEP. It may be the following: “the economic analysis of DKSHEP shall verify whether the decision of building the plant contributes positively to the medium / long term sustainable economic development of Nepal”. To access this contribution, the economic analysis shall indicate that the economic cost of operating and expanding the interconnected system of Nepal is lower “with” the DKSHEP than “without” it.

DKSHEP is a candidate for financing by International Financing Institutions (IFIs), among them the Asian Development Bank, which is bearing the cost of this feasibility study and detailed design. The definition above is always valid for any International Financing Institution examining the possibility to finance the project.

Government of Nepal (GoN) shall have exactly the same perspective. The same objective is also valid for NEA as long as it is correct the assumption that the benefit of Nepal as a whole is coincident with the benefit of NEA, the national utility with a national mission. In the current context of Nepal also this assumption is fair enough.

Therefore, the economic analysis is coincident and valid from all three perspectives, GoN, IFIs and NEA.

The Avoided Cost Method, as selected and applied to this analysis, has the effect to make practically uninfluential the use of Shadow Prices. Indeed, the Conversion Factors would

[6] The beginning of the construction in 2022 has been considered in the present economic analysis.

impact in a practically identical way the project and the avoided cost. Moreover, there is no indication of economic choices that are patently distorting the prices.

The analysis will consider the Economic Value of the Investment Cost equal to the nominal cost.

The results of the Economic Analysis are summarized in the following table.

MAIN RESULTS - CONSTANT MONEY		
(1) Total Present Value of Costs	**MUSD**	1,870.3
(2) Total Present Value of Benefits	**MUSD**	3,018.6
(3) Project NPV (2) - (1)	**MUSD**	1,148.3
(4) Benefit to Cost ratio, B/C		1.61
(5) Economic Internal Rate of Return	**%**	18.9%
(6) Project NPV at IRR (=0)	**MUSD**	0.0

Financial Analysis

The financial analysis considers the DKSHEP as implemented and managed by NEA through a Special Purpose Vehicle (SPV) with the participation of other bodies.

Results of the financial analysis are reported in the following table.

		Dudhkoshi Project Layout
Installed Capacity	MW	670
Construction Period	years	7
Base Electricity Tariff (Wet Season)	NPR/kWh	10.3
Base Electricity Tariff (Dry Season)	NPR/kWh	10.3
Energy Generation (Wet Season)	GWh/y	2125
Energy Generation (Dry Season)	GWh/y	1252
Average Annual Energy Production	GWh/y	3377
Loan share of Investment		70%
Equity share of Investment		30%
Interest rate on loan		5.0%
Expected Return on Equity		16%
Grace period (after commissioning)	years	8
Maturity of Loan (after grace)	years	30
Investment Cost including VAT and Price Escalation during construction. Excluding IDC	M USD	1,951
Investment Cost including VAT, Price Escalation during construction, IDC	M USD	2,155
Project IRR		**9.2%**
Average Debt Service Coverage Ratio		**2.5**
Project NPV	M USD	201
WACC		8.3%

The Consultant assumed that the project will be co-financed by International Financing Institutions, e.g. ADB, by the Government of Nepal through NEA and by other.

The project financial analysis follows a classic scheme of financial model: flow of disbursements and incomes, Financing and Investment Plan, Profit & Loss, Cash Flow projection.

The Weighted Average Cost of Capital (WACC) is 8.3%, obtained by an expected return on equity of 16%, an interest rate on loan equal to 5% and a debt-equity ratio of 70:30.

The analysis includes Royalties as well as Bonus and Welfare Fund.

Outcomes

The Economic Analyses indicate that the DKSHEP is economically sound.

In broader terms, a Storage Hydropower Project fits well in the expected generation mix of Nepal even when a greater percentage of Peak Run-of-River hydropower plants, compared with the current mix of purely Run-of-River plants, is expected to be developed by the private sector as a consequence of the new PPA tariff system.

The performed sensitivity analyses highlight that, even with an increase of the construction costs and of the construction period, the economic performance is still satisfactory.

Its sound economic performance, as possible Storage Hydropower Project candidate, is dramatically strengthened by the negligible social impact, limited to few tens of households.

Identified but not quantified economic benefit further enhance the attractiveness of the project.

The outcomes of the Financial Analysis indicate that DKSHEP is financially sound.

The debt-service indicators as well as the Project Financial Internal Rate of Return are higher than the reference figures for similar cases.

The Project Financial Internal Rate of Return at 9.2% compares favorably with the estimated WACC of 8.3% and the financial net present value is positive, therefore substantiating the financial viability of the project.

As per any project, results of the sensitivity analyses show that the project is financially sensitive to an increase of the construction costs, to a decrease of the produced energy, to an increase of the construction period and to an increase of the interest rate. In particular, the Net Present Value is sensitive to a worsening of the parameters, while the Average Debt Service Coverage Ratio is stably higher than the minimum reference values (1.5 - 2).

Storage Hydroelectric Projects play a key role in supporting safe, reliable and economical grid operations, however it is complex to assess the full value of all services and contributions to the grid, to the market and to the entire economy.

The estimation of the values of different services and contributions shall include the following key aspects and drivers, in addition to value of bulk power capacity and energy, already analyzed above (if internalized, they would increase the EIRR of both alternatives):

- Value of ancillary services,
- Power system stability benefits,
- Reduction of system production costs and other portfolio effects [Positive downstream impact on existing and planned generation assets] and
- Non-energy benefits (Induced local development and, though marginal for this project, Irrigation leading to increased agricultural yields, Improved flood control, etc.)

Indeed, the Project Layout is fully in line with the result of the Dudhkoshi River System Studies, financed by ADB in July 2016. Such study was designed to demonstrate the clear opportunities to develop equitable and efficient means to manage water resources through economically and environmentally sustainable development, including under the challenges of a changing climate. The study developed strategies for integrated water resources management and development. The outputs of the study represent a strategic planning framework for the Dudhkoshi river system (the study was designed to provide support for the planning of the DKSHEP, contributing to a basin wide strategic planning perspective).

The above list will allow for the stacking of non-conflicting benefit streams, but co-optimization may be needed to avoid double-counting of benefits.

Among non-energy benefits the following shall be considered:

- Irrigation leading to increased agricultural yields;
- Improved flood control; and
- Induced local development.

The additional duty of releasing an environmental flow in the reach of river downstream of the dam until the conjunction with the confluence with Sunkoshi since the very first months of operation may make the balance for the decision.

The detailed financial plan of the project may offer financial opportunities to optimize the financing and fiscal strategy of the project.

Risks

Efficient risk allocation and mitigation are central to develop infrastructure projects and to providing appropriate incentives during construction and operation. Efficient risk allocation occurs where risks are assumed by the party best able to manage them.

Obtaining financing for a project is hitherto a fairly complex and specialized expertise. For complex infrastructures such as DKSHEP to continue spreading, government officials, investors, and lenders will need to become familiar with the risk mitigation and management techniques used by project financiers.

A matrix identifies the major risks for the project development mainly from a financial perspective as well as risk mitigation and risk transfer plans arrangements.

Corresponding institutional and financial arrangement

There are three institutional arrangements currently commonly implemented in Nepal for the development of the Hydroelectric Project under development or construction namely:

- the Single Purpose Vehicle (SPV);
- the NEA national utility;
- the Independent Power Producer (IPP).

The SPV, in its possible variants, is the one originally developed by Nepal, though most probably only for this transitional phase, to obtain multiple objectives:

- More accountability (compared with undifferentiated corporate accounting);
- The benefit of participation of the Private Sector (with its capability to hybridize public sector practices and to play a role of guarantor of the profitability of the investment);
- The possibility to receive significant amount of concessional credit, so necessary to support the needs of infrastructure development of a fast-growing country.

The SPV appears the Institutional Arrangement to be recommended.

The detailed organizational structure for implementing DKSHEP can be defined only after the final definition and validation of the procurement strategy as well as of the details of each package until the definition of the price items and or the design responsibilities.

The key driver is the assumption that the project overall organization shall be coherent with the details of the contractual arrangement.

16 ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

DKSHEP is a storage-type hydroelectric project proposed on the Dudhkoshi River. Its influence spans the districts of Okhaldhunga, Khotang, and Solukhumbu, located in Koshi Province. Specifically, the project area includes three municipalities in Okhaldhunga district, three municipalities in Khotang district, and two municipalities in Solukhumbu district.

The feasibility study of the project envisions several key components:

- A 220 meter high Concrete Face Rockfill Dam (CFRD)
- A 13.2 kilometer long headrace tunnel
- A main powerhouse with an installed capacity of 600 MW
- A dam toe powerhouse with an additional installed capacity of 70 MW.

In total, the project aims for an installed capacity of 670 MW, designed to harness the hydroelectric potential of the Dudhkoshi River and provide significant power generation capacity.

Under Nepal's Environmental Protection Act, 2019 and Environmental Protection Rule, 2020, the Dudhkoshi Storage Hydroelectric Project (DKSHEP) is classified as a project requiring an Environmental Impact Assessment (EIA). The Asian Development Bank (ADB) is identified as the lead development partner to provide financial support for the project, with additional development partners being considered to form a consortium for co-financing.

According to the ADB’s Safeguard Policy Statement (2009), the DKSHEP is categorized as a "Category A" project for environmental impact, necessitating the preparation of an EIA. This classification reflects the significant potential environmental impacts of the project. In compliance with both the ADB's Safeguard Policy Statement (2009) and Nepal's national environmental regulations, a comprehensive EIA has been prepared. This assessment covers all project components, evaluates their environmental impacts, and proposes a detailed environmental management plan.

A total of 2,499.38 ha of land is required for the projects, including 2,094.07 ha for the reservoir, 107.78 ha for reservoir rim, 194.84 ha for project structures and access roads, 102.69 ha for site establishment areas. Most land use will be permanently transformed, except for some site establishment areas, which will be in part rehabilitated post-project.

Considering specifically the forest component, the project will require the permanent removal of vegetation to create the reservoir and establish key project components. A total of 1,043.70 ha of forested land will be impacted, with 920.09 ha designated for the reservoir (90.25% of the total affected forest area), 62.50 ha for the reservoir rim zone (6.0%), and 47.71 ha for project components and access roads (4.6%). Additionally, 13.40 ha of forested land will be cleared to establish Site Establishment Areas. The reservoir rim zone, covering 62.50 ha of forested land, will be dedicated to conservation efforts, with the existing forest preserved and extensive replanting conducted to enhance its ecological integrity.

The construction will cause the loss of approximately 315,161 trees, including poles and mature trees, with the highest losses occurring in the reservoir area. To mitigate the environmental impact of tree cutting, a compensatory plantation will be undertaken at a ratio of 1:10. This means that for every tree felled, 10 seedlings will be planted. Thus, a total of 3,151,610 seedlings will need to be replanted. This extensive reforestation effort is designed to ensure environmental sustainability and compensate for the ecological loss incurred by the project.

The project area does not encompass any national parks or biodiversity-protected areas. However, some critically endangered species have been recorded in the project vicinity, including the Chinese Pangolin, Irrawaddy Squirrel, Porcupine, Small Indian Mongoose, Rhesus Macaque, Yellow-throated Marten, King Cobra, Bengal monitor lizard, Yellow monitor. These species use the area occasionally for passage or as a stopover, but not for breeding purposes. Although the project area is not particularly notable for avifauna, 132 bird species have been reported. Of these, up to 80% are residential, while the remaining are migratory.

The aquatic habitat is expected to be significantly impacted by the project. The operation of the dam is predicted to obstruct the migratory route of fish, particularly the Golden Mahseer. Among the 54 recorded fish species, 6 are long-distance migratory, 6 are medium-distance migratory, and the rest are resident species. Additionally, the operation of the tailrace is likely to cause fish stranding. Since fish ladders are unsuitable for high dams (over 40 m), the project proposes compensatory measures such as establishing a fish hatchery with seasonal releases and catching and hauling fish fingerlings to maintain the fish population upstream of the reservoir.

The project is anticipated to have significant impacts on local social and economic areas. Approximately 3,177 households are expected to be adversely affected, with 208 of these households being displaced from their homes and ancestral land, necessitating resettlement. Community properties such as suspension bridges, concrete bridges, roads, grazing lands, cremation sites, resting places, micro-hydro facilities, temples, early childhood development centres, community houses, and public lands will also be affected by the project. To mitigate these impacts, the project must develop extensive compensation, rehabilitation, and livelihood enhancement programs to support the affected families and communities.

The EIA is based on findings from various surveys and studies that identify potentially significant impacts associated with all project facilities planned for construction and operation phases. These impacts have been thoroughly assessed within the EIA. Mitigation measures and a monitoring program have been developed to mitigate potential adverse impacts and enhance positive impacts where feasible.

The project will bring wide opportunity for socio-economic development at local and national context. Some of the beneficial impacts of the project are following:

- enhance community wellbeing and economic opportunities through, among others, plans for immediate catchment management, reforestation in the immediate catchment area of the reservoir, potential for aquaculture, and the provision of livelihood enhancement support;
- the project will support in addressing peak demand and power shortage during dry season, and stop necessity to import electricity from India at higher cost and strengthen the foreign currency reserve;
- availability of renewable clean energy and labour in the country, opportunity for industrial business will be available, and health & education will be improved and quality of life of people will increase with availability of job and income;
- local economy will be operational with money injected through wages of local people, service to project staff through small scales businesses, shops and restaurants;
- replacement of fossil fuel and biomass (particularly in rural Nepal) based energy by clean renewable energy will help in reducing Greenhouse Gases (GHG) and meeting targets agreed with Paris Agreement;
- the balance between the project GHG emissions (due to construction activities and reservoir emissions) and the avoided emissions of an equivalent thermal power plant is strongly positive and will result in a net reduction in GHG emissions;
- opportunity to learn skill through training and working in the project, which will ensure long term work opportunity and better earning overseas as skilled workers.

The key anticipated adverse impacts of the project are identified as the following, which are mostly reversible and minimized or compensated by using mitigation measures.

- loss of land and property of project affected people due to land permanently acquired by the project;
- resettlement and related livelihood and income, quality of life and socio-cultural stress in the resettled community;
- changes related to the dam forming reservoir but affecting connectivity of aquatic life, causing impacts on endangered species and their population;
- Loss of traditional livelihood practices of local fishermen due to depletion in fish population;
- loss of forest area causing habitat loss and fragmentation, and impact on endangered species of wildlife and avifauna;
- Occupational health and safety related risks, especially during the construction of the hydropower complex;

- Migration of outsiders for job opportunity, which may generate social conflict, increase in crime, and stress on social services. This may slowly cause dilution of local social and cultural practices, festivals and rituals;
- Risk due to possible emergency scenarios, to be managed, mitigated and prevented by means of provisions included in the Emergency Preparedness and Response Plan.

Because of this assessment, it is concluded that all potential adverse impacts arising from the project can be effectively managed, mitigated or compensated, provided that recommended mitigation measures are implemented, and regular monitoring is undertaken. No potentially insurmountable impacts were identified which would necessitate a fundamental alteration of proposed Project design parameters. Further information regarding potential impacts and mitigation measures can be found in the EIA document. The robust mitigation measures will help minimize the scale of ecological footprint of the project.

In addition, the Site-specific Environmental Management Plan (SSEMP) and Occupational Health and Safety (OHS) plan shall be developed by contractors with mitigation measures and monitoring plan for such area of work. The following recommendations are suggested by the EIA.

- conduct environmental quality monitoring programs (air quality, noise, vibration) during the pre-construction period to provide essential baseline data and construction period to minimize them. In addition, it will be of benefit to establish permanent water quality monitoring stations for Dudhkoshi Basin to regularly monitor the water quality prior to and after reservoir inundation.
- the management of the environmental flows downstream of the dam should be strictly maintained as suggested at 30 m^3/sec, increased to 40 m^3/s in April, and monitored to determine their effectiveness at protecting downstream biodiversity and ecosystem services. A real time monitoring and decision-making system will be prepared to complement the environmental flow regime. An adaptive management framework should also be utilized to amend flow strategies based on water quality and biological data on downstream reaches.
- the management of the watershed is a critical component for managing the aquatic habitat and ecosystem services values of the Dudhkoshi River. A comprehensive watershed management framework is required that could manage identified risks, propose collaborative efforts with other stakeholder interests and actively engages GoN in administering and managing the values of the watershed. This framework should be developed as the overarching approach to achieving sustainable development in the watershed.
- to be able to predict downstream flood events, in the Dudhkoshi dewatered zone (between the dam and the confluence with the Sunkoshi River), hydrological data in the project area and vicinity should be gathered, along with the development of flood

models. This is to assure and disseminate information to the public that water released from the dam during the wet season will not cause flooding at the downstream areas.

- to include all proposed mitigation measures, monitoring programs, as well as obligations and commitments in relation to environmental protection in all construction contracts. The involvement of contractors, especially during the construction period, will help to achieve and maintain environmental protection. Based on the environmental obligations, as addressed in the contract, contractors shall put the environmental management and OHS into practice through effective implementation and manage risks to the environment and safety arising from all construction activities during the construction phase.

The EIA including EMP are considered sufficient to meet the environmental assessment requirements for the project. In case of any unanticipated impact (including a scope or design change) occurring during project implementation, the EIA and EMP will be further updated by DKSHEP and cleared by MOFE and ADB before any related works commence.

According to the Terms of Reference, the Environmental Impact Assessment (EIA) of the DKSHEP has been conducted in accordance with the requirements of the Environmental Protection Act, 2019 and Environmental Protection Regulations, 2020 as well as requirements established by the Asian Development Bank for Category A projects.

17 LIST OF REPORTS AND DRAWINGS

The Final Detailed Design consists of the following volumes:

Vol. 0 - Executive summary

Vol. 1 - Main report

Vol. 2 - Hydrological and Meteorological Report

Vol. 3 - Sedimentological Report

Vol. 3B - Glacial Lake Outburst Floods (GLOF) Assessment

Vol. 4B - Topographic report – LIDAR and Bathymetry

Vol. 5 - Geological report and Annex

Vol. 6 - Seismic Hazard Assessment Report

Vol. 7 - Geotechnical Baseline Report

Vol. 8 - Main Dam Report

Vol. 9 - Energy Production Report

Vol. 10 - Spillway and Other Hydraulic Structures Design

Vol. 10B - Physical Model

Vol. 11A - Cost Estimate Report

Vol. 11B - Construction Schedule

Vol. 12 - Econ&Fin Analysis

Vol. 13 - Powerhouse Report (Hydro-mechanical)

Vol. 14 - Transmission Line Report

Vol. 15 - Access Road

Vol. 16 - Design Criteria

Vol. 17 - Structural design

Vol. 18 - Water Resources Management Report

Vol. 19 - Dam break and EPP

Vol 20 - Powerhouse 3D FDM Model

Vol. 21 - Electromechanical equipment

Vol. 22 - Dam 3D Model

Vol. 23 - Selection of the Alternatives

Vol. 24 - Tunnel risk analysis report

Vol. 24B - TBM HRT Risk Analysis

Vol. 25 - Sensitivity and Cost Risk Analysis

Vol. 26 - Alternatives Analysis and E-Flow Scenario Assessment

Vol. 27 - Climate change

Vol. 28 - Dam Safety Report

Vol. 29 - Landslide and Reservoirs Report

Vol 30 - PQ and BD Lot 1

Vol 31 - PQ and BD Lot 2

Vol 32 - PQ and BD Lot 3

Vol 33 - PQ and BD Lot 4

Vol 34 - GBR Lot 1

Vol 35 - GBR Lot 2

Vol. 36 - TBM Alternative Solution for HRT

Vol. 37 - Drawings

Vol. 38 - Pangolin Management Plan

Vol. 39 - Wildlife Management Plan

Vol. 40 - Forest Management Plan

The following drawings are attached to the Executive Summary:

ACCESS ROADS - MAIN ACCESS ROAD TO DAMSITE

ACCESS ROADS - RESERVOIR ROADS

ACCESS ROADS - DAMSITE-MAIN POWERHOUSE AREA CONNECTING ROADS

DAMSITE GENERAL LAYOUT

GEOLOGICAL MAP OF DAM SITE

CFRD - TYPICAL CROSS SECTION

GEOLOGICAL CROSS SECTION OF DAM SITE - SECTION A-A'

GEOLOGICAL LONGITUDINAL SECTION OF DAM SITE - SECTION G-G'

SPILLWAY - GENERAL PLAN VIEW

SPILLWAY - QUARRY AREA EL 648 - GENERAL PLAN VIEW

DAM TOE POWERPLANT – GENERAL PLAN, LONGITUDINAL PROFILE AND SECTIONS

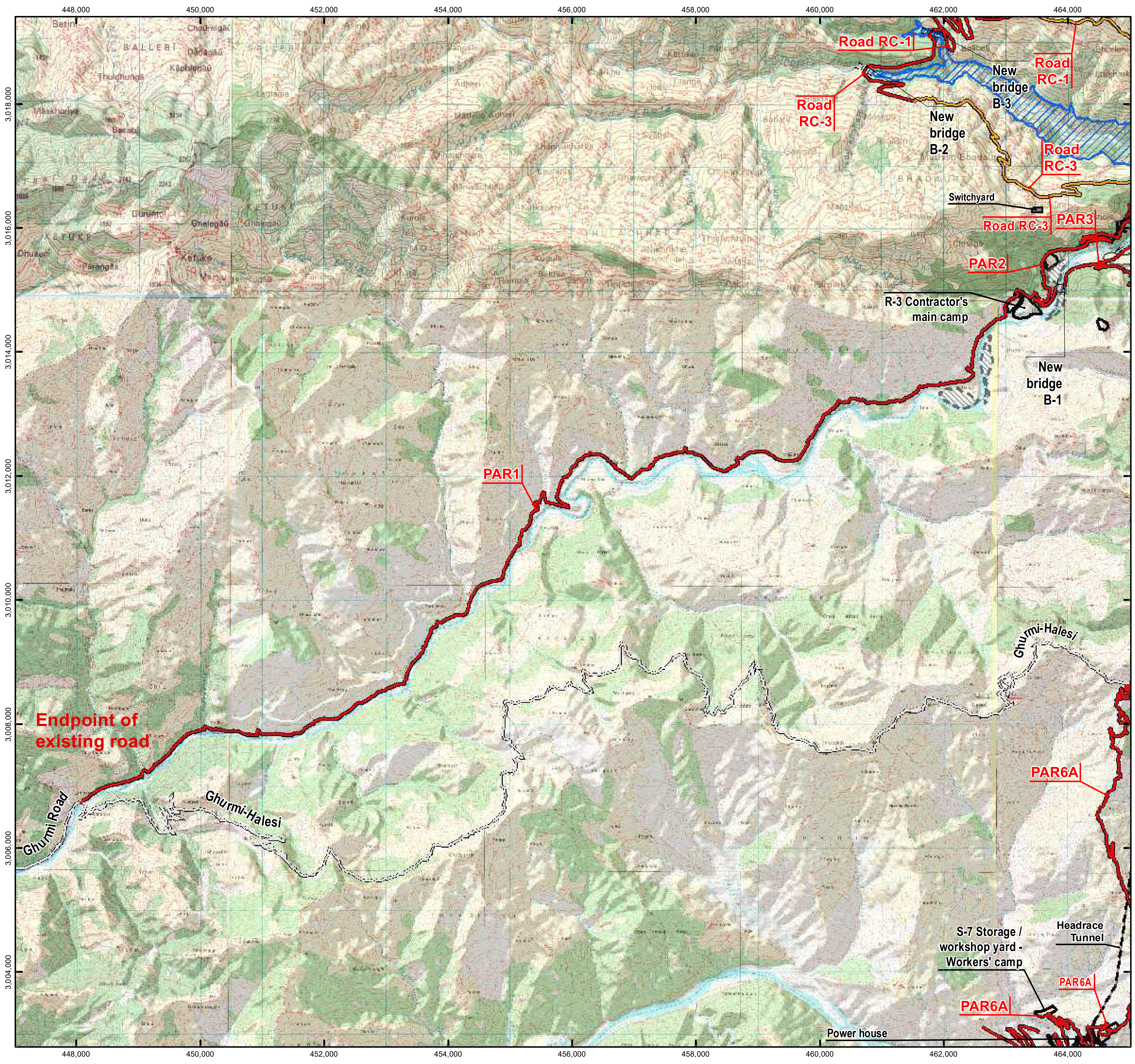
MAIN POWERPLANT – HEADRACE TUNNEL – GENERAL PLAN VIEW AND LONGITUDINAL PROFILE

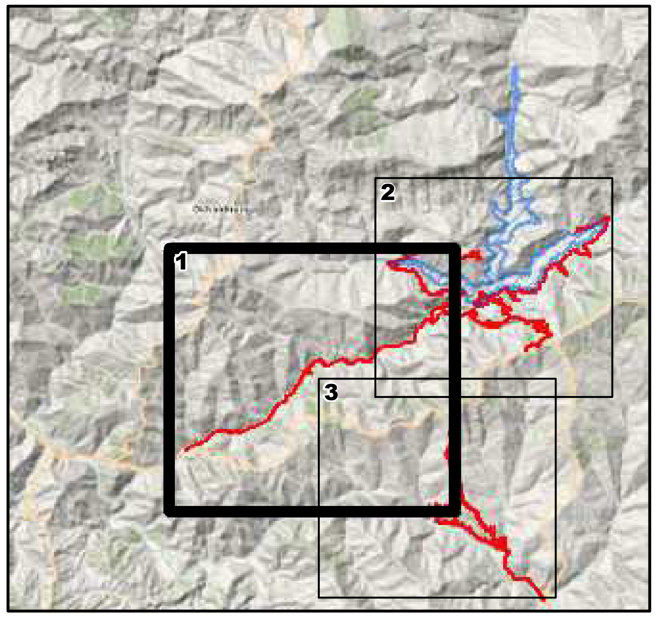
MAIN POWERPLANT – PENSTOCK - PLAN VIEW AND PROFILE

Updated Feasibility Study and Detailed Design of DUDHKOSHI STORAGE HYDROELECTRIC PROJECT

ANNEX A
SELECTED DRAWINGS

ELC Electroconsult, Milan, Italy
NEWJEC Inc., Osaka, Japan





Legend

- New roads
- Upgrade of existing roads
- Existing roads
- Reservoir at El. 640 m a.s.l.
- Quarries and borrow areas
- Disposal areas

0 0.5 1 2 3 4 km

Topographic base: Nepal 50k topographic map

Reference system: Modified UTM 87
Datum: Nepal Nagarkot
Spheroid: Everest_Adjustment_1937
Semimajor Axis: 6,377,276.345
Inverse Flattening: 300.8017

REV.	Revisions	Day Month Year	Drawn	Checked	Approved
3	Issue for comments	26/8/2024	ELC	LGA	PAR
2	Issue for comments	3/2/2020	ELC	LGA	PAR
1	Issue for comments	28/1/2020	ELC	LGA	PAR
0	First issue	15/8/2019	ELC	LGA	PAR

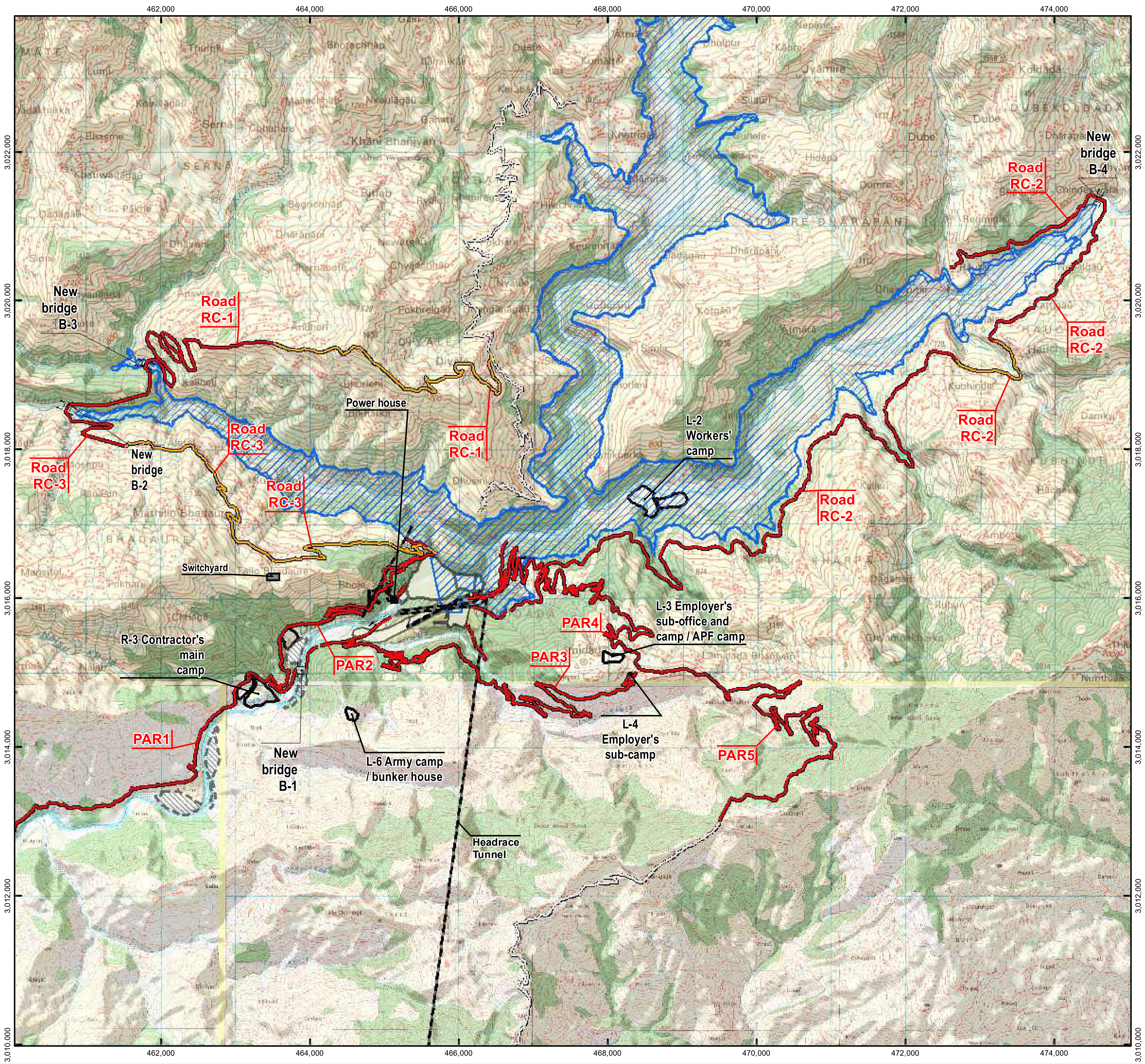
ELC NEWJEC

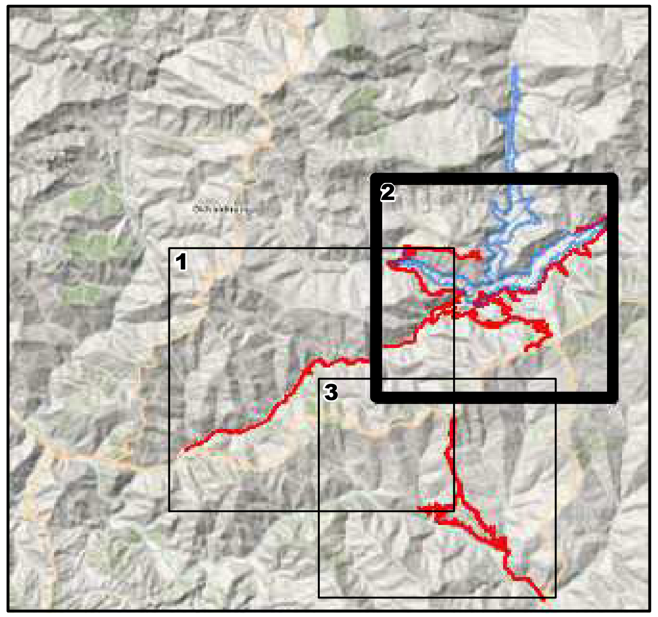
DUDHKOSHI HYDROPOWER PROJECT

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

DETAILED DESIGN
ACCESS ROADS
MAIN ACCESS ROAD TO DAMSITE

1765-T4-D-ARG-0001-0101-03	Size	A3	Scale	1:60,000





Legend

- New roads
- Upgrade of existing roads
- Existing roads
- Reservoir at El. 640 m a.s.l.
- Quarries and borrow areas
- Disposal areas

0 0.5 1 2 3 4 km

Topographic base: Nepal 50k topographic map

Reference system: Modified UTM 87
Datum: Nepal Nagarkot
Spheroid: Everest_Adjustment_1937
Semimajor Axis: 6,377,276.345
Inverse Flattening: 300.8017

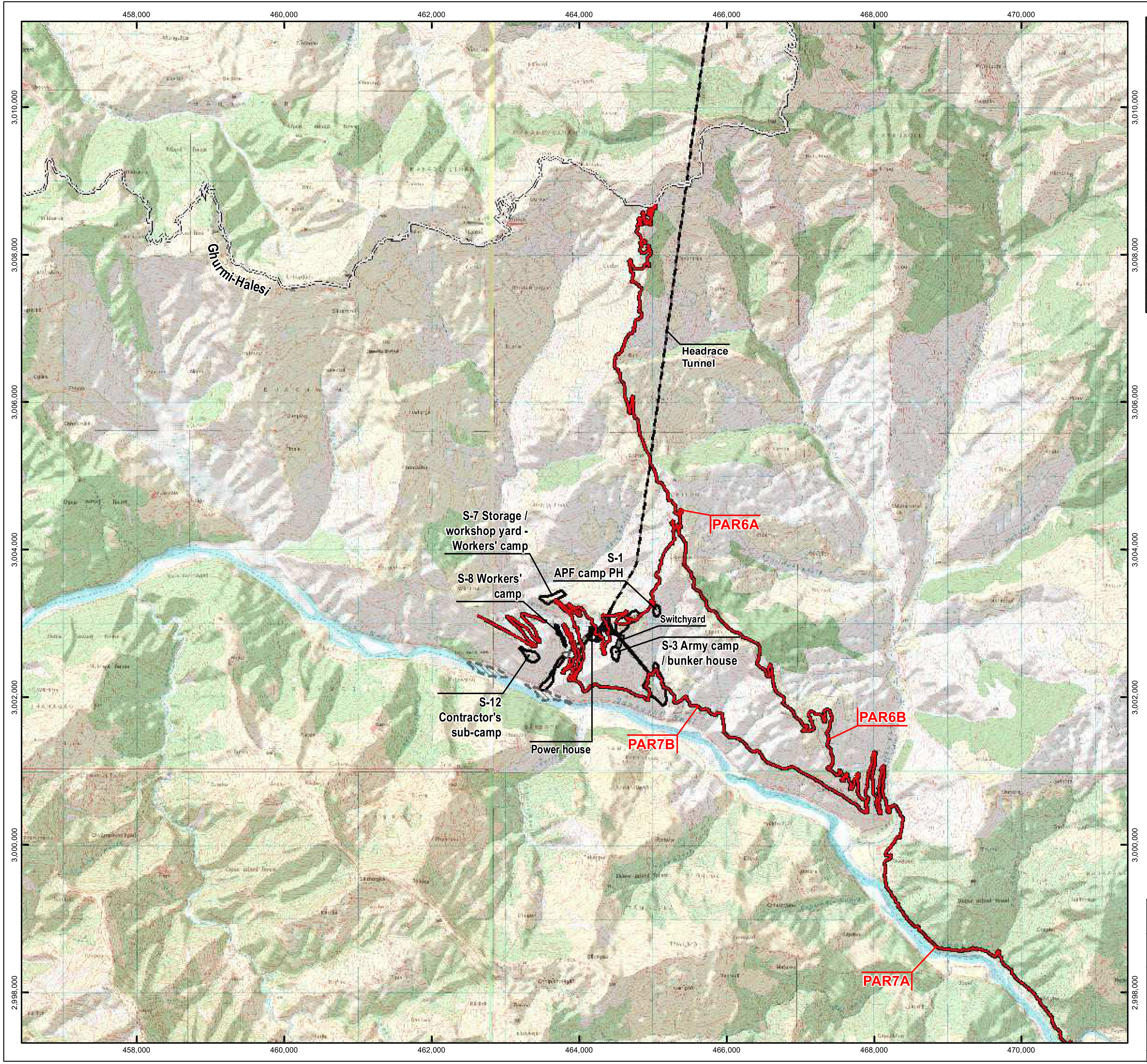
3	Issue for comments	26/8/2024	ELC	LGA	PAR
2	Issue for comments	3/2/2020	ELC	LGA	PAR
1	Issue for comments	28/1/2020	ELC	LGA	PAR
0	First issue	15/8/2019	ELC	LGA	PAR
REV.	**Revisions**	**Day Month Year**	**Drawn**	**Checked**	**Approved**

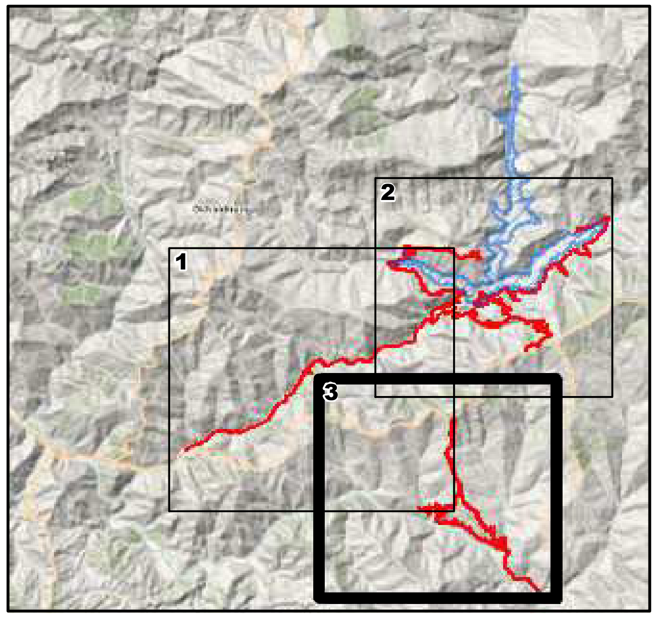
DUDHKOSHI HYDROPOWER PROJECT

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

DETAILED DESIGN
ACCESS ROADS
RESERVOIR ROADS

1765-T4-D-ARG-0002-0101-03	Size A3	Scale 1:50,000





Legend

- New roads
- Upgrade of existing roads
- Existing roads
- Reservoir at El. 640 m a.s.l.
- Quarries and borrow areas
- Disposal areas

0 0.5 1 2 3 4 km

Topographic base: Nepal 50k topographic map

Reference system: Modified UTM 87
Datum: Nepal Nagarkot
Spheroid: Everest_Adjustment_1937
Semimajor Axis: 6,377,276.345
Inverse Flattening: 300.8017

REV.	Revisions	Day Month Year	Drawn	Checked	Approved
3	Issue for comments	26/8/2024	ELC	LGA	PAR
2	Issue for comments	3/2/2020	ELC	LGA	PAR
1	Issue for comments	28/1/2020	ELC	LGA	PAR
0	First issue	15/8/2019	ELC	LGA	PAR

ELC ELECTROCONSULT | NEWJEC

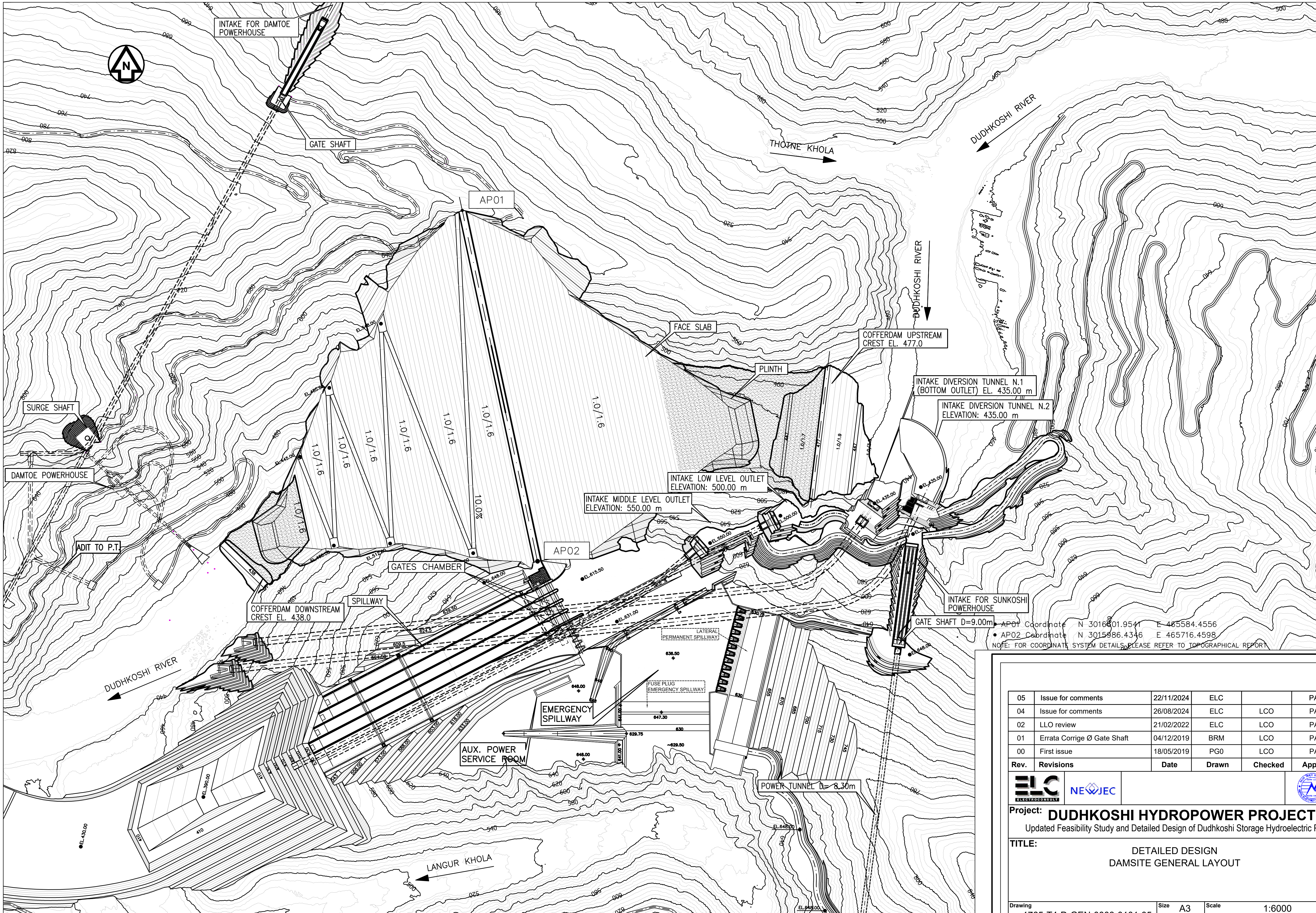
DUDHKOSHI HYDROPOWER PROJECT

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

DETAILED DESIGN
ACCESS ROADS
DAMSITE-MAIN P.H. AREA CONNECTING ROADS

1765-T4-D-ARG-0003-0101-03 | Size A3 | Scale 1:50,000

GENERAL LAYOUT OF CFRD DAM – (CREST EL. 648.00 m.a.s.l.)



Rev.	Revisions	Date	Drawn	Checked	Approved
05	Issue for comments	22/11/2024	ELC		PAR
04	Issue for comments	26/08/2024	ELC	LCO	PAR
02	LLO review	21/02/2022	ELC	LCO	PAR
01	Errata Corrige Ø Gate Shaft	04/12/2019	BRM	LCO	PAR
00	First issue	18/05/2019	PG0	LCO	PAR

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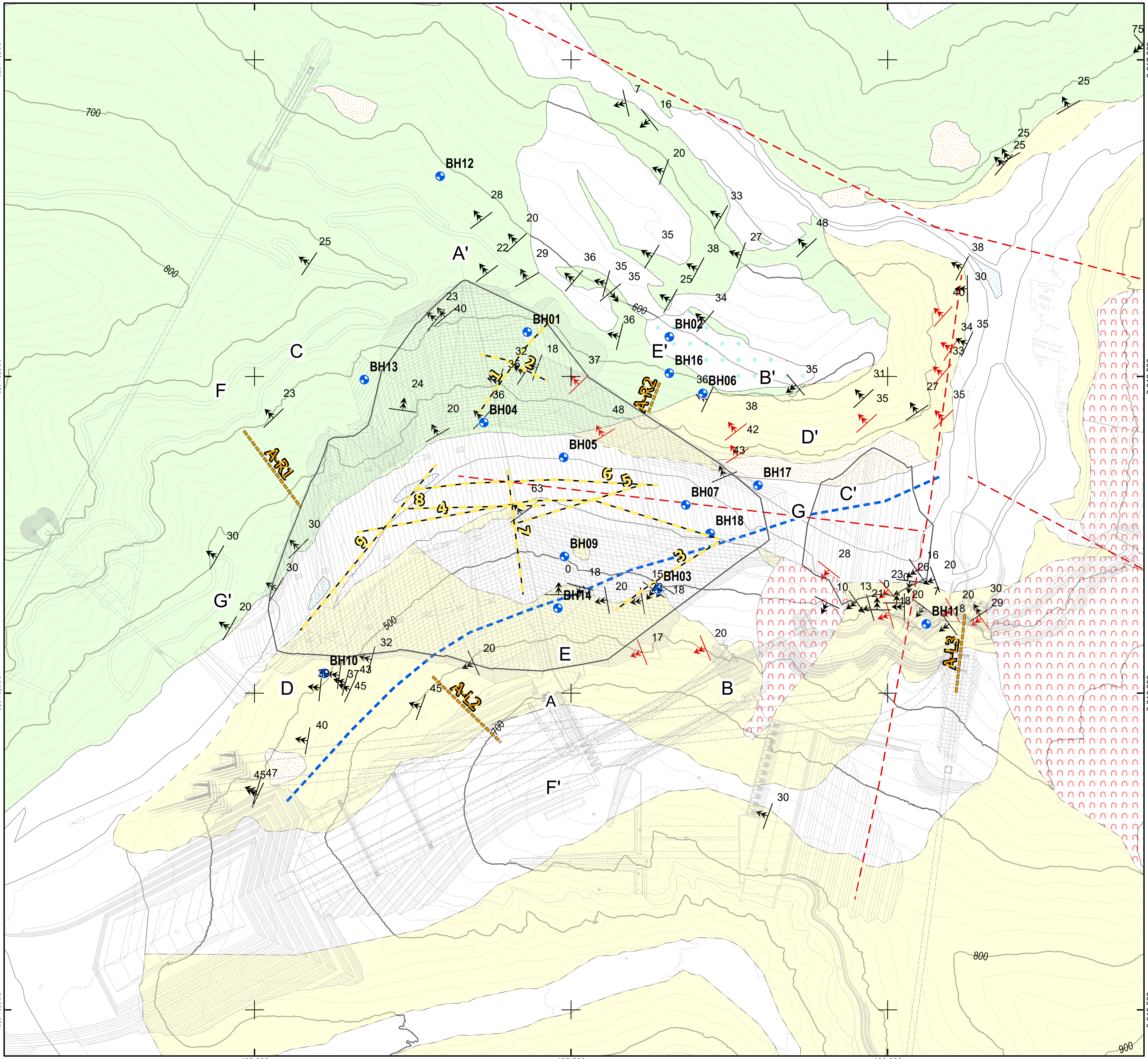
Project: **DUDHKOSHI HYDROPOWER PROJECT**
Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

TITLE:
DETAILED DESIGN
DAMSITE GENERAL LAYOUT

Drawing	Size	Scale
1765-T4-D-GEN-0003-0101-05	A3	1:6000



N

Legend

- Boreholes
- Adit tunnels
- Seismic profiles
- Inferred faults from LIDAR analysis
- Foliation Dip Direction
- TLS - Foliation Dip Direction
- Fold axial plane

Geological units

- Alluvial and terrace deposits, alluvial fans: sand, gravel and boulders
- Slope deposits: heterogeneous soil, debris, colluvium.
- Landslide deposits
- Glacial deposits: gravel and boulders of different lithotypes (phyllite, quartzite, gneiss)
- Quartzites: white, pinkish, greenish, grey coarse grained quartzites with intercalation of phyllites
- Phyllites: greenish, grey phyllites, fine to medium grained with quartz veins and intercalations of quartzites

0 50 100 200 300 400 Meters

Topographic base: Nepal 50k topographic map

Reference system: Modified UTM 87
Datum: Nepal Nagarkot

Spheroid: Everest_Adjustment_1937
Semimajor Axis: 6,377,276.345
Inverse Flattening: 300.8017

04	Project layout overlay	29/11/2024	ELC		PAR
03		26/08/2024	AGM	AGM, TAM	PAR
02	Geology Update	02/07/2024	AGM	AGM, TAM	PAR
01	Issue for comments	24/01/2020	SIA	SIA, TAM	PAR
00	Issue for comments	18/5/2019	SIA	SIA, TAM	PAR
	Revisions	Date	Drawn	Checked	Approved

ELC NEWJEC

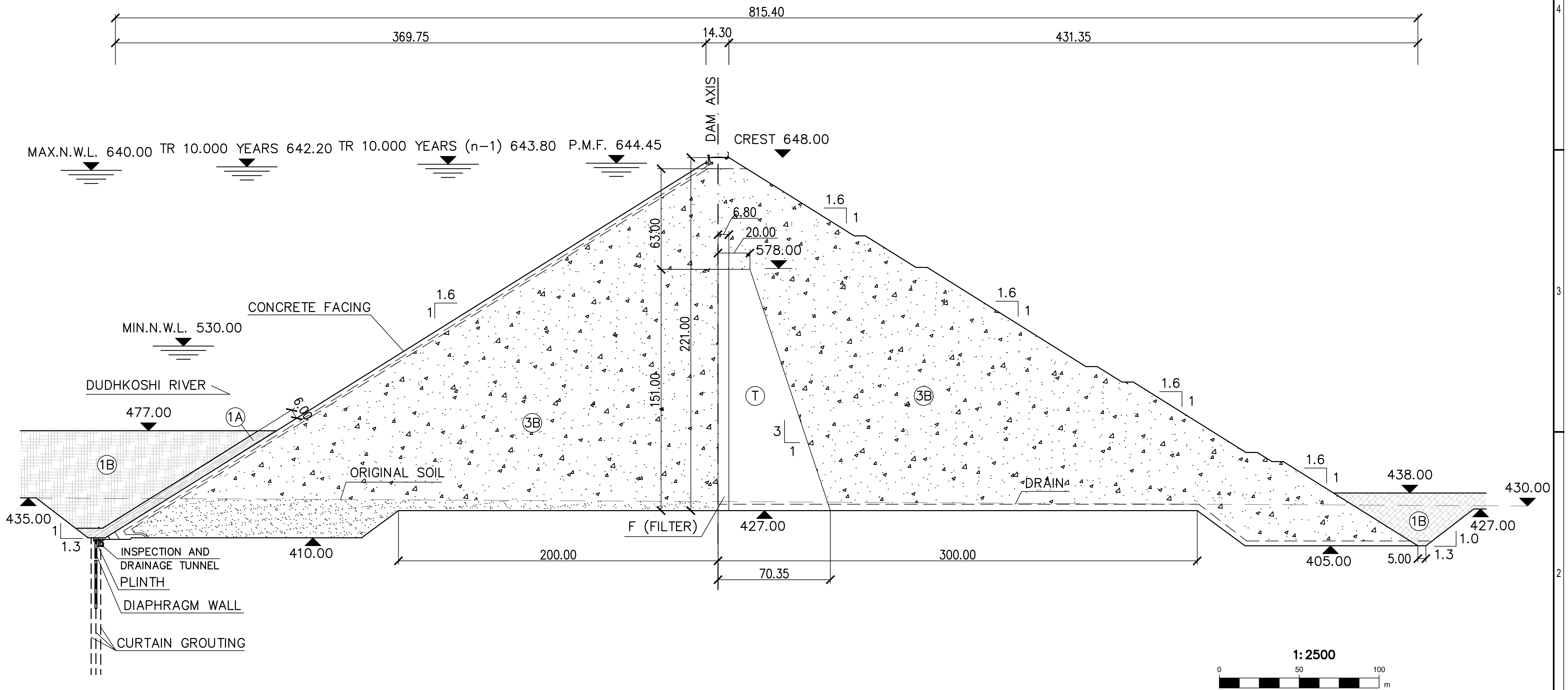
DUDHKOSHI HYDROPOWER PROJECT

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

GEOLOGICAL MAP OF DAM SITE

1765-T4-D-GEG-0002-0101-04	Size A3	Scale 1:6,000

DAM TYPICAL CROSS SECTION



MATERIAL (ZONE)	SPECIFICATION
1A COHESIONLESS SOIL	Compacted by construction equipments
1B RANDOM MATERIAL	Compacted by construction equipments
2A PROCESSED MATERIAL (ømax 34")	Manual compaction
2B PROCESSED MATERIAL (ømax 3"-4")	4-6 passes of 12 ton vibratory roller
3A SELECTED SMALL ROCK PLACED IN SAME LAYER THICKNESS AS ZONE 2	
3B QUARRY RUN ROCKFILL, ABOUT 0.60m TO 0.80m LAYERS	4-6 passes of 12 ton vibratory roller
T QUARRY RUN ROCKFILL (ø max 400-600mm), ABOUT 0.40m TO 0.60m LAYERS	4 passes of 10 ton vibratory roller

Rev.	Revisions	Date	Drawn	Checked	Approved
03	Grouting gallery	06/11/2024	ELC		
02	Layout Revision	09/10/2024	PER	PER	PAR
01	Revision of Dam Zones	04/12/2019	BRM	LCO	PAR
00	First issue	18/05/2019	PG0	LCO	PAR

NEWJEC

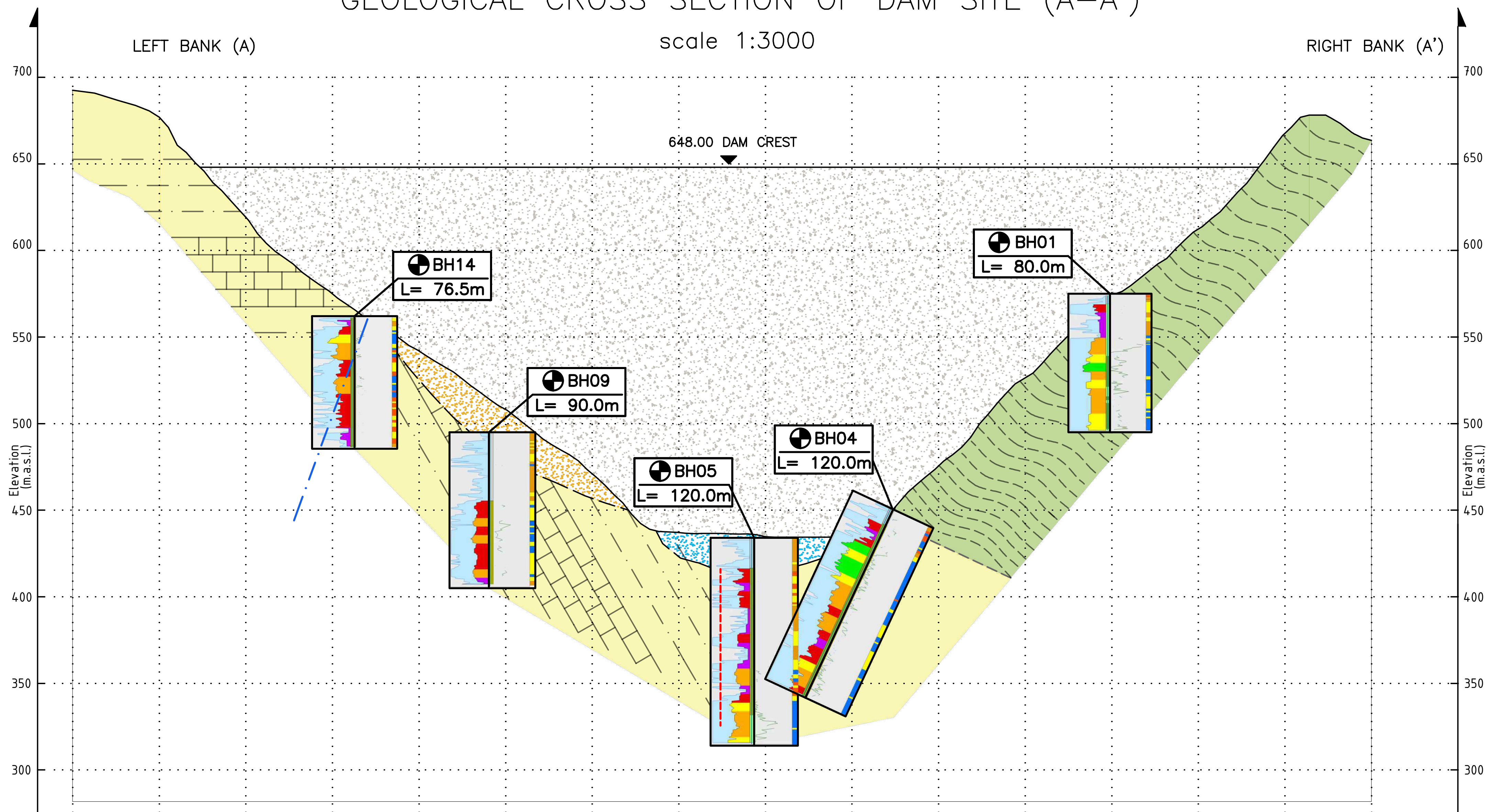
Project: **DUDHKOSHI HYDROPOWER PROJECT**
Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

TITLE:
DETAILED DESIGN
CFRD
TYPICAL CROSS SECTION

Drawing	Size	Scale
1765-T4-D-DAM-0004-0101-03	A3	1:2500

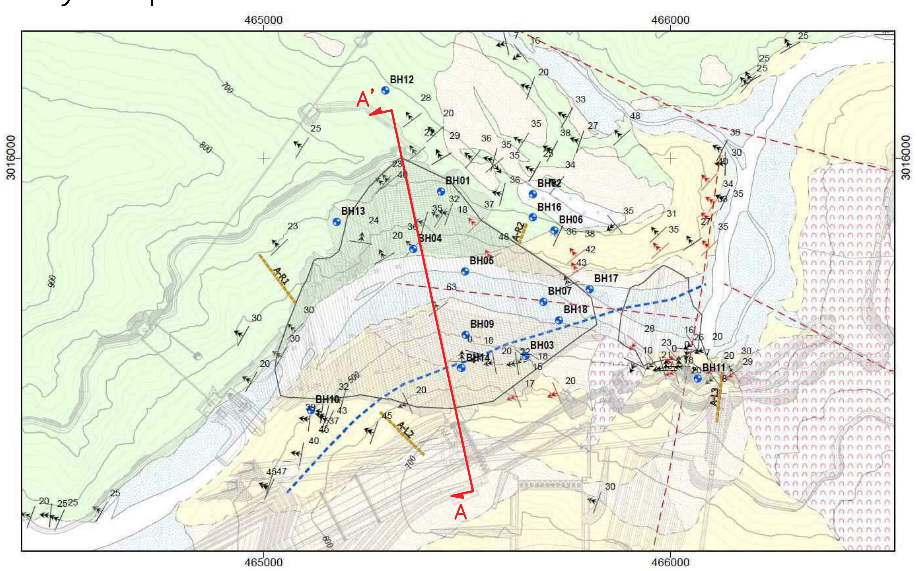
GEOLOGICAL CROSS SECTION OF DAM SITE (A–A')

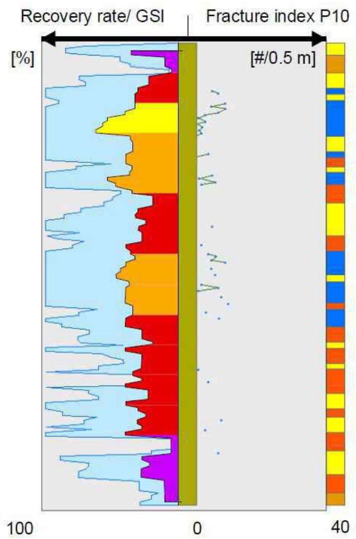
scale 1:3000



Partial distances (m)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Progressive distances (m)	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750
Hectometre distances (m)																
Existing level (m)	748.28	682.18	622.40	567.42	522.24	493.29	459.64	430.91	430.67	431.12	487.46	525.76	555.61	605.08	657.69	645.45

Key Map





Fracturation State

- Not recovered
- Sludge
- Rubble
- Recovered

GSI

- 5 – 25
- 25 – 35
- 35 – 45
- 45 – 55
- 55 – 65

Legend:

- Boreholes
- Dam – Section along Dam axis
- Dam – Key Map
- Headrace Tunnel

Quaternary deposits

- Active landslide scarps
- Active landslide
- Alluvial Deposits
- Slope Deposits
- Glacial Deposits

Bedrock

- Foliation Dip – Key Map
- Phyllites
- Quartzites
- Recovery Rate
- Faults inferred
- Fold axis Plain
- Foliation or Bedding
- Fracture Index
- Tectonic boundary

Scales:

1:3000

0 30.0 60.0 90.0 m

Rev.	Revisions	Date	Drawn	Checked	Approved
02	REVISION no. 02	04/07/2024	AGM	AGM / TAM	PAR
01	REVISION no. 01	31/12/2020	SIA	SIA / TAM	PAR
00	First issue	18/05/2019	SIA	SIA / TAM	PAR

ELC ELECTROCONSULT
NEWJEC

Project: **DUDHKOSHI HYDROPOWER PROJECT**

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

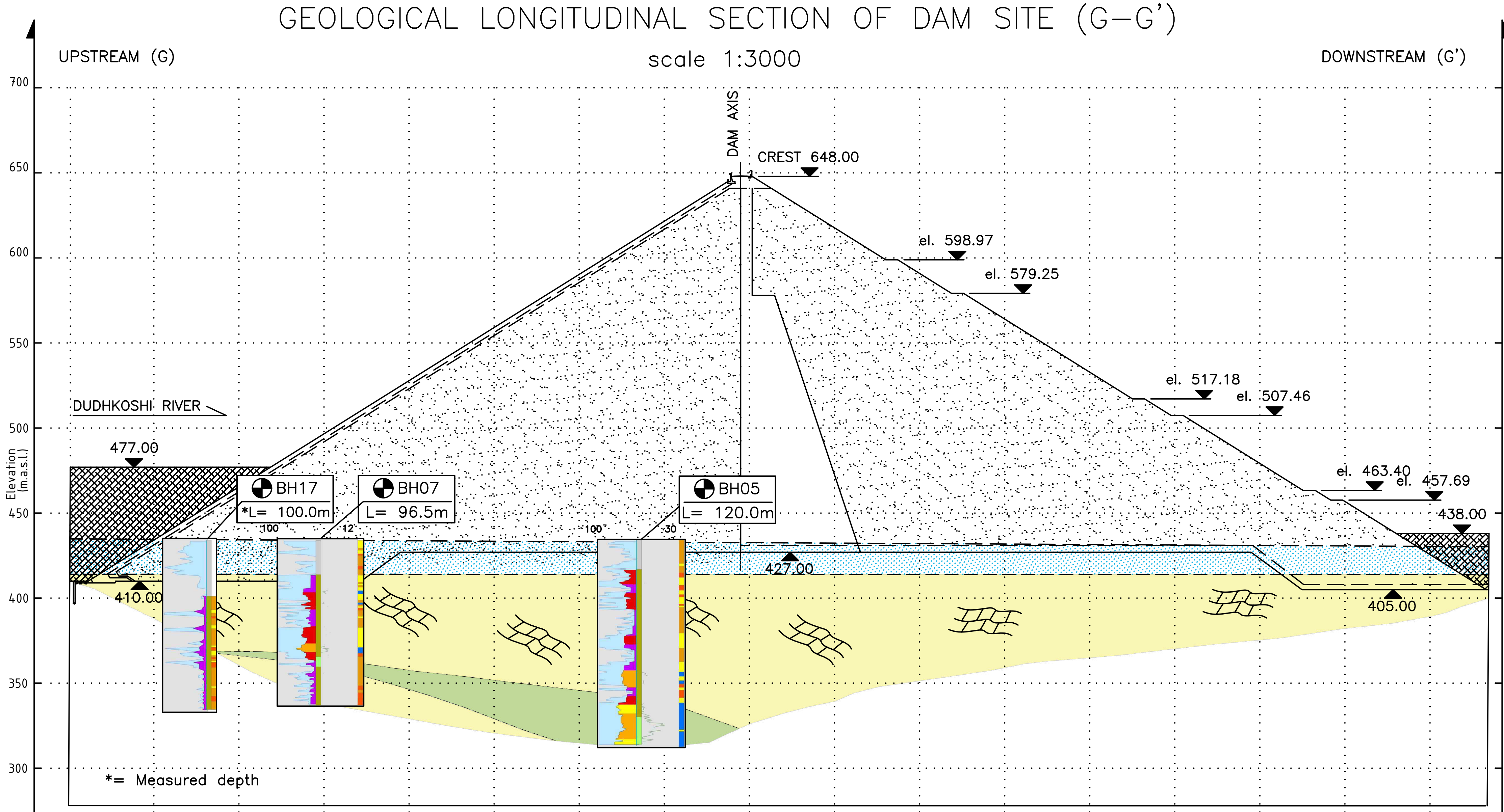
TITLE:

DETAILED DESIGN
GEOLOGICAL CROSS SECTION OF DAM SITE
SECTION A-A'

Drawing	Size	Scale
1765-T4-D-GEG-0007-0101-02	A3	1:3000

GEOLOGICAL LONGITUDINAL SECTION OF DAM SITE (G–G')

scale 1:3000



Partial distances (m)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Progressive distances (m)	0	135.41	323.98	800												
Hectometre distances (m)																
Existing level (m)	435.00	434.00														

Legend:

- Boreholes
- Dam – Section along Dam axis
- Dam – Key Map
- Headrace Tunnel

Quaternary deposits

- Active landslide scarps
- Active landslide
- Alluvial Deposits
- Slope Deposits
- Glacial Deposits

Bedrock

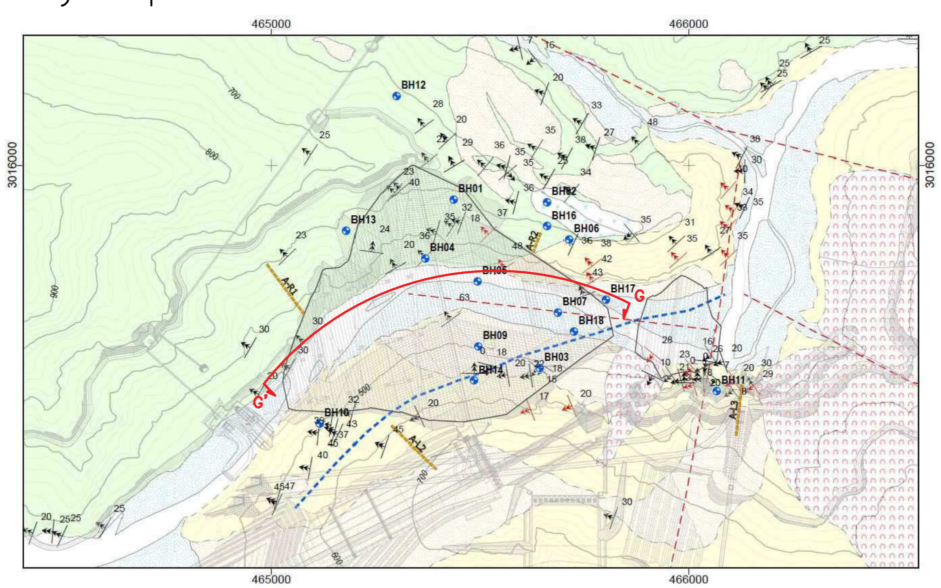
- Foliation Dip – Key Map
- Phyllites
- Quartzites
- Recovery Rate
- Faults inferred
- Fold axis Plain
- Foliation or Bedding
- Fracture Index
- Tectonic boundary
- Perpendicular sections
- Adit Tunnels

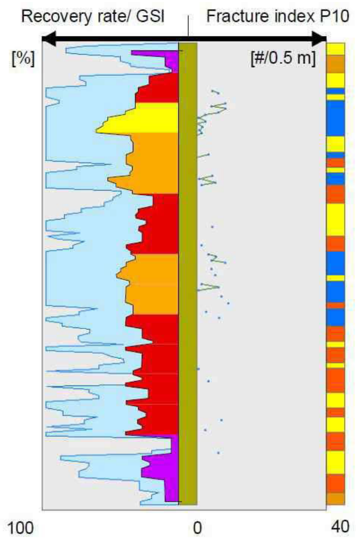
Scales:

1:3000

0 30.0 60.0 90.0 m

Key Map





Fracturation State

- Not recovered
- Sludge
- Rubble
- Recovered

GSI

- 5 – 25
- 25 – 35
- 35 – 45
- 45 – 55
- 55 – 65

Rev.	Revisions	Date	Drawn	Checked	Approved
02	REVISION no. 02	02/07/2024	AGM	AGM	PAR
01	REVISION no. 01	31/12/2020	SIA	SIA / TAM	PAR
00	First issue	18/05/2019	SIA	SIA / TAM	PAR

ELC ELECTROCONSULT — NEWJEC

Project: DUDHKOSHI HYDROPOWER PROJECT

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

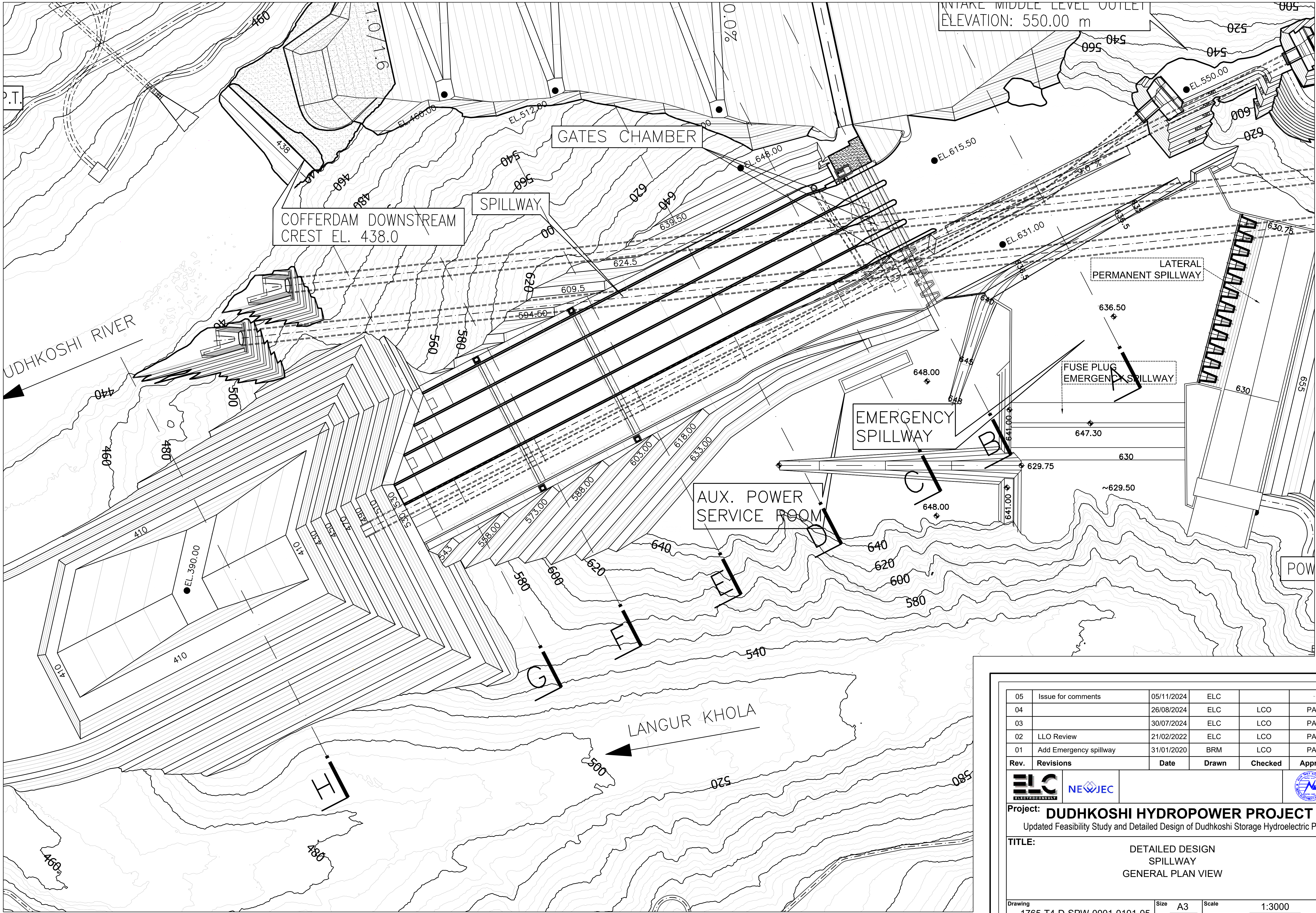
TITLE:

DETAILED DESIGN
GEOLOGICAL LONGITUDINAL SECTION OF DAM SITE
SECTION G-G'

Drawing	Size	Scale
1765-T4-D-GEG-0009-0101-02	A3	1:3000

SPILLWAY GENERAL PLAN VIEW

scale 1: 3000



Rev.	Revisions	Date	Drawn	Checked	Approved
05	Issue for comments	05/11/2024	ELC		-
04		26/08/2024	ELC	LCO	PAR
03		30/07/2024	ELC	LCO	PAR
02	LLO Review	21/02/2022	ELC	LCO	PAR
01	Add Emergency spillway	31/01/2020	BRM	LCO	PAR

ELC ELECTROCONSULT NEWJEC

Project: DUDHKOSHI HYDROPOWER PROJECT

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

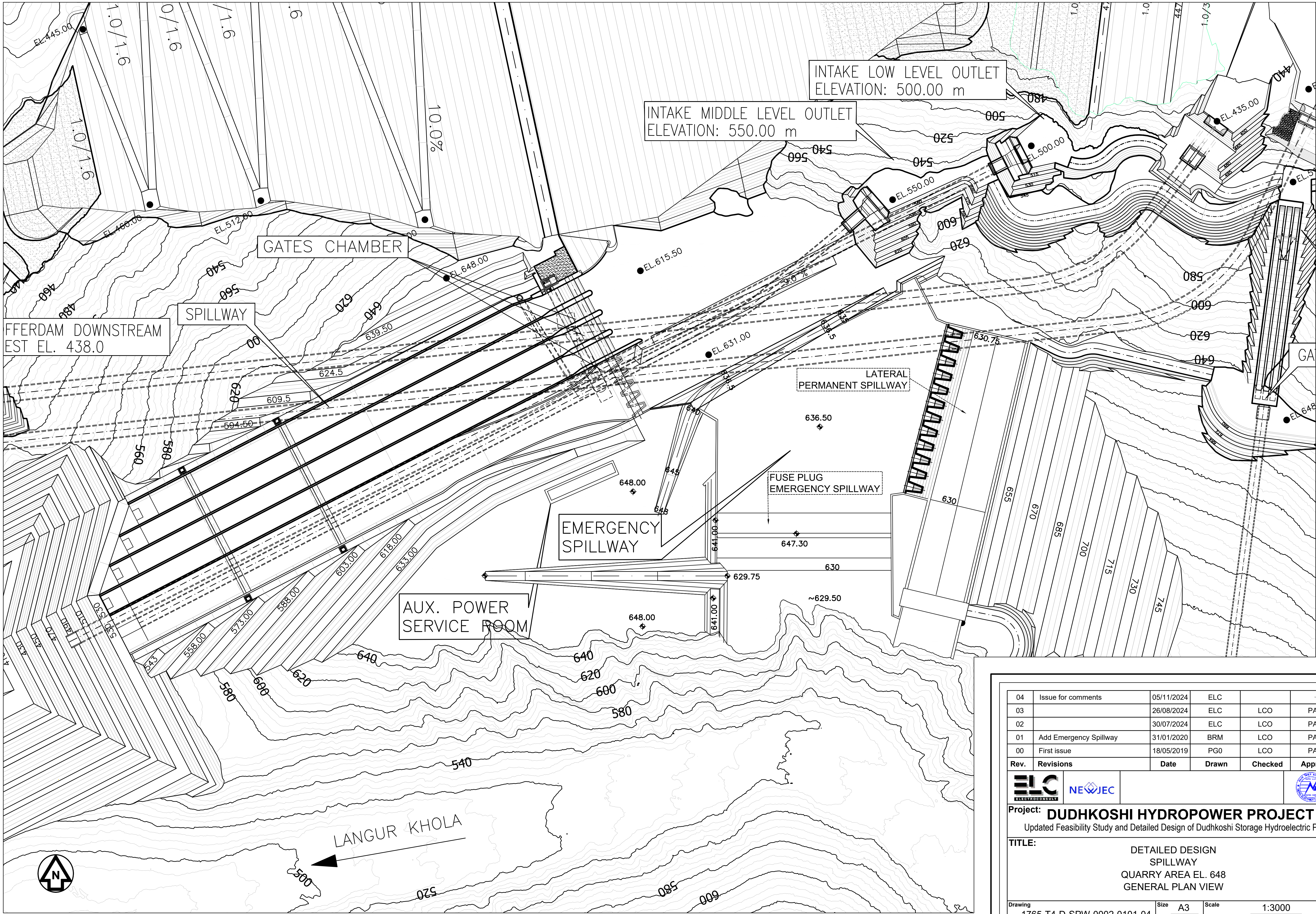
TITLE:

DETAILED DESIGN
SPILLWAY
GENERAL PLAN VIEW

Drawing: 1765-T4-D-SPW-0001-0101-05 | Size: A3 | Scale: 1:3000

QUARRY AREA EL. 648.0 m – GENERAL PLAN VIEW

scale 1: 3000



Rev.	Revisions	Date	Drawn	Checked	Approved
04	Issue for comments	05/11/2024	ELC		-
03		26/08/2024	ELC	LCO	PAR
02		30/07/2024	ELC	LCO	PAR
01	Add Emergency Spillway	31/01/2020	BRM	LCO	PAR
00	First issue	18/05/2019	PG0	LCO	PAR

ELC ELECTROCONSULT NEWJEC

Project: **DUDHKOSHI HYDROPOWER PROJECT**

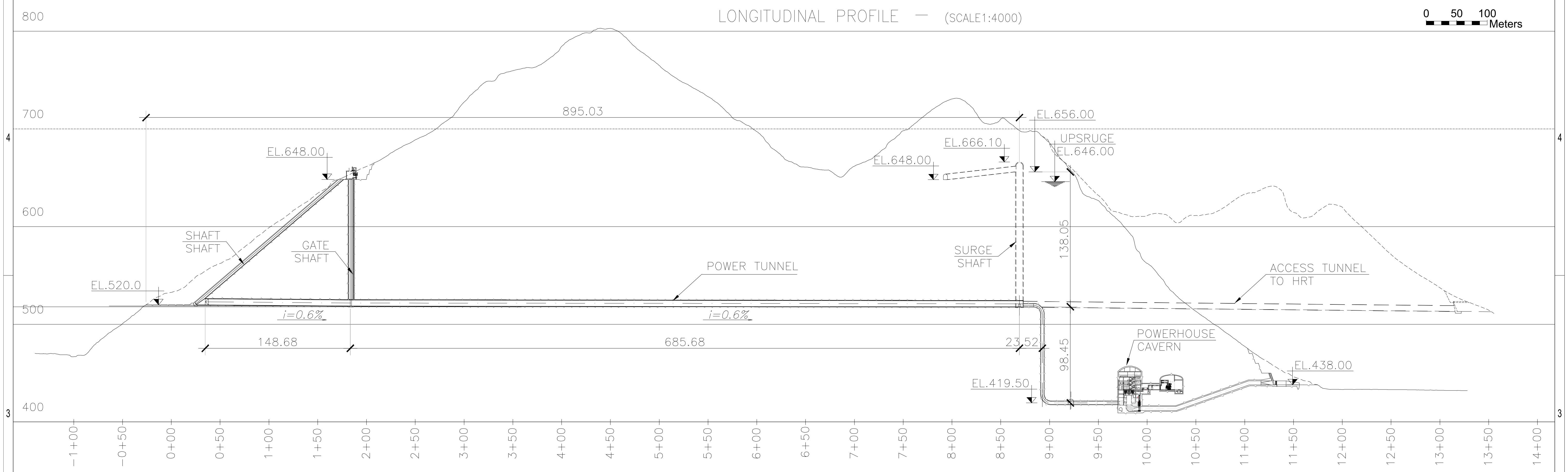
Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

TITLE:

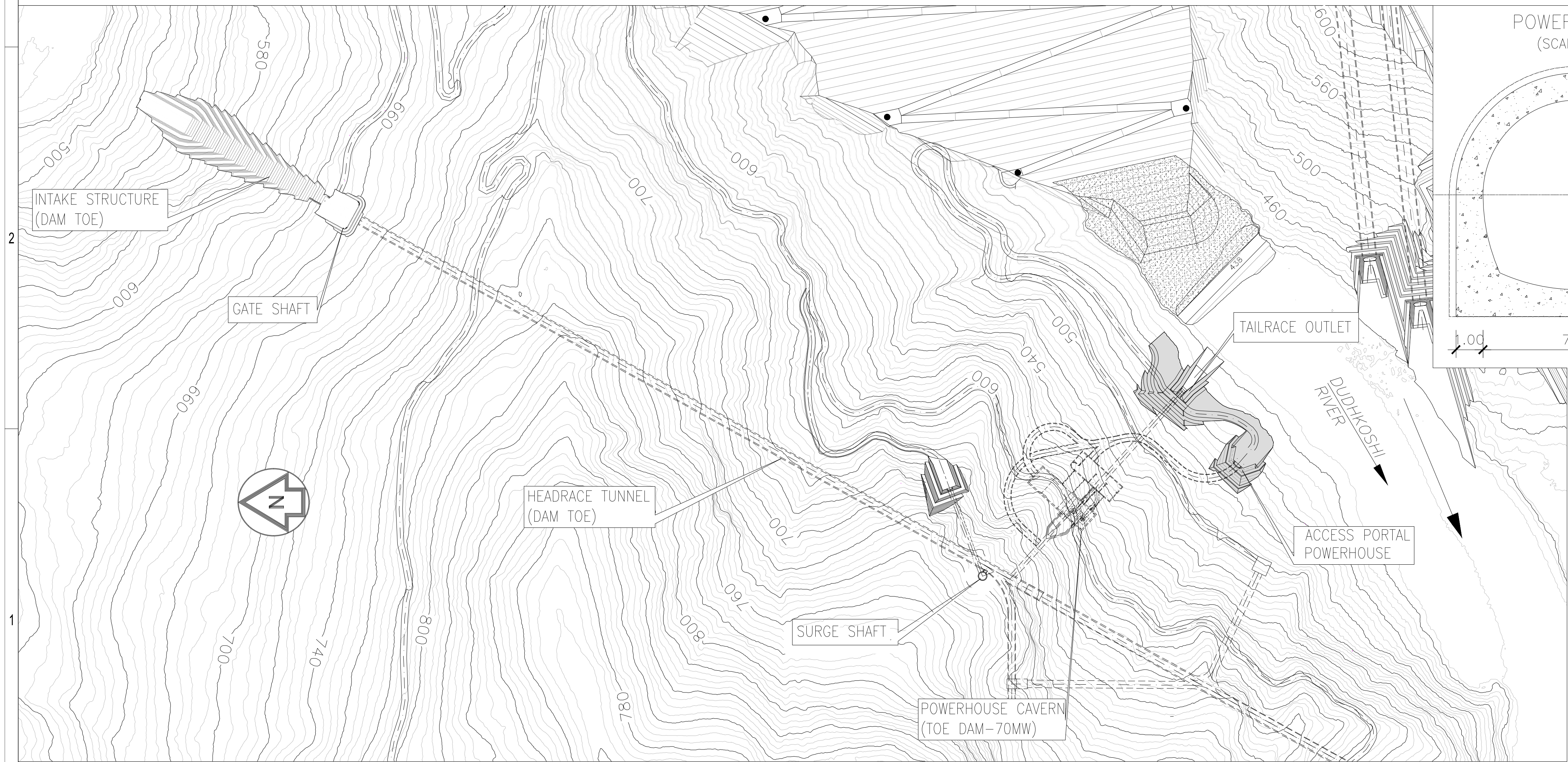
DETAILED DESIGN
SPILLWAY
QUARRY AREA EL. 648
GENERAL PLAN VIEW

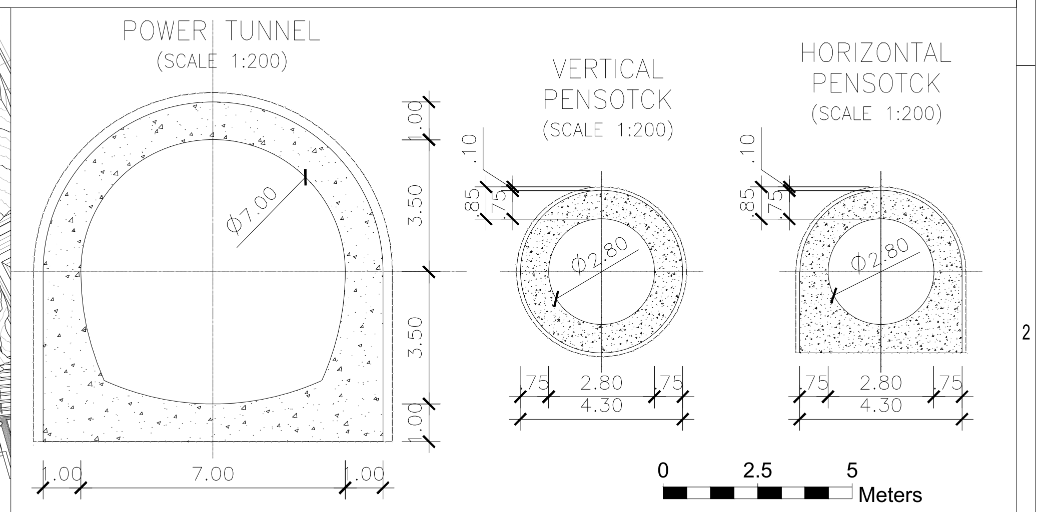
Drawing	Size	Scale
1765-T4-D-SPW-0002-0101-04	A3	1:3000

LONGITUDINAL PROFILE — (SCALE1:4000)



GENERAL PLAN — (SCALE1:5000)





Rev.	Revisions	Date	Drawn	Checked	Approved
03	New layout	26/11/2024	ELC	LCO	PAR
02	New layout	31/07/2024	ELC	LCO	PAR
01	Change Ø Penstock	31/01/2020	BRM	LCO	PAR
00	FIRST ISSUED	18/05/2019	BRM	LCO	PAR

ELC ELECTROCONSULT NEWJEC

Project: **DUDHKOSHI HYDROPOWER PROJECT**

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

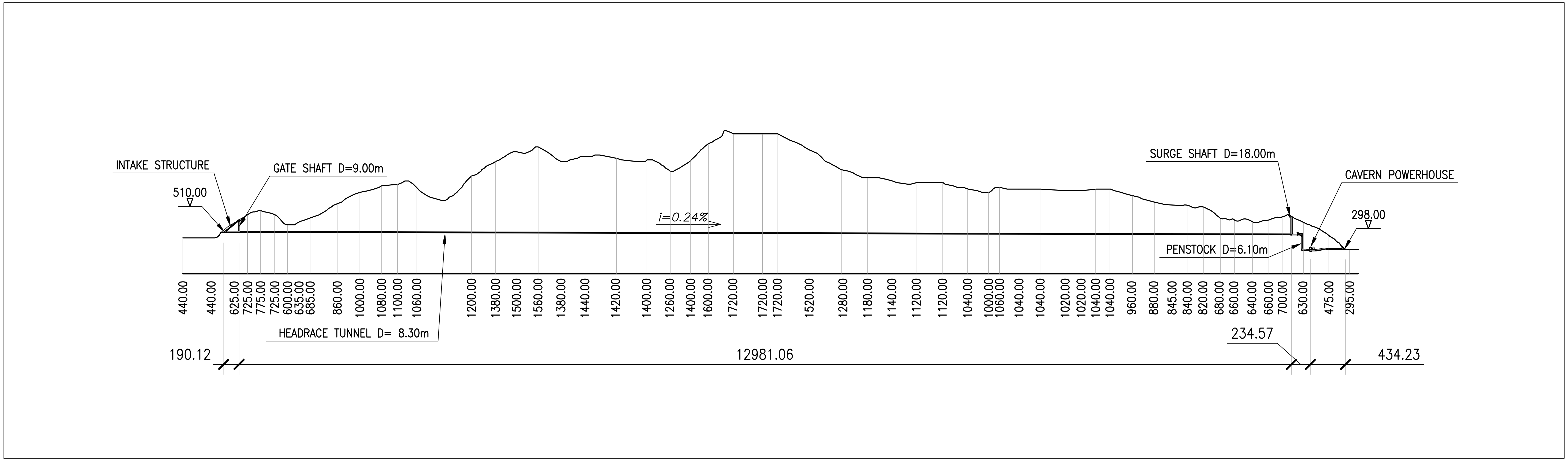
TITLE:

DETAILED DESIGN
DAM TOE POWER PLANT
GENERAL PLAN, LONGITUDINAL PROFILE AND SECTIONS

Drawing	Size	Scale
1765-T4-D-DTP-0001-0101-03	A3	Various

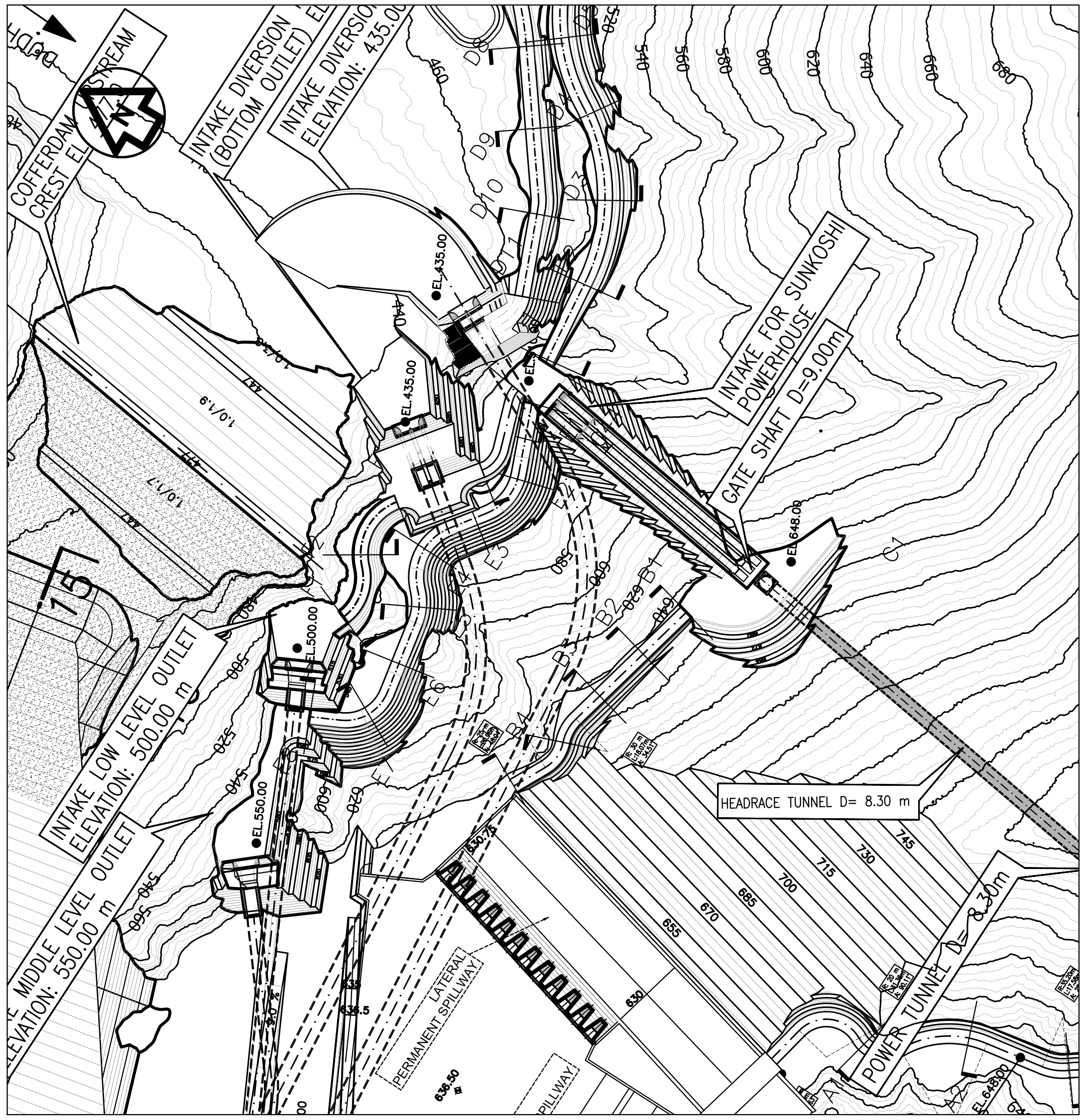
LONGITUDINAL PROFILE OF HEADRACE TUNNEL

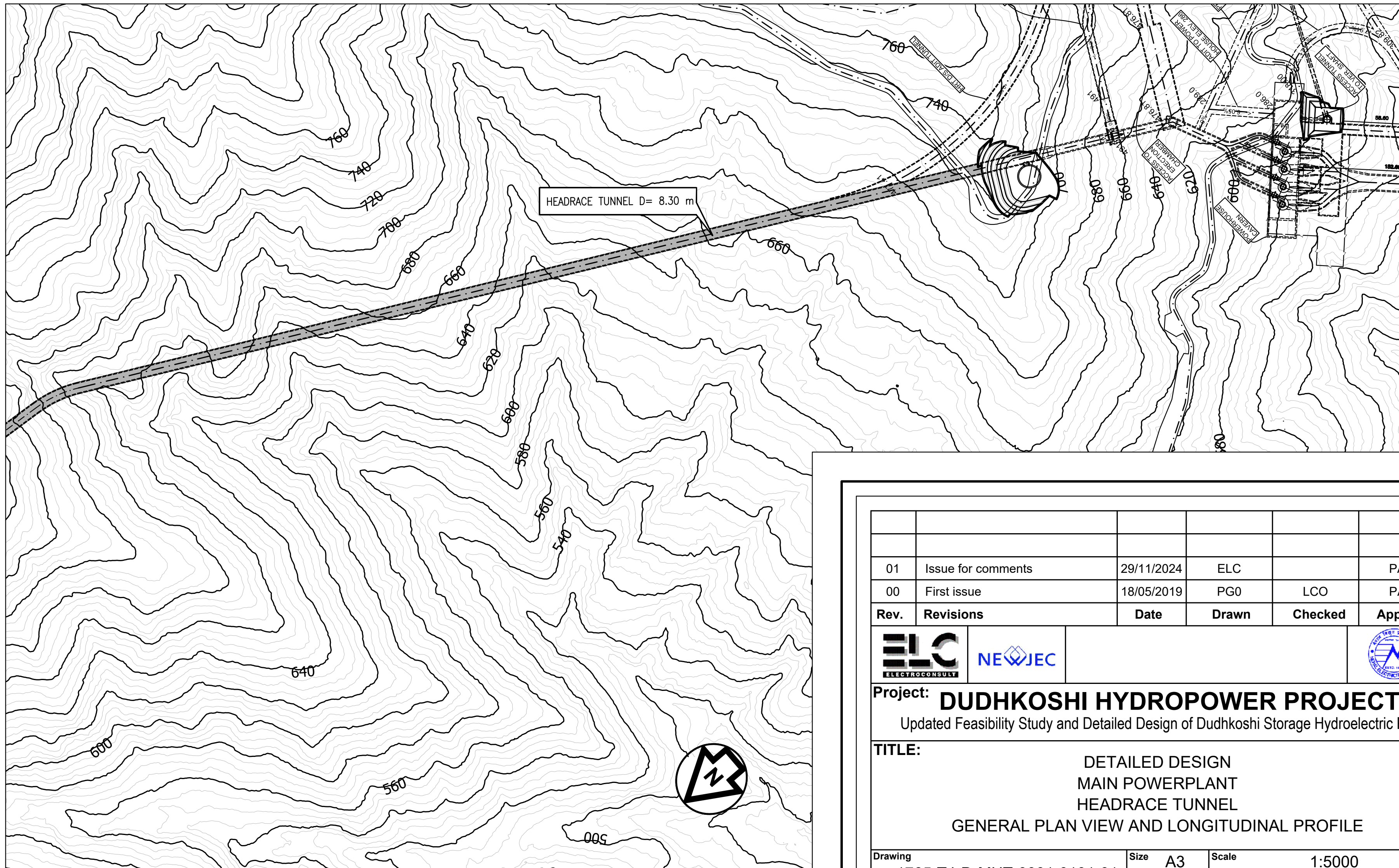
scale 1:50000



GENERAL PLAN VIEW

scale 1:5000





Rev.	Revisions	Date	Drawn	Checked	Approved
01	Issue for comments	29/11/2024	ELC		PAR
00	First issue	18/05/2019	PG0	LCO	PAR

ELC ELECTROCONSULT — NEWJEC

Project: DUDHKOSHI HYDROPOWER PROJECT

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

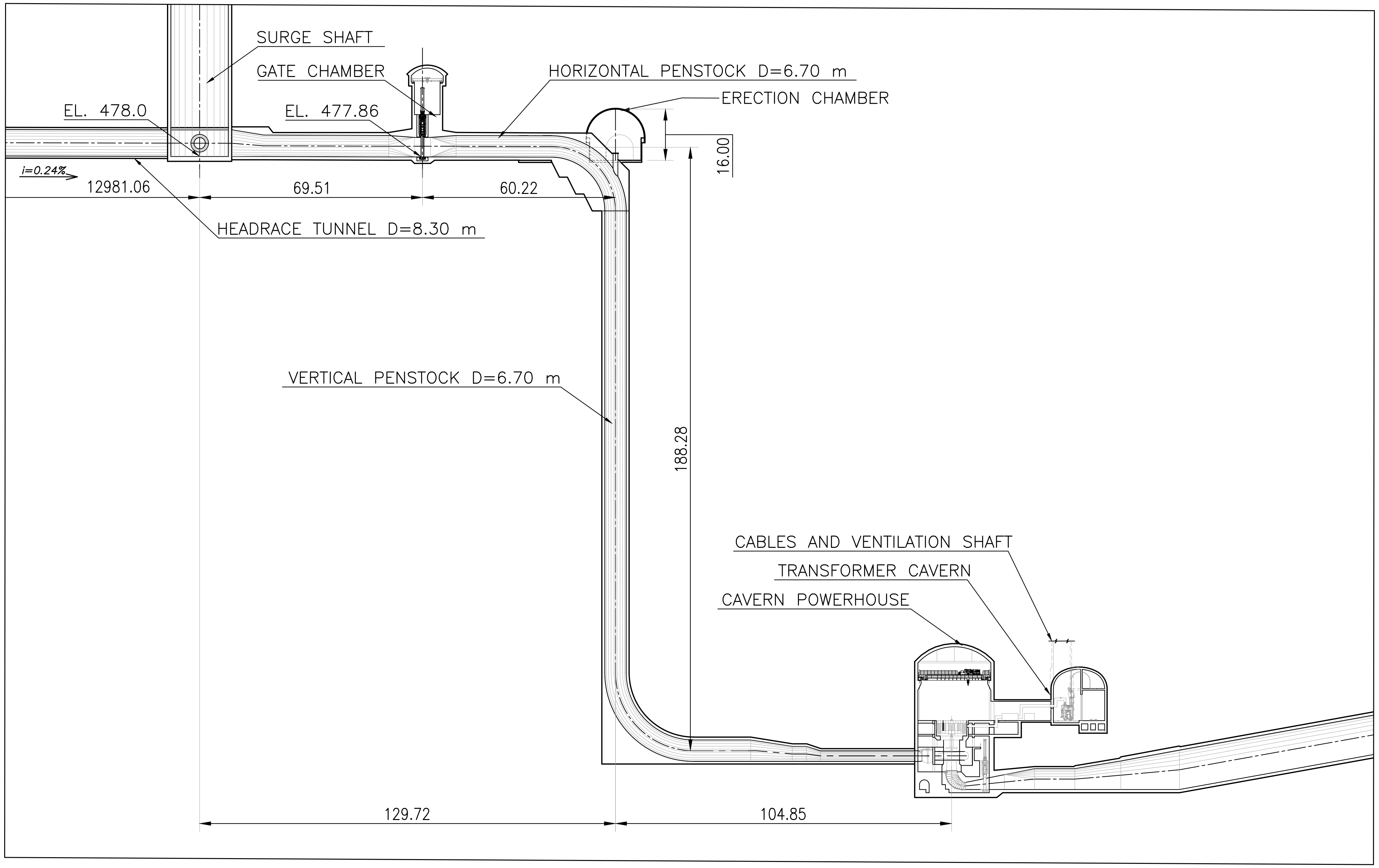
TITLE:

DETAILED DESIGN
MAIN POWERPLANT
HEADRACE TUNNEL
GENERAL PLAN VIEW AND LONGITUDINAL PROFILE

Drawing	Size	Scale
1765-T4-D-MHT-0001-0101-01	A3	1:5000 / 1:50000

LONGITUDINAL PROFILE

scale 1:1500



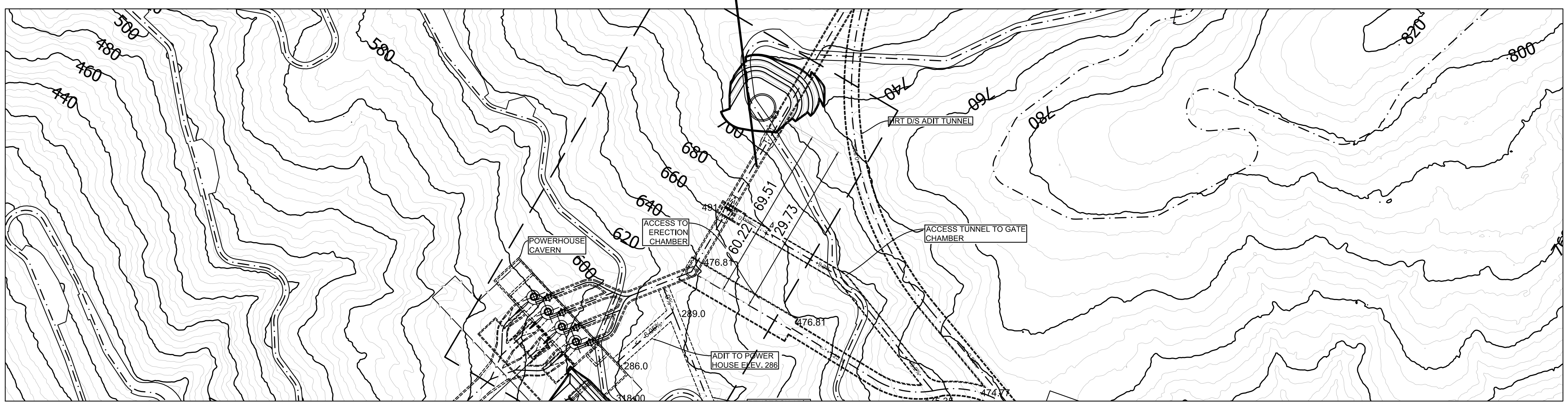
1:1500 :
0 15 30 45 m

1:4000 :
0 40 80 120 m

PLAN VIEW

horizontal and vertical penstock

scale 1:4000



Rev.	Revisions	Date	Drawn	Checked	Approved
03	Issue for comments	15/10/2024	ELC		PAR
02	Updated Survey	31/05/2023	AC	LCO	PAR
01	Changes of diameter H-Penstock	13/12/2019	BRM	LCO	PAR
00	First issue	18/05/2019	PG0	LCO	PAR

ELC ELECTROCONSULT NEWJEC

Project: **DUDHKOSHI HYDROPOWER PROJECT**

Updated Feasibility Study and Detailed Design of Dudhkoshi Storage Hydroelectric Project

TITLE:

DETAILED DESIGN
MAIN POWERPLANT
PENSTOCK
PLAN VIEW AND PROFILE

Drawing	Size	Scale
1765-T4-D-MPK-0001-0101-03	A3	1:1500 / 1:4000