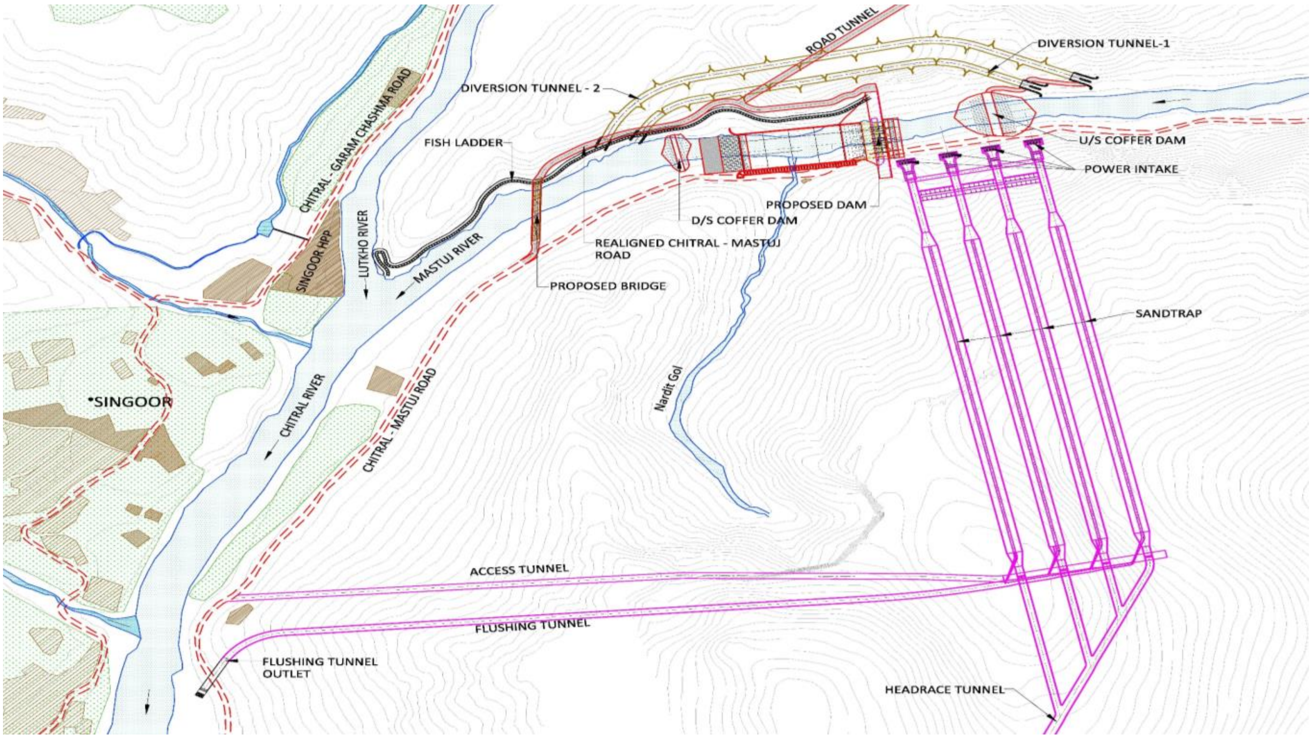
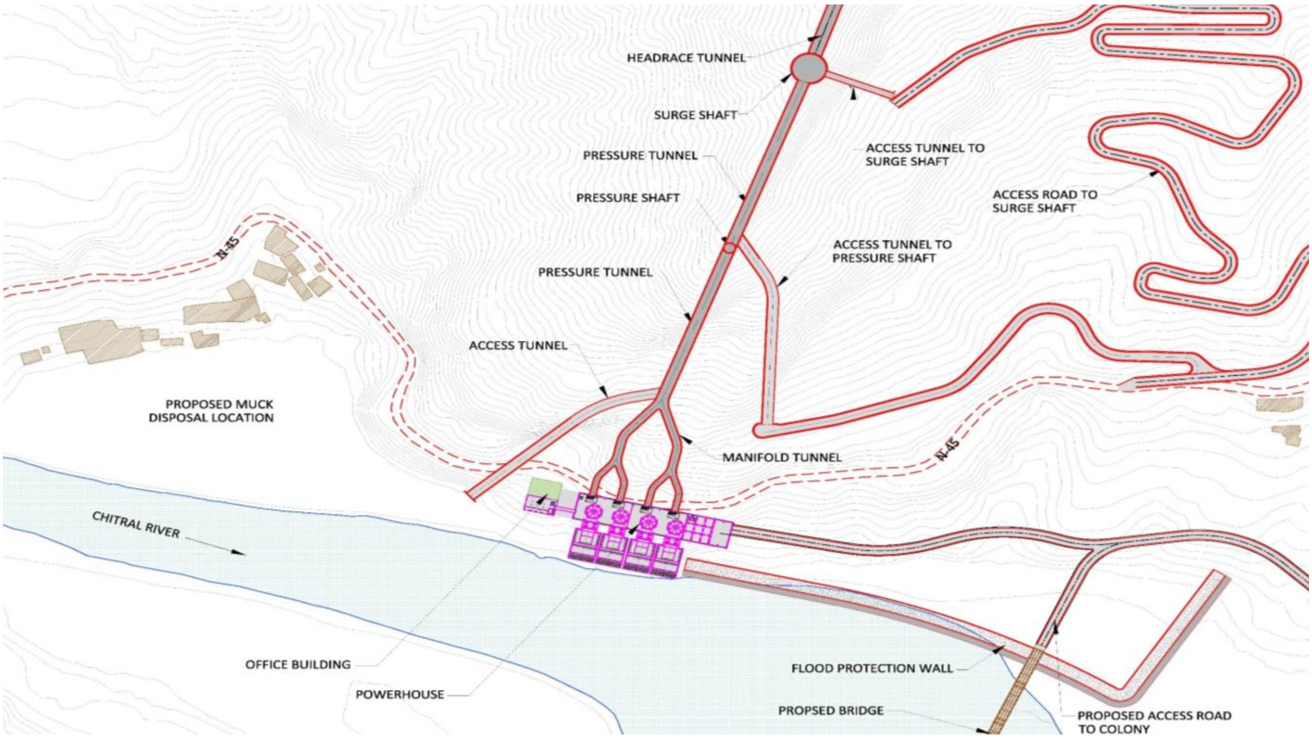
PAKHTUNKHWA ENERGY DEVELOPMENT ORGANIZATION (PEDO)
GOVERNMENT OF KHYBER PAKHTUNKHWA

FEASIBILITY REPORT
KARI MUSKHUR HYDROPOWER PROJECT (495MW)
DISTRICT CHITRAL



VOLUME – I
EXECUTIVE SUMMARY



Consultants AGES | DOLSAR | team

REPORT COMPOSITION

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EXECUTIVE SUMMARY

1 THE PROJECT

The proposed Kari Muskhur Hydropower Project (495MW) is run of the river scheme on the Mastuj River. The project major structures include dam, sandtrap, headrace & road tunnels, diversion tunnels, flushing tunnels, access tunnels, surge shaft, pressure shaft, powerhouse, residential colony, access roads and bridges on the Chitral River. The dam/intake site, proposed 2.6km D/S of Kari village, is accessible through Chitral-Mastuj road whereas adits to the headrace tunnel, powerhouse and colony will be accessed through N-45 road (Chakdara-Chitral road).

Under the project, concrete gravity dam of 40m height will be constructed across the Mastuj River to divert 345m^3/sec design discharge to the power waterway of KMHPP. Headrace tunnel of 27.22km length and 10.8m diameter (Circular) through Hindu Raj mountains will carry the design discharge to powerhouse, identified at left bank of the Chitral River in Gang village. The project residential colony, proposed in Shedi village, will be accessed through construction of 293m long bridge across the river. Also, along right bank of the Mastuj River, 3.19km long road tunnel will be constructed in place of the inundated section of Chitral-Mastuj road.

Four vertical shaft Francis turbines, each 123.75MW capacity with generators, powerhouse overhead gantry crane of 2x175 tonnes capacity, Supervisory Control and Data Acquisition (SCADA) and Power Line Carrier (PLC) are some of the major equipment and monitoring/communication systems to be installed under the project electromechanical works.

Gas Insulated Switchyard (GIS) has been proposed on top of the powerhouse building, and power evacuation from the power plant to National Grid through loop-in loop-out arrangement of the proposed 500kV Chitral transmission line. On average, KMHPP will add 2164.94 GWh annual energy to National Grid.

Figure 1 presents layout plan of the project whereas plan of the dam and powerhouse sites along with appurtenant structures are attached as Figure 3 and Figure 4.

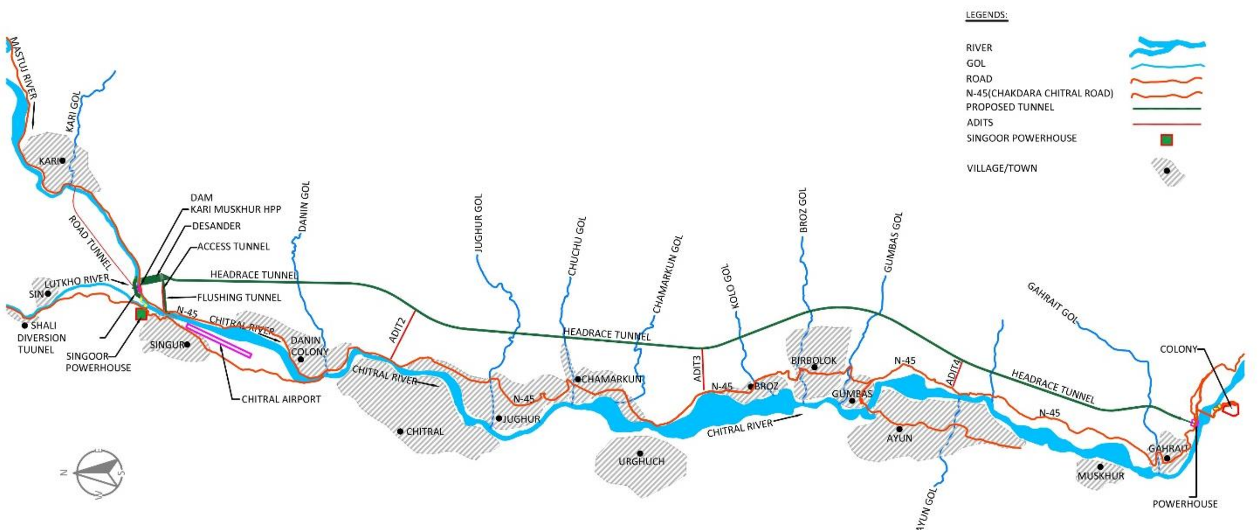

Figure 1: Project Layout Plan

2 BACKGROUND

Kari Muskhur Hydropower Project (KMHPP) was identified as run of the river scheme on the Mastuj River during the study "**Identification of Hydropower Development Potential in Chitral Valley"** conducted in 1999-2001 by Ministry of Water & Power through Hydroelectric Planning Organization (HEPO) of WAPDA and SHYDO in collaboration with German Agency for Technical Cooperation (GTZ). Two alternatives i.e. Alternative-I and Alternative-II, with estimated capacity of 362 and 446MW were identified under the scheme.

Pakhtunkhwa Energy Development Organization (PEDO) awarded Feasibility Study and Detailed Engineering Design of 446MW Kari Muskhur Hydropower Project to a Joint Venture (JV) of consulting firms comprising AGES (Lead Firm), ACE, EGC, TEAM and MCE (Sub Consultant) from Pakistan, HCE from Nepal and DOLSAR from Turkey, on November 20, 2017 for a period of two years. Later on, vide Addendum No.1 to the Contract, the Consultancy period was extended by about four months i.e. up to March 31, 2020.

Following are the key deliverables under the Consultancy Scope of Services;

(i) Inception Report, (ii) Mid Term Report (iii) Feasibility Study Report (iv) Detail Design Report and (v) Project PC-I

3 INITIAL LAYOUT PLANNING

During the inception stage studies, as shown in Table 1, Consultants identified two (2) alternatives with three (3) different powerhouse locations which were common for both the alternatives. The two (2) alternatives were based on consideration of development of the project either:

i. under Cascade Arrangement i.e. after development of the proposed three (3) projects namely, Jamshill Turen More HPP (260MW), Turen More Kari HPP (2350MW) on the Mastuj River and Shogo Sin HPP (132MW) on the Lutkho River; or

ii. development of the project as independent scheme.

Table 1: Alternative Layout Options

Alternative Option		Powerhouse Location	Discharge (m^3/Sec)	Power Potential (MW) With single Tunnel of 10m dia	Power Potential (MW) With Twin Tunnels of 9.5m dia
Alternative-I, Cascade	CPH-1	Juti Lasht	370	311	368
	CPH-2	Muskhur	370	467	557
	CPH-3	**Gahirat**	**370**	**508**	**603**
Alternative-II, Weir	WPH-1	Juti Lasht	370	313	358
	WPH-2	Muskhur	370	468	546
	WPH-3	**Gahirat**	**370**	**501**	**584**

Out of the six (6) options, two (2) options i.e. CPH-3 of Alternative-I Cascade, and WPH-3 of Alternative-II, Weir were recommended to the Client for further studies in the Mid Term Report level studies. Both the options were to be evaluated with single and twin tunnel arrangements.

Consequently, the two (2) options under single and twin tunnel arrangements were evaluated further during the Mid Term studies. The studies support the single tunnel dia of 10.8m as it is less costly as compare to twin tunnel arrangement. It was also revealed that option WPH3 presented major risk of associated socio-environmental impact issues at maximum reservoir level of 1541m asl. Therefore, to minimize the socio-environmental impacts on Kari village, an optimization study was conducted by reducing maximum reservoir level by 10m interval. As the maximum reservoir level of 1531m asl for option WPH3 offers optimum results, therefore, selected for further studies. Main features of the two options are given in Table 2 below.

Table 2: Main Features of the Alternative Options CPH-3 and WPH-3

Description	Option CPH-3 (Alternative-I, Cascade)	WPH-3 (Alternative-II, Weir)
	Mastuj + Lutkho	Mastuj only
Max. Headwater/ Reservoir Level (m asl)	1541	1531
Design Discharge (m^3/s)	345	345
Power (MW)	525	490
Tunnel Size (m)	10.5	10.5
Energy (GWh)	2,226.59	2,180
Plant Factor	48.4%	50.63%
Total Cost (PKR) million	167,492.36	177,462
Cost/MW (USD) million	2.28	2.58
Generation Cost (PKR / kWh)	7.12	7.71
FIRR (%)	18.11%	16.93%
EIRR (%)	23.04%	20.02%

Both the options were found to be economically and financially viable however, further studies on option CPH-3 were stopped due its dependence mainly on the development of three (3) upstream projects as clarified above.

4 TOPOGRAPHIC SURVEY

For the chosen option WPH-3, topographic survey studies covering about $10km^2$ area, were conducted using different surveying technique such as Global Positioning System (GPS), Drone, and Total Station method. With reference to Survey of Pakistan (SOP) Bench Marks at Moroi, Kuju and Drosh, a total of 37 control points were established at various important locations of the project such as dam & reservoir, powerhouse, four (4) adits portals, at various points in valleys crossing headrace tunnel, alternate powerhouse locations and colony area.

Around $10km^2$ area of dam & reservoir, adit tunnels portal, surge shaft, pressure shaft, pressure tunnel, powerhouse, colony area and muck disposal area was surveyed using Drone technology. The data collected during topographic survey was plotted at 1:3000 scale.

5 HYDROLOGICAL AND SEDIMENTATION STUDIES

During hydrological & sedimentation studies, the Consultants collected and processed hydrological, sedimentation and meteorological data from the sources tabulated below.

Table 3: Hydrology and Meteorological Data Sources

Agency	Description of the Data	River/Station	Period	Location of the Gauge/Met. Station
SWHP, WAPDA	Hydrological	Chitral	1964-2015	Chitral Town
SWHP, WAPDA	Hydrological	Golen Gol	1993-2015	Mastuj/Babuka Bridge
PEDO	Hydrological	Lutkho	2006-2016	Shoghore
SWHP, WAPDA	Sediments	Chitral	1964-2015	Chitral Town
PMD, Lahore	Meteorological	Chitral Town	1981-2017	Met. Station Chitral Town, Drosh and Buni

Using above data, the following flow duration curve was developed for flow availability at various exceedance probabilities.

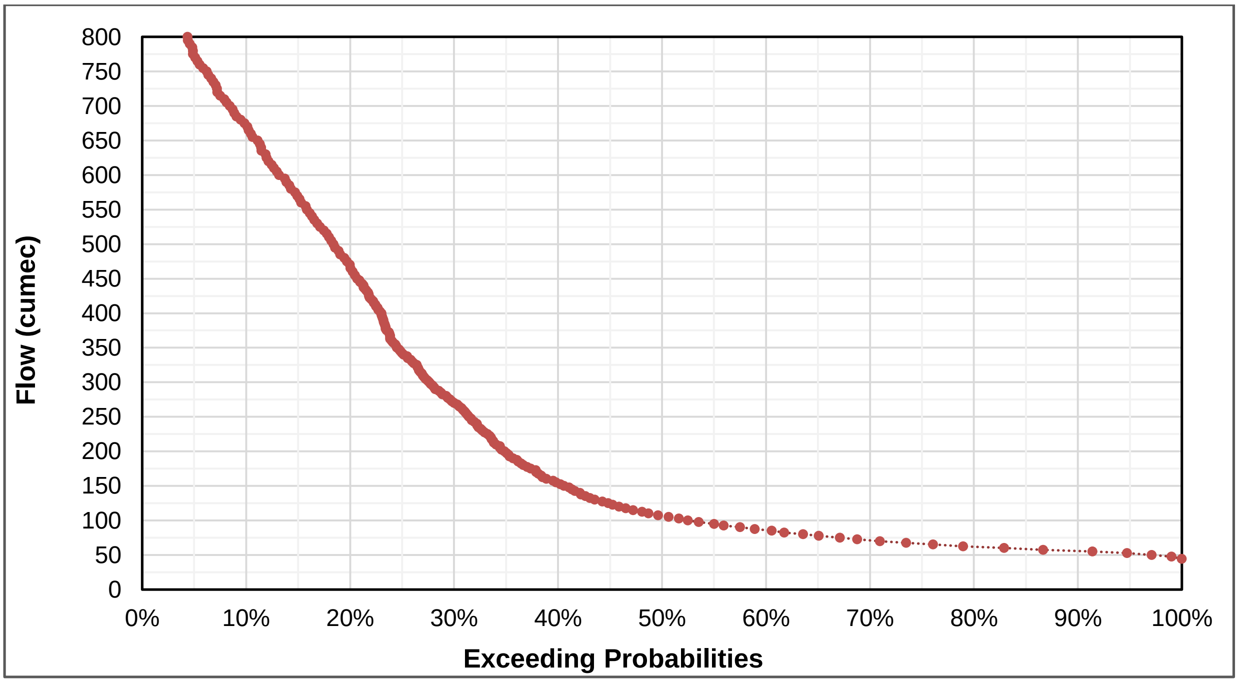

Figure 2: Flow Duration Curves of the Mastuj River at the Dam

The flow duration curve shows that the design discharge of 345 m^3/sec will be available for 25% (3 months) of the year.

Frequency analyses of instantaneous peak floods were carried out through Gumbel Extreme Value (GEV) and Log Pearson Type III distributions. Based on better fitness, peak flood values of Log Pearson type-III were adopted as the design floods for diversion during construction and the dam.

Table 4: Design Floods at Various Return Period

Design Flood (Return Period)	Diversion Flood (10Year)	Dam Design (100Year)	Dam Design (1000Year)	Dam Design (10000Year)
Discharge (m^3/sec)	1237	1748	2400	3262

In addition to the above, following are some of the findings covering other aspects of the hydrology and sedimentation studies.

i. Dam break analyses show no impact on Chitral Town except nominal impact on built-up property and agriculture land.

ii. Average annual sediments load in the Mastuj River at the dam has been calculated as 25.45 million tonnes.

iii. The incoming sediments load is very high as compared to capacity of the reservoir and needs flushing every year.

6 GEOLOGY

Two major faults namely Main Karakuam Thrust (MKT) and Reshun fault are running parallel to the 27.2km long headrace tunnel. MKT and Reshun fault are at a distance of 22 & 10km from the dam site and 12.6 & 7.3km from the powerhouse site respectively.

Geological studies including surface geological mapping and scan line survey was conducted using handheld GPS, Brunton Compass and measuring tape. The collected data was plotted on rosette diagram, fissure/contour plots and accordingly the headrace tunnel alignment was fixed.

The dam, power intake and appurtenant structures fall within Chitral slates unit whereas headrace tunnel crosses three geological formations i.e. Chitral Slates (18km), Koghozi Green Schist (0.8km) and Gahirat Formation (9.5km). The proposed powerhouse also falls in Gahirat formation.

7 SEISMIC HAZARDS

Seismic hazard evaluation for the project was conducted through the study of regional geological and tectonic information collected from the available literature & maps and collection of historical and updated instrumental earthquake records. On the basis of this data, the critical tectonic features affecting the project area were identified and seismic hazard evaluation was conducted in accordance with the International Commission on Large Dams (ICOLD) guidelines (Bulletin 148, 2016) for selecting the seismic design parameters

Seismic study recommends Safety Evaluation Earthquake (SEE) 0.51g corresponding to a return period of 10,000 years for dam while other project facilities are recommended to be design on Probable Ground Acceleration (PGA) of 0.31g associated with ground motion of Design Basis Earthquake (DBE) having return period of 475 years.

8 GEOTECHNICAL INVESTIGATIONS AND DESIGN

A total of eighteen (18) boreholes with cumulative depth of 1500m were drilled at various project locations including 1 borehole at the Cascade option and 17 boreholes in the Weir option. Following is breakup of the boreholes in Weir option.

Table 5: Break-up of Boreholes in Weir Option (WPH-3)

Location	Dam	HRT	PH	Surge Shaft	Pressure Shaft	Adits
No. of BHs	4	4	3	1	1	4

Out of 18 boreholes, 9 boreholes were found having zero overburden, 6 boreholes with an average of 5m and 3 boreholes with average of 49.2m thick overburden respectively. The cores recovered were tested in the laboratory and results applied to determine the Rock Mass Rating (RMR) and Q values. The corresponding average RMR and Q values are 52 and 2.7 showing that the project area fall in fair rock category as RMR classification. Further analyses were carried out through geotechnical analysis software (Phase2) to determine the rock support for the pertinent underground structures as given in table below.

Table 6: Underground Structure Support Details

Component	Length/Depth (m)	Wire mesh Shotcrete (mm)	Rock bolts (m)	Concrete Lining (mm)
Sand Trap (16*20)m	435	150	7	300
Headrace Tunnel (Horseshoe) 10.5m dia	27220	200	6	500
Surge Shaft (Circular) 27m dia	113	150	7	300
Pressure Shaft & Pressure Tunnel (Circular) 9m dia	120 & 152	100	4	---

It is envisaged that the HRT will excavated through a combination of drill & blast method in a span of 5.8km length and Tunnel Boring Machine (TBM) for the remaining length of 21.4km.

9 OPTIMIZATION OF THE PROJECT

Based on Flow Duration Curve, 20% to 35% available discharge range (190 m^3/sec to 450 m^3/sec) with an interval of 20 m^3/s have been considered for capacity optimization of the selected project layout. Optimization was based on the financial analysis of the estimated benefits (energy) and cost for each discharge. Based on the initial results, the interval between 330 m^3/s and 350 m^3/s was further subdivided at interval of 5 m^3/s for refinement.

Power and energy for the selected range were estimated as presented in the following table for valuation of benefits of the project.

Table 7: Estimated Power and Energy

Design Discharge (m^3/s)	Power (MW)	Tunnel Size	Number of Tunnel	Energy (GWh)	Plant Factor (%)
190	295	9.6	1	1,662.06	64.3%
210	324	10.0	1	1,752.29	61.6%
230	356	10.4	1	1,854.71	59.5%
250	384	10.5	1	1,932.50	57.3%
270	409	10.5	1	1,993.84	55.5%
290	434	10.5	1	2,055.85	54.1%

Design Discharge (m^3/s)	Power (MW)	Tunnel Size	Number of Tunnel	Energy (GWh)	Plant Factor (%)
310	456	10.5	1	2,114.40	52.8%
330	478	10.5	1	2,159.01	51.5%
335	483	10.5	1	2,170.33	51.3%
340	488	10.5	1	2,182.50	51.0%
345	495	10.5	1	2,195.99	50.6%
350	533	8.2	2	2,299.12	49.2%
370	558	8.2	2	2,343.61	47.9%
390	597	8.8	2	2,427.54	46.4%
410	622	8.8	2	2,482.43	45.5%
430	647	8.8	2	2,526.20	44.6%
450	680	9.2	2	2,587.26	43.4%

Likewise, costs of the scheme for all the selected flows were estimated. Results of the financial analysis tabulated below indicate that the most attractive results are for the discharge of 345 m^3/s with minimum generation cost, highest NPV, highest B/C ratio and maximum IRR.

In addition to discharge, dam height and tunnel diameter optimization were also studied. The limitation for maximum dam height was the proposed upstream Turen More Kari HPP Powerhouse which corresponds to 1537m asl (43m pond depth) normal conservation level. However, dam beyond 34m pond depth was resulting in social problems due to submergence of substantial infrastructure, graves, built-up property and agriculture land of Kari village; therefore, maximum possible pond depth of 34m corresponding to 1528m asl as normal conservation level was adopted. For the optimized discharge of 345 m^3/s, the optimized tunnel diameter was worked out as 10.5m.

Table 8: Result of Financial Analysis

Design Discharge (m^3/s)	Power (MW)	Total Cost (M PKR)	Generation Cost (PKR / kWh)	Net Present Worth; million Rs.	Benefit to Cost Ratio	Financial Internal Rate of Return (%)
190	295	147,010.29	8.37	39,004.90	1.38	15.745%
210	324	154,741.89	8.36	41,340.91	1.39	15.773%
230	356	162,922.89	8.31	44,408.90	1.39	15.848%
250	384	167,113.39	8.18	48,213.00	1.42	16.064%
270	409	169,892.40	8.06	51,607.56	1.44	16.272%
290	434	172,712.05	7.95	55,028.73	1.46	16.473%
310	456	175,167.66	7.84	58,392.62	1.48	16.671%
330	478	177,670.22	7.79	60,539.32	1.49	16.774%
335	483	178,201.90	7.77	61,154.06	1.50	16.807%
340	488	178,792.43	7.75	61,798.05	1.50	16.840%
345	495	179,869.07	7.75	62,220.56	1.50	16.845%

Design Discharge (m^3/s)	Power (MW)	Total Cost (M PKR)	Generation Cost (PKR / kWh)	Net Present Worth; million Rs.	Benefit to Cost Ratio	Financial Internal Rate of Return (%)
350	533	215,946.95	8.89	45,393.82	1.30	15.017%
370	558	218,511.89	8.82	47,502.76	1.31	15.120%
390	597	234,767.27	9.15	43,246.95	1.27	14.663%
410	622	237,300.99	9.05	46,258.58	1.28	14.814%
430	647	239,823.76	8.99	48,333.45	1.29	14.908%
450	680	251,733.43	9.21	45,203.51	1.26	14.604%

10 STRUCTURAL DESIGN OF THE PROJECT

Design Manuals of US Army Corp of Engineers (USACE), American Concrete Institute (ACI), AASHTO LRFD Bridge Design Specifications, Building Code of Pakistan, SP 2007 and other relevant codes and standards have been used in design of the project components. Structural design of the project components has been done considering stability and safety of the structures against expected encountered forces/loads. For design of the project components i.e. dam, power intake, tunnel portals, bridges across the river, and powerhouse & other buildings, finite element analysis software, SAP2000 has been used.

11 HYDRO-MECHANICAL EQUIPMENT

For design of hydro mechanical equipment TURBNPRO KC4 (USA), HydroHelp 2 (Canada) software and USBR Monograph 20, Water Power & Dam Construction Magazine 1976, 1978 have been used. With given rated head and discharge vertical-shaft Francis turbines have been selected using monograph 20. Apart from turbines and auxiliary equipment, two overhead cranes, each 175 tons capacity are proposed in the powerhouse for the installation and repair/maintenance of the E & M equipment.

12 ELECTRICAL COMPONENTS

For the design of 137.5MVA, 11 kV, 50Hz vertical shaft synchronous generators and 50.5MVA transformers, the Consultants applied standards of International Electro-Technical Commission (IEC), Institute of Electrical & Electronic Engineers (IEEE), International Organization for Standardization, British Standards (BS), Verband Deutscher Elektrotechnik (VDE, Testing & Certification Institute of Germany), American Society for Testing & Materials (ASTM), National Fire Protection Association (NFPA), American National Standards Institute (ANSI).

13 POWER EVACUATION

The corridor for power evacuation is limited which has already been occupied by 132kV transmission line of WAPDA's 108MW Golen Gol Hydropower Plant. As capacity of the line is limited hence out of the PEDO identified potential of nearly 2800MW in Chitral valley, it can only accommodate the 69MW Lawi HPP.

During feasibility and detail design studies, the Consultants covered the power evacuation issues through analysis/investigations of:

(i). evacuation of power through loop-in, loop-out arrangement of the proposed 500kV Chitral TL which is being under implementation by PEDO through a study titled “Feasibility Study for Power Evacuation from Chitral to Chakdara Grid Station”; and

(ii). in the absence of option (i) above, through construction of independent 155km long, 220kV TL from Chitral to Chakdara grid station with an estimated cost of PKR 4.7 billion.

14 ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT STUDIES

The project Environmental and Social Impact Assessment Studies (ESIA) were conducted in close consultation with the stakeholders while keeping the guidelines of KPEPA at fore. Similarly, the project Land Acquisition and Resettlement Plan (LARP) has been prepared under the provision of Land Acquisition Act 1894 in conjunction with other applicable laws.

In total, 696 kanal land will permanently be acquired for the project while 1,705 trees including fruit and non-fruit trees will be uprooted during execution. The project potentially affected built-up property and utilities include, a high school, a residential house, a garage, a communal suspension foot bridge, two irrigation channels of 2,250m length and 52 No. transmission line towers (49,11kv of Reshun HPP and 3,132 Kv of Golen Gol HPP). Due to ponding impact, around 102 graves need to be shifted to a location identified with the consent of the community.

To compensate depletion of water in the Chitral River, a minimum of 15cumec water will be ensured in low flow period.

The project negative impacts will be mitigated/minimized through Environmental and Social Management Plan (ESMP) as outlined in the ESIA report.

15 SALIENT FEATURES

The project Key Salient Features are tabulated below whereas maps showing project layout, dam and powerhouse sites, are attached as **Figure 1 to 3**.

Table 9: Key Salient Features

Description	Features
Design Discharge	345 m^3/sec
Gross Head	189m
Net Head	159m
Installed Capacity	495MW
Plant Factor	50%
Annual Energy	2,164.94 (GWh)
Low Pressure Headrace Tunnel (Circular shape)	10.8m dia 27.22km length, Velocity 3.77m/s
Dam	Concrete Gravity Dam on Diaphragm Walls, 40m Ht.
Sandtrap (Cavern)	4 Chambers (16x20)m and 435m long, velocity .42m/sec
Surge Shaft (Circular)	27m dia.113m high
Steel Lined Pressure Shaft (Circular)	9m dia.120m high

Description	Features
Steel Lined Pressure Tunnel (Circular)	9m dia, 152m long
Project Developmental Cost	PKR 193.08 billion
Construction Cost/MW	USD 2.48 million
Generation Cost/kWh	PKR 4.30
Benefit Cost Ratio with CDM	1:1.61
Benefit Cost Ratio without CDM	1:1.51
EIRR	24.37%
FIRR	15.69%

16 ECONOMIC AND FINANCIAL ANALYSIS

The economic and financial analyses of the project were carried out to check its viability along with sensitivity analysis under different scenarios comprising 10% cost overrun, 10% decrease in project benefits and combination of both. During the economic and financial analysis, a total of seven (7) years construction period was considered which includes one (1) year pre-construction phase, five (5) years construction and one (1) year Defect Liability Period (DLP). Following assumptions were applied:

- Price Datum: June 2019.
- Custom Duty: 5%
- Opportunity cost of capital: 12%
- Operation and maintenance cost: 1.5% of the base cost per annum
- Interest rate: 6.62%

Results of the economic, financial and sensitivity analyses are summarized hereunder:

Table 10: Summary of Economic Analysis

Economic Indicators	CCG Turbine		Furnace Oil Plant	
	With CDM	Without CDM	With CDM	Without CDM
Present worth of benefits (Rs. million)	150,871.80	141,031.98	198,795.99	184,582.92
Present worth of costs (Rs. million)	93,655.52	93,655.52	93,655.52	93,655.52
Net Present Worth (Rs. million)	57,216.28	47,376.46	105,140.47	90,927.40
Benefit Cost Ratio (BCR)	1.61	1.51	2.12	1.97
EIRR %	24.37%	22.53%	48.40%	46.16%

Table 11: Summary of Financial Analysis

Financial Analysis	
PW of benefits @ 12%; (Rs. million)	362,582.07
PW of costs @ 12%; (Rs. million)	133,802.44
Net Present Worth; (Rs. million)	228,779.63
Benefit Cost Ratio	2.71
FIRR	15.69%

Table 12: Sensitivity of Financial Analysis

Financial Analysis - FIRR	
Base Case	15.69%
10% Less Benefits	14.39%
10% cost Over-Run	14.51%
Combined Impact	13.28%

Results of economic analysis clearly demonstrate that the project is technically sound and economically viable. Also, the project yields larger benefits as compared to equivalent thermal combined cycle gas turbine.

Similarly, for the estimation of benefits under financial analysis of the project, the published average sale price of PKR. 13.0/kWh has been projected at 5% annually to the commissioning year which results in PKR 19.2/kWh.

17 PROJECT DEVELOPMENT SCHEDULE

Pre-Construction Phase: After establishment of PMU and hiring of Consultants, pre-construction activities will be commenced which are scheduled to be completed within one year.

Construction Phase: Project construction phase activities will be completed within five (5) years.

Defect Liability Period: Upon successful completion of the Civil and E&M Works, the project operational capacity and works quality will be monitored for one (1) year.

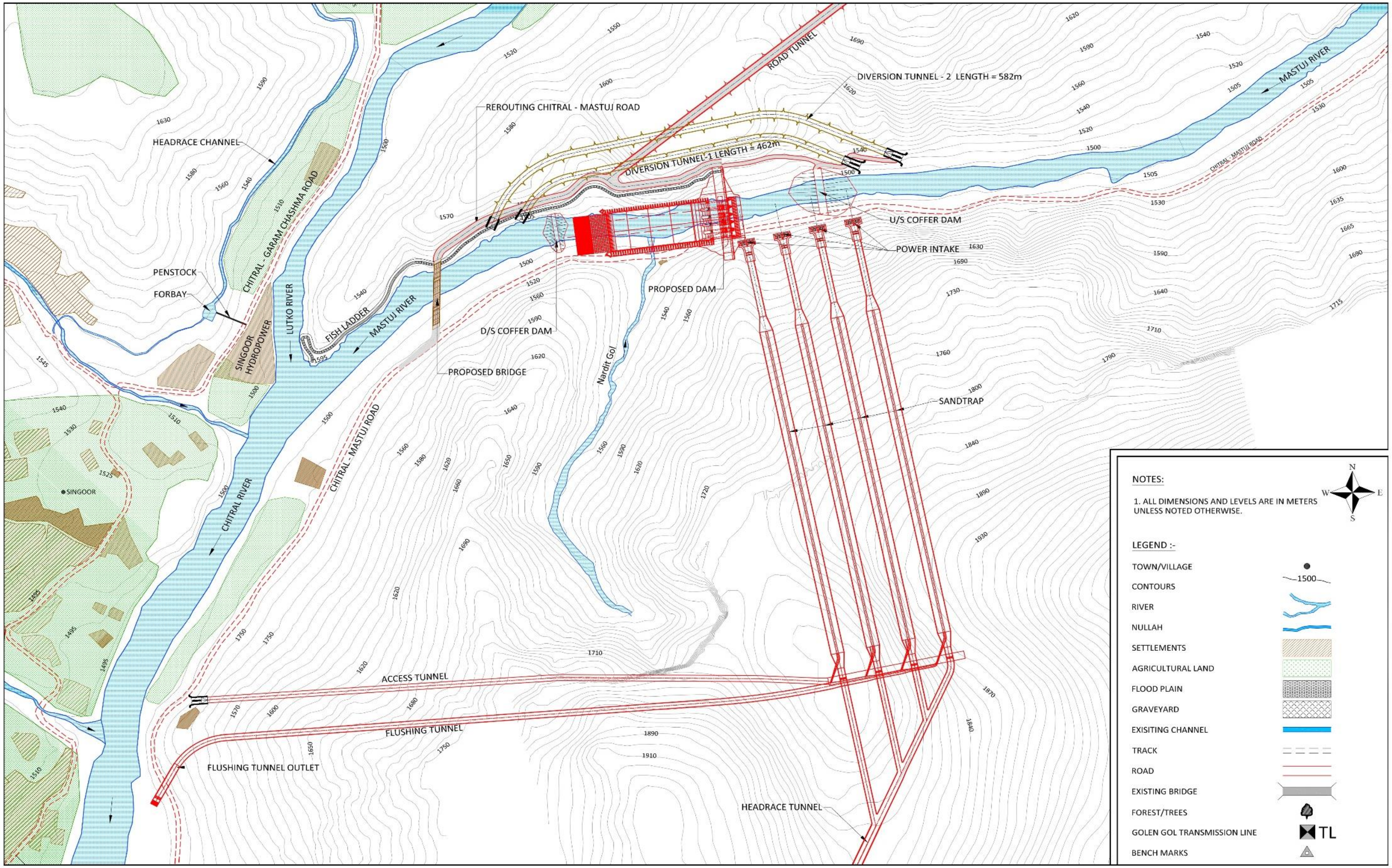

Figure 3: Layout Plan Dam and Appurtenant Structures

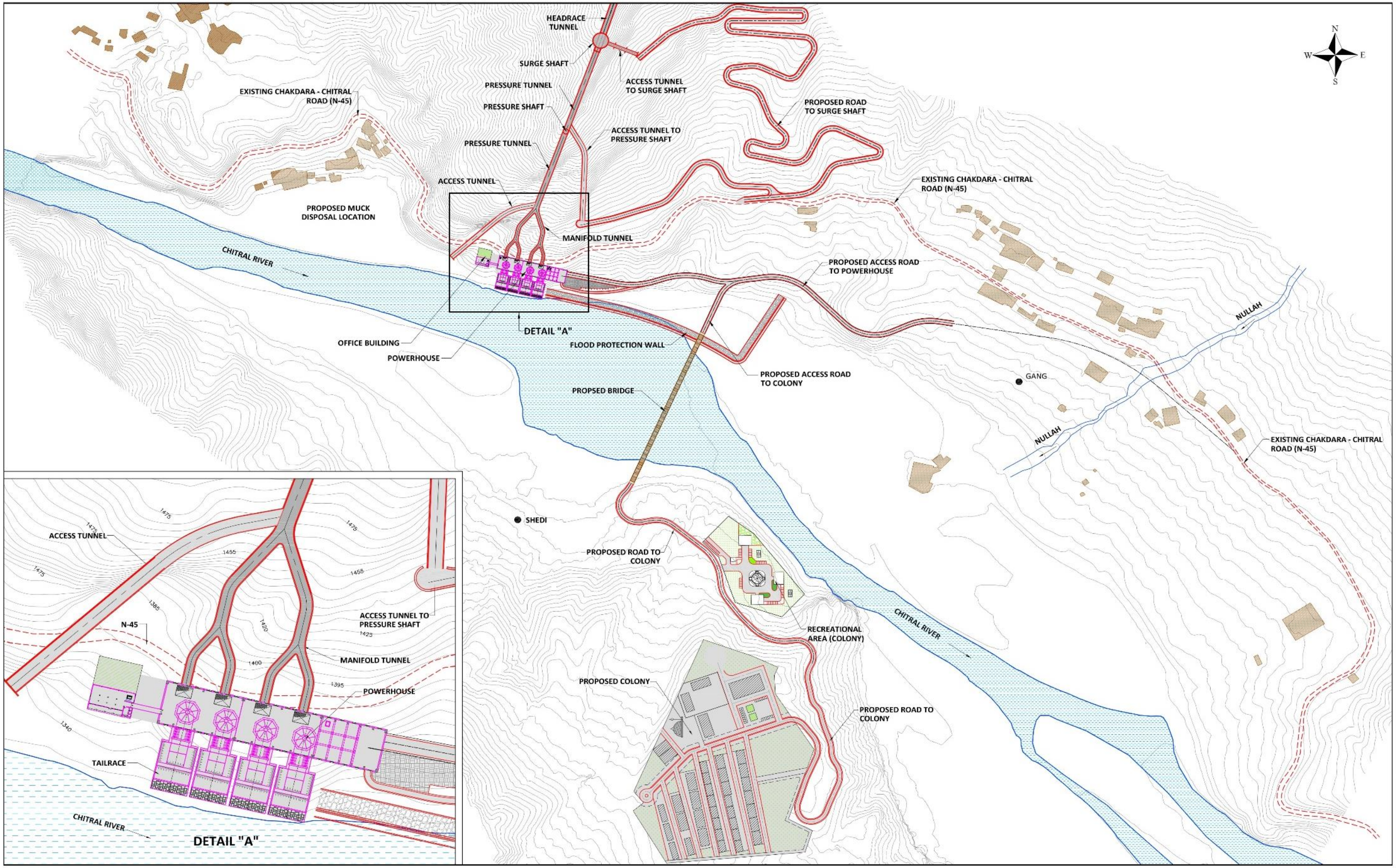

Figure 4: Layout Plan Powerhouse and Appurtenant Structures