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0 Executive Summary

0.1 Introduction

During the seventies, rapid development in all sectors of the economy led to an abrupt increase in power demand and a serious shortage of energy was experienced throughout Pakistan. According to the Electricity Marketing Handbook (June 2008), published by PEPCO there is a shortage of 3, 648 MW. According to the Daily Dawn Newspaper of 24 December, 2009, this shortage has now increased to 4,200 MW.

The hydropower potential of the Chitral Region had been studied first during 1982-84 by WAPDA and MONENCO of Canada who prepared an inventory and ranking study of potential storage and hydropower generation sites along the upper reaches of the Indus and its main tributaries, Jehlum (above Mangla) Swat and Chitral Rivers. No hydropower scheme was proposed in the Chitral Region. Later, during 1987-1992 and 1999-2000, the Sarhad Hydel Development Organization (SHYDO) and Hydro-electric Planning Organization (HEPO), WAPDA, in collaboration with German Agency for Technical Co-operation (GTZ) , carried out studies in the Azad Jammu and Kashmir (AJK), Northwest Frontier Province (NWFP) and Northern areas to identify hydropower potential and rank schemes. A number of small and medium hydropower schemes including Shogo-Sin and Shusghai-Zendoli were identified.

The Islamic Republic of Pakistan received financing from the Asian Development Bank (ADB) as Technical Assistance (TA) Loan and Technical Assistance Grant for infrastructure and development projects under the Power Sector component of the ADB TA Loan 2178-PAK (SF). Following financing, the Government of Pakistan (GOP) through its Ministry of Power and Water decided to use a portion of the loan to carry out Bankable Feasibility of International Standard for Shogo-Sin Hydropower Project and Shushghai-Zhendoli Hydropower Project under the Private Power and Infrastructure Board (PPIB) as the Executing Agency (EA).

On the basis of International Competitive Bidding (ICB) process, a team of Consultants and Sub-Consultants with Mirza Associates Engineering Services Ltd

(Pakistan) as the lead Consultant were selected for carrying out the feasibility studies for the two projects.

The Client's Notice to Proceed was issued on 14 February, 2009. The completion date of the studies as per the Contract is 14 April, 2010.

0.2 Topographic and Hydrographic Surveys

Topographic survey has been conducted for weir (260 hectares) and powerhouse (460 hectares) areas and longitudinal profiles of the Tirich Gol and Turkho River have been prepared. Tirich Gol Valley cross-sections have been observed at weir site, as well as on the upstream and downstream of the weir site. For Turkho River, cross-sections have been taken at powerhouse site and on its upstream and downstream. For the inaccessible areas of tunnels alignment, topographic maps were developed with the help of high resolution digital elevation models (DEM).

Topographic sheets of survey of Pakistan (SOP) at scales, 1:250,000 and 1:50,000 were used to start with the survey work. Detailed maps of Project Area on 1:1,000 scales with contour interval of two (02) meters have been prepared. The detailed topographic survey has been carried-out with Sokkia Total Stations. All important features falling in the area, like roads, tracks, nullahs, rivers, huts, water channels have been recorded according to their geographical positions. In order to prepare topographic maps at large scale, reference grid has been established by connecting the area to be surveyed with SOP Grid. The coordinates of SOP Bench Mark at Reshun have been used to establish the horizontal and vertical control for the Project Area. From Reshun, traversing and leveling has been carried-out first to powerhouse site in Turkho Valley and then to weir area in Tirich Gol Valley.

For conducting the hydrographic survey, geodetic network for topographic survey has been used for linking the river bed cross-sections and connecting nodes. The following equipment has been used for hydrographic survey work.

- ECO-sounder Survey Recorder (Raytheon Make) made in UK, adjustable chart speed operated by 12 volt battery.
- Transducer (Narrow Beam) Model 7245A depth range 400-500 meters..

0.3 Hydrology and Sedimentation

For the Shushghai-Zhendoli Hydropower project, three stream flow gauging stations were established by the Consultants; one on the upstream of the Shushghai weir site, second on the downstream of the weir site and third on the downstream of the Zhendoli Powerhouse Site. On all three stream gauging stations, staff gauges have been installed where flow measurements were made on six hourly basis at 06:00 a.m., 12:00 noon and 06:00 p.m

Discharge measurements with the current meter were made only at one site due to availability of suspension bridge i.e. the downstream of the Shushghai weir site. Discharge measurements were started from 01st May, 2009 at the rate of twice per week in summer season and once per week in winter season. The water and sediment sampling was continued till January, 2010.

.At Chitral Climatological station maximum daily precipitation was observed as 109 mm. Mean maximum monthly precipitation appears in the month of March with a magnitude of 111 mm, whereas, lowest precipitation appears in the month of August. The month of August has also the highest average evaporation and January the lowest i.e. 97 mm and 49 mm, respectively. Average annual evaporation at Chitral stream gauging station is 898 mm. July is the warmest month with temperature of about 27.96 ^{o}C and January is the coldest month with temperature of 4.61^{o}C on mean monthly basis.

The elevation in the watershed varies from 2819 to 7172 meters. The average elevation of the Shushghai watershed is 4937 m. The highest slope in the watershed is 98% and lowest 2.56 % with a standard deviation of 16.96% on the basis of 1000 m grid resolution DEM. The average slope of the watershed is 35.08%.

The minimum, average and maximum daily flows at dam site were found as 5.27, 18.1 and 52.66 m^3/s, respectively. The minimum, mean and maximum 10-daily flows at the dam site were computed as 5.29, 18.04 and 51.28 m^3/s, respectively. The minimum, mean and maximum monthly flows at the dam site were worked-out as 5.45, 18.02 and 49.71 m^3/s, respectively.

The minimum, average and maximum daily flows at powerhouse site were found as 18.75, 62.99 and 181.88m^3/s, respectively. The minimum, mean and maximum 10-daily flows at the powerhouse site were computed as 19.24, 62.95 and 176.21 m^3/s, respectively. The minimum, mean and maximum monthly flows at the powerhouse site were worked-out as 19.24, 62.95 and 176.21 m^3/s, respectively.

Floods were estimated by Regional analysis and flood frequency approaches. For the site governing approach is flood frequency analysis being on higher side. Corresponding to 10,000 years return period, the values of floods by using Gumbel's, Log Pearson Type-III, Log Pearson and Log-normal methods and Regional analysis are 770, 667, 667, 660 and 400 m^3/s for the weir site and 1442, 1280, 1627, 1577 and 1210 m^3/s for the powerhouse site. However, for the design flood Gumbel distribution is recommended for weir site giving a AEP 1:10000 flood of 770 m^3/s and Log-normal distribution is recommended for Powerhouse site giving and AEP 1:10000 flood of 1577 m^3/s being best fitting to the observed flood data.

The design floods for the dam site and powerhouse site are recommended as follows in Table 0.1

Table 0.1 Design Floods for Shushghai-Zhendoli Dam and Powerhouse Sites

Return period (Yrs)	2	5	10	25	30	50	100	200	500	1000	2000	5000	8000	10000
Weir Site (m3/sec)	345	399	435	481	490	515	548	582	626	659	693	737	759	770
P/H Site (m3/sec)	587	701	778	877	897	953	1031	1111	1221	1308	1399	1526	1594	1627

Elevation area capacity curves for the weir site were developed which shows that capacity of the proposed reservoir is 0.509 Mm^3 (413 AF) and the gross area is 5.77 hectares (14.25 acres).

Due to comparatively small height of the dam, the area/storage above spillway crest between El. 2654 m.a.s.l to 2664 m.a.s.l is inadequate to absorb a maximum portion of the peak discharge of a flood hydrograph. Therefore attenuation of the peaks during routing process is not significant.

Dam break analysis based on the worst breach condition (breach depth as 16 m, breach width as 60 m, full breach formation time taken as half an hour and side slope of the breach developed as 1:1.5) and with a 10,000 years return period flood from upstream, the generated results show that, the flood wave peak will reach in 10 minutes at Shushghai with flood stage value slightly higher than the settlement elevations at few places.

Sediment studies show that the average specific suspended sediment yield at Shushghai weir site is about 640 tons/km^2/year. Average suspended sediment load at weir is about 0.52 MCM (421 AF). Average bed load at weir site is about 0.13 MCM (105 AF). Average annual sediment inflow to weir is about 0.65 MCM (524 AF).

Trap efficiency of reservoir computed on the basis of Churchill curve is 13 %. The recommended trap efficiency is 56 % based on total sands and coarse material. Average annual trapped sediment load in the proposed reservoir would be 0.367 MCM (298 AF).

Flushing discharge required to carryout flushing of the reservoir would be equal to or greater than 36 m^3/s, whereas flushing duration required would be around 4-7 hours depending on the flow available for the purpose.

The life of the reservoir can be enhanced to about 40 years by constructing a boulder trap at the upstream end of the reservoir and with appropriate flushing operations at the rate of two flushings per year in the months of July and August.

It is proposed to construct a boulder trap at the upstream end of the proposed reservoir to stop the entry of boulders in the reservoir. This has been incorporated in the civil structures design.

To carry out efficient flushing, the sediment delta in the reservoir should be monitored every year before flushing. Moreover, operator must be fully vigilant on the coming forecasted flows which may offer suitable flushing opportunity.

0.4 Geological and Geotechnical Investigations and Seismic Hazard Assessment

Geotechnical and geological investigations have been carried out for the project in accordance with the norms and standards generally followed for the feasibility studies for hydropower project. These investigations included office and field work, laboratory testing, evaluation and interpretation of field as well as laboratory data. The field work comprised some 700m of drilling of boreholes at structural locations, coring and logging of bore holes, performance of field tests, surface geological mapping, geophysical testing, and excavation of test pits.

Detailed geological mapping has been carried out in the weir area, along the headrace tunnel alignment, and in the powerhouse area. On the basis of these maps, most favorable locations of various project structures have been selected. Main geological formations identified within the project area include Chitral Slates and Reshun Formation. Various unconsolidated geological units covering the project area include overburden, and scree deposits. The rock types encountered within the project area comprise slates, phyllite, greywacke, sandstone, and marble.

The valley at the weir site is approximately 75 m wide at riverbed level. The right abutment slopes are composed of metamorphic rocks including quartz-mica schist with intrusions of grey marble and sheared limestone. Dip angle and dip direction of the foliation ranges from 27° - 30° and 155° - 175°.

The left abutment slopes are composed mainly of river deposits and scree with some moraine deposits and overburden at some locations. Rocks are exposed on the left bank at about elevation 2950 m.a.s.l.

River bed deposits are mainly sandy gravels and boulders. The gravels are mostly fine to coarse grained and of igneous and metamorphic origin.

A subsurface profile at the weir axis shown in Section 4, based on surface geological mapping, drilling and in-situ testing of boreholes, geophysical investigations and discontinuity mapping shows that adjacent to the right bank in the active river channel on, the alluvium thickness varies from 6.5 m to 9 m below the river bed whereas adjacent to the left bank, bed rock is not encountered even at a depth of 50 m.

On the basis of information gathered through scan line survey, rock core testing and other laboratory tests, design parameters have been established for carrying out feasibility stage design of surface and underground structures. Similarly, on the basis of information gathered from the site and laboratory testing, sources of suitable construction materials have been identified.

Detailed neo-tectonic and seismic hazard assessment has been carried out due to the proximity of the Tirich Mir and Reshun Faults to the weir and powerhouse sites.

The results of these investigations have been detailed in Volume 3 – Geology, Geotechnical and Seismo -Tectonic Aspects.

0.5 Site Selection (Project Layout Studies)

Thirteen (13) possible alternate layouts of the project were identified on the specified stretch of Tirich Gol/Turkho rivers based on topography and estimated flows at the weir and intake which were checked in the field during site visits and screening of these alternatives was performed on the basis of standardized criteria. Based on the parameters adopted for screening viz; good topographical, hydrological and geological conditions; minimal environmental issues and capacity per meter length of waterway, the following alternatives were screened out for further studies and investigations:

1. ALT – 01 A (Shushghai-Zhendoli)
2. ALT – 01 B (Shushghai-Zhendoli with Rosh Gol)
3. ALT – 10 (Shushghai – Muzhgol)

Topographic surveys, Geological mapping and socio-economic/environmental surveys were carried out in the field for comparison of these alternatives. Comparison level costs and power/energy estimates of each alternative along with economic analysis have been performed.

Based on the results of topography, geologic, hydrology and environment investigations the conditions of the components of the three alternatives were compared and more detailed comparison was made based on the results of power/energy estimates, costs comparison of preliminary economic analysis of these alternatives.

Finally the three sites were evaluated on the basis of technical, environmental and economic results and it was concluded that Alt. 01A Shushghai – Zhendoli was the best and selected for detailed studies which are summarized below.

0.6 Project Sizing

For the selected project layout, project sizing that is, optimization of the type of plant and its capacity, fixing of maximum reservoir level and diameters of the headrace tunnel and shaft have been performed.

The methodology of sizing/optimizations of the plant and reservoir level uses the assumed design discharges values ranging from14 m^3/s to 32 m^3/s at incremental intervals of 2 m^3/s. For each assumed design discharge preliminary costs of the project was estimated by using Hydro Power Costing (HPC) computer programme and power /energy calculations were performed which were taken as benefits of the project. Net Present Value (NPV) calculations were performed for each discharge value, the highest NPV value was the deciding factor of the sizing/optimization process.

The diameters of headrace tunnel and pressure shaft were optimized on the basis of construction cost and the cost of loss of energy due to hydraulic losses occurring as a result of change in diameter. The headrace tunnel and steel lined pressure shaft is optimized as 4.2m and 2.9m respectively.

For optimization of plant capacity, run-off river and peak options were evaluated and sensitivity analysis was performed. It was found that 4 - hour Peak plant with design discharge of 28 m^3/s and plant capacity of 144 MW will be the optimum. The maximum. reservoir level was optimized as 2664.0 m.a.s.l and minimum as 2654.0 m.a.s.l.

0.7 Civil Engineering Studies

Under civil engineering studies, hydraulic analysis and sizing of project structures, computational hydraulic modeling, tunnel support design and structural analysis and design have been carried out to feasibility level design level.

Feasibility level design of the following structures have been carried out.

0.7.1 Diversion Structure:

The diversion structure consists of a composited concrete/embankment type dam. The crest level of the dam is at elevation 2669.0 m.a.s.l and its maximum height is 26.4m above river bed level. The concrete section containing the spillway is located on the right side of the river and is founded completely on rock while the embankment section extends from the interface with the concrete section to the left abutment. The embankment is a central clay core rockfill dam and the concrete section is a standard ogee/gravity section. The composite structure has been designed to safely withstand AEP 1:10000 flood and design earthquake without damage.

0.7.2 Spillways

Both gated and un-gated overflow spillways are provided in the concrete section of the dam to pass the AEP 1:10000 flood. The gated spillway has two hydraulically operated radial gates. The spillway can pass the AEP 1:10000 flood with both gates open or with one gate in-operative in conjunction with the un-gated overflow spillway. In the latter case the reservoir rises to its maximum level of 2666.7 m.a.s.l. A stilling basin is provided downstream of the spillway weir as an energy dissipation device for the spillways.
Computational hydraulic modeling of the spillway has been carried out. The results show that performance is acceptable.

0.7.3 Low Level Flushing Outlets

Four low level outlets are also provided in the concrete section for reservoir drawdown and flushing of sediment from the reservoir and the front of the power intakes. The invert level of these low level outlets is set at 2642.0 m.a.s.l. The low level outlets can also be used to discharge flood in the case of extreme events as a back up to the spillway. Their discharge capacity at maximum operation level is 441m^3/s.

0.7.4 River Diversion Works:

Provision has been made of two coffer dams and two diversion tunnels of 5.5m diameter with lengths of 270m and 310m respectively for river diversion works. The design flood adopted for river diversion is with an AEP of 1:50. The crest level of the upstream coffer dam has been set at 2652.5 m.a.s.l and that of the downstream coffer dam at 2648.0 m.a.s.l. The upstream coffer dam is reinforced at crest and the downstream face to allow for overtopping in case of higher floods.
Conventional ring cofferdams with sufficient space provision for construction activities and access will be used for construction of the diversion intakes and tunnels and the power intakes and connecting tunnels.

0.7.5 Power Intakes

Two power intakes are provided on the right bank to convey a total discharge of 33.6m^3/s. Orientation of the intakes in relation to the diversion structure has been set to minimize sediment entry and invert elevation has been set at 2648.25 m.a.s.l providing sufficient depth for submergence.

0.7.6 Desander Chambers

Two 180m long desander chambers have been provided to remove suspended sediment particles greater than or equal to 0.2mm from entry into the head race tunnel and consequently the hydraulic turbines. Provision has been made for continuous flushing of settled sediment from the desanding chambers back into Tirich Gol River.

0.7.7 Power Waterways

The power waterways consist of two connecting tunnels from each of the intakes and desanding chambers optimized for a design discharge of 16.8m^3/s and the low pressure tunnel, the high pressure shaft and pressure tunnel and penstocks, all optimized for a design discharge of $28m^3/s$. Temporary and permanent lining for the power waterways have been provided.

0.7.8 Surge Chamber

For regulation and response to load changes at the turbine/generators it has been found necessary to provide a surge tank. A surge tank diameter of 4.5m for surge tank stability and height 72m to cater for maximum upsurge at turbine load rejection.

0.7.9 Penstocks

Three 1.4m diameter penstocks have been provided at the end of the pressure tunnel after a trifurcation to connect to the turbine inlet valves and turbines. Penstock transient analysis has been carried out to provide for rapid wicket gate closure and pressure will rise in the penstocks.

0.7.10 Power House Complex

The powerhouse layout accommodates the main power generating electromechanical plant and the ancillary plant for operation and maintenance. It comprises two caverns a powerhouse machine hall cavern and a transformer hall cavern separated from the main cavern. The caverns are interconnected by three busduct passages and one connecting passage. The caverns are parallel and their long axes are orientated considering the geological and geo-technical conditions. The switchyard is external.

0.8 Hydro-Mechanical Studies

0.8.1 Turbines and Ancillaries

Pelton turbines are considered the only suitable turbine type for the net head available at the Shushghai- Zhendoli Project site. Three Pelton turbines have been proposed to give reliability of service and to meet the energy demand during both summer and winter seasonal flows. Because of their size, that is, each turbine is 49.4 MW the turbines must be of the vertical type. To accommodate likely high sediment loadings that the turbines must pass, coating of turbine runners and nozzles with tungsten carbide is proposed. Moreover closed circuit cooling water systems have been recommended to alleviate clogging of water pipes by sediment. Access around the powerhouse has been provided so that a turbine runner can be quickly dismantled and taken to the Erection Bay Floor for repair. One spare runner will be held in store to enhance machine availability.

0.8.2 Spillway and Low Level Outlets

Shushghai Spillway will incorporate two radial type spillway gates to pass high reservoir inflows. Seasonal flows greater than those drawn from the reservoir for generation will also be released through four low level outlets to flush sediment build-up in front of the Power Intakes. Each low level outlet has a maintenance and service gates to regulate flows. The capacity of Low Level Outlets is 440 m^3/sec. The spillway gates will be operated as necessary to pass excess flow.

0.8.3 Power Intakes

Two power intakes have been provided, each having upstream trashracks, a bulkhead stoplogs and a guard gate. Guard gates are of the fixed wheel type and will be capable of closing under full tunnel flow. A trashrake and gantry crane have been provided on the Power Intake service deck for cleaning debris or trash handling the stoplogs and maintaining the gate equipment.

0.8.5 Desander Basins

To control sediment entry to the turbines, desanders have been provided downstream of the power intakes. Each desander has been provided with isolating gates and stoplogs to permit inspection and maintenance tasks. The pair of slide type flushing gates (one service the other maintenance) has been provided in the flushing outlets of each desander for continuous or intermittent flushing of sediment while the power tunnel is in operation. Sediment flushed from the desanders will be discharged through the flushing tunnel downstream of the dam back into Trich Gol River.

0.8.6 Powerhouse Equipment

At the powerhouse, temperatures and humidity in the underground caverns will be controlled by a forced, re-circulating / exhaust ventilation system. Fresh air will be drawn into the power cavern through the main access tunnel and exhausted through the cable/ventilation tunnel. Chilled water will reticulate around the caverns to assist cooling of air and the removal of heat from around the plant. Wall mounted chilled water type air conditioners (fan coil units) will be provided in the control room for the comfort of station operating personnel and for the protection of control equipment. Should a fire erupt in a cavern, suppression of the fire will be affected by a combination of water spray and CO_2 fire extinguishers. Two independent escape routes from the cavern, pressurization of stairs and a ‘smokeless’ room has been provided for the safety of personnel. A fire in a generator or transformer cell will be extinguished by the automatic release of argonite.

0.9 Electrical Engineering Studies

0.9.1 Electrical Equipment

The hydrological, mechanical and economical studies have led to the conclusion that three Pelton turbines with synchronous speed of 500 rpm fulfil the conditions given by net head and design flow.

The total installed capacity of the project has been fixed as 144 MW.

The following main equipment has been selected.

0.9.2 Generator

Three vertical shaft synchronous generators with the following main design features have been selected.

Main Design Features

Capacity	:	56.47 MVA
Out put	:	48 MW

Power Factor	:	0.85 lagging
Rated Voltage	:	11 kV
Rated speed	:	500 rpm

A static, thyristor controlled excitation system with high speed Automatic Voltage Regulator will be provided for each generator.

Each generator will be provided a completely independent fire detection and fire protection system. Argonite will be used as fire suppression medium.

0.9.3 Isolated Phase Bus Duct (IPB)

The electrical connection between the generator and step-up transformers will be enclosed in isolated phase bus ducts. The system will be designed for natural cooling. Each enclosure will be air pressurized with dedicated air compressor.

0.9.4 11 / 132 / √3 kV Step-up Transformers

The generators will be directly connected with the single phase, step-up transformers via IPB. The transformers have been proposed to be single phase keeping in view the transportation limits. These will be placed in the transformer cavern taking all required fire protection measures.

Main Design Features

Type of construction	:	single phase, two windings
Capacity	:	18.82 MVA
Voltage ratio	:	11 / 132 / √3 kV

0.9.5 132 kV High Voltage Cables

Each step-up transformer will be connected to the 132 kV switchyard via single core, single phase 132 kV, XLPE cables.

The fire protection arrangement in the cable tunnel will be made as per NFPA 851.

0.9.6 Protection Equipment

Separate relay protection cubicles comprising numerical relays will be installed. The relays will be organized in two groups so that one group provides back up protection for the other. The control supply will be taken from 110 VDC system.

0.9.7 Station AC Auxiliary Supply

The medium 11 kV and low voltage (400 VAC) installations have been planned to provide a reliable AC supply for all functions of the power house. Emergency diesel generator has been planned for providing AC auxiliary supply in case of a breakdown to ensure a safe shutdown or black start up of the plant.

0.9.8 110 V DC Supply

The DC system will be provided to supply uninterruptible power for control, protection, protection instrumentation, and other specific controls and critical DC operated equipment. Two independent 110 V DC systems will provided for this purpose.

0.9.9 Plant Control System

The control room has been equipped with Plant Control System (PCS). Local computerized control units inside the powerhouse and intake area have been specified to perform all automatic functions and have been connected to the PCS by a fibre optic bus.

All equipment and systems have been specified in accordance with state of the art technology and proven reliability.

0.10 Power and Energy Potential

With the optimized reservoir levels of 2664.0 m.a.s.l. and 2654 m, hydrological estimates, compensation releases and rating curves at weir and powerhouse sites, the power and energy estimations of the project have been performed with following basic assumptions:

- The residual flows in Tirich Gol during low flow period has been taken as 0.8 m^3/s in winter months and 1.5 m^3/s in summer months. It is based on provision of water for sediment flushing requirements and minimum flows required in the river for environmental purpose.

- The variations in the efficiencies of generating units due to change of net heads have not been considered. For design discharge available to powerhouse, an efficiency of 90.5%, 98.0% and 99% have been used for the turbine, generator and transformers, respectively.

- The head loss has been considered as 12.61m to estimate net head at the turbines. The losses would be less for a discharge less than the design discharge. The net head varies from about 593m to 603m.

- Sediment flushing is assumed to be carried out every year during summer months. The maximum flow in the river occurs from June to August. The sediment flushing would be carried out when the flows in Tirich Gol are more than power generation design discharge.

- During low flow periods, when the discharge in Tirich Gol is less than 28 m^3/s, the live storage is used to store water during off peak hours to improve the flows for power generation in peak hours.

- Energy is calculated on 10-daily basis by multiplying the number of days by 24 hours (in a day). For power and energy during peak and off peak hours, the volume of water available for storage and inflow volume in 24 hours is used to calculate the corresponding discharge. The power during peak and off peak hours is used to calculate the corresponding energy.

The calculated annual energy, for years 2003 (average year), 2005 (wet year) and 1982 (dry year), is 611.865, 682.576 and 530.018 GWh respectively.

For the purpose of this study, average annual energy is taken as 611.865 GWh produced in the “average year” 2003.

0.11 Power System and Transmission Studies

0.11.1 Power System Study

Based on the future load demand and future generation expansion program supplied by PEPCO, balance of Demand/Supply has been worked out with and without Shushghai-Zhendoli Hydropower Project. The Project mitigates deficit and increases the Reserves to some extent.

0.11.2 Transmission Study

In order to establish a reliable, economical and viable interconnection scheme for dispersal of power from the 144 MW Shushghai-Zhendoli Hydropower Project to the proposed Chitral grid station to be constructed by NTDC, a transmission line corridor has been identified after physical survey. 132 kv D/C transmission line conductor has been found the best choice, meeting technical requirements as well as being the most economical.

0.11.3 Transmission System Studies.

Following studies were carried out for the proposed interconnection scheme, using Soft ware PSS/E of Siemens-PTI;

a) Load Flow Study

b) Short Circuit Study

c) Transient Satiability

All studies established that proposed interconnection scheme has no constrained in terms of steady state performance, short circuit currents and remain STABLE under Transient conditions.

0.11.4 Design and Engineering of Proposed Interconnection Scheme

The following is the proposed scheme of interconnection scheme.

a) 132 Kv line with Greely conductor from Shushghai-Zhendoli HPP to the proposed Chitral grid is to constructed by NTDC. Approximate Line length will be 82 km.

b) 132 kv out door switch yard will be constructed for the project, which will be of single bus configuration, having three bays for Generators, two bays for transmission lines and one bay for station service transformer.

0.12 Socio-Economic and Environmental Studies

Under the socio-economic and environmental studies, the main baseline conditions were studied covering upper area of project, reservoir area, dam site located at Shushghai Village, intake structures area and power house site located at Zhendoli village.

The environmental water requirement releases from project dam site to downstream is 0.75 cumecs (26.5 cusecs) even during low flow period. This will fully meet the environmental requirements of downstream areas. This will be joined with other inflows from streams and nullahs to meet the environmental requirements of downstream reach of the river.

Majority (80%) of the farmers in the Chitral district have small landholdings ranging from 0.5 to 1.5 ha dependent on rainfed agriculture. Based on the acquisition of land and average land holding (1.5 acres) only, 9 households/families with 68 persons will be affected The agriculture income is supplemented by income from livestock.

Shushghai-Zhendoli Hydropower Project will spread over two main areas (i) Reservoir area formed by the weir (ii) Power house at Zhendoli Village 30 Km downstream the weir. Reservoir and dam structure will cover 5.79 ha (14.30 acres) while powerhouse and switchyard will cover 0.41 ha (1.0 acres). This project will have impacts at submergence level of EL. 2666 m.a.s.l. The project colony and offices will occupy 2.63 ha (6.50 acres) and road alignment will need 0.51 ha (1.25 acre). Overall, the project will require 10.34 ha (25.55 acres) permanently. Only 13.90 acres of private land will come permanently under project implementation. In addition to this 1.21 ha (3.0 acres) land will be required temporarily for contractor's camp/offices etc. The rest of land belongs to the government for which no land compensation is needed. 550 plants (500 forest and 50 fruit) will also be affected. There will be insignificant impact on wildlife during construction.

The major adverse impact of the project will be on the 30 km stretch of river length downstream dam site. The diversion of water for most of the time through power tunnel to power house site, will leave this river length dry. Compensation water of 0.75 cumecs (26.5 cusecs) is proposed. The other adverse impacts arising are,(i) changes in river bed morphology downstream, (ii) reduction in the aesthetic value of 30 km length of Turkho River downstream reservoir, (iii) increased flood levels and frequency during head pond flushing and (iv) some minor impacts on flora and wild life are likely to occur.

During construction, the monitoring will be done for air quality, noise and vibration, drinking water quality, sewage effluent, solid waste, explosive material used, hazardous/toxic materials and its proper disposal, flora/fauna, excavated material and traffic handling systems etc. The internal and external environmental monitoring is very important component during the execution of this project especially due to the introduction of tunnel technology. Mitigation measures for these issues have been included in the EMP.

The environmental cost amounts to Rs. 19.59 millions.

The project is environmental friendly and it will contribute substantially in the economy of Pakistan. The project will have major positive socio-economic impacts on the population living on the periphery of the reservoir and on person living off site the project area. The benefits of emoluments during construction, better transportation means created by the project and economic activities generated as a spin of positive impact on whole of Chitral area.

0.13 Project Implementation and Construction Planning

Project implementation period is estimated to be 5 years (Phases II and III overlap) excluding pre-construction activities as given below.

- **Phase I: Pre-Construction Activities and Award of Contract on EPC Basis.**

  Completion Period: 24 months are required

- **Phase II: Project Construction Works with Detailed Engineering Design of Project Components**

  Completion Period: 60 months will be consumed for completion of all the components of the Project works.

- **Phase III: Testing and Commissioning of Turbines**

  A period of 4 months will be required for accomplishment of the requisite tests which shall be done simultaneously with in the time scheduled of Phase-II.

Details of project implementation and construction planning are given in Section 14 of the Main Report and Volume 5 – Drawings.

0.14 Bill of Quantities and Cost Estimates

The Bill of Quantities and cost estimates for various works including Infrastructure development and site installations, Civil, Hydro-mechanical, Hydraulic Steel Structures, Electrical & Substation were prepared by multiplying unit rates with the relevant quantities of different structures. The Cost estimate for Environmental Mitigation Programme was prepared after collection of data during site visit and evaluated and then estimated.

The methodology applied to the estimation of cost is carried out proceeding the following steps in accordance with the requirements of a bankable feasibility study.

- Define Basis of Cost Estimation
- Estimate Basic Project Cost
- Estimate Costs of Engineering, Administration, Erection, Transportation etc
- Determine Bill of Quantities
- Estimate Total Project Costs

Basic costs of labor, material, consumables and equipment were inquired, unit costs calculated and compared with unit rates of hydropower projects of similar size and type presently under development in Pakistan.

The unit and lump sum prices for Civil Works were prepared after doing rate analysis for various items and consulting and escalating the unit prices for certain items given in the feasibility study of Golen Gol Hydropower Project. The unit rates were taken from the above said project and then escalated at the rate of 6.5% per annum.

All prices are quoted in Pakistan Rupees. For Local & Foreign cost component the rate of 1 US$ = Rs. 84.50 on January 2010 price level has been adopted.

The cost for Infrastructure improvement / development, Environmental Mitigations, Land compensation, Preparatory works and Site Installations is estimated as **12.690** Million US$.

Based on the feasibility design as documented by the corresponding design drawings the Consultants have calculated the quantities of the major civil structures. For minor works provisions in terms of the miscellaneous items rates have been made. Cost of civil works is estimated as **82.29** Million US$.

Cost of Hydro-mechanical and Electrical equipments is based on budgetary prices from reputed manufactures both local and foreign. The cost of Hydro-mechanical equipment is estimated as **20.604** Million US$ and that of Electrical equipment is estimated as **32.92** Million US$.

The cost of Hydraulic Steel structures is estimated as **8.377** Million US$.

The Substation cost of Shushghai-Zhendoli HPP is estimated as **4.00** Million US$.

The total cost of the project by summing up all the costs mentioned above is presented below:

Total Cost (PKR) **15,157.23 Million Pak Rupees**

Total Cost (US$) **179.38 Million US$**

0.15 Economic and Financial Analysis

Economic analysis carried out indicate that the plant would be economic if benefits were the long run marginal costs (LRMC) of supply , this implies that the plant would form a part of the least cost expansion plan and is therefore feasible on that count. The NPV for the project at 12% interest rate was US$M 66 and the IRR 17.89%.

Since there is uncertainty related to the assumptions and inputs, a sensitivity analysis was carried out and is summarized as follows in Table 0.2 :

Table 0.2 Economic Sensitivity Analysis Based on LRMC

Sensitivity Analysis		NPV M.$	IRR
		at 12%	%
1	Base Case	66	17.89
2	Cost +10%	51	16.29
3	Benefit -10%	45	16.12
4	Cost +10%,Benefit -10%	35	15.08

Economics of the project were verified on basis of benefits quantified as Willingness to Pay basis and gave an NPV of US$M 51 at 12% interest rate and an IRR of 15.84%

Sensitivity analysis was carried out and is summarized as follows in Table 0.3.

Table 0.3 Economic Sensitivity Analysis Based on WTP

Sensitivity Analysis		NPV M.$	IRR
		at 12%	%
1	Base Case	51	15.84
2	Cost +10%	37	14.59
3	Benefit -10%	32	14.47
4	Cost +10%,Benefit -10%	18	13.28

The economic internal rate of return (EIRR) and the economic net present value (ENPV) for the proposed project have been calculated. LRMC at 132 kV level were used as avoided costs and the economic feasibility of the plant was established.

The benefits were also estimated on basis of 68.83 % of the WTP which resulted in the WTP at generation level to be Rs.5.95 c/kWh.

The project appears to be feasible on both counts, the economic feasibility when benefits were quantified on basis of LRMC signifies the inclusion of the plant in the least cost expansion plan as LRMC are derived using the long term expansion program as an input. The project seems to be robust and will remain economic for various changes in assumptions, including price increases and benefit reduction.

The financial analysis of the proposed hydropower plant has been carried out in accordance with the Asian Development Bank's (ADB) *Financial Management and Analysis of Projects*. All financial costs and benefits have been expressed at early 2010 constant prices. Cost streams used for the purposes of financial internal rate of return (FIRR) determination (i.e., capital investment, operations and maintenance, insurance costs and taxes) reflect costs of delivering the estimated benefits. The NEPRA approved tariff for Khan Khwar, a high head hydroelectric project, was used to estimate the financial benefits.

The financial internal rate of return (FIRR) was calculated at 10.69% for the project. The overall rate compares favorably with the estimated WACC of 9.22%, substantiating the financial viability of the project.

The project seems to be financially feasible. Risks are quantified by the sensitivity analysis as in Table 0.4 below.

Table 0.4 Financial of Sensitivity Analyses Results

Item	**FIRR** (%)
Base case	10.69%
20% increase in capital cost	8.68%
20% decrease in tariff	8.25%
Combination of above	6.39%

The project is financially feasible on central assumptions; the project is sensitive to cost overruns and decrease in tariffs. The above analysis, however, have been carried out on benefits/tariffs significantly less than the calculated tariff for the plant, at which the project will be feasible financially and will be robust and will be able to stand reasonable uncertainties.

The project seems to be both economically and financially feasible.

0.16 Conclusions and Recommendations

The project is technically, economically and financially viable.

The Shushghai-Zhendoli HPP is feasible and beneficial to continue to develop until project implementation.

The following recommendations are made to ensure that the required investigations for detailed design are made and consideration given to project implementation methodology.

0.16.1 Hydrological Investigations

Long term hydrological and meteorological information is not available at the weir site at Shushghai and the power house site at Zhendoli. Systematic measurements were able to be made only for the durations of this Feasibility Study which covered only a period of about 01 year. It is recommended that measurement stations be established and flow and sediment measurements, river gauging and meteorological measurements be carried out commencing from 2010 so as to provide as much data as possible for detailed design stage.

0.16.2 Geotechnical Investigations and Testing

The time and funding available for geotechnical investigations did not permit drilling investigations along the tunnel trace, adit tunnel or access tunnel traces. It is recommended that these investigations be carried out.

It is also recommended that in-situ testing such as in adits, direct in-situ shear tests etc. be carried out at detailed design stage to supplement data obtained during this Feasibility Study.

0.16.3 Physical Hydraulic Modelling

It is recommended that physical hydraulic modeling of the headworks structures and sedimentation basins be carried out at detailed design stage to confirm,

- Alignments of the headworks structures,
- Functioning of the low level outlets at the weir for sediment flushing,
- Spillway and low level outlet energy dissipation, and,
- Functioning of the sedimentation basins for efficiency of sediment settlement and flushing.

0.17 Project Configuration

The project concept is based on generation of electric power by diversion of part flows of Tirich Gol by means of a diversion structure located across Tirich Gol via a headrace tunnel to a powerhouse located on Turkho River utilizing a rated head of some 600m. The project is planned to develop the available head by means of a run-of-the river peaking scheme generating 144MW of power.

The project configuration consists of the following major components:

- Diversion weir of 26.4 m height from river bed comprising concrete gravity weir/embankment with low level outlets, un-gated and gated spillways
- Lateral power Intake structure on right bank of river that comprises two intakes to accommodate the design and flushing discharge of 33.6m^3/s to the desanders
- Two connecting tunnels each of 3.4 m diameter, to take the discharge from intake to desanders
- Transitions of length of 15m starting from the end of connecting tunnels and ending at the start of desander chamber.
- Two underground desanders, each 180m long starting from the end of transitions

- Low pressure headrace tunnel having total length of 8460 m and 4.2 m diameter.
- Vertical surge shaft of 72 m height and 4.5 m diameter
- Concrete lined pressure shaft of 3.20 m diameter having total length of 473 m
- High pressure tunnel of 2.9 m diameter having a total length of 360 m
- Penstocks of 1.4 m diameter having a length of 70 m
- Underground powerhouse with transformer cavern
- Free flow 480 m long tailrace tunnel

The diversion structure on Tirich Gol is a composite concrete/embankment dam structure with its crest level at elevation 2669.0 m.a.s.l and is 26.4m above river bed level. The concrete section containing the spillway is located on the right side of the river and is founded completely on rock while the embankment section extends from the interface with the concrete section and is founded mainly on alluvium. The composite structure has been designed to safely withstand AEP 1:10000 flood and design earthquake without damage. Care has been taken to provide defensive design measures in the structures and particularly at the interface between the concrete section and the embankment. These are detailed in Volume 5 – Drawings.

The concrete weir structure is equipped with two hydraulically operated spillway radial gates for flood discharge and four bottom outlets for flushing sediment entering the reservoir. Two free-overflow sections have been provided in the weir for safety in case of gate failure. The spillway, bottom outlets and the free-overflow sections discharge onto a stilling basin on the downstream of the weir for energy dissipation before being released into Tirich Gol. Provisions have been made to close off each spillway bay and bottom outlet by stoplogs for maintenance work.

The gated spillway is designed to pass the 1: 10000 AEP flood of 770m^3/s with all gates open. It can also pass the 1: 10000 AEP flood of 770 m^3/s with one gate inoperative utilizing the free-overflow sections. In this case the reservoir level rises to its maximum flood level of 2666.7m.a.s.l.

The embankment section of the composite structure is a central clay core rockfill dam founded on alluvium. A wide core and adequately thick l filter layers have been provided in the embankment together with flat 3H:1V upstream and downstream shells to ensure low foundation stresses and provide for any differential movement during earthquake.

Foundation seepage control measures for the structures have been provided by a grout curtain beneath the concrete structure and a bentonite/cement slurry wall below the embankment section. Provision has also been made for a grouting gallery and grout curtain on the left abutment contact to cut off any seepage through the abutment.

Considerable sediment inflow is expected into the reservoir during the glacier/snow melt runoff and also during rains. In order to maintain the power intake free of sediment build up it is located close to the weir and the four low level outlets which have been provided in the concrete spillway section will be used to periodically flush sediment from the reservoir.

Due to the high river bed gradient it is expected that large size boulders will travel along the river bed towards the weir with a consequent possibility of blocking the bottom outlets. To prevent this phenomenon, g, provision has been made to clear the reservoir bed area of all movable boulders at construction stage and dispose to waste or other use before impoundment of the reservoir. Provision has also been made to build a low “flow-through” rockfill boulder trap at the upstream end of the reservoir to trap any moving boulders or bed material.

River diversion of Tirich Gol during construction of the concrete/embankment diversion structure will be accomplished by the construction of upstream and downstream cofferdams with impervious cut off provided by intersecting columns of jet grouting together with diversion tunnels. The upstream coffer dam is reinforced at its crest and downstream face to allow for overtopping during construction. The existing road at the weir site needs to be relocated for a length of approximately 1 km.

Diversion tunnel intakes and tunnels and power tunnel intakes will be constructed in the dry by employing conventional ring type cofferdams abutting onto the right bank which provide adequate working space and construction access.

The headrace commences at the twin intakes on the right bank with two short connecting tunnels connecting the intakes to two desanding basins and thereafter to the low pressure tunnel. The desanding basins are provided with flushing tunnels and gates for evacuation of sediment. Gates have also been provided at the downstream end for closing off each basin as required for maintenance while allowing one basin to operate and enable reduced power generation. Construction of the low pressure tunnel will be expedited by the one adit to ensure additional construction faces.

At the downstream end of the low pressure tunnel a surge tank is provided to limit pressure rise in the in the waterway system and allow flexibility in power plant operation. A vertical pressure shaft and horizontal pressure tunnel and short penstocks lead to three vertical shaft pelton turbines arranged in an underground cavern type powerhouse. The steel lined pressure tunnel and penstocks have been kept short to achieve economy. Transformers are arranged in an underground cavern separated from the powerhouse. The switchyard is above ground located some distance away. A 480m long tailrace releases generation flows back to the Turkho River.

Further design details are provided in Volume 5 – Drawings of the Feasibility Report and in Sections 8 to 10 of the Main Report.

0.18 Salient Features

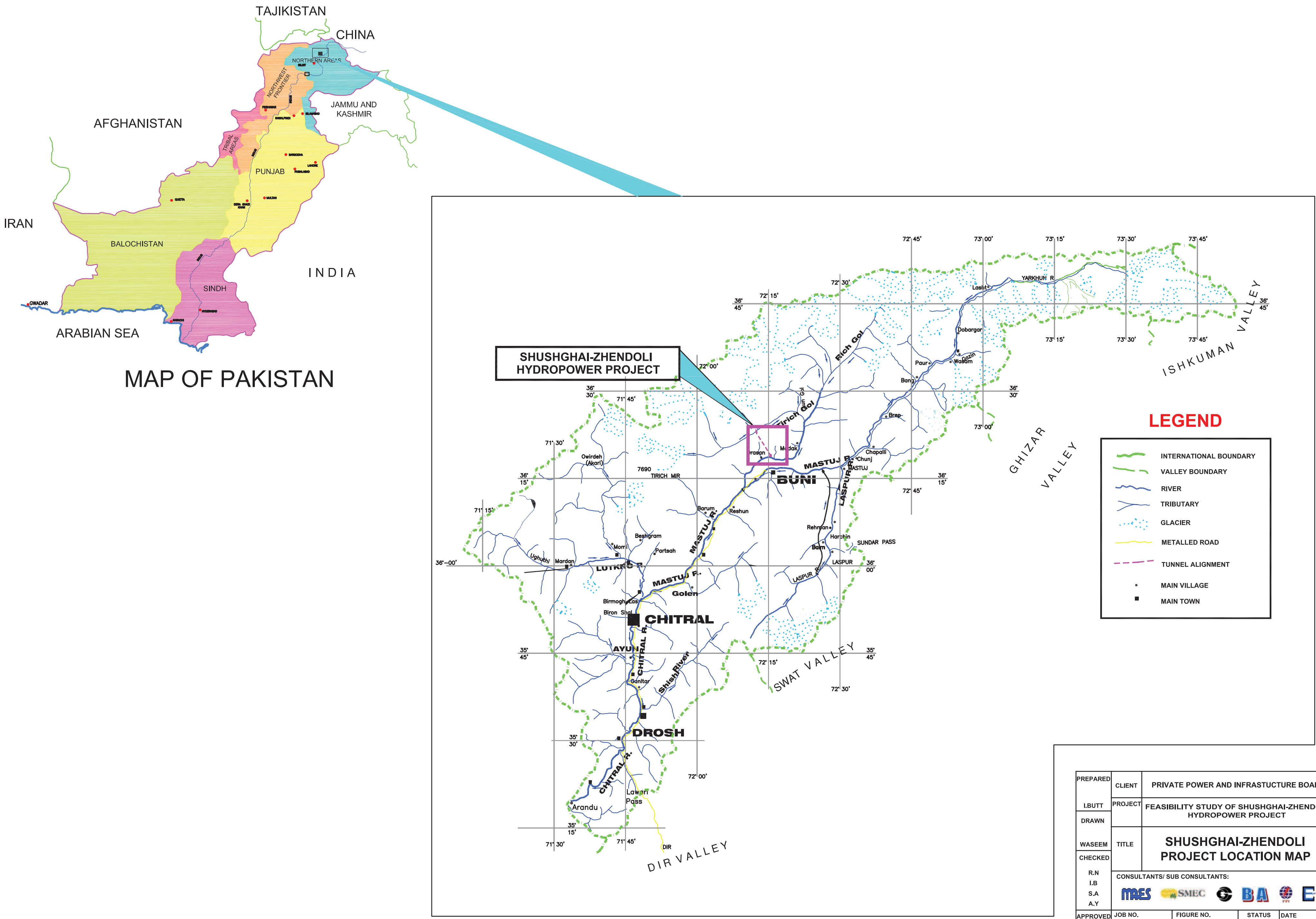
The salient features of the project as per feasibility level designs are given below:

Hydrology (Design flows)		
Design discharge	28	m^3/s
Flushing discharge	5.6	m^3/s
Design flood (10,000 Year Flood)	770	m^3/s
Reservoir		
Reservoir length	686	m
Reservoir area	57,687	m^2
Max. reservoir operating level	2664	m.a.s.l
Min. reservoir operating level	2654	m.a.s.l
Max. flood level	2666	m.a.s.l
Reservoir capacity at 2664 m.a.s.l	0.508	MCM
Reservoir capacity at 2654 m.a.s.l	0.124	MCM
Weir Structure		
Weir height	26.4	m, above riverbed
Weir crest level	2669	m.a.s.l
Spillways		
Ungated overflow spillways		
Number of bays	2	Nos.
Width of opening	16	m
Height of opening	4	m
Gated surface spillways		
Number of bays	2	Nos.
Gate Type	Radial	
Width of gate	7.5	m
Height of gate	10.5	m
Discharge capacity	854	m^3/s
Low level outlets		
No. of outlets	4	Nos.
Gate type	Vertical lift gate	
Gate size (WxH)	3.0 x 3.0	m

Discharge capacity	440	m^3/s
Power Waterways		
Power Intake		
Type	Lateral intakes	
No. of gates	2	
Gate size (WxH)	2.8 x 3.25	m
Deck elevation	2669	m.a.s.l
Intake sill level	2648.25	m.a.s.l
Connecting Tunnels		
Diameter	3.4	m each
Lengths	135 and 150	m
Desanders (Underground)		
No. of chambers	2	Nos.
Size of chamber (WxH)	7.0 x 9.0	m each
Length of chamber	180	m each
Low Pressure Headrace Tunnel		
Diameter	4.2	m
Length	8460	m
Surge Shaft		
Diameter	4.5	m
Height	72	m
Pressure Shaft		
Concrete Lined		
Diameter	3.2	m
Length	473	m
Steel Lined		
Diameter	2.9	m
Length	100	m
High Pressure Tunnel (Steel Lined)		
Diameter	2.9	m
Length	360	m
Penstocks		
No. of penstocks	3	

Diameter	1.4	m
Total Length of 3 penstocks	70	m
Power Generation		
Max.Gross head (HWL-Turbine centre line)	615.4	m
Max. net head	614	m
Min. net head	592.78	m
Rated net head	600	m
Rated discharge	28	m^3/s
Installed plant capacity	144	MW
Plant factor	49.00	%
Mean annual energy for an average year (2003)	613.27	GWh
Powerhouse type	Cavern/underground	
Size of powerhouse (LxWxH)	77 x 16.2 x 38	m
Switchyard	Open outdoor type	
Turbine type	Pelton	
No of units	3	Nos.
Turbine centerline level	2048.6	m.a.s.l
Generator	3	Nos.
Transmission line	132	KV
Tailrace Tunnel		
Diameter of tailrace tunnel	7.0 x 4.5	m
Length of tailrace tunnel	480	m
Additional Project Parameters		
Total project cost including IDC	255	million US $

FIGURES



PREPARED	CLIENT	PRIVATE POWER AND INFRASTUCTURE BOARD
I.BUTT	PROJECT	FEASIBILITY STUDY OF SHUSHGHAI-ZHENDOLI HYDROPOWER PROJECT
DRAWN		
WASEEM	TITLE	SHUSHGHAI-ZHENDOLI PROJECT LOCATION MAP
CHECKED	CONSULTANTS/ SUB CONSULTANTS:	
R.N I.B S.A A.Y		

APPROVED	JOB NO.	FIGURE NO.	STATUS	DATE
MAES	SZ/214/5065033	0.1	FINAL	30-03-2010